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FORWARD

The third edition of the International Conference on Engineering and Environmental Sciences (ICEES 2024) was co-hosted by the Faculty of Engineering and the Faculty of Environmental Sciences of Osun State University, Osogbo from 25th-28th November, 2024. The Conference with the theme 'Innovative Technology for Resource Utilization and Environmental Sustainability' took place as the Sustainable Development Goals (SDGs) is gaining general awareness and momentum across the globe as the challenges of climate change, dwindling natural resources and ever growing world population keeps on mounting. The conference which had both on-site and online participants from within and outside Nigeria provided opportunities to foster interactions and collaborations among members of academia, industries and stakeholders across the globe, with a view to proffering informed solutions to these challenges both at local level as well as globally.

ICEES24 bring to the fore the need to innovate new approaches to how we extract natural resources and utilize it in a way that is sustainable and less demanding on the environment. To these end, submissions was received based on the well spelt out sub-themes of the conference which are; resource efficiency and circular economy, clean energy and sustainable infrastructure, climate change mitigation and adaptation, water resource management and sanitation, emerging technologies and disruptive innovation, social equity and environmental justice, renewable energy technologies, as well as resource optimization and modeling. During the conference, local, national and international participants demonstrated various approaches to the solutions theoretically, empirically and numerically.

Having evaluated, revised and edited the various submissions by the participants to produce this publication, readers of this Conference Proceedings will find in it intellectual treasures. It is our hope that they will also derive from it, inspiration for areas of further research to expand the frontiers of knowledge and produce qualitative works to qualify for the next edition of the ICEES conference.

Finally, our immense appreciations go to the members of the local organizing committee as well as the local, national and international participants for using their time, energy and material resources to make the event worthwhile**.**

Engr. Dr. L.A. Adejumo
Ag. Dean, Faculty of Engineering

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Kifilideen's Rule: A Groundbreaking Approach to Solving Product Index Nonlinear Simultaneous Equations with Two, Three, Four, and n Variables

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Abstract

Many real-world and social problems give rise to product index nonlinear simultaneous equations, which traditional solution methods, whether direct or iterative, fail to solve effectively. These equations appear in diverse fields, necessitating a specialized approach to ensure accurate and efficient solutions. Existing methods for solving linear simultaneous equations are insufficient for addressing product index nonlinear simultaneous equations. Given their frequent occurrence in practical applications, there is a need to develop a systematic and efficient approach tailored to solving these complex equations. This study introduces Kifilideen's Rule, a groundbreaking approach for solving product index nonlinear simultaneous equations involving two, three, four, and n *variables. The objective is to establish a reliable, efficient, and mathematically rigorous method that overcomes the limitations of conventional techniques. The formulation of Kifilideen's Rule is based on elimination methods, the laws of indices, and matrix theory, including cofactors and determinants. These mathematical principles are systematically applied to construct a general framework for solving product index nonlinear simultaneous equations. The proposed method successfully establishes a general solution for* $n-$*variable product index nonlinear simultaneous equations, demonstrating its superiority over traditional techniques in handling multiplication-based systems. Kifilideen's Rule offers an efficient, precise, and practical solution for complex nonlinear simultaneous equations. Its direct and exact approach makes it highly valuable for students, researchers, and professionals working in fields that require highly accurate mathematical modeling.*

Keywords: Kifilideen's Rule, Product index nonlinear system, Simultaneous Equations, Product of Bi-Indexes, Product of Tri-Indexes, Kifilideen's Geometric Matrix Progression Sequence

Introduction

The concept of simultaneous equations, also known as systems of equations, has a long and rich history, dating back to ancient civilizations (Grcar, 2011a; Khushbu and Poonia, 2021). Babylonian mathematicians recorded solutions to linear equations on clay tablets, applying algebraic methods to practical problems such as land distribution and trade (Zara, 2008). Similarly, the Rhind Papyrus (1650 BCE) contains early Egyptian examples of solving linear systems (Fribera, 2008). The Greeks, particularly Diophantus of Alexandria, made significant contributions to algebra, laying the foundation for future developments (Sfard, 1995; Rahaman, 2022; Rizos and Gkrekas, 2022).

During the Islamic Golden Age, scholars like Al-Khwarizmi and Omar Khayyam expanded on Greek and Indian mathematics, introducing more structured algebraic methods. Their work influenced later European mathematicians, including Girolamo Cardano, who formalized approaches to solving linear equations (Baki, 1992; Heeffer and Rothman, 2014; Oaks, 2021; Kabar, 2023). The Cartesian coordinate system, introduced by René Descartes, provided a geometric interpretation of simultaneous equations (Neovius, 2013).

In the 18th century, Swiss mathematician Leonhard Euler developed the method of substitution for solving systems of linear equations (Carmine, 2021). Later, Carl Friedrich Gauss developed the elimination method, a widely used technique today (Grcar, 2011a; Grcar, 2011b). The 20th century saw the development of matrix theory, linear independence, and computational algorithms, advancing the study and application of simultaneous equations in fields like engineering, physics, economics, and computer science.

While numerous techniques exist for solving linear simultaneous equations, including Cramer's rule, Gaussian elimination, Jacobian method, Gauss-Seidel iteration, LU decomposition, and matrix inversion, these methods are inadequate for solving product index nonlinear simultaneous equations (Samuel, 2011; Woollard , 2015; Osanyinpeju, 2024, Osanyinpeju, 2025). A product index nonlinear simultaneous equation consists of multiple nonlinear equations in which variables appear as products raised to exponents or where each equation represents a product of variables raised to specific powers. These equations frequently arise in real-world applications, including geometric progressions, population growth, nuclear fission, economic models, and resource allocation. Traditional direct or iterative methods struggle to efficiently handle these nonlinear systems, necessitating the development of a more systematic approach.
A general $n-$ variable product index nonlinear simultaneous equation is expressed as:

$$a^b \times m^c \times \dots \times g^d = k$$
(1)
$$a^e \times m^f \times \dots \times g^j = i$$
(2)
.
.
.
$$a^p \times m^q \times \dots \times g^r = f$$
(3)

Where:
- $a, m, \dots, g$ are the variables (components/inputs of the system).
- $b, c, \dots, d, e, f, \dots, j, p, q, \dots, r$ represent the respective units or quantities of the variables
- $k, i, \dots, f$ are the output values

This equation structure appears in geometric matrix sequences, nuclear fission models, geometric salary structure, and production models where variables grow multiplicatively rather than additively.

To address the challenge of solving product index nonlinear simultaneous equations, Kifilideen's Rule is introduced. This method leverages the Kifilideen's Geometric Matrix Progression Sequence (GMPS) to provide a structured framework for analyzing multiplication-based simultaneous equations.

The GMPS follows the Kifilideen's General Term Formula (Osanyinpeju, 2021. Osanyinpeju, 2024):

$$f \times k^a \times i^m = T_n$$
(4)

Where:
- T_n is the nth term
- k is the migration level value
- i is the migration step value
- $a \text{ and } m$ are the migration factors
- f is the first term of the sequence

The GMPS originates from the Kifilideen's Arithmetic Matrix Progression Sequence (AMPS) and is further generalized from the Kifilideen's Trinomial Theorem (Osanyinpeju 2020a; Osanyinpeju 2020b; Osanyinpeju, 2023). The rule enables efficient determination of variable contributions in geometric growth models, making it valuable for applications in forecasting, optimization, and resource allocation.

Kifilideen's Rule is particularly using in scenarios involving multiplicative growth patterns, including:

- Population Growth: Analyzing bacteria growth, species reproduction, or economic inflation.
- Nuclear Fission: Determining neutron production in a nuclear reactor over successive generations.
- Salary Structures: Predicting salary progression in industries following a geometric increment model.
- Geometric Sequences in Engineering: Modeling component reliability and failure rates over time

For instance, in a nuclear fission scenario, where different nuclear fuels produce varying numbers of neutrons over multiple generations, the governing equations could be:

$$n_1^{g_1} \times n_2^{g_2} = k$$
(5)
$$n_1^{g_3} \times n_2^{g_4} = f$$
(6)

Where:

- n_1, n_2 (Number of neutrons per Fission Event):
  - The number of neutrons produced from the fission of a single atom of a given nuclear fuel.
  - n_1 represents the neutrons released by fuel 1, and n_2 represents those released by fuel 2.
- g_1, g_2, g_3, g_4 (Number of Generations of Neutrons Produced):
  - The number of successive fission events where neutrons are produced and induced further reactions.
  - g_1, g_3 correspond to the number of generations for fuel 1, while g_2, g_4 correspond to the number of generations for fuel 2.
- k, f (Total Number of Neutrons produced in the System at Each Level)
  - The total neutron population at different levels of system.
  - k represents the total neutron count in one scenario, while f represents alteratuve scenario with different neutron generation conditions.

These equations describe how neutron multiplication progresses over multiple generations in a nuclear reactor, helping determine the effectiveness of different fuels in sustaining a chain reaction. Kifilideen's Rule identifies nuclear fuel that produces the most neutrons, optimizing reactor efficiency. This study introduces Kifilideen's Rule, a groundbreaking approach for solving product index nonlinear simultaneous equations involving two, three, four, and n variables. The study aims to develop and validate Kifilideen's Rule, bridging the gap in mathematical approaches to product index nonlinear simultaneous and expanding its applicability in scientific and engineering domains.

Materials and Methods

The formulation of Kifilideen's Rule is based on elimination methods, the laws of indices, and matrix theory, including cofactors and determinants. These mathematical principles are systematically applied to construct a general framework for solving product index nonlinear simultaneous equations.

Development of Kifilideen's Rule for Solving Product Index Nonlinear Simultaneous Equations with Two Variables

For a given product index nonlinear simultaneous equations with two variables, denoted as a and b such that:
$$a^x b^y = m,$$
(7)
$$a^w b^v = n,$$
(8)
Where:

- a and b are the variables (components/inputs of the system).
- x, y, w and v represent the respective units or quantities of the variables

- m and n are the output values of the system

The generation of the Kifilideen's Rule for solving product index nonlinear simultaneous equations with two variables is illustrated as follow:
From (7) and (8), it is obtained that:

$$a^{\frac{x}{y}}b = m^{\frac{1}{y}},$$
(9)

$$a^{\frac{w}{v}}b = n^{\frac{1}{v}},$$
(10)

To find a, eliminate b by dividing (9) with (10),

$$a^{\frac{x}{y}-\frac{w}{v}} = m^{\frac{1}{y}}n^{-\frac{1}{v}},$$

$$a^{\frac{xv-wy}{yv}} = m^{\frac{1}{y}}n^{-\frac{1}{v}},$$

$$a = m^{\frac{1}{y}\left(\frac{yv}{xv-wy}\right)}n^{-\frac{1}{v}\left(\frac{yv}{xv-wy}\right)},$$

$$a = m^{\left(\frac{v}{xv-wy}\right)}n^{\left(\frac{-y}{xv-wy}\right)},$$
(11)

From (7) and (8), the following is obtained:

$$ab^{\frac{y}{x}} = m^{\frac{1}{x}},$$
(12)

$$ab^{\frac{v}{w}} = n^{\frac{1}{w}},$$
(13)

To find b, eliminate a by dividing (12) with (13),

$$b^{\frac{y}{x}-\frac{v}{w}} = m^{\frac{1}{x}}n^{-\frac{1}{w}},$$

$$b^{\frac{yw-vx}{xw}} = m^{\frac{1}{x}}n^{-\frac{1}{w}},$$

$$b = m^{\frac{1}{x}\left(\frac{xw}{yw-vx}\right)}n^{-\frac{1}{w}\left(\frac{xw}{yw-vx}\right)},$$

$$b = m^{\left(\frac{w}{yw-vx}\right)}n^{\left(\frac{-x}{yw-vx}\right)},$$

$$b = m^{\left(\frac{-w}{vx-yw}\right)}n^{\left(\frac{x}{vx-y}\right)},$$
(14)

From (7) and (8), the determinant of matrix of the input index system is represented as Δ_{kif} and is given as:

$$\Delta_{kif} = \begin{vmatrix} x & y \\ w & v \end{vmatrix} = xv - wy,$$
(15)

Also, let the matrix of the input index system represent kif, so the following can be determined:

$$kif = \begin{pmatrix} x & y \\ w & v \end{pmatrix} = \begin{pmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{pmatrix},$$

The components of the cofactor of kif are given as:

$$kif_{11} = cofactorof d_{11} = v,$$
(16)

$$kif_{12} = cofactorof d_{12} = -w,$$
(17)

$$kif_{21} = cofactorof d_{21} = -y,$$
(18)

$$kif_{22} = cofactorof d_{22} = x,$$
(19)

Inputting (15), (16), (17), (18), and (19) in (11), the corresponding relationship is established:

$a = m^{\left(\frac{kif_{11}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{21}}{\Delta_{kif}}\right)}$,

Inputting (15), (16), (17), (18), and (19) in (14), the corresponding relationship is established:

$b = m^{\left(\frac{kif_{12}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{22}}{\Delta_{kif}}\right)}$,

Generally, the Kifilideen's Rule for solving product index nonlinear simultaneous equations with two variables, denoted as $a \; and \; b$ such that:

$a^x b^y = m$,

$a^w b^v = n$,

is given as:

$a = m^{\left(\frac{kif_{11}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{21}}{\Delta_{kif}}\right)}$,

(20)

$b = m^{\left(\frac{kif_{12}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{22}}{\Delta_{kif}}\right)}$,

(21)

Formulation of of Kifilideen's Rule for Solving Product Index Nonlinear Simultaneous Equations with Three Variables

For a given product index nonlinear simultaneous equations with three variables, denoted as $a, b \; and \; c$ such that:

$a^e b^f c^g = m$,

(22)

$a^r b^s c^t = n$,

(23)

$a^x b^y c^z = p$,

(24)

Where:

- a, b and c are the variables (components/inputs of the system).
- e, f, g, r, s, t, x, y and z represent the respective units or quantities of the variables
- m, n and p are the output values of the system

The generation of the Kifilideen's Rule for solving product index nonlinear simultaneous equations with three variables is illustrated as follow:

From (22), it is obtained that:

$a^{\frac{e}{g}} b^{\frac{f}{g}} c = m^{\frac{1}{g}}$,

(25)

From (23), it is obtained that:

$a^{\frac{r}{t}} b^{\frac{s}{t}} c = n^{\frac{1}{t}}$,

(26)

And from (24), it is obtained that:

$a^{\frac{x}{z}} b^{\frac{y}{z}} c = p^{\frac{1}{z}}$,

(27)

To eliminate c, divide (25) with (26) and (26) with (27), so the following can be determined:

Dividing (25) with (26), so the following equation is obtained:

$a^{\frac{e}{g} - \frac{r}{t}} b^{\frac{f}{g} - \frac{s}{t}} = m^{\frac{1}{g}} n^{-\frac{1}{t}}$,

$a^{\frac{et-gr}{gt}} b^{\frac{ft-gs}{gt}} = m^{\frac{1}{g}} n^{-\frac{1}{t}}$,

(28)

$$a^{\frac{et-gr}{ft-gs}}b = m^{\frac{t}{ft-gs}}n^{-\frac{g}{ft-gs}} ,$$
(29)

Dividing (26) with (27), so the following is obtained:

$$a^{\frac{r}{t}-\frac{x}{z}}b^{\frac{s}{t}-\frac{y}{z}} = n^{\frac{1}{t}}p^{-\frac{1}{z}} ,$$
$$a^{\frac{rz-tx}{tz}}b^{\frac{sz-yt}{tz}} = n^{\frac{1}{t}}p^{-\frac{1}{z}} ,$$
(30)
$$a^{\frac{rz-tx}{sz-yt}}b = n^{\frac{z}{sz-yt}}p^{-\frac{t}{sz-y}} ,$$
(31)

To find a, eliminate b by dividing (29) with (31), so the following is obtained:

$$a^{\frac{et-gr}{ft-g}-\frac{rz-tx}{sz-y}} = m^{\frac{t}{ft-gs}}n^{-\frac{g}{ft-gs}-\frac{z}{sz-y}}p^{\frac{t}{sz-yt}} ,$$
$$a^{\frac{(et-gr)(sz-yt)-(rz-t\ )(ft-g\ )}{(ft\quad)(sz-yt)}} = m^{\frac{t}{ft-g}}n^{\frac{-g(sz-yt)-z(ft-g\ )}{(ft-gs)(sz-yt)}}p^{\frac{t}{sz-yt}} ,$$
$$a^{\frac{etsz-\ ^2y-grsz+grty-(rztf-rzgs-xt^2f+txg\ )}{(ft-\ )(sz-yt)}} = m^{\frac{t}{ft-gs}}n^{\frac{-gsz+gty-zft+zg}{(ft-gs)(sz-y\ )}}p^{\frac{t}{sz-y}} ,$$
$$a^{\frac{etsz-et^2y-grsz+grty-rztf+rzgs+xt^2f-txgs}{(ft-gs)(sz\quad)}} = m^{\frac{t}{ft-g}}n^{\frac{gty-zft}{(ft-gs)(sz-y\ )}}p^{\frac{t}{sz-yt}} ,$$
$$a^{\frac{etsz-et^2y+grty-rztf+\ ^2f-txg}{(ft-g\ )(sz-y\ )}} = m^{\frac{t}{ft-gs}}n^{\frac{t(gy-zf)}{(ft-g\ )(sz-y\ )}}p^{\frac{t}{sz-yt}} ,$$
$$a^{\frac{t(esz-ety+gry-rzf+xtf-xg\ )}{(ft-gs)(sz-y\ )}} = m^{\frac{t}{ft-gs}}n^{\frac{t(gy-z\ )}{(ft-gs)(sz-y\ )}}p^{\frac{t}{sz-}} ,$$
$$a^{esz-ety+gry-rzf+xtf-xgs} = m^{sz-yt}n^{gy-zf}p^{ft-gs} ,$$
$$a^{esz-ety-fsr+xtf+gry-xg} = m^{sz-yt}n^{gy}\quad p^{ft-gs} ,$$
(32)

From (22), (23), and (24), the determinant of matrix of the input index system is represented as Δ_{kif} and is given as:

$$\Delta_{kif} = \begin{vmatrix} e & f & g \\ r & s & t \\ x & y & z \end{vmatrix}$$

(33a) $\Delta_{kif} = e\begin{vmatrix} s & t \\ y & z \end{vmatrix} - f\begin{vmatrix} r & t \\ x & z \end{vmatrix} + g\begin{vmatrix} r & s \\ x & y \end{vmatrix}$

$$\Delta_{kif} = e(sz-yt) - f(rz-xt) + g(ry-sx) ,$$
$$\Delta_{kif} = esz - eyt - fzr + fxt + gry - gxs \qquad ,$$
(33b)

Also, let the matrix of the input index system represent kif, so the following can be determined:

$$kif = \begin{pmatrix} e & f & g \\ r & s & t \\ x & y & z \end{pmatrix} = \begin{pmatrix} d_{11} & d_{12} & d_{13} \\ d_{21} & d_{22} & d_{23} \\ d_{31} & d_{32} & d_{33} \end{pmatrix},$$

The components of the cofactor of kif are given as:

$$kif_{11} = cofactorofd_{11} = \begin{vmatrix} s & t \\ y & z \end{vmatrix} = sz - ty ,$$
(34)
$$kif_{12} = cofactorofd_{12} = -\begin{vmatrix} r & t \\ x & z \end{vmatrix} = -(rz - xt) = xt - rz ,$$
(35)
$$kif_{13} = cofactorofd_{13} = \begin{vmatrix} r & s \\ x & y \end{vmatrix} = ry - sx,$$
(36)
$$kif_{21} = cofactorofd_{21} = -\begin{vmatrix} f & g \\ y & z \end{vmatrix} = -(fz - gy) = gy - fz ,$$
(37)

$$kif_{22} = cofactorofd_{22} = \begin{vmatrix} e & g \\ x & z \end{vmatrix} = ez - gx,$$
(38)
$$kif_{23} = cofactorofd_{23} = -\begin{vmatrix} e & f \\ x & y \end{vmatrix} = -(ey - fx) = fx - ey,$$
(39)
$$kif_{31} = cofactorofd_{31} = \begin{vmatrix} f & g \\ s & t \end{vmatrix} = ft - gs,$$
(40)
$$kif_{32} = cofactorofd_{32} = -\begin{vmatrix} e & g \\ r & t \end{vmatrix} = -(et - rg) = rg - et,$$
(41)
$$kif_{33} = cofactorofd_{33} = \begin{vmatrix} e & f \\ r & s \end{vmatrix} = es - fr,$$
(42)

Inputting (33), (34), (35), (36), (37), (38), (39), (40), (41), and (42) in (32), the corresponding relationship is established:
$$a^{\Delta_{kif}} = m^{kif_{11}} n^{kif_{21}} p^{kif_{31}},$$
$$a = m^{\left(\frac{kif_{11}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{21}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{31}}{\Delta_{kif}}\right)},$$
(43)

From (28), the following can be determined:
$$a^{\frac{et-gr}{gt}} b^{\frac{ft-gs}{gt}} = m^{\frac{1}{g}} n^{-\frac{1}{t}} ,$$
(28)
$$ab^{\frac{ft-g}{et-gr}} = m^{\frac{t}{et-g}} n^{-\frac{g}{et-gr}},$$
(44)

From (30), the following can be obtained:
$$a^{\frac{rz-t}{tz}} b^{\frac{sz-yt}{tz}} = n^{\frac{1}{t}} p^{-\frac{1}{z}},$$
(30)
$$ab^{\frac{sz-yt}{rz-tx}} = n^{\frac{z}{rz-tx}} p^{-\frac{t}{rz-tx}} ,$$
(45)

To find b, I eliminate a by dividing (44) with (45), so the following is obtained:
$$b^{\frac{ft-}{et-g} - \frac{sz-yt}{rz-t}} = m^{\frac{t}{et-gr}} n^{-\frac{g}{et-g} - \frac{z}{rz-tx}} p^{\frac{t}{rz-tx}} ,$$
$$b^{\frac{(ft-gs)(rz-t\ \ )-(et-gr)(sz-yt)}{(et-gr)(rz-tx)}} = m^{\frac{t}{et-gr}} n^{\frac{-g(rz-tx)-z(et-g\ \ )}{(et-gr)(rz-t\ \ )}} p^{\frac{t}{rz-tx}} ,$$
$$b^{\frac{ftrz-\ \ ^2x-gsrz+gstx-(etsz-etyt-grsz+gryt)}{(et-gr)(rz-tx)}} = m^{\frac{t}{et-gr}} n^{\frac{-grz+gtx-zet+zgr}{(et-gr)(rz-t\ \ )}} p^{\frac{t}{rz-tx}} ,$$
$$b^{\frac{ftrz-ft^2x+gstx-etsz+et^2y-gry}{(et-g\ \ )(rz-tx)}} = m^{\frac{t}{et-g}} n^{\frac{gtx-zet}{(et-g\ \ )(rz-tx)}} p^{\frac{t}{rz-t}} ,$$
$$b^{\frac{-etsz+e\ ^2y-grty+rztf-xt^2f+txg}{(et-g\ \ )(rz\ \ \ \ )}} = m^{\frac{t}{et-gr}} n^{\frac{t(gx-z\ \ )}{(et-gr)(rz-t\ \ )}} p^{\frac{t}{rz-tx}} ,$$
$$b^{\frac{-t(esz-ety+gry-rzf+xtf-xgs)}{(et-g\ \ )(rz-t\ \ )}} = m^{\frac{t}{et-gr}} n^{\frac{t(gx-ze)}{(et-gr)(rz-t\ \ )}} p^{\frac{t}{rz-tx}} ,$$
$$b^{\frac{-t(esz-ety+gry-rzf+xtf-x\ \ \ )}{(et-gr)(rz-tx)}} = m^{\frac{t}{et-gr}} n^{\frac{t(gx-ze)}{(et-g\ \ )(rz-t\ \ )}} p^{\frac{t}{rz-tx}} ,$$
$$b^{esz-ety+gry-rzf+xtf-xg} = m^{-(rz-tx)} n^{-(gx-ze)} p^{-(rt-g\ \ )} ,$$
$$b^{esz-ety-fsr+xtf+gry} = m^{-(rz-tx)} n^{ez-gx} p^{-(rt-gr)} ,$$
(46)

Inputting (33), (34), (35), (36), (37), (38), (39), (40), (41), and (42) in (46), the corresponding relationship is established:
$$b^{\Delta_{kif}} = m^{kif_{12}} n^{kif_{22}} p^{kif_{32}},$$

$$b = m^{\left(\frac{kif_{12}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{22}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{32}}{\Delta_{kif}}\right)},$$
(47)

From (22), it is obtained that:

$$a^{\frac{e}{f}} b c^{\frac{g}{f}} = m^{\frac{1}{f}},$$
(48)

From (23), it is obtained that:

$$a^{\frac{r}{s}} b c^{\frac{t}{s}} = n^{\frac{1}{s}},$$
(49)

And from (24), it is obtained that:

$$a^{\frac{x}{y}} b c^{\frac{z}{y}} = p^{\frac{1}{y}},$$
(50)

To eliminate b, divide (48) with (49) and (49) with (50), so the following is obtained:

Dividing (48) with (49), so the following equation is formulated:

$$a^{\frac{e}{f}-\frac{r}{s}} c^{\frac{g}{f}-\frac{t}{s}} = m^{\frac{1}{f}} n^{-\frac{1}{s}},$$
$$a^{\frac{es-fr}{fs}} c^{\frac{gs-ft}{fs}} = m^{\frac{1}{f}} n^{-\frac{1}{s}},$$
(51)

$$a c^{\frac{gs-ft}{es-fr}} = m^{\frac{s}{es-fr}} n^{-\frac{f}{es-fr}},$$
(52)

Dividing (49) with (50), so the following equation is formulated:

$$a^{\frac{r}{s}-\frac{x}{y}} c^{\frac{t}{s}-\frac{z}{y}} = n^{\frac{1}{s}} p^{-\frac{1}{y}},$$
$$a^{\frac{ry-sx}{sy}} c^{\frac{ty-sz}{sy}} = n^{\frac{1}{s}} p^{-\frac{1}{y}},$$
(53)

$$a c^{\frac{ty-sz}{ry-sx}} = n^{\frac{y}{ry-sx}} p^{-\frac{s}{ry-sx}},$$
(54)

To find c, eliminate a by dividing (52) with (54), so the following can be determined:

$$c^{\frac{gs-ft}{es-fr}-\frac{ty-sz}{ry-sx}} = m^{\frac{s}{es-fr}} n^{-\frac{f}{es-fr}-\frac{y}{ry-sx}} p^{\frac{s}{ry-sx}},$$
$$c^{\frac{(gs-ft)(ry-sx)-(ty-sz)(es-fr)}{(es-fr)(ry-sx)}} = m^{\frac{s}{es-fr}} n^{\frac{-f(ry-sx)-y(es-fr)}{(es-fr)(ry-sx)}} p^{\frac{s}{ry-sx}},$$
$$c^{\frac{gsry-gs^2x-ftry+ftsx-(tyes-tyfr-es^2z+szfr)}{(es-fr)(ry-sx)}} = m^{\frac{s}{es-fr}} n^{\frac{-fry+fsx-yes+}{(es-fr)(ry-sx)}} p^{\frac{s}{ry-sx}},$$
$$c^{\frac{gsry-gs^2x-ftry+ftsx-tyes+tyfr+es^2z-szfr}{(es-fr)(ry-s\ )}} = m^{\frac{s}{es-fr}} n^{\frac{fsx-yes}{(es-f\ )(ry-s\ )}} p^{\frac{s}{ry-s}},$$
$$c^{\frac{es^2z-tyes+gsry-szfr+ftsx-gs^2x}{(es-fr)(ry-sx)}} = m^{\frac{s}{es-fr}} n^{\frac{s(fx-ye)}{(es-fr)(ry-s\ )}} p^{\frac{s}{ry-sx}},$$
$$c^{\frac{s(esz-ety+gry-rzf+xtf-xgs)}{(es-fr)(ry-sx)}} = m^{\frac{s}{es-f}} n^{\frac{s(fx-ye)}{(es-fr)(ry-sx)}} p^{\frac{s}{ry-sx}},$$
$$c^{esz-ety+gry-rzf+xtf-xgs} = m^{ry-sx} n^{fx-y}\ p^{es-fr},$$
$$c^{esz-ety-fsr+xtf+gry-xgs} = m^{ry-sx} n^{fx-ye} p^{es-fr},$$
(55)

Inputting (33), (34), (35), (36), (37), (38), (39), (40), (41), and (42) in (55), the corresponding relationship is established:

$$c^{\Delta_{kif}} = m^{kif_{13}} n^{kif_{23}} p^{kif_{33}},$$
$$c = m^{\left(\frac{kif_{13}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{23}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{33}}{\Delta_{kif}}\right)},$$
(56)

Generally, Kifilideen's Rule or Model for solving product index nonlinear simultaneous equations with three variables, denoted as a, b and c, in the form:
$a^e b^f c^g = m$,
$a^r b^s c^t = n$,
$a^x b^y c^z = p$,
is given as:

$$a = m^{\left(\frac{kif_{11}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{21}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{31}}{\Delta_{kif}}\right)},$$

$$b = m^{\left(\frac{kif_{12}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{22}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{32}}{\Delta_{kif}}\right)},$$

$$c = m^{\left(\frac{kif_{13}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{23}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{33}}{\Delta_{kif}}\right)},$$

Generally, Kifilideen's Rule or Model for solving product tetra-index nonlinear simultaneous equations with four variables, denoted as a, b, c and d, in the form:
$a^e b^f c^g d^h = m$,
$a^r b^s c^t d^j = n$,
$a^x b^y c^z d^l = p$,
$a^u b^v c^w d^k = q$,
is given as:

$$a = m^{\left(\frac{kif_{11}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{21}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{31}}{\Delta_{kif}}\right)} q^{\left(\frac{kif_{41}}{\Delta_{kif}}\right)},$$

$$b = m^{\left(\frac{kif_{12}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{22}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{32}}{\Delta_{kif}}\right)} q^{\left(\frac{kif_{42}}{\Delta_{kif}}\right)},$$

$$c = m^{\left(\frac{kif_{13}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{23}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{33}}{\Delta_{kif}}\right)} q^{\left(\frac{kif_{43}}{\Delta_{kif}}\right)},$$

$$d = m^{\left(\frac{kif_{14}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{24}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{34}}{\Delta_{kif}}\right)} q^{\left(\frac{kif_{44}}{\Delta_{kif}}\right)},$$

Results

The Kifilideen's Rule was implemented as a model for solving complex problems involving product index nonlinear simultaneous equations with two and three variables. Furthermore, the general solution for solving product n −indexes nonlinear simultaneous equations with n variables using Kifilideen's Rule was unveiled. The proposed method successively establishes a comprehensive approach, demonstrating its effectiveness and superiority over traditional techniques in handling multiplication-based systems.

Implementation of Kifilideen's Rule for solving product bi-index nonlinear simultaneous equations with two variables

1. Solve the product bi-index nonlinear simultaneous equations with two variables using Kifilideen's Rule given that:
$x^5 y^2 = 288$,
(57)
$x^3 y^4 = 648$,
(58)

Solution

The Δ_{kif}= the determinant of matrix of the input index system

$\Delta_{kif}= \begin{vmatrix} 5 & 2 \\ 3 & 4 \end{vmatrix} = 20 - 6$,

$\Delta_{kif}= 14$,

kif =the matrix of the input index system

$kif = \begin{pmatrix} 5 & 2 \\ 3 & 4 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}$,

The components of the cofactor of kif are given as:

$kif_{11} = cofactor\ of\ a_{11} = 4$,

$kif_{12} = cofactor\ of\ a_{12} = -3$,

$kif_{21} = cofactor\ of\ a_{21} = -2$,

$kif_{22} = cofactor\ of\ a_{22} = 5$,

Using Kifilideen's Rule, the following equations are obtained:

$x = m^{\left(\frac{kif_{11}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{21}}{\Delta_{kif}}\right)}$,

$x = 288^{\left(\frac{4}{14}\right)} 648^{\left(\frac{-2}{14}\right)}$,

$x = (288^4 648^{-2})^{\frac{1}{14}}$,

$x = (16384)^{\frac{1}{14}}$,

$x = 2$,

$y = m^{\left(\frac{kif_{12}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{22}}{\Delta_{kif}}\right)}$,

$y = (288^{-3} 648^5)^{\frac{1}{14}}$,

$y = (4782969)^{\frac{1}{14}}$,

$y = 3$,

So, $x = 2$ and $y = 3$.

The implementation of Kifilideen's Rule for solving product bi-index nonlinear simultaneous equations with two variables

is short, effective, accurate and easy to understand and comprehend. It can also be applied if the indexes are negative values.

Utilization of Kifilideen's Rule for solving product tri-index simultaneous equations with three variables

2. Solve the product tri-index simultaneous equations with three variables using Kifilideen's Rule given that:

$r^3 s^4 t^2 = 18,000$,

(59)

$r^1 s^5 t^6 = 116,640$,

(60)

$r^2 s^3 t^1 = 600$,

(61)

Solution

The Δ_{kif}= the determinant of matrix of the input index system

$\Delta_{kif}= \begin{vmatrix} 3 & 4 & 2 \\ 1 & 5 & 6 \\ 2 & 3 & 1 \end{vmatrix}$

$\Delta_{kif}= 3 \begin{vmatrix} 5 & 6 \\ 3 & 1 \end{vmatrix} - 4 \begin{vmatrix} 1 & 6 \\ 2 & 1 \end{vmatrix} + 2 \begin{vmatrix} 1 & 5 \\ 2 & 3 \end{vmatrix}$

$\Delta_{kif}= 3(5 - 18) - 4(1 - 12) + 2(3 - 10)$,

$\Delta_{kif} = 3(-13) - 4(-11) + 2(-7),$
$\Delta_{kif} = -39 + 44 - 14,$
$\Delta_{kif} = -9,$
kif =the matrix of the input index system

$$kif = \begin{pmatrix} 3 & 4 & 2 \\ 1 & 5 & 6 \\ 2 & 3 & 1 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

The components of the cofactor of kif are given as:

$kif_{11} = cofactor\ of\ a_{11} = \begin{vmatrix} 5 & 6 \\ 3 & 1 \end{vmatrix} = 5 - 18 = -13,$

$kif_{12} = cofactor\ of\ a_{12} = -\begin{vmatrix} 1 & 6 \\ 2 & 1 \end{vmatrix} = -(1 - 12) = 11,$

$kif_{13} = cofactor\ of\ a_{13} = \begin{vmatrix} 1 & 5 \\ 2 & 3 \end{vmatrix} = 3 - 10 = -7,$

$kif_{21} = cofactor\ of\ a_{21} = -\begin{vmatrix} 4 & 2 \\ 3 & 1 \end{vmatrix} = -(4 - 6) = 2,$

$kif_{22} = cofactor\ of\ a_{22} = \begin{vmatrix} 3 & 2 \\ 2 & 1 \end{vmatrix} = 3 - 4 = -1,$

$kif_{23} = cofactor\ of\ a_{23} = -\begin{vmatrix} 3 & 4 \\ 2 & 3 \end{vmatrix} = -(9 - 8) = -1,$

$kif_{31} = cofactor\ of\ a_{31} = \begin{vmatrix} 4 & 2 \\ 5 & 6 \end{vmatrix} = 24 - 10 = 14,$

$kif_{32} = cofactor\ of\ a_{32} = -\begin{vmatrix} 3 & 2 \\ 1 & 6 \end{vmatrix} = -(18 - 2) = -16,$

$kif_{33} = cofactor\ of\ a_{33} = \begin{vmatrix} 3 & 4 \\ 1 & 5 \end{vmatrix} = 15 - 4 = 11$,

Using Kifilideen's Rule, so the following equations are obtained:

$r = m^{\left(\frac{kif_{11}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{21}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{31}}{\Delta_{kif}}\right)},$
$r = (18,000^{-13} \times 116,640^{\,2} \times 600^{\,14})^{\frac{-1}{9}},$
$r = (18,000^{13} \times 116,640^{\,-2} \times 600^{\,-14})^{\frac{1}{9}},$
$r = (1953125)^{\frac{1}{9}},$
$r = 5,$
$s = m^{\left(\frac{kif_{12}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{22}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{32}}{\Delta_{kif}}\right)},$
$s = (18,000^{11} \times 116,640^{\,-1} \times 600^{\,-16})^{\frac{-1}{9}},$
$s = (18,000^{-11} \times 116,640^{\,1} \times 600^{\,16})^{\frac{1}{9}},$
$s = (512)^{\frac{1}{9}},$
$s = 2,$
$t = m^{\left(\frac{kif_{13}}{\Delta_{kif}}\right)} n^{\left(\frac{kif_{23}}{\Delta_{kif}}\right)} p^{\left(\frac{kif_{33}}{\Delta_{kif}}\right)},$
$t = (18,000^{-7} \times 116,640^{\,-1} \times 600^{\,11})^{\frac{-1}{9}},$
$t = (18,000^{7} \times 116,640^{\,1} \times 600^{\,-11})^{\frac{1}{9}},$
$t = (18683)^{\frac{1}{9}},$
$t = 3,$
So, $r = 5,\ \ s = 2$ and $t = 3$.

The utilization of Kifilideen's Rule or Model for solving product tri-index simultaneous equations with three variables demonstrates that the model is simple, accurate, and exact. It is also intuitive, straightforward, easy to understand, and highly effective, making it an interesting and practical approach for solving complex mathematical problems. It can also be applied if the indexes are negative values.

Significance of Kifilideen's Rule in solving product index nonlinear simultaneous equations

The Kifilideen's Rule plays a crucial role in solving product index nonlinear simultaneous equations involving two, three, and n variables. Its significance extends across various disciplines, including population growth analysis, neutron-nuclear reactor analysis, forecasting, finance, chemistry, agriculture, biology, computer science, physics, engineering, industry, manufacturing company and game design.

One of its primary applications is in modeling population growth, particularly when it follows a geometric pattern of factor changes over time. For instance, consider a bacterial population P_o, where:

- The first bacterium grows by a factor x each for n cycles, the second for m cycles, and the third for v $cycle$s.
- Subsequently, the same bacteria start growing by a different factor y for u, p and q cycles respectively. At the end of these stages, the total populations of the three bacteria P_1, P_2 and P_3 are given by:

$P_1 = P_o\, x^n y^u$,
$P_2 = P_o\, x^m y^p$ and
$P_3 = P_o\, x^v y^q$.

Using Kifilideen's Rule, the values of the growth factors x and y, as well as the initial population P_o, can be determined precisely, avoiding complex iterative computation.

Beyond population dynamics, Kifilideen's Rule applies to systems that exhibit geometric growth. For example, in economic analysis, the cost of goods may increase by a specific factor at one level for a certain number of cycles and another factor at a higher level. Kifilideen's Rule helps determine these growth factors and initial value before escalation.

Kifilideen's Rule can also be employed to solve geometric sequence problem of the form:
$T_n = ar^{n-1}$
Where, a is the first term and r is the common ratio. This results in product bi-index simultaneous equations with two variables (Xin and Wei, 2018; Liao et al., 2022). The Kifilideen's Rule efficiently determine the value a and r, which has practical implications in engineering and industrial design. For example, in manufacturing, products are often designed in multiple levels or steps. Within each level, the size of a product may increase by a specific factor, and across levels, another scaling factor may apply. Kifilideen's Rule helps compute these growth ratios, ensuring precise product design and optimization. Additionally, it allows for the determination of the initial product size before modifications.

In salary structure, that follows geometric sequence, Kifilideen's Rule aids in breaking down salary components, identifying incremental growth factors, and predicting future salary levels with accuracy.

Benefits of Kifilideen's Rule in solving product index nonlinear simultaneous equations

1. Structured Problem-Solving: Provides a systematic approach for solving nonlinear simultaneous equations involving geometric multiplication.
2. Forecasting and Prediction: Useful in trend analysis across various scientific and economic domains.
3. Simplification of Complex Computations: Reduces intricate problems into manageable equations with exact solutions.
4. Enhancement of Analytical and Cognitive Skills: Encourages critical thinking and logical reasoning.
5. Efficiency and Accuracy: Eliminates trial-and-error approaches, improving the speed and precision of problem-solving.

Application of Kifilideen's Rule to solve multiplication of bi-indexes and tri-indexes simultaneous equations of two variables and three variables respectively

(1) Three bacteria of population, P_o increase by a factor of x each for 5 times for first bacteria, 2 times for second bacteria and 4 times for third bacteria respectively and later on the population of the three bacteria start to increase by a factor of y each for 3 times for first bacteria, 6 times for second bacteria and 2 times for third bacteria respectively. At the end of the 3 times, 6 times and 2 times multiplication of the population of the three bacteria respectively, the total populations of the three bacteria are $P_1 = 432,\ 000, P_2 = 1,458,000$ and $P_3 = 72,000$ respectively. Determine the

(i) initial population, P_o of each of the bacteria,

(ii) the factors, x of the population growth,

(iii) the factors, y of the population growth.

Solution

The mathematical equations of the population growth of the three bacteria are given as:

$P_1 = P_o\, x^5 y^3 = 432,000,$

$P_2 = P_o\, x^2 y^6 = 1,458,000$ and

$P_3 = P_o\, x^4 y^2 = 72,000.$

The $\Delta_{kif}=$ the determinant of matrix of the input index system

$$\Delta_{kif}= \begin{vmatrix} 1 & 5 & 3 \\ 1 & 2 & 6 \\ 1 & 4 & 2 \end{vmatrix}$$

$$\Delta_{kif}= 1\begin{vmatrix} 2 & 6 \\ 4 & 2 \end{vmatrix} - 5\begin{vmatrix} 1 & 6 \\ 1 & 2 \end{vmatrix} + 3\begin{vmatrix} 1 & 2 \\ 1 & 4 \end{vmatrix}$$

$\Delta_{kif}= 1(4-24) - 5(2-6) + 3(4-2),$

$\Delta_{kif}= 1(-20) - 5(-4) + 3(2),$

$\Delta_{kif}= -20 + 20 + 6,$

$\Delta_{kif}= 6,$

kif =the matrix of the input index system

$$kif = \begin{pmatrix} 1 & 5 & 3 \\ 1 & 2 & 6 \\ 1 & 4 & 2 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

The components of the cofactor of kif are given as:

$$kif_{11} = cofactor\ of\ a_{11} = \begin{vmatrix} 2 & 6 \\ 4 & 2 \end{vmatrix} = 4 - 24 = -20,$$

$$kif_{12} = cofactor\ of\ a_{12} = -\begin{vmatrix} 1 & 6 \\ 1 & 2 \end{vmatrix} = -(2-6) = 4,$$

$$kif_{13} = cofactor\ of\ a_{13} = \begin{vmatrix} 1 & 2 \\ 1 & 4 \end{vmatrix} = 4 - 2 = 2,$$

$$kif_{21} = cofactor\ of\ a_{21} = -\begin{vmatrix} 5 & 3 \\ 4 & 2 \end{vmatrix} = -(10-12) = 2,$$

$$kif_{22} = cofactor\ of\ a_{22} = \begin{vmatrix} 1 & 3 \\ 1 & 2 \end{vmatrix} = 2 - 3 = -1,$$

$$kif_{23} = cofactor\ of\ a_{23} = -\begin{vmatrix} 1 & 5 \\ 1 & 4 \end{vmatrix} = -(4-5) = 1,$$

$$kif_{31} = cofactor\ of\ a_{31} = \begin{vmatrix} 5 & 3 \\ 2 & 6 \end{vmatrix} = 30 - 6 = 24,$$

$$kif_{32} = cofactor\ of\ a_{32} = -\begin{vmatrix} 1 & 3 \\ 1 & 6 \end{vmatrix} = -(6-3) = -3,$$

$$kif_{33} = cofactor\ of\ a_{33} = \begin{vmatrix} 1 & 5 \\ 1 & 2 \end{vmatrix} = 2 - 5 = -3 \qquad ,$$

Using Kifilideen's Rule, so the following are obtained:

$P_o = (432,000)^{\left(\frac{kif_{11}}{\Delta_{kif}}\right)}(1,458,000)^{\left(\frac{kif_{21}}{\Delta_{kif}}\right)}(72,000)^{\left(\frac{kif_{31}}{\Delta_{kif}}\right)}$,
$P_o = (432,000)^{\left(\frac{-20}{6}\right)}(1,458,000)^{\left(\frac{2}{6}\right)}(72,000)^{\left(\frac{24}{6}\right)}$,
$P_o = ((432,000)^{-2}\ (1,458,000)^{2}(72,000)^{24})^{\frac{1}{6}}$,
$P_o = (1.5625 \times 10^{16})^{\frac{1}{6}}$,
P_o =initial population of each of the bacteria$= 500$,
$x = (432,000)^{\left(\frac{kif_{12}}{\Delta_{kif}}\right)}(1,458,000)^{\left(\frac{kif_{22}}{\Delta_{kif}}\right)}(72,000)^{\left(\frac{kif_{32}}{\Delta_{kif}}\right)}$,
$x = (432,000)^{\left(\frac{4}{6}\right)}(1,458,000)^{\left(\frac{-1}{6}\right)}(72,000)^{\left(\frac{-3}{6}\right)}$,
$x = ((432,000)^{4}(1,458,000)^{-1}(72,000)^{-3})^{\frac{1}{6}}$,
$x = (64)^{\frac{1}{6}}$,
$x = 2$
The factors, x of the population growth $= 2$
$y = (432,000)^{\left(\frac{kif_{13}}{\Delta_{kif}}\right)}(1,458,000)^{\left(\frac{kif_{23}}{\Delta_{kif}}\right)}(72,000)^{\left(\frac{kif_{33}}{\Delta_{kif}}\right)}$,
$y = (432,000)^{\left(\frac{2}{6}\right)}(1,458,000)^{\left(\frac{1}{6}\right)}(72,000)^{\left(\frac{-3}{6}\right)}$,
$y = ((432,000)^{2}(1,458,000)^{1}(72,000)^{-3})^{\frac{1}{6}}$,
$y = (729)^{\frac{1}{6}}$,
$y = 3$
The factors, y of the population growth $= 3$

(2) The initial salary of a staff in an organization is ₦a. If the salary of the staff is increasing geometrically as the staff migrates from his initial organization to higher organizations due to the complexity of the nature of work carry out by the staff in the higher organizations. After the increase in salary of the staff by a factor of u for 4 times as the staff migrates to higher organizations, the staff is receiving ₦$480,000$. If after the increase in salary of the staff by a factor of u for 7 times as the staff migrates to higher organizations, the staff is receiving ₦$3,840,000$. Determine the
(i) the initial salary of the staff, ₦a in the first organization,
(ii) the factor, u, at which the salary of the staff is increasing.

Solution
The mathematical equations of the salary growth of staff are given as:
$au^4 =$ ₦$480,000$,
$au^7 =$ ₦$3,840,000$,
The Δ_{kif}= the determinant of matrix of the input index system
$\Delta_{kif}= \begin{vmatrix} 1 & 4 \\ 1 & 7 \end{vmatrix} = 7 - 4$,
$\Delta_{kif}= 3$,
kif =the matrix of the input index system
$kif = \begin{pmatrix} 1 & 4 \\ 1 & 7 \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}$,
The components of the cofactor of kif are given as:
$kif_{11} = cofactor\ of\ a_{11} = 7$,
$kif_{12} = cofactor\ of\ a_{12} = -1$,
$kif_{21} = cofactor\ of\ a_{21} = -4$,
$kif_{22} = cofactor\ of\ a_{22} = 1$,

Using Kifilideen's Rule, so the following are obtained:

$₦a = (480,000)^{\left(\frac{kif_{11}}{\Delta_{kif}}\right)}(3,840,000)^{\left(\frac{kif_{21}}{\Delta_{kif}}\right)}$,

$₦a = (480,000)^{\left(\frac{7}{3}\right)}(3,840,000)^{\left(\frac{-4}{3}\right)}$

$₦a = ((480,000)^{7}(3,840,000)^{-4})^{\frac{1}{3}}$,

$₦a = (2.7 \times 10^{13})^{\frac{1}{3}}$,

$₦a = ₦30,000$,

The initial salary of the staff, $₦a$ in the first organization$= ₦30,000$

$u = (480,000)^{\left(\frac{kif_{12}}{\Delta_{kif}}\right)}(3,840,000)^{\left(\frac{kif_{22}}{\Delta_{kif}}\right)}$,

$u = (480,000)^{\left(\frac{-1}{3}\right)}(3,840,000)^{\left(\frac{1}{3}\right)}$

$u = ((480,000)^{-1}(3,840,000)^{1})^{\frac{1}{3}}$,

$u = (8)^{\frac{1}{3}}$,

$u = 2$,

The factor, u, at which the salary of the staff is increasing$= 2$

Let us give the following theorem without proof

Theorem. Let the following equation be the system.

$$\prod_{i=1}^{n} x_{1i}^{t_{1i}} = b_1,$$

$$\prod_{i=1}^{n} x_{1i}^{t_{2i}} = b_2 \text{ , where } n \in Z^{+}$$

$$\vdots$$

$$\prod_{i=1}^{n} x_{1i}^{t_{ni}} = b_n.$$

If the solution of the system of equations has only one solution, then

$$x_{11} = \prod_{i=1}^{n} b_i^{\left(\frac{kif_{i1}}{\Delta_{kif}}\right)},$$

$$x_{12} = \prod_{i=1}^{n} b_i^{\left(\frac{kif_{i2}}{\Delta_{kif}}\right)},$$

$$\vdots$$

$$x_{1n} = \prod_{i=1}^{n} b_i^{\left(\frac{kif_{in}}{\Delta_{kif}}\right)}.$$

The proposed method successively establishes a comprehensive approach, demonstrating its effectiveness and superiority over traditional techniques in handling multiplication-based systems.

Conclusion

This study introduces Kifilideen's Rule, a groundbreaking approach for solving product index nonlinear simultaneous equations involving two, three, four, and n variables. The objective is to establish a reliable, efficient, and mathematically rigorous method that overcomes the limitations of conventional techniques. The formulation of Kifilideen's Rule is based on elimination methods, the laws of indices, and matrix theory, including cofactors and determinants. These mathematical principles are systematically applied to construct a general framework for solving product index nonlinear simultaneous equations. The proposed method successfully establishes a general solution for $n-$variable product index nonlinear simultaneous equations, demonstrating its superiority over traditional techniques in handling multiplication-based systems. Kifilideen's Rule offers an efficient, precise, and practical solution for complex nonlinear simultaneous equations. Its direct and exact approach makes it highly valuable for students, researchers, and professionals in fields that require highly accurate mathematical modeling. Kifilideen's Rule provides a systematic and efficient framework for solving product index simultaneous equations, enabling analysis of variables contributing to a system's output.

Conflict of Interest

No conflict of interests.

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Expanding Choice and Inclusion: Application of Kifilideen's Arithmetic Matrix Progression Sequence (KAMPS) in Product Design, Economic Distribution, and Structural Frameworks

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Abstract

Mathematical sequences plays a crucial role in structuring systems across industries, including product design and economic distribution. Traditional arithmetic progression models impose rigid constraints that limit flexibility and inclusivity. Kifilideen's Matrix Arithmetic Progression Sequence (KMAPS) offers a dynamic and scalable alternative for optimizing hierarchical frameworks and ensuring fair distribution. Existing arithmetic models lack adaptability, leading to restricted product customization, inequitable resource allocation, and inefficient hierarchical structuring in industries such as manufacturing, salary distribution, and game development. A more inclusive mathematical framework is needed to effectively accommodate multi-level systems. KMAPS introduces a structured yet flexible approach that ensures equitable distribution, customizable product scaling, and efficient hierarchical organization. Unlike traditional methods, KMAPS expands choice and inclusion across industries, making it a superior alternative. This study develops and applies KMAPS to optimize decision-making in product design, economic distribution, game development, and structural frameworks while ensuring inclusivity. Using mathematical modeling, matrix progression, and structural framework analysis, KMAPS was formulated as a sequence that expands progressively, increasing members at each level. Its applications in salary structuring, product sizing, and task distribution were analyzed. KMAPS proved more adaptable, inclusive and scalable than traditional arithmetic models. It successfully structured hierarchical differentiation, fair distribution, and multi-tiered organization, making it ideal for industries requiring precision and equity. KMAPS emerges as a transformational mathematical tool for structuring systems, optimizing resource allocation, and enhancing decision-making. Its ability to enhance choice and inclusion makes it a superior alternative to conventional arithmetic sequences, with potential for broader industrial applications.

Keywords: Kifilideen's Matrix, Arithmetic Progression Sequence, Optimization, Inclusion, Fair Distribution, Hierarchical Structuring

Introduction

Mathematics is the backbone of a nation and the scientific world, enabling scientists to make accurate and precise predictions about future events and forecast (Kolawole, 2004; Kolawole and Ojo, 2019; Osanyinpeju, 2021). Mathematics develops thinking, reasoning, and problem-solving skills that help individuals navigate real-world challenges (Bonotto and Santo, 2015; Ozdemir and Celik, 2021; Osanyinpeju, 2022). In order to excel in mathematics, mathematical thinking and reasoning must come to play in the establishment of fact (Osanyinpeju *et al.,* 2019; Ozdemir and Celik, 2020).

Considering a cluster of different hierarchical order with various barrier levels; designing a structural framework can effectively identify, differentiate, analyze, and formulate and provisional values to cluster members at various barrier levels and steps. There is no structured flow available for organizing cluster members into a framework with different levels and steps. Matrix progression sequence into structural framework has practical application in area of hierarchical clusters, competition for resource, sharing formula among members of cluster and food chain. The educational sector is in hierarchical order which can be formulated into structural framework (Moja, 2000; Ikechukwu, 2015). Nigeria as a case study, the educational sector is divided into levels which are nursery, primary, secondary and tertiary levels which represent the levels of a structural framework (Amaghionyeodiwe and Osinubi, 2006; Ezeanochie and Alamgir, 2021). In each level there are categories of steps which represent the steps in the structural framework. For example, the primary level has primary 1 to 6 which serves as the steps; secondary school level has JS 1 – 3 and SS 1 – 3 while the tertiary level has 100 – 500 levels (Ndidi, 2013; Nakpodia, 2020; Kinika-Nsirim and Okeah, 2021).

The nursery level has the largest number of students which in turn requires the largest number of teachers/members/staff in the clusters of the educational sectors. The rewards given to members/staff/teachers in the highest step in the nursery level is the smallest reward compared to the highest steps in other levels (primary, secondary and tertiary levels) of the educational sector. As we move down the steps in the nursery levels, the reward decreases. What contributes to the lowest reward in the nursery level compare to other levels in the educational sector are low skill, low qualification, simplicity of job, low demanding of effort, low task and effort, low input and low level of expertise. There is hierarchy within the nursery level in which staff/members/teachers are in various steps depending on their qualifications, experience and number of years spend in the organisation. The most senior staff/officer in the nursery level has the highest reward or pay or remuneration and the reward or pay or remuneration decreases as the hierarchy drops at the nursery level in the structural framework. To migrate from the nursery level to another level, there is need to meet up with the criteria required in the higher level. Also, within a nursery level or other levels, members can migrate from one step to another which can come as a result of addition of more skill, experience, exposure in the field and more years spent in the level.

As we migrate to higher level in the structural framework, the number of steps and also the number of members reduce. The highest step in the primary level receives more reward than the highest step in the nursery level. Within the primary level, as we move down, the level the degree of steps drops so, reward decreases. Within every level in the educational sector, hierarchical order is present. Furthermore, at the secondary level, the number of students further reduced which may come as a result of loss of interest in the part of the student, insufficient fund to further the education, no availability of sponsor, having low potential to cope, low performance and more effectiveness to trade. The lesser number of students in the secondary school results to lesser number of teachers; although the reward is more for each teacher/member/staff in this level due to the complexity of task they undergo, more skill, and more expertise. Migrating to the tertiary level, the number of students drops more alongside the number of teacher/staff. The drop in the number of students is as a result of some students not meeting up with the prerequisite to be students in the tertiary; and tertiary level is more demanding, making only the strong ones among be able to proceed. Also, to move to the higher level, it requires more fund which some students may not be able to meet up. Each teacher/member/staff at this level gets more reward than the lower levels (nursery, primary and secondary levels) because teacher/member/staff at this level uses sophisticated and complex tools which require more skill, advancement, expertise, experience, input, effort and relative complexity. For each of the levels, there is hierarchical order within their level where each member within a level is placed in step. For example, at the secondary school level; staff handling senior class would be placed at a higher step and be rewarded more than the staff at the junior class. Placing the member of the cluster of the educational sector in a structural framework would help to formulate sharing formula of reward to the member of the cluster of the sector.

Furthermore, in secondary school educational sector, a cluster of members is formed in hierarchical order which is grouped into levels which are subject teachers, head of department HoD, vice principal and principal (Bello *et al.,* 2016; Munje *et al.,* 2020; Irvine, 2022). The order of increase in levels span from subject teachers, head of department HoD, vice principal and principal (Maja, 2016; Osuji and Etuketu, 2019; Abdullah and Salihu, 2020). As we migrate from one level into higher levels the number of members decreases. The class teachers have the largest number of members but each member in that level is less skilled and less rewarded compare to the other levels such as the head of department (HoD), vice principal and principal. At the head of department level, more skill, input and display diversity of knowledge and experience which bring more reward are required, the same trend is applied to the vice principal and principal. The principal has the lowest number of members but the most skill, highly experienced in the field and has the highest complexity of task. Within each level, there is present of steps. Each member of a particular level would pass through steps to get to the peak step such a level. To migrate from one level to other members, have to upgrade themselves to fit into the next level which result to more reward for such member (Arikewuyo, 2009). The cluster of members in the secondary school sector can be formulated into structural framework.

Mathematics serves as the foundation for structuring and optimizing real-world systems, enabling precise modeling in field such as engineering, economics, product design, and game development. One of the fundamental tools in structuring hierarchical systems is arithmetic progression, which provides a systematic way of organizing levels, distributing resources, and designing scalable frameworks. However, traditional arithmetic sequences often impose rigid constraints that fail to account for the diversity of subgroups within a structured system. This limitation restricts product customization, fair economic distribution, and multi-tiered structuring, leading to inefficiencies in industries that require dynamic allocation and hierarchical organization.

To address these limitations, this paper introduces Kifilideen's Matrix Arithmetic Progression Sequence (KMAPS), a generalized and adaptable framework that expands the traditional arithmetic sequence to optimize inclusivity, resource distribution, and structural flexibility. KMAPS originates from the generalization of the Kifilideen's Matrix Structural Framework, which was developed based on the Kifildeen Trinomial Theorem. This sequence is designed to progressively expand, ensuring that each level and sublevel accommodates an increasing number of members in a structured yet adaptable manner. By integrating KMAPS, systems can achieve greater efficiency, scalability, and inclusivity across multiple sectors.

The primary aim of this study is to develop and apply KMAPS as an advanced mathematical framework for optimizing hierarchical structuring equitable resource distribution, and multi-level decision-making. Specifically, the study seeks to:

1. Establish KMAPS as an alternative to conventional arithmetic sequences for structural decision-making.
2. Demonstrate its application in optimizing product design, economic distribution, and game development.
3. Validate its effectiveness in structuring hierarchical systems, ensuring adaptability across multiple industries
4. Develop mathematical models that enhance fairness, inclusion, and scalability in structured frameworks.

KMAPS has broad applicability across various domains, including:

1. Product Design: Ensuring products are available in diverse sizes and specifications, catering to different consumer needs
2. Economic Distribution: Providing a structured and fair salary allocation system that accounts for hierarchical levels and progression.
3. Game Development: Designing game levels and task distributions that maintain a logical progression for users.
4. Hierarchical Structuring: Creating adaptable organizational models that efficiently classify members based on their role, experience, and contributions.

By introducing KMAPS, this study provides an innovative solution that enhances choice, inclusion, and structured decision-making across industries. Unlike traditional arithmetic progressions, which are fixed and restrictive, KMAPS allows for scalable growth and adaptability, making it highly relevant in industries that rely on dynamic structuring and fair distribution.

Materials and Methods

The methodology used to validate Kifilideen's mathematical formulation for generating the infinite sequence of increasing members across successive levels, starting with a single member at the first level, is proven using mathematical induction in this paper.

A Kifilideen's Clustered Framework presented in this paper consists of sets of entities with related attributes, each uniquely represented, thereby forming different levels and steps within those levels. Furthermore, levels are represented as columns, while steps are represented as rows in Kifilideen's Matrix Structural Framework for cluster members. Image an array of related sequential Kifilideen's Generalized Matrix Progression of infinite term for a cluster, with a view to expand the chain as the trend advances say in order of Table 1, where each term is a function defined as T_n for $\{n = 1, 2, 3, 4, \dots\}$.

Table 1. The Kifilideen's Matrix Structural Framework for an infinite term

	$Level$ 1	$Level$ 2	$Level$ 3	$Level$ 4	$Level$ 5	…
$Step$ 1	T_1					
$Step$ 2		T_2				
$Step$ 3		T_3	T_4			
$Step$ 4			T_5	T_7		
$Step$ 5			T_6	T_8	T_{11}	
$Step$ 6				T_9	T_{12}	.
$Step$ 7				T_{10}	T_{13}	..
$Step$ 8					T_{14}	…
$Step$ 9					T_{15}	…
$Step$ 10						…
$Step$ 11						…

System of Kifilideen Generalized Matrix Progression Sequence of Infinite Term

The system of progression of Kifilideen's Generalized Matrix Sequence of infinite term of increasing members of successive levels with first level having one member is generated as:

$$k(0) + i(0) + f; k(1) + i(0) + f, \quad k(1) + i(1) + f; \ k(2) + i(0) + f, \quad k(2) + i(1) + f \ , k(2) + i(2) + f;$$
$$k(3) + i(0) + f, k(3) + i(1) + f, k(3) + i(2) + f, k(3) + i(3) + f; \ k(4) + i(0) + f \ , k(4) + i(1) + f,$$
$$k(4) + i(2) + f, k(4) + i(3) + f, k(4) + i(4) + f; \ k(5) + i(0) + f \ , k(5) + i(1) + f, k(5) + i(2) + f,$$
$$k(5) + i(3) + f, k(5) + i(4) + f, k(5) + i(5) + f; \ \ k(6) + i(0) + f, k(6) + i(1) + f, k(6) + i(2) + f,$$
$$k(6) + i(3) + f, k(6) + i(4) + f, k(6) + i(5) + f, k(6) + i(6) + f; \ \ k(7) + i(0) + f, k(7) + i(1) + f,$$
$$k(7) + i(2) + f \ , k(7) + i(3) + f, k(7) + i(4) + f, k(7) + i(5) + f, k(7) + i(6) + f, k(7) + i(7) + f; \dots.$$

The Kifilideen's Generalized Matrix Sequence of infinite term of increasing members of successive levels with first level having one member has endless terms. The progression of the sequence has beginning without end. The placement of the progression of each term of the infinite term of the Kifilideen's Generalized Matrix Sequence in standardized order in the Kifilideen's Matrix Structural Framework is displayed in Table 2. From the Table 2; Level $1, \ 2, \ 3{,}4, \ 5, \ \dots$ has $1, 2, 3, 4, 5, \dots$ member (s) respectively. The coefficients of k and i are the same for the last member in each level.

Table 2. The placements of infinite term in the Kifilideen's Matrix Structural Framework.

	l_1	l_2	l_3	l_4	l_5	…
s_1	$k(0)+i(0)+f$					
s_2		$k(1)+i(0)+f$				
s_3		$k(1)+i(1)+f$	$k(2)+i(0)+f$			
s_4			$k(2)+i(1)+f$	$k(3)+i(0)+f$		
s_5			$k(2)+i(2)+f$	$k(3)+i(1)+f$	$k(4)+i(0)+f$	
s_6				$k(3)+i(2)+f$	$k(4)+i(1)+f$	.
s_7				$k(3)+i(3)+f$	$k(4)+i(2)+f$	..
s_8					$k(4)+i(3)+f$	…
s_9					$k(4)+i(4)+f$	…
s_{10}						…
s_{11}						…

The coefficient of k for member (s) in levels $1, 2, 3,4, 5, \dots$ are $0, 1, 2, 3, 4, \dots$ respectively. The coefficient of i is increasing in the level from 0 to one magnitude less than the value of the level in the analyzed level. For any particular sequence, the value of k, i and f have fixed value. k, i and f are the migration level value, migration step value and first term respectively. From the analysis of Table 2, generally step 1 and 2; 3 and 4; 5 and 6; 7 and 8;... have 1; 2; 3; 4;... member (s) respectively. The value of the coefficient of k is fixed for any particular level and step but varies from level and step to another level and step. From one level to another successive level the number of members increases by one. The first level has one member.

Kifilideen's Term Mathematical Formula of Infinite Term

The stepwise mathematical induction of the generation of the Kifilideen's term mathematical formula of infinite term of the Kifilideen's Generalized Matrix Progression Sequence is analyzed as follow:

Level 1, $\boldsymbol{l}$ = 1; $T_1 = k(0) + i(0) + f$

$$T_1 = k(1-1) + i(1-1) + f$$

Level 2, $\boldsymbol{l}$ = 2; $T_2 = k(1) + i(0) + f$

$$T_2 = k(2-1) + i(2-2) + f$$

$$T_3 = k(1) + i(1) + f$$

$$T_3 = k(2-1) + i(3-2) + f$$

Level 3, $\boldsymbol{l}$ = 3; $T_4 = k(2) + i(0) + f$

$$T_4 = k(3-1) + i(4-4) + f$$
$$T_5 = k(2) + i(1) + f$$
$$T_5 = k(3-1) + i(5-4) + f$$
$$T_6 = k(2) + i(2) + f$$
$$T_6 = k(3-1) + i(6-4) + f$$
.
.
.

Level l, $l = l$;

$$T_n = k(a) + i(s) + f$$
$$T_n = k(l-1) + i(n-m) + f$$
.
.
.

Generally, from the stepwise mathematical induction of the Kifilideen's term mathematical formula of infinite term of Kifilideen's Generalized Matrix Progression Sequence increasing members for successive levels with first level having one member is achieved as:

$$T_n = k(l-1) + i(s) + f \quad (1)$$

$$T_n = k(a) + i(n-m) + f \quad (2)$$

Comparing (1) and (2), $a = l - 1$ and $s = n - m$ (3)

Where T_n is the value of the n^{th} term, f is the first term, k is the migration level value, i is the migration step value, n is the number of term, a is the migration level factor, m is the migration step factor, l is the level value of the term and s is the migration term step difference factor.

Table 3 presents the value of l, a and m for each level of the Kifilideen's Matrix Structural Framework of the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive levels with first level having one member. From the Table, when the values of l (level) are $1, 2, 3, 4, 5, 6, \ldots, l, \ldots, \ldots$ the values of a are $0, 1, 2, 3, 4, 5, \ldots, a, \ldots, \ldots$ respectively while the values of m are $(1) \to 1, (1+1) \to 2, (1+1+2) \to 4, (1+1+2+3) \to 7, (1+1+2+3+4) \to 11, (1+1+2+3+4+5) \to 16, \ldots, m, \ldots, \ldots$ respectively.

So, generally, for infinite term of the Kifilideen's Generalized Matrix Progression Sequence of increasing members for successive levels with first level having one member, we have:

For $a = a = l - 1, m = 1 + 1 + 2 + 3 + 4 + 5 + \cdots$

Let $m = 1 + \beta$, where $\beta = 1 + 2 + 3 + 4 + 5 + \cdots$ (4)

The series of β is arithmetic progression series. From Table 2, omitting the first term of the series of m in the Table, the number of term of β is equivalent to the value of a.

Using the summation of arithmetic progression formula showcased by Stroud and Booth (2007), Oluwasanmi (2011); we have:

$$S_z = \frac{z}{2}(2w + (z-1)d)$$

Where S_z is sum of the series, β, z is the number of terms of the series, β, w is the first term, and d is the common difference between two successive terms of the series, β.

From (4), $S_z = \beta$, $w = 1, d = T_2 - T_1 = 2 - 1 = 2, z = a =$ migration level factor (5)

$z = a,$ since it has been deduced that number of term of the series of β is equivalent to the value of a when the first term of the series of m is ommitted in the Table 1.

Table 3. The value of l, a and m for each level of the Kifilideen's Matrix Structural Framework of the infinite term.

l	a	m
1	1	$1 = 1$
2	1	$1 + 1 = 2$
3	2	$1 + 1 + 2 = 4$
4	3	$1 + 1 + 2 + 3 = 7$
5	4	$1 + 1 + 2 + 3 + 4 = 11$
.	.	.
.	.	.
l	$l - 1$	$1 + 1 + 2 + 3 + 4 + 5 + 6 + \cdots + (l - 1) = 1 + 1 + 2 + 3 + 4 + 5 + 6 + \cdots + a$
.	.	.
.	.	.
.	.	.

$$S_z = \beta = \frac{a}{2}(2 \times 1 + (a - 1) \times 1)$$

$$\beta = \frac{a(a+1)}{2}$$

(6)

Put (6) in (4), we have: $$m = 1 + \beta = 1 + \frac{a(a+1)}{2}$$

$$m = \frac{a^2+a+2}{2}$$

(36), we have: $$a = l - 1$$

Put (46) in (45), we have: $$m = \frac{(l-1)^2+(l-1)+2}{2}$$

$$m = \frac{l^2-l+2}{2}$$

In all, the Kifilideen's term mathematical formula of infinite term of Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive levels having one member in the first level is obtained as:

$$T_{\boldsymbol{n}} = k(a) + i(n - m) + f$$

(7)

$$a = l - 1, \quad m = \frac{a^2+a+2}{2}, \; m = \frac{l^2-l+2}{2}$$

Where T_n is the value of the n[th] term, f is the first term, k is the migration level value and i is the migration step value, n is the number of term, a is the migration level factor, m is migration step factor, l is the level value of the term and s is the migration term step difference factor.

Mathematical Formulation of the Migration Level Factor, a of Infinite Term

Table 1 layouts the placement of the terms of the Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive levels having one member in the first level. The mathematical formulation of the migration level factor, a of the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive levels having one member in the first level is demonstrated as follows:

From Table 1, level 1 contains T_1 having $a = 0$; level 2 contains T_2, T_3 all having $a = 1$; level 3 contains T_4, T_5, T_6 all having $a = 2$; level 4 contains T_7, T_8, T_9, T_{10} all having $a = 3$; level 5 contains T_{11}, $T_{12}, T_{13}, T_{14}, T_{15}$ all having $a = 4$; ... , ... , ...

Table 3 displays the relationship of the migration level factor, a and the term of the first member of each level. Taking into consideration term of the first member of each level, we have:

Level 1, $\quad a = 0, \quad n = 1 = 1$

Level 2, $\quad a = 1, \quad n = 1 + 1 = 2$

Level 3, $\quad a = 2, \quad n = 1 + 1 + 2 = 4$

Level 4, $\quad a = 3, \quad n = 1 + 1 + 2 + 3 = 7$

.
.
.

Level l, $\quad a = l - 1, \quad n = 1 + 1 + 2 + 3 + 4 + 5 + 6 + \cdots + a$ (8)

.
.
.

Let $n = 1 + \varphi$ in the series of n in (8) where $\varphi = 1 + 2 + 3 + 4 + 5 + \cdots$ (9)

The series of φ is arithmetic progression series. From the summation of arithmetic progression formula presented by Ilori *et al.* (2000), Nwabuwanne (2001); we have:

$$S_q = \frac{q}{2}(2w + (q - 1)d)$$

Where S_q is sum of the series, φ, q is the number of terms of the series, φ, w is the first term, and d is the common difference between two successive terms of the series, φ.

From (8), omitting the first term of the series n, the number of term of φ is equivalent to the value of a.

From (9), $S_q = \varphi, q = a =$ migration level factor, $w = 1, d = T_2 - T_1 = 2 - 1 = 1$

$$S_q = \varphi = \frac{a}{2}(2 \times 1 + (a - 1) \times 1)$$

$$\varphi = \frac{a(a+1)}{2} \quad (10)$$

Put (10) in (9), we have: $$n = 1 + \varphi = 1 + \frac{a(a+1)}{2}$$

$$a^2 + a + 2 - 2n = 0$$

Using quadratic formula presented by Adu (2004), Asuquo *et al.* (2007); we have:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$a = 1, b = 1, c = 2 - 2n$ and $x = a$

$$a = \frac{-1 \pm \sqrt{(1)^2 - 4 \times 1 \times (2 - 2n)}}{2 \times 1}$$

$$a = \frac{-1 \pm \sqrt{8n - 7}}{2}$$

Since a is positive, therefore: $$a = \frac{-1 + \sqrt{8n - 7}}{2}$$

(11)

From Table 1, level 1 contains T_1 having $a = 0$; level 2 contains T_2, T_3 all having $a = 1$; level 3 contains T_4, T_5, T_6 all having $a = 2$; level 4 contains T_7, T_8, T_9, T_{10} all having $a = 3$; level 5 contains T_{11}, $T_{12}, T_{13}, T_{14}, T_{15}$ all having $a = 4$; ... , ... , ...

The value of a for the first term of each level in the Kifilideen's Matrix Structural Framework is the same as the other terms in that level. This indicates that the value of a is the same for all terms in the same level. So, (11) can be used to obtain the value of migration level factor, a for any term of the infinite term of the Kifilideen's Generalized Matrix Progression Sequence for increasing members of successive levels and having one member in the first level.

Generally, the Kifilideen's term mathematical formula for infinite term of Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive levels and having one member in the first level is achieved as:

$$T_n = k(a) + i(n - m) + f$$

$$a = \text{migration level factor} = \frac{-1 + \sqrt{8n - 7}}{2} \quad \text{and}$$

$$m = \text{migration step factor} = m = \frac{a^2 + a + 2}{2} = \frac{l^2 - l + 2}{2}$$

(12)

Kifilideen's Level Mathematical Formula for the Infinite Term

The generation of the Kifilideen's level formula for the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive levels and having one member in the first level is generated as:

From (3), we have: $$l = a + 1$$

(13)

Put (11) into (13), we have: $$l = \frac{-1 + \sqrt{8n - 7}}{2} + 1$$

$$l = \frac{1 + \sqrt{8n - 7}}{2}$$

The Kifilideen's level mathematical formula for the infinite term of the Kifilideen's Generalized Matrix Progression Sequence is attained as:

$$l = \frac{1 + \sqrt{8n - 7}}{2}$$

Where n is the number of term of the Kifilideen's Generalized Matrix Progression Sequence and l is the level value of the term in the Kifilideen's Matrix Structural Framework of the Kifilideen's Generalized Matrix Progression Sequence.

Kifilideen's Position Mathematical Formula of the Infinite Term

Table 4 displays the position of each term of the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive levels and one member in the first level in the Kifilideen's Matrix Structural Framework. In level 1: T_1 is in position 1; in level 2: T_2, T_3 are in positions 1 and 2 respectively; in level 3: T_4, T_5, T_6 are in position 1, 2 and 3 respectively; in level 4: T_7, T_8, T_9, T_{10} are in position 1, 2, 3 and 4 respectively; in level 5: $T_{11}, T_{12}, T_{13}, T_{14}, T_{15}$ are in position 1, 2, 3, 4 and 5 respectively; …, …, …,

The stepwise analysis of the mathematical induction of the Kifilideen's position mathematical formula of infinite term of the Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive levels and one member in the first level is illustrated as follows:

Level 1; position $= p = 1$; $\quad T_1 = k(0) + i(0) + f$

$$T_1 = k(1-1) + i(1-1) + f$$

Level 2; position $= p = 1$; $\quad T_2 = k(1) + i(0) + f$

$$T_2 = k(2-1) + i(1-1) + f$$

Level 2; position $= p = 2$; $\quad T_3 = k(1) + i(1) + f$

$$T_3 = k(2-1) + i(2-1) + f$$

Level 3; position $= p = 1$; $\quad T_4 = k(2) + i(0) + f$

$$T_4 = k(3-1) + i(1-1) + f$$

Level 3; position $= p = 2$; $\quad T_5 = k(2) + i(1) + f$

$$T_5 = k(3-1) + i(2-1) + f$$

Level 3; position $= p = 3$; $\quad T_6 = k(2) + i(2) + f$

$$T_6 = k(3-1) + i(3-1) + f$$

.
.
.

Level ; position $= p = \boldsymbol{p}$; $\quad T_n = k(\boldsymbol{l} - 1) + i(\boldsymbol{p} - 1) + f$

.
.
.

Generally, the Kifilideen's position mathematical formula for Kifilideen's Generalized Matrix Progression Sequence is generated as:

$$T_n = k(\boldsymbol{l} - 1) + i(\boldsymbol{p} - 1) + f \tag{14}$$

Table 4. The position of each term of the infinite term in the Kifilideen's Matrix Structural Framework.

	l_1	l_2	l_3	l_4	l_5	…
s_1	$p_1 \to T_1$					
s_2		$p_1 \to T_2$				
s_3		$p_2 \to T_3$	$p_1 \to T_4$			
s_4			$p_2 \to T_5$	$p_1 \to T_7$		
s_5			$p_3 \to T_6$	$p_2 \to T_8$	$p_1 \to T_{11}$	
s_6				$p_3 \to T_9$	$p_2 \to T_{12}$	
s_7				$p_4 \to T_{10}$	$p_3 \to T_{13}$	.
s_8					$p_4 \to T_{14}$	..
s_9					$p_5 \to T_{15}$	…
s_{10}						…

s_{11}	…
s_{12}	…

Comparing (7) and (14), we have:
$$n - m = p - 1$$
$$n = m + p - 1$$
(15)

Where T_n is the value of the n^th term, f is the first term, k is the migration level value, i is the migration step value, n is the number of terms, a is the migration level factor, m is migration step factor respectively, l is the level value of the term and p is the position of the n^th term in the Kifilideen's Matrix Structural Framework.

From (12), $m =$ migration step factor $= m = \frac{a^2+a+2}{2} = \frac{l^2-l+2}{2}$
(16)

Put (16) in (15), we have:
$$n = \frac{a^2+a+2}{2} + p - 1$$
$$n = \frac{a^2+a+2p}{2}$$
(17)

OR

Equation (17) can be inaugurated as follows:
Table 5 shows the relationship between l, p, n and a of the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive levels and one member in the first level.
From Table 5; we have:

Position 1
$l = 1, \quad a = 0; \quad n = \mathbf{1} = 1$
$l = 2, \quad a = 1; \quad n = \mathbf{1} + 1 = 2$
$l = 3, \quad a = 2; \quad n = \mathbf{1} + 1 + 2 = 4$
$l = 4, \quad a = 3; \quad n = \mathbf{1} + 1 + 2 + 3 = 7$
.
.
.

Position 2
$l = 2, \quad a = 1; \quad n = \mathbf{2} + 1 = 3$
$l = 3, \quad a = 2; \quad n = \mathbf{2} + 1 + 2 = 5$
$l = 4, \quad a = 3; \quad n = \mathbf{2} + 1 + 2 + 3 = 8$
..
.

Position 3
$l = 3, \quad a = 2; \quad n = \mathbf{3} + 1 + 2 = 6$
$l = 4, \quad a = 3; \quad n = \mathbf{3} + 1 + 2 + 3 = 9$
.
.
.

Position 4
$l = 4, \quad a = 3; \quad n = \mathbf{4} + 1 + 2 + 3 = 10$
$l = 5, \quad a = 4; \quad n = \mathbf{4} + 1 + 2 + 3 + 4 = 14$
.
.
.

Position p
$l = l, a = a; \quad n = \boldsymbol{p} + 1 + 2 + 3 + 4 + 5 + \cdots + a$

Let $n = \boldsymbol{p} + \tau$ in the series of n in (18) where $\tau = 1 + 2 + 3 + 4 + 5 + \cdots$ (18)

The series of τ is arithmetic progression series. The summation of arithmetic progression series presented by Bunday and Mulhollsnd (2014); Godman *et al.* (1984) is utilized which as follows:

$$S_v = \frac{v}{2}(2y + (v-1)d)$$

Where S_v is sum of the series, τ, v is the number of terms of the series, τ, y is the first term, and d is the common difference between two successive terms of the series, τ.

From (18), $S_v = \tau, v = a =$migration level factor, $y = 1,\ d = T_2 - T_1 = 2 - 1 = 1$

$$S_v = \tau = \frac{a}{2}(2 \times 1 + (a-1) \times 1)$$

Table 5. The relationship between l, p, n and a of the infinite term.

l	a	p	n
1	0	**1**	$\mathbf{1} = 1$
2	1	**1**	$\mathbf{1} + 1 = 2$
2	1	**2**	$\mathbf{2} + 1 = 3$
3	2	**1**	$\mathbf{1} + 1 + 2 = 4$
3	2	**2**	$\mathbf{2} + 1 + 2 = 5$
3	2	**3**	$\mathbf{3} + 1 + 2 = 6$
.	.	.	.
.	.	.	.
.	.	.	.
l	$a = l - 1$	$\boldsymbol{p}$	$\boldsymbol{p} + 1 + 2 + 3 + 4 + 5 + \cdots + \cdots + \cdots + a$
.	.	.	.
.	.	.	.
.	.	.	.

$$\tau = \frac{a(a+1)}{2} \quad (19)$$

Put (19) in (18), we have:

$$n = \boldsymbol{p} + \tau = \boldsymbol{p} + \frac{a(a+1)}{2}$$

$$n = \frac{a^2 + a + 2p}{2} \quad (20)$$

Where n is the number of terms, a is the migration level factor and p is the position of the n[th] term in the Kifilideen's Matrix Structural Framework.

This (20) is the same as what was obtained in (17).

Kifilideen's Term Step Level Mathematical Formula of the Infinite Term

Table 6 layouts the step and level of each term of the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive levels with one member in the first level in the Kifilideen's matrix structural framework. In level 1: T_1 is in step level (s,l): $(1,1)$; in level 2: T_2, T_3 are in step level (s,l): $(2,2)$ and $(3,2)$ respectively; in level 3: T_4, T_5, $T_6$are in step level (s,l): $(3,3)$, $(4,3)$ and $(5,3)$ respectively; in level 4: T_7, T_8, T_9, T_{10} are in step level (s,l): $(4,4)$, $(5,4)$, $(6,4)$ and $(7,4)$ respectively; in level 5: T_{11}, T_{12}, T_{13}, T_{14}, T_{15} are in step level (s,l): $(5,5)$, $(6,5)$, $(7,5)$, $(8,5)$ and $(9,5)$ respectively; …, …, …,

The stepwise analysis of the mathematical induction of the Kifilideen's term step level mathematical formula of the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive levels with one member in the first level is presented as:

Step 1, **Level** 1; $sl_{11}, \quad T_1 = k(0) + i(0) + f$

Step 1, Level 1; $sl_{11}, \quad T_1 = k(1-1) + i(1-1) + f$

Step 2, **Level** 2; $sl_{22}, \quad T_2 = k(1) + i(0) + f$

Step 2, Level 2; $sl_{22}, \quad T_2 = k(2-1) + i(2-2) + f$

Step 3, Level 2; $sl_{32}, \quad T_3 = k(1) + i(1) + f$

Step 3, Level 2; $sl_{32}, \quad T_3 = k(2-1) + i(3-2) + f$

Step 3, **Level** 3; $sl_{33}, \quad T_4 = k(2) + i(0) + f$

Step 3, Level 3; $sl_{33}, \quad T_4 = k(3-1) + i(3-3) + f$

Step 4, Level 3; $sl_{43}, \quad T_5 = k(2) + i(0) + f$

Step 4, Level 3; $sl_{43}, \quad T_5 = k(3-1) + i(4-3) + f$

Step 5, Level 3; $sl_{53}, \quad T_6 = k(2) + i(0) + f$

Step 5, Level 3; $sl_{53}, \quad T_6 = k(3-1) + i(5-3) + f$

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.

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Step ***s*****,** Level ***l***; $sl_{rc}, \quad T_n = k(l-1) + i(s-l) + f$

..

.

Table 6. The layout of the step and level of each term of the infinite term

	l_1	l_2	l_3	l_4	l_5	…
s_1	$sl_{11} \rightarrow T_1$					
s_2		$sl_{22} \rightarrow T_2$				
s_3		$sl_{32} \rightarrow T_3$	$sl_{33} \rightarrow T_4$			
s_4			$sl_{43} \rightarrow T_5$	$sl_{44} \rightarrow T_7$		
s_5			$sl_{53} \rightarrow T_6$	$sl_{54} \rightarrow T_8$	$sl_{55} \rightarrow T_{11}$	
s_6				$sl_{64} \rightarrow T_9$	$sl_{65} \rightarrow T_{12}$	
s_7				$sl_{74} \rightarrow T_{10}$	$sl_{75} \rightarrow T_{13}$	.
s_8					$sl_{85} \rightarrow T_{14}$	..
s_9					$sl_{95} \rightarrow T_{15}$	…
s_{10}						…

s_{11}	…
s_{12}	…

Generally, the Kifilideen's term step level mathematical formula of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive levels with one member in the first level is expressed as:

$$T_n = k(\boldsymbol{l} - 1) + i(\boldsymbol{s} - \boldsymbol{l}) + f \quad (21)$$

Comparing (7) with (21); we have:

$$n - m = s - l$$

$$n = m + s - l \quad (22)$$

From (16),

$$m = \frac{l^2 - l + 2}{2} \quad (23)$$

Put (23) in (22); we have:

$$n = \frac{l^2 - l + 2}{2} + s - l$$

$$n = \frac{l^2 - 3l + 2s + 2}{2}$$

$$s = \frac{2n - l^2 + 3l - 2}{2}$$

Note: In any particular level of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive levels with one member in the first level in the Kifilideen's Matrix Structural Framework,

$$s \geq l$$

Also, in any particular level of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive levels with one member in the first level in the Kifilideen's Matrix Structural Framework, the level accommodates members until the coefficient of k and i are the same.

From (21),

$$T_n = k(l - 1) + i(s - l) + f \quad (24)$$

So, at the last member of a particular level in the Kifilideen's Matrix Structural Framework of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive levels with one member in the first level the coefficient of k and i are the same.

Therefore, we have:

$$l - 1 = s - l$$

$$s = 2l - 1 \quad (25)$$

So, the maximum value of step, s is obtained for any particular level, l using the (25).

At the start of any step in the Kifilideen's Matrix Structural Framework of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive levels with one member in the first level, the first member in that level is in equal value of step and level, that is:

$$s = l$$

Comparing (14) with (24); we have:

$$p - 1 = s - l$$

$$p = s - l + 1 \quad (26)$$

Kifilideen's Step – Level Mathematical Formula of the Infinite Term

Table 7 presents the layout of the step – level of each term of the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive levels with one member in the first level in the Kifilideen's Matrix Structural Framework. In level 1: T_1 is in step level (sl): 11; in level

2: T_2, T_3 are in step level (sl): 22 and 32 respectively; in level 3: T_4, T_5, T_6 are in step level (sl): 33, 43 and 53 respectively; in level 4: T_7, T_8, T_9, T_{10} are in step level (sl): 44, 54, 64 and 74 respectively; in level 5: T_{11}, T_{12}, T_{13}, T_{14}, T_{15} are in step level (sl): 55, 65, 75, 85 and 95 respectively; … , … , … ,

Table 7. The layout of the step and level of each term of the infinite term

	l_1	l_2	l_3	l_4	l_5	…
s_1	$11 \rightarrow T_1$					
s_2		$22 \rightarrow T_2$				
s_3		$32 \rightarrow T_3$	$33 \rightarrow T_4$			
s_4			$43 \rightarrow T_5$	$44 \rightarrow T_7$		
s_5			$53 \rightarrow T_6$	$54 \rightarrow T_8$	$55 \rightarrow T_{11}$	
s_6				$64 \rightarrow T_9$	$65 \rightarrow T_{12}$	
s_7				$74 \rightarrow T_{10}$	$75 \rightarrow T_{13}$	.
s_8					$85 \rightarrow T_{14}$	..
s_9					$95 \rightarrow T_{15}$	…
s_{10}						…
s_{11}						…
s_{12}						…

The stepwise analysis of the mathematical induction of the Kifilideen's step – level mathematical formula of the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive levels with one member in the first level is generated as follows:

The arrangement of the step and level sl in the Kifilideen's Matrix Structural Framework is in the form of infinite term of the Kifilideen's Generalized Matrix Progression Sequence of increasing members of successive level with one member in the first level. In Table 7,

f =first term $= 11,$

k =migration level value $= T_2 - T_1 = 22 - 11 = 11$

i =migration step value $= T_3 - T_2 = 32 - 22 = 10$

Where f is the first term, k is the migration level value, i is the migration step value, T_1 is the value of the first term, T_2 is the value of the second term and T_3 is the value of the third term of the Kifilideen's Matrix Structural Framework of Table 7.

The stepwise analysis of the mathematical induction of the Kifilideen's step **– level** mathematical formula of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive levels with one member in the first level is established as:

Using Kifilideen's term formula invented in (7) for the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive levels with one member in the first level, we have:

Step 1 Level 1; T_1; $sl = 11(0) + 10(0) + 11 = 11$

Step 1 Level 1; $T_{\mathbf{1}}$; $sl = 11(0) + 10(\mathbf{1} - 1) + 11 = 11$
Step 2 Level 2; T_2; $sl = 11(1) + 10(0) + 11 = 22$
Step 2 Level 2; $T_{\mathbf{2}}$; $sl = 11(1) + 10(\mathbf{2} - 2) + 11 = 22$
Step 3 Level 2; T_3; $sl = 11(1) + 10(1) + 11 = 23$
Step 3 Level 2; $T_{\mathbf{3}}$; $sl = 11(1) + 10(\mathbf{3} - 2) + 11 = 23$
Step 3 Level 3; T_4; $sl = 11(2) + 10(0) + 11 = 33$
Step 3 Level 3; $T_{\mathbf{4}}$; $sl = 11(2) + 10(\mathbf{4} - 4) + 11 = 33$
Step 4 Level 3; T_5; $sl = 11(2) + 10(1) + 11 = 43$
Step 4 Level 3; $T_{\mathbf{5}}$; $sl = 11(2) + 10(\mathbf{5} - 4) + 11 = 43$
Step 5 Level 3; T_6; $sl = 11(2) + 10(2) + 11 = 53$
Step 5 Level 3; $T_{\mathbf{6}}$; $sl = 11(2) + 10(\mathbf{6} - 4) + 11 = 53$

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.
.

Step s Level l; $T_{\boldsymbol{n}}$; $sl = 11(a) + 10(\boldsymbol{n} - m) + 11 = sl$

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Generally, the Kifilideen's step – level mathematical formula for the infinite term of the Kifilideen's Generalized Matrix Progression Sequence of infinite term of increasing members of successive level with one member in the first level is invented as:

$$sl = 11(a) + 10(n - m) + 11 \quad (26)$$

Where n is the number of term, a is the migration level factor, m is the migration step factor, and sl is the step – level value of the term.

Results and Discussion

The applications of Kifilideen's Structural Matrix Framework for the Generalized Matrix Progression Sequence, which features an infinite term of increasing members across successive levels with a single member at the first level, are presented below:

The Applications of the Kifilideen's Generalized Matrix Progression Sequence of infinite term

[1] If an agricultural processing company wishes to adopt Kifilideen's Generalized Matrix Progression Sequence of infinite term to develop salary structure for the staff of the company, the staff of the company in the $5^{th}, 10^{th}$ and 13^{th} terms of the Kifilideen's Structural Matrix Framework receive monetary incentives of ₦ $95,000$, ₦ $125,000$ and ₦ $140,000$ respectively. Determine the following:
(i) the level, the step and the position of the staff in the $5^{th}, 10^{th}$ and 13^{th} terms of the Kifilideen's Structural Matrix Framework;
(ii) the migration level value of the salary structure;
(iii) the migration step value of the salary structure;
(iv) the salary received by the staff in the first term of the Kifilideen's Structural Matrix Framework;
(v) find the salary to be received by a staff in the 15^{th} term of the Kifilideen's Structural Matrix Framework; Also, state the level, the step and the position of the term of the staff;
(vi) produce the Kifilideen's Structural Matrix Framework for the salary structure of the company for the first six levels.

Solution

1(ia) The level, the step and the position of the staff in the 5^{th} term of the Kifilideen's Structural Matrix Framework is obtained as follows:

For 5^{th} term, $n = 5$, $T_5 = ₦\,95,000$

The migration level factor, a of the staff in the 5^{th} term is achieved as:

Migration level factor of the staff in the 5^{th} term $= a = \frac{-1+\sqrt{8n-7}}{2} = \frac{-1+\sqrt{8\times5-7}}{2} = \mathbf{2}.3723 = 2$

(27)

So, the migration level factor, a of the staff in the 5^{th} term is 2.

For the migration step factor, m of the staff in the 5^{th} term, we have:

Migration step factor of the staff in the 5^{th} term $= m = \frac{a^2+a+2}{2} = \frac{2^2+2+2}{2} = 4$

(28)

So, the migration step factor, m of the staff in the 5^{th} term is 4.

The migration level factor, a of the staff in the 5^{th} term obtained in (27) is used to obtain the value of the level of the staff in the 5^{th} term which is presented as follow:

Level of the staff in the 5^{th} term = $l = a + 1 = 2 + 1 = 3$

(29)

So, the staff in 5^{th}term is in level 3.

The value of the level of the staff in the 5^{th} term attained in (28) and number of terms of the staff in the 5^{th} term are used to determine the value of the step of the staff in the 5^{th} term which is obtained as follow:

Step of the staff in the 5^{th} term = $s = \frac{2n-l^2+3l-2}{2} = \frac{2\times5-3^2+3\times3-2}{2} = 4$

(30)

Therefore, the staff in the 5^{th}term is in step 4.

The number of term and the migration step factor, m of the staff in the 5^{th} term are used to determine the value of the position of the staff in the 5^{th} term which is presented as follow:

Position of the staff in the 5^{th} term $= n - m + 1 = 5 - 4 + 1 = 2$

(31)

So, the staff in the 5^{th}term is in position 2.

The equation generated for the 5^{th}term using the Kifilideen's term formula of the Kifilideen's Generalized Matrix Progression Sequence is presented as follow:

$T_n = k(a) + i(n-m) + f$

Number of term, n of the staff in the 5^{th}term is 5, the migration level factor, a of the staff in the 5^{th} term is 2 and the migration step factor, m of the staff in the 5^{th} term is 4. From the question [1] the staff in the 5^{th} term received monetary incentives of $₦\,95,000$, so the equation generated for the 5^{th}term is given as:

Fifth term $= T_5 = k(2) + i(5-4) + f = 2k + i + f = ₦\,95,000$

(32)

From (29), (30) and (31), the staff in the 5^{th} term is in level 3, step 4 and position 2 in the Kifilideen's Structural Matrix Framework

1(ib) The level, the step and the position of the staff in the 10^{th} term of the Kifilideen's Structural Matrix Framework is obtained as follows:

For 10th term, $n = 10$, $T_{10} = ₦\,125,000$

The migration level factor, a of the staff in the 10^{th} term is achieved as:
Migration level factor of the staff in the 10^{th} term $= a = \frac{-1+\sqrt{8n-7}}{2} = \frac{-1+\sqrt{8\times10-7}}{2} = \mathbf{3}.7720 = 3$
(33)
So, the migration level factor, a of the staff in the 10^{th} term is 3.

For the migration step factor, m of the staff in the 10^{th} term, we have:
Migration step factor of the staff in the 10^{th} term $= m = \frac{a^2+a+2}{2} = \frac{3^2+3+2}{2} = 7$
(34)
So, the migration step factor, m of the staff in the 10^{th} term is 7.

The migration level factor, a of the staff in the 10^{th} term obtained in (33) is used to obtain the value of the level of the staff in the 10^{th} term which is presented as follow:
Level of the staff in the 10^{th} term = $l = a + 1 = 3 + 1 = 4$
(35)
So, the staff in 10^{th}term is in level 4.

The value of the level of the staff in the 10^{th} term attained in (35) and number of terms of the staff in the 10^{th} term are used to determine the value of the step of the staff in the 10^{th} term which is obtained as follow:
Step of the staff in the 10^{th} term = $s = \frac{2n-l^2+3l-2}{2} = \frac{2\times10-4^2+3\times4-2}{2} = 7$
(36)
Therefore, the staff in the 10^{th}term is in step 7.

The number of terms and the migration step factor, m of the staff in the 10^{th} term are used to determine the value of the position of the staff in the 10^{th} term which is presented as follow:
Position of the staff in the 10^{th} term$= n - m + 1 = 10 - 7 + 1 = 4$
(37)
So, the staff in the 10^{th}term is in position 4.

The equation generated for the 10^{th}term using the Kifilideen's term formula of the Kifilideen's Generalized Matrix Progression Sequence is presented as follow:
$T_n = k(a) + i(n - m) + f$
Number of term, n of the staff in the 10^{th}term is 10, the migration level factor, a of the staff in the 10^{th} term is 3 and the migration step factor, m of the staff in the 10^{th} term is 7. From the question [1] the staff in the 10^{th} term received monetary incentives of ₦$125,000$, so the equation generated for the 10^{th}term is given as:
Tenth term $= T_{10} = k(3) + i(10 - 7) + f = 3k + 3i + f =$ ₦$125,000$
(38)

From (35), (36) and (37) the staff in the 10^{th} term is in level 4, step 7 and position 4 in the Kifilideen's Structural Matrix Framework.

1(ic) The level, the step and the position of the staff in the 13^{th} term of the Kifilideen's Structural Matrix Framework is obtained as follows:
For 13th term, $n = 13, \quad T_{13} =$ ₦$140,000$
The migration level factor, a of the staff in the 13^{th} term is achieved as:

Migration level factor of the staff in the $13^{\,th}$ term $= a = \frac{-1+\sqrt{8n-7}}{2} = \frac{-1+\sqrt{8\times13-7}}{2} = \mathbf{4}.4244 = 4$
(39)
So, the migration level factor, a of the staff in the 13^{th} term is 4.

For the migration step factor, m of the staff in the 13^{th} term, we have:
Migration step factorof the staff in the $13^{\,th}$ term $= m = \frac{a^2+a+2}{2} = 11$
(40)
So, the migration step factor, m of the staff in the 13^{th} term is 11.

The migration level factor, a of the staff in the 13^{th} term obtained in (39) is used to obtain the value of the level of the staff in the $13^{\,th}$ term which is presented as follow:
Level of the staff in the $13^{\,th}$ term = $l = a + 1 = 4 + 1 = 5$
(41)
So, the staff in 13^{th}term is in level 5.

The value of the level of the staff in the $13^{\,th}$ term attained in (41) and number of term of the staff in the $13^{\,th}$ term are used to determine the value of the step of the staff in the $13^{\,th}$ term which is obtained as follow:
Step of the staff in the $13^{\,th}$ term = $s = \frac{2n-l^2+3l-2}{2} = \frac{2\times13-5^2+3\times5-2}{2} = 7$
(42)
Therefore, the staff in the 13^{th}term is in step 7.

The number of term and the migration step factor, m of the staff in the 13^{th} term are used to determine the value of the position of the staff in the $13^{\,th}$ term which is presented as follow:
Position of the staff in the $13^{\,th}$ term $= p = n - m + 1$
$= 13 - 11 + 1 \;\; = 3$ (43)
So, the staff in the 10^{th}term is in position 3.

The equation generated for the 13^{th}term using the Kifilideen's term formula of the Kifilideen's Generalized Matrix Progression Sequence is presented as follow:
$T_n = k(a) + i(n - m) + f$
Number of term, n of the staff in the 13^{th}term is 13, the migration level factor, a of the staff in the 13^{th} term is 4 and the migration step factor, m of the staff in the 13^{th} term is 11. From the question [1] the staff in the 13^{th} term received monetary incentives of ₦ $140,000$, so the equation generated for the 13^{th}term is given as:
Thirteenth term $= T_{13} = k(4) + i(13 - 11) + f =$ ₦ $140,000$
$4k + 2i + f =$ ₦ $140,000$
(44)

From (41), (42) and (43), the staff in the $13^{\,th}$ term is in level 5, step 7 and position 3 in the Kifilideen's Structural Matrix Framework

1(ii) the value of the migration level value, $k,$ the migration step value, $i,$ and the salary received by the staff in the first term, f of the salary structure is obtained as follow:
From (32), (38) and (44), we have:
$2k + i + f =$ ₦ $95,000$
(45)

$3k + 3i + f = ₦\,125,000$
(46)
$4k + 2i + f = ₦\,140,000$
(47)

Using Kifilideen Extermination and Determinant of Matrix method (KEDM) (Osanyinepju, 2024; Osanyinpeju, 2025), the following is obtained:

$$\begin{array}{cc} C_k \quad C_i & C_f \quad C_i \end{array} \qquad\qquad \begin{array}{cc} C_o \qquad C_i & C_f \quad C_i \end{array}$$

$$\left|\begin{matrix} \begin{vmatrix} 2 & 1 \\ 3 & 3 \end{vmatrix} & \begin{vmatrix} 1 & 1 \\ 1 & 3 \end{vmatrix} \\ \begin{vmatrix} 3 & 3 \\ 4 & 2 \end{vmatrix} & \begin{vmatrix} 1 & 3 \\ 1 & 2 \end{vmatrix} \end{matrix}\right| k = \left|\begin{matrix} \begin{vmatrix} 95,000 & 1 \\ 125,000 & 3 \end{vmatrix} & \begin{vmatrix} 1 & 1 \\ 1 & 3 \end{vmatrix} \\ \begin{vmatrix} 125,000 & 3 \\ 140,000 & 2 \end{vmatrix} & \begin{vmatrix} 1 & 3 \\ 1 & 2 \end{vmatrix} \end{matrix}\right|$$

$$\begin{vmatrix} 3 & 2 \\ -6 & -1 \end{vmatrix} k = \begin{vmatrix} 160,000 & 2 \\ -170,000 & -1 \end{vmatrix}$$

$9k = 180,000$
$k = \#20,000$

$$\begin{array}{cc} C_i \quad C_f & C_k \quad C_f \end{array} \qquad\qquad \begin{array}{cc} C_o \qquad C_f & C_k \quad C_f \end{array}$$

$$\left|\begin{matrix} \begin{vmatrix} 1 & 1 \\ 3 & 1 \end{vmatrix} & \begin{vmatrix} 2 & 1 \\ 3 & 1 \end{vmatrix} \\ \begin{vmatrix} 3 & 1 \\ 2 & 1 \end{vmatrix} & \begin{vmatrix} 3 & 1 \\ 4 & 1 \end{vmatrix} \end{matrix}\right| i = \left|\begin{matrix} \begin{vmatrix} 95,000 & 1 \\ 125,000 & 1 \end{vmatrix} & \begin{vmatrix} 2 & 1 \\ 3 & 1 \end{vmatrix} \\ \begin{vmatrix} 125,000 & 1 \\ 140,000 & 1 \end{vmatrix} & \begin{vmatrix} 3 & 1 \\ 4 & 1 \end{vmatrix} \end{matrix}\right|$$

$$\begin{vmatrix} -2 & -1 \\ 1 & -1 \end{vmatrix} i = \begin{vmatrix} -30,000 & -1 \\ -15,000 & -1 \end{vmatrix}$$

$3i = 15,000$
$i = \#5,000$

$$\begin{array}{cc} C_f \quad C_i & C_k \quad C_i \end{array} \qquad\qquad \begin{array}{cc} C_o \qquad C_i & C_k \quad C_i \end{array}$$

$$\left|\begin{matrix} \begin{vmatrix} 1 & 1 \\ 1 & 3 \end{vmatrix} & \begin{vmatrix} 2 & 1 \\ 3 & 3 \end{vmatrix} \\ \begin{vmatrix} 1 & 3 \\ 1 & 2 \end{vmatrix} & \begin{vmatrix} 3 & 3 \\ 4 & 2 \end{vmatrix} \end{matrix}\right| f = \left|\begin{matrix} \begin{vmatrix} 95,000 & 1 \\ 125000 & 3 \end{vmatrix} & \begin{vmatrix} 2 & 1 \\ 3 & 3 \end{vmatrix} \\ \begin{vmatrix} 125000 & 3 \\ 140000 & 2 \end{vmatrix} & \begin{vmatrix} 3 & 3 \\ 4 & 2 \end{vmatrix} \end{matrix}\right|$$

$$\begin{vmatrix} 2 & 3 \\ -1 & -6 \end{vmatrix} f = \begin{vmatrix} 160,000 & 3 \\ -170,000 & -6 \end{vmatrix}$$

$-9f = -450,000$
$f = \#50,000$

1(ii) the migration level value of the salary structure $= k = ₦\,20,000$;
1(iii) the migration step value of the salary structure $= i = ₦\,5,000$;
1(iv) the salary received by the staff in the first term $= f = ₦\,50,000$.

1(v) For 15^{th} term, $n = 15$,
The migration level factor, a of the staff in the 15^{th} term is achieved as:
Migration level factor of the staff in the 15^{th} term $= a = \frac{-1+\sqrt{8n-7}}{2} = \frac{-1+\sqrt{8\times 15-7}}{2} = \mathbf{4}.8151 = 4$

So, the migration level factor, a of the staff in the 15^{th} term is 4.

For the migration step factor, m of the staff in the 15^{th} term, we have:
Migration step factor$= m = \frac{a^2+a+2}{2} = \frac{4^2+4+2}{2} = 11$
So, the migration step factor, m of the staff in the 15^{th} term is 11.

The salary to be received by a staff in the 15^{th} term is obtained as:
$T_n = k(a) + i(n - m) + f$
Fifteenth term $= T_{15} = 20,000 \times (4) + 5,000 \times (15 - 11) + 50,000$
$T_{15} =$ **the salary received by a staff in the** 15^{th} **term** $=$ ₦ $150,000$

Level of the staff in the 15^{th} term = $l = a + 1 = 4 + 1 = 5$
(48)
So, the staff in 15^{th}term is in level 5.

Step of the staff in the 15^{th} term = $s = \frac{2n-l^2+3l-2}{2} = \frac{2\times 15-5^2+3\times 5-2}{2} = 9$
(49)

Therefore, the staff in the 15^{th}term is in step 9.

Position of the staff in the 15^{th} term$= p = n - m + 1 = 15 - 11 + 1 = 5$
(50)
So, the staff in the 15^{th}term is in position 5.

From (48), (49) and (50), the staff in the 15^{th} term is in level 5, step 9 and position 5 in the Kifilideen's Structural Matrix Framework

1(vi) To produce the Kifilideen's Structural Matrix Framework for the salary structure of the company for the first five levels we have:
The migration level value of the salary structure $= k =$ ₦ $20,000$; the migration step value of the salary structure $= i =$ ₦ $5,000$ and the first term $= f =$ ₦ $50,000$. So, the Kifilideen's Structural Matrix Framework for the salary structure of the company for the first five levels is presented in Table 4.

Table 8. The salary structure of the company of question 1 for the first five levels.

	l_1	l_2	l_3	l_4	l_5
s_1	$T_1 =$ ₦ $50,000$				
s_2		$T_2 =$ ₦ $70,000$			
s_3		$T_3 =$ ₦ $75,000$	$T_4 =$ ₦ $90,000$		
s_4			$T_5 =$ ₦ $95,000$	$T_7 =$ ₦ $110,000$	
s_5			$T_6 =$ ₦ $100,000$	$T_8 =$ ₦ $115,000$	$T_{11} =$ ₦ $130,000$
s_6				$T_9 =$ ₦ $120,000$	$T_{12} =$ ₦ $135,000$
s_7				$T_{10} =$ ₦ $125,000$	$T_{13} =$ ₦ $140,000$
s_8					$T_{14} =$ ₦ $145,000$

s_9	$T_{15} = ₦\,150,000$

From the Table 8, the salary structure increases from one level to another towards the right and also increases down within a level. The Table indicates that the migration level value is $₦\,20,000$, and the migration step value is $₦\,5,000$. Additionally, the difference between the salaries of the last member in a level and the last member in the successive level is $₦\,25,000$. This is obtained by the addition of the migration level value, k and the migration step value, i.

Conclusion

This study introduced Kifilideen's Matrix Arithmetic Progression Sequence (KMAPS) as a transformative mathematical framework that expands the limitations of traditional arithmetic sequences. By integrating progressive structuring, inclusivity, and scalable distribution, KMAPS offers a more dynamic and adaptable approach to hierarchical organization across various industries. Unlike conventional arithmetic progression models, which impose rigid constraints, KMAPS ensures that each level and sublevel within a structured system is progressively optimized to accommodate a wider range of participants, products, or resource allocations. The methodology employed in this research involved mathematical modeling, matrix structural framework analysis, and sequence progression techniques to establish a structured yet flexible system. The results demonstrated that KMAPS effectively optimizes product customization, salary distribution, game development, and hierarchical classification, ensuring a fair, scalable, and efficient allocation mechanism. The sequence's ability to expand dynamically while maintaining logical consistency and mathematical precision makes it highly suitable for applications requiring structured decision-making. This study's significance lies in its ability to expand choice and inclusion, enabling fair economic distribution, adaptable product structuring, and multi-tiered decision frameworks. The successful implementation of KMAPS across multiple domains confirms its potential as an innovative and superior alternative to conventional arithmetic sequences.

Further studies can explore advanced computational models and real-world case studies to extend the applicability of KMAPS in other fields such as supply chain management, financial modeling, and complex organizational structures. Additionally, integrating machine learning and artificial intelligence with KMAPS could further enhance automated decision-making processes for hierarchical structuring. By redefining how structured systems allocate resources and organize hierarchical frameworks, KMAPS paves the way for a more inclusive, scalable, and mathematically optimized approach to decision-making across industries.

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Kifilideen's Sum Formula for Infinite Matrix Arithmetic Progression Series: A Novel Approach to Summation with Real-World Applications

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Abstract

Infinite series play a crucial role in mathematical modeling, optimization, and real-world applications, yet their summation remains a challenge in many complex systems. Kifilideen's General Matrix Arithmetic Progression Series of infinite terms offers a structured approach to organizing and computing summations in progressive numerical systems. Existing summation methods struggle with structured matrix progression sequences, resulting in computational inefficiencies, particularly in real-world applications such as financial planning, resource allocation, and production forecasting. A systematic and efficient summation formula is needed to handle the progressive nature of such series. The development of a dedicated sum formula tailored for Kifilideen's General Matrix Progression Series will enhance computational efficiency, provide a robust mathematical framework for structured series, and facilitate real-world applications requiring large-scale summation operations. The study aims to establish and apply Kifilideen's Sum Formula for the summation of infinite terms in a General Matrix Progression Series, demonstrating its effectiveness through real-world applications in various industries. Mathematical induction was used to derive and validate sum formulas for bi-number product progression series, forming the foundation for Kifilideen's Sum Formula. The proposed progression systems, including manufacturing, financial modeling, and resource distribution, were evaluated for their practicality. The established Kifilideen's Sum Formula successfully streamlined the summation process, reducing computational complexity while maintaining accuracy. Application case studies demonstrated its effectiveness in optimizing structured numerical progressions across different domains. Kifilideen's Sum Formula offers an innovative and efficient approach to summing infinite matrix progression series. Its structured methodology enhances the computation of progressive sequences, making it a valuable tool for mathematical analysis and real-world problem solving. Future research can explore further refinements and broader applications in scientific and engineering computations.

Keywords: Kifilideen's Sum Formulas, Infinite Matrix Progression, Summation Techniques, Structured Series, Mathematical Induction, Real-World Applications

Introduction

Kifilideen's General Matrix Progression Sequence of infinite terms is a sequence of pattern in which its members are arranged into levels and steps within the levels in Kifilideen's Matrix Structural Framework (Osanyinpeju, 2021; Osanyinpeju, 2023). This sequence consists of an infinite number of terms and members (Osanyinpeju, 2022a). In the Kifilideen's Matrix Structural Framework for Kifilideen's General Matrix Progression Sequence of infinite terms, the 1^{st} level has one step, 2^{nd} level has two steps, 3^{rd} level has three steps, and so on. This type of sequence has endless levels in the Kifilideen's Matrix Structural Framework. The Kifilideen's Structural Framework of the Kifilideen's General Matrix Progression Sequence of infinite terms is provided in Table 1.

Table 1. Kifilideen's Structural Framework of the Kifilideen's General Matrix Progression Sequence of infinite terms

		Level, l					
		l_1	l_2	l_3	l_4	…	l_l
	s_1	$k(0) + i(0) + f$					
	s_2		$k(1) + i(0) + f$				
Step, s	s_3		$k(1) + i(1) + f$	$k(2) + i(0) + f$			
	s_4			$k(2) + i(1) + f$	$k(3) + i(0) + f$		
	s_5			$k(2) + i(2) + f$	$k(3) + i(1) + f$	.	
	s_6				$k(3) + i(2) + f$	..	
	s_7				$k(3) + i(3) + f$	…	…
	s_8						…
	s_9						…

For the sequence of the Kifilideen's General Matrix Progression of infinite terms is presented as:
$k(0) + i(0) + f; k(1) + i(0) + f, k(1) + i(1) + f;\ k(2) + i(0) + f,\ k(2) + i(1) + f, k(2) + i(2) + f; k(3) + i(0) + f,\ k(3) + i(1) + f\ ,\ k(3) + i(2) + f\ , k(3) + i(3) + f; \ldots, \ldots, \ldots,$

More so, according to (Osanyinpeju, 2023), the Kifilideen's General Term Formula for the Kifilideen's General Matrix Progression sequence of infinite terms is given as:

$$T_n = k(a) + i(n - m) + f$$

(1)

Where T_n is the n^{th} term of the sequence, k is the migration column value, i is the migration row value, a is the migration column factor, m is the migration row factor, n is the number of terms and f is the first term. The formula for the value of migration column factor, a is obtained from Osanyinpeju (2020a) as:

$$a = \frac{-1+\sqrt{8n-7}}{2} \quad \text{and } a = l - 1$$

(2)

Where a is the migration column factor, n is the number of terms and l is the level of the term. Meanwhile, the formula for the value of the migration row factor, m is attained using equation presented by (Osanyinpeju, 2020b) which is given as:

$$m = \frac{a^2+a+2}{2}$$

(3)

Where m is the migration row factor and a is the migration row factor. The first term, f is the value of the first member of the Kifilideen's General Matrix Progression Sequence of infinite terms. Also, the first term, f is the value of the first level and first step member in the Kifilideen's Matrix Structural Framework (Osanyinpeju, 2020b). The migration column value, k is the difference between the value of the first member of one level and the value of the first member of immediate previous level. The migration row value, i is the difference between the value of a step in a level and the value of the immediate previous step in the same level (Osanyinpeju, 2022b).

The summing infinite series is fundamental in mathematics, with applications spanning engineering, economics, and computational sciences. Traditional summation techniques often struggle with structured numerical progressions, particularly when dealing with complex hierarchical sequences. Kifilideen's General Matrix Progression Series of infinite terms introduces a novel structured approach, where members are arranged in progressive levels and steps. However, the efficient computation of the sum of such series remains a challenge, particularly in real-world applications requiring rapid and accurate aggregation of structured numerical sequences.

Existing summation methods do not offer a dedicated approach to handling matrix-based progression sequences with hierarchical structures. This limitation affects fields such as financial analysis, inventory planning, and resource distribution, where structured summation is critical for decision-making. Without a systematic summation formula, evaluating these structured series becomes computationally expensive and impractical for large-scale applications. This paper aims to establish and apply Kifilideen's Sum Formula to efficiently compute the summation of infinite matrix progression series. The proposed formula is derived using mathematical induction and validated through real-world applications, demonstrating its computational efficiency and practical utility. The development of Kiflideen's Sum Formula provides an efficient framework for computing structured summations in various fields. Potential applications include:

1. Manufacturing and Production: Modeling product variations across multiple levels and subcategories (e.g., battery capacities, phone storage models)
2. Financial Forecasting: Computing progressive investment returns, structured tax systems, and hierarchical financial allocations
3. Resource Allocation and Planning: Optimizing large-scale distribution systems such as energy metering, transportation networks, and industrial logistics.

Materials and Methods

This study begins by deriving sum formulas for bi-number product progression series using mathematical induction. These formulas serve as the foundation for deriving Kifilideen's Sum Formula, which is then applied to structured matrix progression series.

Mathematical Induction of Sum Formula for the Series of Bi – Numbers Product Progression

$S_n = 1 \times 2 + 2 \times 3 + 3 \times 4 + 4 \times 5 + 5 \times 6 + 6 \times 7 + \cdots + n[n+1]$

(4)

$S_n = \sum_{n=1}^{n} n[n+1] \ = \frac{n[n+1][n+2]}{3}$

(5)

Proof

The mathematical induction of the sum formula (4) of the series of bi – numbers product progression is provided as follows:

$S_1 = 1 \times 2 \ = [1+1]$

$S_2 = 1 \times 2 + 2 \times 3 = \ [1+1] + [2+2+2]$

(6)

$$S_2 = \boxed{\begin{array}{ccccc} 1 & + & 1 & + & 1 \\ & & + & & \\ 2 & + & 2 & + & 2 \end{array}} - 1$$

(7)

In (6), the addition of 1 appears two times [that is $1+1$] and addition of 2 appears three times [that is $2+2+2$] but in (7), the rectangle contains addition of three 1 and three 2. So, 1 has to be removed from the rectangle in (7) for (7) to be equal to (6). More so, the rectangle in (7) contains three $[1+2]$. Using the sum of arithmetic progression formula presented by (Tuttuh, 2014) to solve each of the $[1+2]$, (7) can be generated as:

$S_2 = 3 \times \frac{2\times 3}{2} - 1 = 3 \times \frac{2\times 3}{2} - {}^{3}_{0}C = 8$

(8)

$S_3 = 1\times 2 + 2\times 3 + 3\times 4 = \; [1+1] + [2+2+2] + [3+3+3+3]$

(9)

$$S_3 = \boxed{\begin{array}{ccccccc} 1 & + & 1 & + & 1 & + & 1 \\ & & & + & & & \\ 2 & + & 2 & + & 2 & + & 2 \\ & & & + & & & \\ 3 & + & 3 & + & 3 & + & 3 \end{array}} - \begin{array}{ccc} 1 & + & 1 \\ & & + \\ & & 2 \end{array}$$

(10)

In (9), the addition of 1 appears two times [that is $1+1$], addition of 2 appears three times [that is $2+2+2$] and addition of 3 appears four times [that is $3+3+3+3$] but in (10), the rectangle contains addition of four 1, four 2 and four 3 altogether. So, $[1+1]$ and $[2]$ has to be removed from the rectangle in (10) for (10) to be equal to (9). More so, the rectangle in (10) contains four $[1+2+3]$. Using the sum of arithmetic progression formula given by Bunday and Mulholland (2014) to solve each of the $[1+2+3]$, (10) can be generated as:

$S_3 = 4 \times \frac{3\times 4}{2} - 4 = 4 \times \frac{3\times 4}{2} - {}^{4}_{1}C = 20$

(11)

$S_4 = 1\times 2 + 2\times 3 + 3\times 4 \; + 4\times 5 = \; [1+1] + [2+2+2] + [3+3+3+3] \; + \; [4+4+4+4+4]$ (12)

$$S_4 = \boxed{\begin{array}{ccccccccc} 1 & + & 1 & + & 1 & + & 1 & + & 1 \\ & & & & + & & & & \\ 2 & + & 2 & + & 2 & + & 2 & + & 2 \\ & & & & + & & & & \\ 3 & + & 3 & + & 3 & + & 3 & + & 3 \\ & & & & + & & & & \\ 4 & + & 4 & + & 4 & + & 4 & + & 4 \end{array}} - \begin{array}{ccccc} 1 & + & 1 & + & 1 \\ & & + & & \\ 2 & & + & & 2 \\ & & + & & \\ & & 3 & & \end{array}$$

(13)

In (12) the addition of 1 appears two times [that is $1+1$], addition of 2 appears three times [that is $2+2+2$], addition of 3 appears four times [that is $3+3+3+3$] and addition of 4 appears five times [that is $4+4+4+4+4$] but in (13), the rectangle contains addition of five 1, five 2, five 3 and five 4 altogether. So, $[1+1+1]$, $[2+2]$ and [3] has to be removed from the rectangle in (13) for (13) to be equal to (12). More so, the rectangle in (13) contains five $[1+2+3+4]$. Using the sum of arithmetic progression formula presented by Rice and Scott (2005) to solve each of the $[1+2+3+4]$, (13) can be generated as:

$S_4 = 5 \times \frac{4\times 5}{2} - 10 = 5 \times \frac{4\times 5}{2} - {}^{5}_{2}C = 40$

(14)

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$S_n = (n+1) \times \frac{n(n+1)}{2} - {}^{(n+1)}_{(n-2)}C$
(15)

$S_n = \frac{n(n+1)^2}{2} - {}^{(n+1)}_{(n-2)}C$
(16)

In summary, the mathematical induction of the sum formula (4) of the series of bi – numbers product progression is provided as follows:

$S_1 = 2 \times \frac{1\times 2}{2} - {}^{2}_{-1}C = 2 - \frac{2!}{-1!(2-(-1))!} = 2 - \frac{2!}{-1!3!} = 2 - \frac{2\times1\times0\times-1!}{-1!3!} = 2 - 0 \quad = 2$
(17)

$S_2 = 3 \times \frac{2\times 3}{2} - 1 = 3 \times \frac{2\times 3}{2} - {}^{3}_{0}C = 8$
(18)

$S_3 = 4 \times \frac{3\times 4}{2} - 4 = 4 \times \frac{3\times 4}{2} - {}^{4}_{1}C = 20$
(19)

$S_4 = 5 \times \frac{4\times 5}{2} - 10 = 5 \times \frac{4\times 5}{2} - {}^{5}_{2}C = 40$
(20).

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$S_n = (n+1) \times \frac{n(n+1)}{2} - {}^{(n+1)}_{(n-2)}C$

$S_n = \frac{n(n+1)^2}{2} - \frac{(n+1)!}{((n+1)-(n-2))!(n-2)!}$

$S_n = \frac{n(n+1)^2}{2} - \frac{(n+1)!}{(3)!(n-2)!}$

$S_n = \frac{n(n+1)^2}{2} - \frac{(n+1)(n)(n-1)(n-2)!}{(3)!(n-2)!}$

$S_n = \frac{n(n+1)^2}{2} - \frac{(n+1)(n)(n-1)}{(3)!}$

$S_n = \frac{n(n+1)^2}{2} - \frac{(n+1)(n)(n-1)}{6}$

$S_n = \frac{3n(n+1)^2-(n+1)(n)(n-1)}{6}$

$S_n = \frac{n(n+1)(3(n+1)-(n-1))}{6}$

$S_n = \frac{n(n+1)(3n+3-n+1)}{6}$

$S_n = \frac{n(n+1)(2n+4)}{6}$

$S_n = \frac{2n(n+1)(n+2)}{6}$

$S_n = \frac{n(n+1)(n+2)}{3}$

Proved

Note that the transformation part of (18), (19), (20) and other series into combination are obtained from the Pascal's triangle in Figure 2.1 as follows:

4th Diagonal

1
1 2 1
1 3 3 1 (${}^{3}_{0}C$)
1 4 6 4(${}^{4}_{1}C$) 1
1 5 10 10 (${}^{5}_{2}C$) 5 1
1 6 15 20(${}^{6}_{3}C$) 15 6 1

Figure 2.1: Pascal's triangle

Mathematical Induction of Sum Formula for the Series of Bi – Similar Numbers Product Progression

$S_n = 1^2 + 2^2 + 3^2 + 4^2 + 5^2 + 6^2 + \cdots + n^2$
(21)

$S_n = \sum_{n=1}^{n} n^2 = \frac{n[n+1][2n+1]}{6}$
(22)

Proof

The mathematical induction of the sum formula (21) of the series of bi – similar numbers product progression is provided as follows:

$S_1 = 1^2 = 1$
(23)

$S_2 = 1^2 + 2^2 = [1] + [2+2]$
(24)

$$S_2 = \boxed{\begin{matrix} 1 + 1 \\ + \\ 2 + 2 \end{matrix}} - 1 \qquad (25)$$

In (24) the addition of 1 appears once [that is 1] and addition of 2 appears two times [that is $2+2$] but in (24), the rectangle contains addition of two 1 and two 2. So, 1 has to be removed from the rectangle in (25) for (25) to be equal to (24). More so, the rectangle in (25) contains two $[1+2]$. Using the sum of arithmetic progression formula presented by Stroud and Booth (2007) to solve each of the $[1+2]$, (25) can be generated as:

$S_2 = 2 \times \frac{2\times3}{2} - 1 = 2 \times \frac{2\times3}{2} - {}^{3}_{0}C = 5$

$S_3 = 1^2 + 2^2 + 3^2 = [1] + [2+2] + [3+3+3]$
(26)

$$S_3 = \boxed{\begin{matrix} 1 + 1 + 1 \\ + \\ 2 + 2 + 2 \\ + \\ 3 + 3 + 3 \end{matrix}} - \begin{matrix} 1 + 1 \\ + \\ 2 \end{matrix} \qquad (27)$$

In (26) the addition of 1 appears once [that is 1], addition of 2 appears two times [that is $2+2$] and addition of 3 appears three times [that is $3+3+3$] but in (27), the rectangle contains addition of three 1, three 2 and three 3 altogether. So, $[1+1]$ and $[2]$ has to be removed from the rectangle in (27) for (27) to be equal to

(26). More so, the rectangle in (27) contains three $[1+2+3]$. Using the sum of arithmetic progression formula presented by Macrae et al. (2001) to solve each of the $[1+2+3]$, (27) can be generated as:

$$S_3 = 3 \times \frac{3\times4}{2} - 4 = 3 \times \frac{3\times4}{2} - {}^{4}_{1}C = 14$$
(28)

$$S_4 = 1^2 + 2^2 + 3^2 + 4^2 = [1] + [2+2] + [3+3+3] + [4+4+4+4]$$
(29)

$$S_4 = \boxed{\begin{array}{c} 1+1+1+1 \\ + \\ 2+2+2+2 \\ + \\ 3+3+3+3 \\ + \\ 4+4+4+4 \end{array}} - \begin{array}{c} 1+1+1 \\ + \\ 2+2 \\ + \\ 3 \end{array}$$
(30)

In (29) the addition of 1 appears once [that is 1], addition of 2 appears two times [that is $2+2$], addition of 3 appears three times [that is $3+3+3$] and addition of 4 appears four times [that is $4+4+4+4$] but in (30), the rectangle contains addition of four 1, four 2, four 3 and four 4 altogether. So, $[1+1+1]$, $[2+2]$ and [3] has to be removed from the rectangle in (30) for (30) to be equal to (29). More so, the rectangle in (30) contains four $[1+2+3+4]$. Using the sum of arithmetic progression formula to solve each of the $[1+2+3+4]$, (30) can be generated as:

$$S_4 = 4 \times \frac{4\times5}{2} - 10 = 4 \times \frac{4\times5}{2} - {}^{5}_{2}C = 30$$
(31).

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$$S_n = (n) \times \frac{n(n+1)}{2} - {}^{(n+1)}_{(n-2)}C$$
(32)

$$S_n = \frac{n^2(n+1)}{2} - {}^{(n+1)}_{(n-2)}C$$
(33)

In summary, the mathematical induction of the sum formula (21) of the series of bi – similar numbers product progression is provided as follows:

$$S_1 = 1 \times \frac{1\times2}{2} - {}^{2}_{-1}C = 1 - \frac{2!}{-1!(2-(-1))!} = 1 - \frac{2!}{-1!3!} = 1 - \frac{2\times1\times0\times-1!}{-1!3!} = 1 - 0 = 1$$

$$S_2 = 2 \times \frac{2\times3}{2} - 1 = 2 \times \frac{2\times3}{2} - {}^{3}_{0}C = 5$$

$$S_3 = 3 \times \frac{3\times4}{2} - 4 = 3 \times \frac{3\times4}{2} - {}^{4}_{1}C = 14$$

$$S_4 = 4 \times \frac{4\times5}{2} - 10 = 4 \times \frac{4\times5}{2} - {}^{5}_{2}C = 30$$

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$$S_n = (n) \times \frac{n(n+1)}{2} - {}^{(n+1)}_{(n-2)}C$$

$$S_n = \frac{n^2(n+1)}{2} - \frac{(n+1)!}{((n+1)-(n-2))!(n-2)!}$$

$$S_n = \frac{n^2(n+1)}{2} - \frac{(n+1)!}{(3)!(n-2)!}$$

$$S_n = \frac{n^2(n+1)}{2} - \frac{(n+1)(n)(n-1)(n-2)!}{(3)!(n-2)!}$$

$$S_n = \frac{n^2(n+1)}{2} - \frac{(n+1)(n)(n-1)}{(3)!}$$

$$S_n = \frac{n^2(n+1)}{2} - \frac{(n+1)(n)(n-1)}{6}$$

$$S_n = \frac{3n^2(n+1)-(n+1)(n)(n-1)}{6}$$

$$S_n = \frac{n(n+1)(3(n)-(n-1))}{6}$$

$$S_n = \frac{n(n+1)(3n-n+1)}{6}$$

$$S_n = \frac{n(n+1)(2n+1)}{6}$$

Proved

2.3 The Series of the Kifilideen's General Matrix Progression of Infinite Terms

The series of the Kifilideen's General Matrix Progression Sequence of infinite terms of increasing members' set in successive column and the first column having one member is given as:

$$S_n = [k(0) + i(0) + f] + [k(1) + i(0) + f] + [k(1) + i(1) + f] + [k(2) + i(0) + f] + [k(2) + i(1) + f] + [k(2) + i(2) + f] + [k(3) + i(0) + f] + [k(3) + i(1) + f] + [k(3) + i(2) + f] + [k(3) + i(3) + f] + \ldots, \ldots, \ldots, \quad (34)$$

The series of (34) is an infinite term. The arrangement of the terms of the series in Kifilideen's Matrix Structural Framework is given in Table 1. In Table 1, it can be shown that level 1 has 1 term, level 2 has two terms, level 3 has three terms and level 4 has four terms. Other higher levels in the Kifilideen's Structural Framework for Kifilideen's General Matrix Progression Series of infinite terms follow the same trend. In level 1, the first member starts from step 1 and end in step 1. In level 2, the first member starts from step 2 and end in step 3; in level 3, the first member starts from step 3 and end in step 5; and in level 4, the first member starts from step 4 and in step 7. The higher levels follow the same progressive trend.

2.4 Mathematical Induction of the Kifilideen's Sum Formula for the Kifilideen's General Matrix Progression Series of infinite terms

The mathematical induction of the Kifilideen's Sum Formula for the Kifilideen's General Matrix Progression Series infinite terms is given as:

$$S_n = k(q_n) + i(w_n) + nf \quad (35)$$

Where

$$q_n = \frac{(a)(a+1)(a+2)+3a(n-m-a))}{3} \quad (36)$$

$$w_n = \frac{(a-1)(a)(a+1)+3(n-m)(n-m+1)}{6} \quad (37)$$

Where S_n is the sum of the first n^{th}terms of the series, k is the migration column value, i is the migration row value, f is the first term, n is the value of the number of terms to sum, q_n is the sum migration column factor and w_n is the sum migration row factor.

Proof

The Kifilideen's General Matrix Progression Series of infinite terms is given as:

$S_n = [k(0) + i(0) + f] + [k(1) + i(0) + f] + [k(1) + i(1) + f] + [k(2) + i(0) + f] + [k(2) + i(1) + f] + [k(2) + i(2) + f] + [k(3) + i(0) + f] + [k(3) + i(1) + f] + [k(3) + i(2) + f] + [k(3) + i(3) + f] + \ldots, \ldots, \ldots,$ (38)

Level 1, $l = 1$

$S_1 = k((0)) + i((0)) + f = k(q_1) + i(w_1) + f$ (39)

Level 2, $l = 2$

$S_2 = k((0) + 1) + i((0) + 0) + 2f = k(q_2) + i(w_2) + 2f$ (40)

$S_3 = k((0) + (1 + 1)) + i\big((0) + (0 + 1)\big) + 3f = k(q_3) + i(w_3) + 3f$ (41)

Level 3, $l = 3$

$S_4 = k\big((0) + (1 + 1) + 2\big) + i\big((0) + (0 + 1) + 0\big) + 4f = k(q_4) + i(w_4) + 4f$ (42)

$S_5 = k\big((0) + (1 + 1) + 2 + 2\big) + i\big((0) + (0 + 1) + 0 + 1\big) + 5f = k(q_5) + i(w_5) + 5f$ (43)

$S_6 = k\big((0) + (1 + 1) + (2 + 2 + 2)\big) + i\big((0) + (0 + 1) + (0 + 1 + 2)\big) + 6f = k(q_6) + i(w_6) + 6f$ (44)

Level 4, $l = 4$

$S_7 = k\big((0) + (1 + 1) + (2 + 2 + 2) + 3\big) + i\big((0) + (0 + 1) + (0 + 1 + 2) + 0\big) + 7f$

$S_7 = k(q_7) + i(w_7) + 7f$ (45)

$S_8 = k\big((0) + (1 + 1) + (2 + 2 + 2) + 3 + 3\big) + i\big((0) + (0 + 1) + (0 + 1 + 2) + 0 + 1\big) + 8f$

$S_8 = k(q_8) + i(w_8) + 8f$ (46)

$S_9 = k\big((0) + (1 + 1) + (2 + 2 + 2) + 3 + 3 + 3\big) + i\big((0) + (0 + 1) + (0 + 1 + 2) + 0 + 1 + 2\big) + 9f$

$S_9 = k(q_9) + i(w_9) + 9f$ (47)

$$S_{10} = k\big((0) + (1 + 1) + (2 + 2 + 2) + (3 + 3 + 3 + 3)\big) + i\big((0) + (0 + 1) + (0 + 1 + 2) + (0 + 1 + 2 + 3)\big) + 10f$$

$S_{10} = k(q_{10}) + i(w_{10}) + 10f$ (48)

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Level l, $l = l$

$S_n = k(q_n) + i(w_n) + nf$ (49)

Where S_n is the sum of the first n^{th}terms of the series, k is the migration column value, i is the migration row value, f is the first term, n is the value of the number of terms to sum, q_n is the sum migration column factor and w_n is the sum migration row factor.

From the mathematical induction of (38) to (49), the mathematical induction of sum migration column factor, $q_n$is obtained as:

Level 1, $l = 1$

$$q_1 = (0) = 1 \times \frac{0\times1}{2} - {}_{-2}^{1}C - 0 \times 0 = 0 - \frac{1!}{(-2)!(1-(-2))!} - 0 = \frac{1!}{(-2)!3!} = \frac{1\times0\times(-1)\times(-2)!}{(-2)!3!} = 0$$

(50)

Level 2, $l = 2$

$$q_2 = (0) + 1 = 2 \times \frac{1\times2}{2} - {}_{-1}^{2}C - 1 \times 1 = 2 - \frac{2!}{(-1)!(2-(-1))!} - 1 = 1 - \frac{2!}{(-1)!3!} = 1 - \frac{2\times1\times0\times(-1)!}{(-1)!3!} = 1$$

(51)

$$q_3 = (0) + (1 + 1) = 2 \times \frac{1\times2}{2} - {}_{-1}^{2}C - 1 \times 0 =$$
$$2 - \frac{2!}{(-1)!(2-(-1))!} - 0 = 2 - \frac{2!}{(-1)!3!} = 2 - \frac{2\times1\times0\times(-1)!}{(-1)!3!} = 2 \qquad (52)$$

Level 3, $l = 3$

$$q_4 = (0) + (1 + 1) + 2$$

(53)

$$q_4 = 0 + \begin{array}{c} 1 + 1 \\ + \\ 2 \end{array} = \boxed{\begin{array}{c} 1 + 1 + 1 \\ + \\ 2 + 2 + 2 \end{array}} - 1 - 2 \times 2$$

(54)

In (53), the addition of 0 appears once [that is 0], addition of 1 appears two times [that is $1 + 1$] and addition of 2 appears once [that is 2] but in (54), the rectangle contains addition of three 1 and three 2 altogether. So, $[1]$ and $[2 \times 2]$ has to be removed from the rectangle in (54) for (54) to be equal to (53). More so, the rectangle in (54) contains three $[1 + 2]$. Using the sum of arithmetic progression formula presented by Brown (2013) to solve each of the $[1 + 2]$, (54) can be generated as:

$$q_4 = 3 \times \frac{2\times3}{2} - 1 - 2 \times 2 = 3 \times \frac{2\times3}{2} - {}_{0}^{3}C - 2 \times 2 = 4$$

(55)

$$q_5 = (0) + (1 + 1) + 2 + 2$$

(56)

$$q_5 = 0 + \begin{array}{c} 1 + 1 \\ + \\ 2 + 2 \end{array} = \boxed{\begin{array}{c} 1 + 1 + 1 \\ + \\ 2 + 2 + 2 \end{array}} - 1 - 2 \times 1$$

(57)

In (56), the addition of 0 appears once [that is 0], addition of 1 appears two times [that is $1 + 1$] and addition of 2 appears two times [that is $2 + 2$] but in (57), the rectangle contains addition of three 1 and three 2 altogether. So, $[1]$ and $[2 \times 1]$ has to be removed from the rectangle in (57) for (57) to be equal to (56). More so, the rectangle in (57) contains three $[1 + 2]$. Using the sum of arithmetic progression formula presented by Jones (2011) to solve each of the $[1 + 2]$, (57) can be generated as:

$$q_5 = 3 \times \frac{2\times3}{2} - 1 - 2 \times 1 = 3 \times \frac{2\times3}{2} - {}_{0}^{3}C - 2 \times 1 = 6$$

(58)

$$q_6 = (0) + (1 + 1) + (2 + 2 + 2)$$

(59)

$$q_6 = 0 + \begin{array}{c}1+1\\+\\2+2+2\end{array} = \boxed{\begin{array}{c}1+1+1\\+\\2+2+2\end{array}} - 1 - 2\times 0$$

(60)

In (59), the addition of 0 appears once [that is 0], addition of 1 appears two times [that is $1+1$] and addition of 2 appears three times [that is $2+2+2$] but in (60), the rectangle contains addition of three 1 and three 2 altogether. So, [1] and [2×0] has to be removed from the rectangle in (60) for (60) to be equal to (59). More so, the rectangle in (60) contains three [$1+2$]. Using the sum of arithmetic progression formula presented by Bird (2003) to solve each of the [$1+2$], (60) can be generated as:

$$q_6 = 3\times\frac{2\times 3}{2} - 1 - 2\times 0 = 3\times\frac{2\times 3}{2} - {}^{3}_{0}C - 2\times 0 = 8$$
(61)

Level 4, $l = 4$

$$q_7 = (0) + (1+1) + (2+2+2) + 3$$
(62)

$$q_7 = 0 + \begin{array}{c}1+1\\+\\2+2+2\\+\\3\end{array} = \boxed{\begin{array}{c}1+1+1+1\\+\\2+2+2+2\\+\\3+3+3+3\end{array}} - \begin{array}{c}1+1\\+\\2\end{array} - 3\times 3$$

(63)

In (62), the addition of 0 appears once [that is 0], addition of 1 appears two times [that is $1+1$], addition of 2 appears three times [that is $2+2+2$] and addition of 3 appears once [that is 3] but in (63), the rectangle contains addition of four 1, four 2 and four 3 altogether. So, [$1+1$], [2] and 3×3 has to be removed from the rectangle in (63) for (63) to be equal to (62). More so, the rectangle in (63) contains four [$1+2+3$]. Using the sum of arithmetic progression formula presented by Pontes (2020) to solve each of the [$1+2+3$], (63) can be generated as:

$$q_7 = 4\times\frac{3\times 4}{2} - 4 - 3\times 3 = 4\times\frac{3\times 4}{2} - {}^{4}_{1}C - 3\times 3 = 11$$
(64)

$$q_8 = (0) + (1+1) + (2+2+2) + 3 + 3$$
(65)

$$q_8 = 0 + \begin{array}{c}1+1\\+\\2+2+2\\+\\3+3\end{array} = \boxed{\begin{array}{c}1+1+1+1\\+\\2+2+2+2\\+\\3+3+3+3\end{array}} - \begin{array}{c}1+1\\+\\2\end{array} - 3\times 2$$

(66)

In (65), the addition of 0 appears once [that is 0], addition of 1 appears two times [that is $1+1$], addition of 2 appears three times [that is $2+2+2$] and addition of 3 appears two times [that is $3+3$] but in (66), the rectangle contains addition of four 1, four 2 and four 3 altogether. So, [$1+1$]. [2] and [3×2] has to be removed from the rectangle in (66) for (66) to be equal to (65). More so, the rectangle in (66) contains four $[1+2+3]$. Using the sum of arithmetic progression formula presented by Talbert et al. (1995) to solve each of the $[1+2+3]$, (66) can be generated as:

$$q_8 = 4 \times \frac{3\times4}{2} - 4 - 3 \times 2 = 4 \times \frac{3\times4}{2} - {}^{4}_{1}C - 3 \times 2 = 14$$
(67)

$$q_9 = (0) + (1+1) + (2+2+2) + 3+3+3$$
(68)

$$q_9 = 0 + \begin{array}{c} 1+1 \\ + \\ 2+2+2 \\ + \\ 3+3+3 \end{array} = \boxed{\begin{array}{c} 1+1+1+1 \\ + \\ 2+2+2+2 \\ + \\ 3+3+3+3 \end{array}} - \begin{array}{c} 1+1 \\ + \\ 2 \end{array} - 3 \times 1$$
(69)

In (68), the addition of 0 appears once [that is 0], addition of 1 appears two times [that is $1+1$], addition of 2 appears three times [that is $2+2+2$] and addition of 3 appears three times [that is $3+3+3$] but in (69), the rectangle contains addition of four 1, four 2 and four 3 altogether. So, $[1+1]$. $[2]$ and $[3 \times 1]$ has to be removed from the rectangle in (69) for (69) to be equal to (68). More so, the rectangle in (69) contains four $[1+2+3]$. Using the sum of arithmetic progression formula presented by Wittmann (2020) to solve each of the $[1+2+3]$, (69) can be generated as:

$$q_9 = 4 \times \frac{3\times4}{2} - 4 - 3 \times 1 = 4 \times \frac{3\times4}{2} - {}^{4}_{1}C - 3 \times 1 = 17$$
(70)

$$q_{10} = (0) + (1+1) + (2+2+2) + (3+3+3+3)$$
(71)

$$q_{10} = 0 + \begin{array}{c} 1+1 \\ + \\ 2+2+2 \\ + \\ 3+3+3+3 \end{array} = \boxed{\begin{array}{c} 1+1+1+1 \\ + \\ 2+2+2+2 \\ + \\ 3+3+3+3 \end{array}} - \begin{array}{c} 1+1 \\ + \\ 2 \end{array} - 3 \times 0$$
(72)

In (71), the addition of 0 appears once [that is 0], addition of 1 appears two times [that is $1+1$], addition of 2 appears three times [that is $2+2+2$] and addition of 3 appears four times [that is $3+3+3+3$] but in (72), the rectangle contains addition of four 1, four 2 and four 3 altogether. So, $[1+1]$. $[2]$ and $[3 \times 0]$ has to be removed from the rectangle in (72) for (72) to be equal to (71). More so, the rectangle in (72) contains four $[1+2+3]$. Using the sum of arithmetic progression formula presented by Fowler and Snapp (2014) to solve each of the $[1+2+3]$, (72) can be generated as:

$$S_{10} = 4 \times \frac{3\times4}{2} - 4 - 3 \times 0 = 4 \times \frac{3\times4}{2} - {}^{4}_{1}C - 3 \times 0 = 20$$
(73)

In summary, the mathematical induction of the sum migration column factor formula from (50) to (73) is given as follows:

Level 1, $\boldsymbol{l = 1}$

$$q_1 = 1 \times \frac{0\times 1}{2} - {}_{-2}^{1}C - 0 \times 0 = 1 \times \frac{0\times 1}{2} - {}_{-2}^{1}C - (1-1)\big((1-1)-0\big) = 1 \times \frac{0\times 1}{2} - {}_{-2}^{1}C - (1-1)\big((1-1)-(1-1)\big)$$ (74)

Level 2, $\boldsymbol{l} = 2$

$$q_2 = 2 \times \frac{1\times 2}{2} - {}_{-1}^{2}C - 1 \times 1 = 2 \times \frac{1\times 2}{2} - {}_{-1}^{2}C - (2-1)\big((2-1)-0\big) = 2 \times \frac{1\times 2}{2} - {}_{-1}^{2}C - (2-1)\big((2-1)-(2-2)\big)$$ (75)

$$q_3 = 2 \times \frac{1\times 2}{2} - {}_{-1}^{2}C - 1 \times 0 = 2 \times \frac{1\times 2}{2} - {}_{-1}^{2}C - (2-1)\big((2-1)-1\big) = 2 \times \frac{1\times 2}{2} - {}_{-1}^{2}C - (2-1)\big((2-1)-(3-2)\big)$$ (76)

Level 3, $\boldsymbol{l} = 3$

$$q_4 = 3 \times \frac{2\times 3}{2} - {}_{0}^{3}C - 2 \times 2 = 3 \times \frac{2\times 3}{2} - {}_{0}^{3}C - (3-1)\big((3-1)-0\big) = 3 \times \frac{2\times 3}{2} - {}_{0}^{3}C - (3-1)\big((3-1)-(4-4)\big)$$ (77)

$$q_5 = 3 \times \frac{2\times 3}{2} - {}_{0}^{3}C - 2 \times 1 = 3 \times \frac{2\times 3}{2} - {}_{0}^{3}C - (3-1)\big((3-1)-1\big) = 3 \times \frac{2\times 3}{2} - {}_{0}^{3}C - (3-1)\big((3-1)-(5-4)\big)$$ (78)

$$q_6 = 3 \times \frac{2\times 3}{2} - {}_{0}^{3}C - 2 \times 0 = 3 \times \frac{2\times 3}{2} - {}_{0}^{3}C - (3-1)\big((3-1)-2\big) = 3 \times \frac{2\times 3}{2} - {}_{0}^{3}C - (3-1)\big((3-1)-(6-4)\big)$$ (79)

Level 4, $\boldsymbol{l} = 4$

$$q_7 = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - 3 \times 3 = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - (3-1)\big((3-1)-0\big) = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - (4-1)\big((4-1)-(7-7)\big)$$ (80)

$$q_8 = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - 3 \times 2 = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - (3-1)\big((3-1)-1\big) = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - (4-1)\big((4-1)-(8-7)\big)$$ (81)

$$q_9 = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - 3 \times 1 = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - (3-1)\big((3-1)-2\big) = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - (4-1)\big((4-1)-(9-7)\big)$$ (82)

$$q_{10} = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - 3 \times 0 = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - (3-1)\big((3-1)-2\big) = 4 \times \frac{3\times 4}{2} - {}_{1}^{4}C - (4-1)\big((4-1)-(10-7)\big)$$ (83)

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Level l, $\boldsymbol{l} = \boldsymbol{l}$

$$q_n = \boldsymbol{l} \times \frac{(\boldsymbol{l}-1)\times \boldsymbol{l}}{2} - {}_{(\boldsymbol{l}-3)}^{\;\;\;l}C - (\boldsymbol{l}-1)\big((\boldsymbol{l}-1)-(n-m)\big)$$
(84)

$$q_n = \frac{l^2(l-1)}{2} - \frac{l!}{(l-(l-3))!(l-3)!} - (l-1)(l-1-n+m)$$
(85)

$$q_n = \frac{l^2(l-1)}{2} - \frac{l(l-1)(l-2)(l-3)!}{3!(l-3)!} + (l-1)(n-m-l+1)$$
(86)

$$q_n = \frac{l^2(l-1)}{2} - \frac{l(l-1)(l-2)}{3!} + (l-1)(n-m-l+1)$$
(87)

$$q_n = \frac{l^2(l-1)}{2} - \frac{l(l-1)(l-2)}{6} + (l-1)(n-m-l+1)$$
(88)

$$q_n = \frac{3l^2(l-1)-l(l-1)(l-2)}{6} + (l-1)(n-m-l+1)$$
(89)

$q_n = \frac{l(l-1)\left(3l-(l-2)\right)}{6} + (l-1)(n-m-l+1)$
(90)
$q_n = \frac{l(l-1)(2l+2)}{6} + (l-1)(n-m-l+1)$
(91)
$q_n = \frac{l(l-1)(l+1)}{3} + (l-1)(n-m-l+1)$
(92)
$q_n = \frac{l(l-1)(l+1)}{3} + (l-1)(n-m-l+1)$
(93)
$q_n = \frac{l(l-1)(l+1)+3(l-1)(n-m-l+1)}{3}$
(94)
$q_n = \frac{(l-1)(l)(l+1)+3(l-1)(n-m-l+1))}{3}$
(95)
From (2), $l = a + 1$
(96)
Therefore,
$q_n = \frac{(a)(a+1)(a+2)+3a(n-m-a))}{3}$
(97)
Where q_n is the sum migration column factor, a is the migration column factor, n is the value of the number of terms to sum, m is the migration row factor.

From the mathematical induction of (39) to (48), the mathematical induction of sum migration row factor, $w_n$is obtained as:
Level 1, $l = 1$
$w_1 = (0) = \quad {}_{-2}^{1}C = \frac{2!}{(-1)!(2-(-1))!} \quad = \frac{2!}{(-1)!3!} \quad = \frac{2\times1\times0\times(-1)!}{(-1)!3!} = 0$
(98)
Level 2, $l = 2$
$w_2 = (0) + 0 = \quad {}_{-1}^{2}C + 0 = \frac{2!}{(-1)!(2-(-1))!} \quad +0 = \frac{2!}{(-1)!3!} \quad +0 = \frac{2\times1\times0\times(-1)!}{(-1)!3!} + 0 = 0$
(99)
$w_3 = (0) + (0+1) = {}_{-1}^{2}C + (0+1) = \frac{2!}{(-1)!(2-(-1))!} + (0+1) = \frac{2!}{(-1)!3!} + (0+1) = \frac{2\times1\times0\times(-1)!}{(-1)!3!} + (0+1) = 1$

(100)
Level 3, $l = 3$
$w_4 = (0) + (0+1) + 0$
(101)

$$w_4 = \begin{matrix}0\\+\\0\\+\\0\end{matrix} + 1 = \begin{matrix}0+0\\+\\1\end{matrix} + 0$$

(102)
The circle in (102) contains two 0 and one 1 altogether. Recall [1] is equivalent to ${}_{0}^{3}C$, so, we have
$w_4 = {}_{0}^{3}C + 0 = {}_{0}^{3}C + (4-4)$
(103)

$w_5 = (0) + (0+1) + 0 + 1$
(104)

$$w_5 = \begin{array}{l} 0 \\ + \\ 0 \; + \; 1 \\ + \\ 0 \; + \; 1 \end{array} = \begin{array}{c} 0 + 0 \\ + \\ 1 \end{array} + \quad 0 + 1$$
(105)

The circle in (105) contains two 0 and one 1 altogether. Recall [1] is equivalent to ${}^{3}_{0}C$, so, we have:
$w_5 = {}^{3}_{0}C + 0 + 1 = {}^{3}_{0}C + (4-4) + (5-4)$
(106)

$w_6 = (0) + (0+1) + (0+1+2)$
(107)

$$w_6 = \begin{array}{l} 0 \\ + \\ 0 \; + \; 1 \\ + \\ 0 \; + \; 1 + 2 \end{array} = \begin{array}{c} 0 + 0 \\ + \\ 1 \end{array} + \quad 0 + 1 + 2$$
(108)

The circle in (108) contain two 0 and one 1 altogether. Recall [1] is equivalent to ${}^{3}_{0}C$, so, we have:
$w_6 = {}^{3}_{0}C + 0 + 1 + 2 = {}^{3}_{0}C + (4-4) + (5-4) + (6-4)$
(109)

Level 4, $l = 4$
$w_7 = (0) + (0+1) + (0+1+2) + 0$
(110)

$$w_7 = \begin{array}{l} 0 \\ + \\ 0 \; + \; 1 \\ + \\ 0 \; + \; 1 + 2 \\ + \\ 0 \end{array} = \begin{array}{c} 0 + 0 + 0 \\ + \\ 1 + 1 \\ + \\ 2 \end{array} + 0$$
(111)

The circle in (111) contains three 0, two 1 and one 2 altogether. Recall $[1+1] + [2]$ is equivalent to ${}^{4}_{1}C$, so we have:
w_7
$= {}^{4}_{1}C + 0 = {}^{4}_{1}C + (7-7)$
(112)

$w_8 = (0) + (0+1) + (0+1+2) + 0 + 1$
(113)

$$w_8 = \begin{array}{l} 0 \\ + \\ 0 \; + \; 1 \\ + \\ 0 + 1 + 2 \\ + \\ 0 + 1 \end{array} = \begin{array}{c} 0 + 0 + 0 \\ + \\ 1 + 1 \\ + \\ 2 \end{array} + 0 + 1$$
(114)

The circle in (114) contain three 0, two 1 and one 2 altogether. Recall $[1+1] + [2]$ is equivalent to ${}^{4}_{1}C$, so, we have:
$w_8 = {}^{4}_{1}C + 0 + 1 = {}^{4}_{1}C + (7-7) + (8-7)$
(115)

$q_9 = (0) + (0+1) + (0+1+2) + 0 + 1 + 2$
(116)

$$w_9 = \begin{array}{l} 0 \\ + \\ 0 \; + \; 1 \\ + \\ 0 + 1 + 2 \\ + \\ 0 + 1 + 2 \end{array} = \begin{array}{c} 0 + 0 + 0 \\ + \\ 1 + 1 \\ + \\ 2 \end{array} + 0 + 1 + 2$$
(117)

The circle in (117) contain three 0, two 1 and one 2 altogether. Recall $[1+1] + [2]$ is equivalent to ${}^{4}_{1}C$, so we have:

$w_9 = {}^{4}_{1}C + 0 + 1 + 2 = {}^{4}_{1}C + (7-7) + (8-7) + (9-7)$
(118)

$w_{10} = (0) + (0+1) + (0+1+2) + (0+1+2+3)$
(119)

$$w_{10} = \begin{array}{l} 0 \\ + \\ 0 \; + \; 1 \\ + \\ 0 + 1 + 2 \\ + \\ 0 + 1 + 2 + 3 \end{array} = \begin{array}{c} 0 + 0 + 0 \\ + \\ 1 + 1 \\ + \\ 2 \end{array} + 0 + 1 + 2 + 3$$
(120)

The circle in (120) contain three 0, two 1 and one 2 altogether. Recall $[1+1] + [2]$ is equivalent to ${}^{4}_{1}C$, so we have:
$w_{10} = {}^{4}_{1}C + 0 + 1 + 2 + 3 = {}^{4}_{1}C + (7-7) + (8-7) + (9-7) + (10-7)$
(121)

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In summary, the mathematical induction of the sum migration column factor formula from (98) to (121) is given as follows:
Level 1, $\boldsymbol{l = 1}$

$$w_1 = {}_{-2}^{1}C + 0 = {}_{-2}^{1}C + \frac{0\times 1}{2} = {}_{-2}^{1}C + (1-1) = {}_{(1-3)}^{1}C + \frac{(1-1)\times((1-1)+1)}{2}$$
(122)

$$1 \times \frac{0\times 1}{2} - {}_{-2}^{1}C - 0\times 0 = 1 \times \frac{0\times 1}{2} - {}_{-2}^{1}C - (1-1)\big((1-1)-0\big) = 1 \times \frac{0\times 1}{2} - {}_{-2}^{1}C - (1-1)\big((1-1)-(1-1)\big)$$ (123)

Level 2, $l = 2$

$$w_2 = {}_{-1}^{2}C + 0 = {}_{-1}^{2}C + \frac{0\times 1}{2} = {}_{-1}^{2}C + (2-2) = {}_{(2-3)}^{2}C + \frac{(2-2)\times((2-2)+1)}{2}$$
(124)

$$w_3 = {}_{-1}^{2}C + 0 + 1 = {}_{-1}^{2}C + \frac{1\times 2}{2} = {}_{-1}^{2}C + (2-2) + (3-2) = {}_{(2-3)}^{2}C + \frac{(3-2)\times((3-2)+1)}{2}$$ (125)

Level 3, $l = 3$

$$w_4 = {}_{0}^{3}C + 0 = {}_{0}^{3}C + \frac{0\times 1}{2} = {}_{0}^{3}C + (4-4) = {}_{(3-3)}^{3}C + \frac{(4-4)\times((4-4)+1)}{2}$$
(126)

$$w_5 = {}_{0}^{3}C + 0 + 1 = {}_{0}^{3}C + \frac{1\times 2}{2} = {}_{0}^{3}C + (4-4) + (5-4) = {}_{(3-3)}^{3}C + \frac{(5-4)\times((5-4)+1)}{2}$$
(127)

$$w_6 = {}_{0}^{3}C + 0 + 1 + 2 = {}_{0}^{3}C + \frac{2\times 3}{2}\, {}_{0}^{3}C + (4-4) + (5-4) + (6-4) = {}_{(3-3)}^{3}C + \frac{(6-4)\times((6-4)+1)}{2}$$
(128)

Level 4, $l = 4$

$$w_7 = {}_{1}^{4}C + 0 = {}_{1}^{4}C + \frac{0\times 1}{2} = {}_{1}^{4}C + (7-7) = {}_{(4-3)}^{4}C + \frac{(7-7)\times((7-7)+1)}{2}$$
(129)

$$w_8 = {}_{1}^{4}C + 0 + 1 = {}_{1}^{4}C + \frac{1\times 2}{2} = {}_{1}^{4}C + (7-7) + (8-7) = {}_{(4-3)}^{4}C + \frac{(8-7)\times((8-7)+1)}{2}$$
(130)

$$w_9 = {}_{1}^{4}C + 0 + 1 + 2 = {}_{1}^{4}C + \frac{2\times 3}{2} = {}_{1}^{4}C + (7-7) + (8-7) + (9-7) = {}_{(4-3)}^{4}C + \frac{(9-7)\times((9-7)+1)}{2}$$
(131)

$$w_{10} = {}_{1}^{4}C + 0 + 1 + 2 + 3 = {}_{1}^{4}C + \frac{3\times 4}{2} = {}_{1}^{4}C + (7-7) + (8-7) + (9-7) + (10-7) = {}_{(4-3)}^{4}C + \frac{(10-7)\times((10-7)+1)}{2}$$

(132)

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Level l, $l = l$

$$w_n = {}_{(l-3)}^{l}C + \frac{(n-m)(n-m+1)}{2}$$
(133)

$$w_n = \frac{l!}{(l-(l-3))!(l-3)!} + \frac{(n-m)(n-m+1)}{2}$$
(134)

$$w_n = \frac{l(l-1)(l-2)(l-3)!}{3!(l-3)!} + \frac{(n-m)(n-m+1)}{2}$$
(135)

$$w_n = \frac{l(l-1)(l-2)}{3!} + \frac{(n-m)(n-m+1)}{2}$$
(136)

$$w_n = \frac{l(l-1)(l-2)}{6} + \frac{(n-m)(n-m+1)}{2}$$
(137)

$$w_n = \frac{l(l-1)(l-2)+3(n-m)(n-m+1)}{6}$$
(138)

From (2), $l = a + 1$
(139)

Therefore,

$$w_n = \frac{(a+1)(a)(a-1)+3(n-m)(n-m+1)}{6}$$
(140)

$$w_n = \frac{(a-1)(a)(a+1)+3(n-m)(n-m+1)}{6}$$
(141)

Where w_n is the sum migration row factor, a is the migration column factor, n is the value of the number of terms to sum, m is the migration row factor. Table shows the relationship between the migration column factor, a and migration row factor, m which is obtained from (122) to (141). From Table 2 we have:

$$m = {}^{a+1}_{a-1}C + 1$$
(142)

$$m = \frac{(a+1)!}{((a+1)-(a-1))!(a-1)!} + 1$$
(143)

$$m = \frac{(a+1)!}{(a+1-a+1)!(a-1)!} + 1$$
(144)

$$m = \frac{(a+1)!}{2!(a-1)!} + 1$$
(145)

$$m = \frac{(a+1)(a)(a-1)!}{2!(a-1)!} + 1$$
(146)

$$m = \frac{(a+1)(a)}{2!} + 1$$
(147)

$$m = \frac{a^2+a}{2} + 1$$
(148)

$$m = \frac{a^2+a+2}{2}$$
(149)

So, migration row factor is given as:

$$\text{migration row factor} = m = \frac{a^2+a+2}{2}$$
(150)

Table 2. The relationship between the migration column factor, a and migration row factor, m which is obtained from (142) to (149).

Levels, l	Migration column factor, a	Migration row factor, m
1	**0**	$1 = 0 + 1 = {}^{1}_{-1}C + 1 = {}^{0+1}_{0-1}C + 1$
2	**1**	$2 = 1 + 1 = {}^{2}_{0}C + 1 = {}^{1+1}_{1-1}C + 1$

3	**2**	$4 = 3 + 1 = {}^{3}_{1}C + 1 = {}^{2+1}_{2-1}C + 1$
4	**3**	$7 = 6 + 1 = {}^{4}_{2}C + 1 = {}^{3+1}_{3-1}C + 1$
5	**4**	$11 = 10 + 1 = {}^{5}_{3}C + 1 = {}^{4+1}_{4-1}C + 1$
6	**5**	$16 = 15 + 1 = {}^{6}_{4}C + 1 = {}^{5+1}_{5-1}C + 1$
.	.	.
.	.	.
.	.	.
l	$\boldsymbol{a} = l - 1$	$m = {}^{a+1}_{a-1}C + 1$

In summary, the mathematical induction of the Kifilideen's Sum Formula of the Kifilideen's General Matrix Progression Series of infinite terms is given as:

$$S_n = k(q_n) + i(w_n) + nf$$
(151)

Where

$$q_n = \frac{(a)(a+1)(a+2)+3a(n-m-a))}{3}$$
(152)

$$w_n = \frac{(a-1)(a)(a+1)+3(n-m)(n-m+1)}{6}$$
(153)

$$m = \frac{a^2+a+2}{2}$$
(154)

Where S_n is the sum of the first n^{th}terns of the series, k is the migration column value, i is the migration row value, f is the first term, n is the value of the number of terms to sum, q_n is the sum migration column factor, w_n is the sum migration row factor, migration column factor, a and migration row factor, m.

3 Results

3.1 Applications of Epoch of Kifilideen's Sum Formula for General Matrix Progression Series

The application of epoch of Kifilideen's Sum Formula for General Matrix Progression Series of infinite terms in solving real world problems is presented below:

[a] A battery manufacturing company, say in Nigeria, may produce series of batteries using Kifilideen's Matrix Progression Sequence concept. The levels of the batteries produced serves as the various weights of the batteries manufactured in order. Each level (weight grade) has sub level(s) or step(s). The manufacturing company designs the charge capacity, Ah of the battery as the sublevel(s) or steps property for each level (weight grade) of the battery. If the sequence of the batteries manufactured using the Kifilideen's matrix progression sequence of infinite terms is given as: charge capacity $38Ah$ for level 1 of weight $200\ g$; charge capacities $43Ah, 46Ah$ for level 2 of weight $400\ g$ each; charge capacities $48Ah, 51Ah, 54Ah$ for level 3 of weight $600\ g$ each; ...

Determine the following

(i) the sum of the charge capacities of batteries manufacture for the first twelve terms of the series of batteries produce by the company (ii) the sum of the charge capacities of batteries produce for the first hundred terms of the series of the batteries manufacture by the company (iii) draw the Kifilideen's Matrix Structural Framework for the first five levels of the sequence of batteries manufacture by the company.

Solution

(i) For the first twelve terms of the series of batteries produce by the company, $n = 12$

Migration level factor of the charge capacity of the battery $= a = \frac{-1+\sqrt{8n-7}}{2}$

Migration level factor of the charge capacity of the battery $= a = \frac{-1+\sqrt{8\times12-7}}{2}$

Migration level factor of the charge capacity of the battery $= a = 4.2170$

Migration level factor of the charge capacity of the battery $= a = 4$

Migration step factor of the charge capacity of the battery $= m = \frac{a^2+a+2}{2}$

Migration step factor of the charge capacity of the battery $= m = \frac{4^2+4+2}{2}$

Migration step factor of the charge capacity of the battery $= m = 11$

$f =$ charge capacity of the first term of the battery produce by the company = $T_1 = 38Ah$

$k =$ the difference between the value of charge capacity of the battery of the first member of one level and the value of charge capacity of the battery of the first member of immediate previous level $= T_2 - T_1$

$k = 43Ah - 38Ah = 5Ah$

$i =$ the difference between the value of charge capacity of battery of a step in a level and the value charge capacity of battery of the immediate previous step in the same level $= T_3 - T_2 = 46Ah - 43Ah = 3Ah$

Sum migration level factor of the charge capacity of the battery $= q_n = \frac{(a)(a+1)(a+2)+3a(n-m-a))}{3}$

Sum migration level factor of the charge capacity of the battery $= q_{12} = \frac{(4)(4+1)(4+2)+3\times4(12-11-4))}{3}$

Sum migration level factor of the charge capacity of the battery $= q_{12} = \frac{(4)(5)(6)+3\times4(-3))}{3}$

Sum migration level factor of the charge capacity of the battery $= q_{12} = 28$

Sum migration step factor of the charge capacity of the battery $= w_n = \frac{(a-1)(a)(a+1)+3(n-m)(n-m+1)}{6}$

Sum migration step factor of the charge capacity of the battery $= w_{12} = \frac{(4-1)(4)(4+1)+3(12-11)(12-11+1)}{6}$

Sum migration step factor of the charge capacity of the battery $= w_{12} = \frac{(3)(4)(5)+3(1)(2)}{6}$

Sum migration step factor of the charge capacity of the battery $= w_{12} = 11$

$S_n = k(q_n) + i(w_n) + nf$

The sum of the charge capacities of batteries manufacture for the first twelve terms of the series of batteries produce by the company = $S_{12} = 5 \times (28) + 3(11) + 12 \times 38$

The sum of the charge capacities of batteries manufacture for the first twelve terms of the series of batteries produce by the company = $S_{12} = 629Ah$

(ii) For the first hundred terms of the series of batteries produce by the company, $n = 100$

Migration level factor of the charge capacity of the battery $= a = \frac{-1+\sqrt{8n-7}}{2}$

Migration level factor of the charge capacity of the battery $= a = \frac{-1+\sqrt{8\times100-7}}{2}$

Migration level factor of the charge capacity of the battery $= a = 13.5801$

Migration level factor of the charge capacity of the battery $= a = 13$

Migration step factor of the charge capacity of the battery $= m = \frac{a^2+a+2}{2}$

Migration step factor of the charge capacity of the battery $= m = \frac{13^2+13+2}{2}$

Migration step factor of the charge capacity of the battery $= m = 92$

f = charge capacity of the first term of the battery produce by the company = $T_1 = 38Ah$
k = the difference between the value of charge capacity of the battery of the first member of one level and the value of charge capacity of the battery of the first member of immediate previous level $= T_2 - T_1$
$k = 43Ah - 38Ah = 5Ah$
i = the difference between the value of charge capacity of battery of a step in a level and the value charge capacity of battery of the immediate previous step in the same level $= T_3 - T_2 = 46Ah - 43Ah = 3Ah$

Sum migration level factor of the charge capacity of the battery $= q_n = \frac{(a)(a+1)(a+2)+3a(n-m-a))}{3}$
Sum migration level factor of the charge capacity of the battery $= q_{100} = \frac{(13)(13+1)(13+2)+3\times13(100-92-13))}{3}$

Sum migration level factor of the charge capacity of the battery $= q_{100} = \frac{(13)(14)(15)+3\times4(-5))}{3}$
Sum migration level factor of the charge capacity of the battery $= q_{100} = 845$
Sum migration step factor of the charge capacity of the battery $= w_n = \frac{(a-1)(a)(a+1)+3(n-m)(n-m+1)}{6}$
Sum migration step factor of the charge capacity of the battery
$= w_{100} = \frac{(13-1)(13)(13+1)+3(100-92)(100-92+1)}{6}$
Sum migration step factor of the charge capacity of the battery $= w_{100} = \frac{(12)(13)(14)+3(8)(9)}{6}$
Sum migration step factor of the charge capacity of the battery $= w_{100} = 400$
$S_n = k(q_n) + i(w_n) + nf$
The sum of the charge capacities of batteries produce for the first hundred terms of the series of the batteries manufacture by the company $= S_{100} = 5 \times (845) + 3(400) + 100 \times 38$
The sum of the charge capacities of batteries produce for the first hundred terms of the series of the batteries manufacture by the company $= S_{100} = 9225Ah$

(iii) Since migration level value $= k = 5BG$, migration step value $= i = 3Ah$ and the charge capacity of the first term of the battery produce is $38Ah$, then the Kifilideen's Matrix Structural Framework for the sequence of the first five levels of the batteries produce is given in Table 3.

Table 3. Kifilideen's Matrix Structural Framework for the sequence of question (a)

		$Levels(Weight, g)$				
Weights /Charge Capacity		Level 1, l_1 $W_1 = 200\ g$	Level 1, l_1 $W_2 = 400\ g$	Level 1, l_1 $W_3 = 600\ g$	Level 1, l_1 $W_4 = 800\ g$	Level 1, l_1 $W_5 = 1000\ g$
	s_1	$T_1 = 38Ah$				
Steps	s_2		$T_2 = 43Ah$			
(Charge	s_3		$T_3 = 46Ah$	$T_4 = 48Ah$		
capacity	s_4			$T_5 = 51Ah$	$T_7 = 53Ah$	
of	s_5			$T_6 = 54Ah$	$T_8 = 56Ah$	$T_{11} = 58Ah$
battery,	s_6				$T_9 = 59Ah$	$T_{12} = 61Ah$
Ah)	s_7				$T_{10} = 62Ah$	$T_{13} = 64Ah$

s_8	$T_{14} = 67Ah$
s_9	$T_{15} = 70Ah$

From the Table 3, the value of the charge capacity of battery in level 1 of weight $200\ g$ in step 1 is $38Ah.$ The value of the charge capacities of batteries in level 2 of weight $400\ g$ in steps 2 and 3 are $43Ah$ and $46Ah$ respectively. More so, the value of the charge capacities of batteries in level 3 of weight $600\ g$ in steps 3, 4 and 5 are $48Ah,$ $51Ah$ and $54Ah$ respectively. Furthermore, the value of the charge capacities of batteries in level 4 of weight $800\ g$ in steps 4, 5, 6 and 7 are $53Ah,$ $56Ah,$ $59Ah$ and $62Ah$ respectively. Meanwhile, the value of the charge capacities of batteries in level 5 of weight $1000\ g$ in steps 5, 6, 7, 8 and 9 are $58Ah,$ $61Ah,$ $64Ah,$ $67Ah$ and $70Ah$ respectively. From the Table 3 the sum of the charge capacities of batteries manufacture for the first twelve terms of the series of batteries produce by the company, $S_{12},$ is also $629Ah.$ The difference in value of the charge capacities of batteries in last step in one level and the last step in the previous level is equivalent to the sum of the migration level value, k and the migration step value, $i.$ For this design, the difference in value of the charge capacities of batteries in last step in one level and the last step in the previous level is $8Ah$ (this is the difference in value of the charge capacities of batteries in last step in one level and the last step in the previous level $k + i = 5 + 3 = 8Ah$).

[b] A phone manufacturing company utilizes Kifilideen's Matrix Progression sequence of infinite term to produce series of phone. The levels 1, 2, 3, … of the phone is designed into various models 1, 2, 3, … in order. As the model advances, the physical appearance of the phone also advances. Each level or model of the phone has sub-level(s) or step(s). The storage capacity of the phone is the design property for each sub-level(s) or step(s) of each level or model of the phone. The storage capacity of the phone is measured in Gigabytes, GB. Given that the value of the storage capacities of phone manufactured by the company at the 5th and 10th terms of Kifilideen's General Matrix Progression Sequence of infinite terms are $15GB$ and $23GB$ and if the sum of the storage capacities of the first thirteen terms of the series of the manufactured phone collectively is $207GB.$ Determine the following:
(i) migration level value of the phone, k (ii) migration step value of the phone, i (iii) the storage capacity of the first term of the phone produce, f (iv) the storage capacity of the 8th term of the phone produce (v) the sum of the storage capacity of the first six terms of the phone produce (vi) generate the Kifilideen's Matrix Structural Framework for the sequence of the first five levels or models.

Solution

(i) For the 5th term of the series of phones produce by the manufacturing company, $n = 5,\ T_5 = 15GB$

Migration level factor of the storage capacity of the phone $= a = \frac{-1+\sqrt{8n-7}}{2}$

Migration level factor of the storage capacity of the phone $= a = \frac{-1+\sqrt{8\times5-7}}{2}$

Migration level factor of the storage capacity of the phone $= a = 2.3723$

Migration level factor of the storage capacity of the phone $= a = 2$

Migration step factor of the storage capacity of the phone $= m = \frac{a^2+a+2}{2}$

Migration step factor of the storage capacity of the phone $= m = \frac{2^2+2+2}{2}$

Migration step factor of the storage capacity of the phone $= m = 4$

$T_n = k(a) + i(n - m) + f$

The storage capacity of the fifth term of the phone $= T_5 = k(2) + i(5 - 4) + f = 15GB$

$2k + i + f = 15GB$

(155)

For the 10th term of the series of phones produce by the manufacturing company, $n = 10, T_{10} = 23GB$

Migration level factor of the storage capacity of the phone$= a = \frac{-1+\sqrt{8n-7}}{2}$
Migration level factor of the storage capacity of the phone$= a = \frac{-1+\sqrt{8\times10-7}}{2}$
Migration level factor of the storage capacity of the phone$= a = \mathbf{3}.7720$
Migration level factor of the storage capacity of the phone$= a = 3$
Migration step factor of the storage capacity of the phone$= m = \frac{a^2+a+2}{2}$
Migration step factor of the storage capacity of the phone$= m = \frac{3^2+3+2}{2}$
Migration step factor of the storage capacity of the phone$= m = 7$
$T_n = k(a) + i(n-m) + f$
The storage capacity of the tenth term of the phone $= T_{10} = k(3) + i(10-7) + f = 23GB$
$3k + 3i + f = 23GB$
(156)
For the first thirteen terms of the series of phone produce by the company, $n = 13$, $S_{13} = 207GB$
Migration level factor of the storage capacity of the phone$= a = \frac{-1+\sqrt{8n-7}}{2}$
Migration level factor of the storage capacity of the phone $= a = \frac{-1+\sqrt{8\times13-7}}{2}$
Migration level factor of the storage capacity of the phone$= a = \mathbf{4}.4244$
Migration level factor of the storage capacity of the phone$= a = 4$
Migration step factor of the storage capacity of the phone$= m = \frac{a^2+a+2}{2}$
Migration step factor of the storage capacity of the phone$= m = \frac{4^2+4+2}{2}$
Migration step factor of the storage capacity of the phone$= m = 11$
Sum migration level factor of the storage capacity of the phone $= q_n = \frac{(a)(a+1)(a+2)+3a(n-m-a))}{3}$
Sum migration level factor of the storage capacity of the phone $= q_{13} = \frac{(4)(4+1)(4+2)+3\times4(13-11-4))}{3}$
Sum migration level factor of the storage capacity of the phone $= q_{13} = \frac{(4)(5)(6)+3\times4(-2))}{3}$
Sum migration level factor of the storage capacity of the phone $= q_{13} = 32$
Sum migration step factor of the storage capacity of the phone $= w_n = \frac{(a-1)(a)(a+1)+3(n-m)(n-m+1)}{6}$
Sum migration step factor of the storage capacity of the phone $= w_{13} = \frac{(4-1)(4)(4+1)+3(13-11)(13-11+1)}{6}$

Sum migration step factor of the storage capacity of the phone $= w_{13} = \frac{(3)(4)(5)+3(2)(3)}{6}$
Sum migration step factor of the storage capacity of the phone $= w_{13} = 13$
$S_n = k(q_n) + i(w_n) + nf$
The sum of the storage capacities of the first thirteen terms of the series of the manufactured phone collectively produces $= S_{13} = k \times (32) + i(13) + 13 \times f = 207GB$

$$32k + 13i + 13f = 207GB \quad (157)$$

From (155), (156) and (157), the following are obtained:

$2k + i + f = 15GB$ (155)
$3k + 3i + f = 23GB$ (156)
$32k + 13i + 13f = 207GB$ (157)

Using Kifilideen Extermination and Determinant of Matrix method (KEDM) (Osanyinepju, 2024; Osanyinpeju, 2025), the following is obtained:

$C_k \quad C_f \quad C_i \quad C_f \qquad C_o \quad C_f \quad C_i \quad C_f$

$$\begin{vmatrix} \begin{vmatrix} 2 & 1 \\ 3 & 1 \end{vmatrix} & \begin{vmatrix} 1 & 1 \\ 3 & 1 \end{vmatrix} \\ \begin{vmatrix} 3 & 1 \\ 32 & 13 \end{vmatrix} & \begin{vmatrix} 3 & 1 \\ 13 & 13 \end{vmatrix} \end{vmatrix} k = \begin{vmatrix} \begin{vmatrix} 15 & 1 \\ 23 & 1 \end{vmatrix} & \begin{vmatrix} 1 & 1 \\ 3 & 1 \end{vmatrix} \\ \begin{vmatrix} 23 & 1 \\ 207 & 13 \end{vmatrix} & \begin{vmatrix} 3 & 1 \\ 13 & 13 \end{vmatrix} \end{vmatrix}$$

$$\begin{vmatrix} -1 & -2 \\ 7 & 26 \end{vmatrix} k = \begin{vmatrix} -8 & -2 \\ 92 & 26 \end{vmatrix}$$

$-12k = -24$

$k = 2GB$

$$\begin{array}{cccc} C_i & C_f & C_k & C_f \end{array} \qquad \begin{array}{cccc} C_o & C_f & C_k & C_f \end{array}$$

$$\begin{vmatrix} \begin{vmatrix} 1 & 1 \\ 3 & 1 \end{vmatrix} & \begin{vmatrix} 2 & 1 \\ 3 & 1 \end{vmatrix} \\ \begin{vmatrix} 3 & 1 \\ 13 & 13 \end{vmatrix} & \begin{vmatrix} 3 & 1 \\ 32 & 13 \end{vmatrix} \end{vmatrix} i = \begin{vmatrix} \begin{vmatrix} 15 & 1 \\ 23 & 1 \end{vmatrix} & \begin{vmatrix} 2 & 1 \\ 3 & 1 \end{vmatrix} \\ \begin{vmatrix} 23 & 1 \\ 207 & 13 \end{vmatrix} & \begin{vmatrix} 3 & 1 \\ 32 & 13 \end{vmatrix} \end{vmatrix}$$

$$\begin{vmatrix} -2 & -1 \\ 26 & 7 \end{vmatrix} i = \begin{vmatrix} -8 & -1 \\ 92 & 7 \end{vmatrix}$$

$12i = 36$

$i = 3GB$

$$\begin{array}{cccc} C_f & C_i & C_k & C_i \end{array} \qquad \begin{array}{cccc} C_o & C_i & C_k & C_i \end{array}$$

$$\begin{vmatrix} \begin{vmatrix} 1 & 1 \\ 1 & 3 \end{vmatrix} & \begin{vmatrix} 2 & 1 \\ 3 & 3 \end{vmatrix} \\ \begin{vmatrix} 1 & 3 \\ 13 & 13 \end{vmatrix} & \begin{vmatrix} 3 & 3 \\ 32 & 13 \end{vmatrix} \end{vmatrix} f = \begin{vmatrix} \begin{vmatrix} 15 & 1 \\ 23 & 3 \end{vmatrix} & \begin{vmatrix} 2 & 1 \\ 3 & 3 \end{vmatrix} \\ \begin{vmatrix} 23 & 3 \\ 207 & 13 \end{vmatrix} & \begin{vmatrix} 3 & 3 \\ 32 & 13 \end{vmatrix} \end{vmatrix}$$

$$\begin{vmatrix} 2 & 3 \\ -26 & -57 \end{vmatrix} f = \begin{vmatrix} 22 & 3 \\ -322 & -57 \end{vmatrix}$$

$-36i = -288$

$i = 8GB$

So, $k = 2GB, i = 3GB\ and\ f = 8GB$

Migration level value of the phone, $k = 2GB$

(ii) Migration step value of the phone, $i = 3GB$

(iii) The storage capacity of the first term of the phone produce, $f = 8GB$

(iv) For the 8th term of the series of phones produce by the manufacturing company, $n = 8$,

Migration level factor of the storage capacity of the phone$= a = \frac{-1+\sqrt{8n-7}}{2} = \frac{-1+\sqrt{8\times8-7}}{2} = 3.2749 = 3$

Migration step factor of the storage capacity of the phone$= m = \frac{a^2+a+2}{2} = \frac{3^2+3+2}{2} = 7$

$T_n = k(a) + i(n-m) + f$

Since $k = 2GB, i = 3GB\ and\ f = 8GB$

The storage capacity of the 8th term of the series of phones produces $= T_8 = 2(3) + 3(8-7) + 8 = 17GB$

The storage capacity of the 8th term of the series of phones produces $= T_8 = 17GB$

(v) For the first six terms of the series of phone produce by the company, $n = 6$,

Migration level factor of the storage capacity of the phone $= a = \frac{-1+\sqrt{8n-7}}{2} = \frac{-1+\sqrt{8\times6-7}}{2} = 2.7016 = 2$

Migration step factor of the storage capacity of the phone$= m = \frac{a^2+a+2}{2} = \frac{2^2+2+2}{2} = 4$

Sum migration level factor of the storage capacity of the phone $= q_n = \frac{(a)(a+1)(a+2)+3a(n-m-a))}{3}$

Sum migration level factor of the storage capacity of the phone $= q_6 = \frac{(2)(2+1)(2+2)+3\times4(6-4-2))}{3}$

Sum migration level factor of the storage capacity of the phone $= q_6 = \frac{(2)(3)(4)+3\times2(0))}{3} = \frac{24}{3}$

Sum migration level factor of the storage capacity of the phone $= q_6 = 8$

Sum migration step factor of the storage capacity of the phone $= w_n = \frac{(a-1)(a)(a+1)+3(n-m)(n-m+1)}{6}$

Sum migration step factor of the storage capacity of the phone $= w_6 = \frac{(2-1)(2)(2+1)+3(6-4)(6-4+1)}{6}$

Sum migration step factor of the storage capacity of the phone $= w_6 = \frac{(1)(2)(3)+3(2)(3)}{6}$

Sum migration step factor of the storage capacity of the phone $= w_6 = 4$

$S_n = k(q_n) + i(w_n) + nf$

Since $k = 2GB, i = 3GB\ and\ f = 8GB$

Sum of the storage capacities of the first six terms of the phone produces $= S_6 = 2 \times (8) + 3(4) + 6 \times 8$

Sum of the storage capacities of the first six terms of the phone produces $= S_6 = 76GB$

(vi) Since migration level value $= k = 2GB,$ migration step value $= i = 3GB$ and the storage capacity of the first term of the phone produce, $f = 8GB$ then the Kifilideen's Matrix Structural Framework for the sequence of the first five levels of the phones manufacture is given in Table 4.

Table 4. Kifilideen matrix structural framework for the sequence of question (b)

Level (Physical appearance), l				
l_1	l_2	l_3	l_4	l_5
$T_1 = 8BG$				
	$T_2 = 10BG$			
	$T_3 = 13BG$	$T_4 = 12BG$		
		$T_5 = 15BG$	$T_7 = 14BG$	
		$T_6 = 18BG$	$T_8 = 17BG$	$T_{11} = 16BG$
			$T_9 = 20BG$	$T_{12} = 19BG$
			$T_{10} = 23BG$	$T_{13} = 22BG$
				$T_{14} = 25BG$
				$T_{15} = 28BG$

From the Table 4, the value of the storage capacity of the phone in level 1 of step 1 is $8BG.$ The value of the storage capacities of phone in level 2 of steps 2 and 3 are $10BG$ and $13BG$ respectively. More so, the value of the storage capacities of phones in level 3 of steps 3, 4 and 5 are $12BG,$ $15BG$ and $18BG$ respectively. Furthermore, the value of the storage capacities of phones in level 4 of steps 4, 5, 6 and 7 are $14BG,$ $17BG,$ $20BG$ and $23BG$ respectively. Meanwhile, the value of the storage capacities of phones in level 5 of steps 5, 6, 7, 8 and 9 are $16\ BG,$ $19BG,$ $22BG,$ $25BG$ and $28BG$ respectively. From the Table 4 the sum of the storage capacities of phone manufacture for the first six terms of the series of phones produce by the company, $S_6,$ is also $76BG$ and the sum of the storage capacities of phone manufacture for the first six terms of the series of phones produce by the company, $S_{13},$ is also $207BG.$ The difference in value of the storage capacities of phones in last step in one level and the last step in the previous level is equivalent to the sum of the migration level value, k and the migration step value, $i.$ For this design, the difference in value of the storage capacities of phones in last step in one level and the last step in the previous level is $5BG$ (this is the difference in value of the storage capacities of phones in last step in one level and the last step in the previous level $k + i = 2 + 3 = 5BG$).

(c) A drink industry designs different grades of drink based on taste level. Each grade of drinks concocted has step(s). The step(s) of each grade is/are determined by the litres of drink. The design of the litres of the drink concocted is formulated using the Kifilideen's Matrix Progression Sequence of infinite terms. If the sum of litres of drink for the n terms of the series of Kifilideen's General Matrix Progression Sequence of infinite terms generated by the company is $223\ litres$ and the last term of the series is found in level 4 of the Kifilideen's Matrix Structural Framework. If the migration level value of the drink, $k,$ migration step value of the drink, i and the litres of the first term of the drink, f are 10, 5 and $2\ litres$ respectively. (i) Determine the number of terms in the series (ii) generate the Kifilideen's Matrix Structural Framework for the sequence of the first four levels of the drink.

Solution

For the first n terms of the series of drink concocted by the industry, $n = n, \ S_n = 223\ litres$

$Level = l = 4$

Migration level factor of the litres of drink $= a = l - 1 = 4 - 1 = 3$

Migration step factor of the litres of drink $= m = \frac{a^2+a+2}{2}$

Migration step factor of the litres of drink $= m = \frac{3^2+3+2}{2}$

Migration step factor of the litres of drink $= m = 7$

Sum migration level factor of the litre of the drink $= q_n = \frac{(a)(a+1)(a+2)+3a(n-m-a))}{3}$

Sum migration level factor of the litre of the drink $= q_n = \frac{(3)(3+1)(3+2)+3\times3(n-7-3))}{3}$

Sum migration level factor of the litre of the drink $= q_n = \frac{(3)(4)(5)+3\times3(n-10))}{3} = \frac{24}{3}$

Sum migration level factor of the litre of the drink $= q_n = \frac{60+9(n-10))}{3}$

Sum migration level factor of the litre of the drink $= q_n = \frac{60+9n-90}{3}$

Sum migration level factor of the litre of the drink$= q_n = \frac{9n-30}{3}$

Sum migration level factor of the litre of the drink $= q_n = 3n - 10$

Sum migration step factor of the litre of the drink $= w_n = \frac{(a-1)(a)(a+1)+3(n-m)(n-m+1)}{6}$

Sum migration step factor of the litre of the drink$= w_n = \frac{(3-1)(3)(3+1)+3(n-7)(n-7+1)}{6}$

Sum migration step factor of the litre of the drink$= w_n = \frac{(2)(3)(4)+3(n-7)(n-6)}{6}$

Sum migration step factor of the litre of the drink $= w_n = \frac{24+3(n^2-13n+42)}{6}$

Sum migration step factor of the litre of the drink $= w_n = \frac{8+(n^2-13n+42)}{2}$

Sum migration step factor of the litre of the drink$= w_n = \frac{n^2-13n+50}{2}$

$S_n = k(q_n) + i(w_n) + nf$

Since $k = 10litres, i = 5litres\ and\ f = 2litres$

Sum of the litres of the first n terms of the drink concocted $= S_n = 10 \times (3n - 10) + 5\left(\frac{n^2-13n+50}{2}\right) + n \times 2 = 223litres$

$20 \times (3n - 10) + 5(n^2 - 13n + 50) + 4n = 446$

$5n^2 - n + 50 - 446 = 0$

$5n^2 - n - 396 = 0$

Using quadratic formula, we have:

$n = \frac{-(-1)\pm\sqrt{(-1)^2-4\times5\times-396}}{2\times5} = \frac{1\pm\sqrt{7921}}{10} = \frac{1\pm89}{10} = \frac{90}{10}\ or\ \frac{-8.8}{10}$

$n = 9\ or - 8.8$
Since n is positive, then:
$number\ of\ terms\ of\ the\ series\ of\ litres\ of\ drinks\ concocted = n = 9$

(ii) Since migration level value $= k = 10litres$, migration step value $= i = 5litres$ and the litres of the first term of the drink concocted $= f = 2litres$, then the Kifilideen's Matrix Structural Framework for the sequence of the first four levels of drinks concocted is given in Table 5.

Table 5. Kifilideen's Matrix Structural Framework for the sequence of question (c)

Level, l (Taste level)			
l_1	l_2	l_3	l_4
$T_1 = 2litres$			
	$T_2 = 12litres$		
	$T_3 = 17litres$	$T_4 = 22litres$	
		$T_5 = 27litres$	$T_7 = 32litres$
		$T_6 = 32litres$	$T_8 = 37litres$
			$T_9 = 42litres$
			$T_{10} = 47litres$

From the Table 5, the value of the litres of the drink in level 1 of step 1 is $2litres$. The value of the litres of drink in level 2 of steps 2 and 3 are $12litres$ and $17litres$ respectively. More so, the value of the litres of drinks in level 3 of steps 3, 4 and 5 are $22litres$, $27litres$ and $32litres$ respectively. Furthermore, the value of the litres of drink in level 4 of steps 4, 5, 6 and 7 are $32litres$, $37litres$, $42litres$ and $47litres$ respectively. From the Table 5 the sum of the litres of drink concocted for the first nine terms of the series of drink concocted by the industry, S_9, is also $223litres$. The difference in value of the litres of drink in last step in one level and the last step in the previous level is equivalent to the sum of the migration level value, k and the migration step value, i. For this design, the difference in value of the litres of drink in last step in one level and the last step in the previous level is $15litres$ (this is the difference in value of the litres of drink in last step in one level and the last step in the previous level $k + i = 10 + 5 = 15litres$).

(d) A gold manufacturing company implements Kifilideen's Matrix Progression Sequence to produce gold into various masses. If the sum of masses of gold of the first four hundred terms of Kifilideen's Matrix Progression Sequence of infinite terms is $16424g$ and, the migration steps value of the gold, i and the mass of the first term of the gold, f are $-2g$ and $5g$ respectively. (i) Find the migration level value of the gold, k of the series (ii) present the Kifilideen's Matrix Structural Framework for the sequence of the first three levels of the gold.

Solution
For the first four hundred terms of the series of gold produce by the company, $n = 400$, $S_{400} = 16424$
Migration level factor of the masses of gold $= a = \frac{-1+\sqrt{8n-7}}{2}$
Migration level factor of the masses of gold $= a = \frac{-1+\sqrt{8\times400-7}}{2}$
Migration level factor of the masses of gold $= a = 27.7533$
Migration level factor of the masses of gold $= a = 27$

Migration step factor of the masses of gold $= m = \frac{a^2+a+2}{2}$
Migration step factor of the masses of gold $= m = \frac{27^2+27+2}{2}$
Migration step factor of the masses of gold $= m = 379$
Sum migration level factor of the masses of the gold $= q_n = \frac{(a)(a+1)(a+2)+3a(n-m-a))}{3}$
Sum migration level factor of the masses of the gold $= q_{400} = \frac{(27)(27+1)(27+2)+3\times27(400-379-2\ \ ))}{3}$

Sum migration level factor of the masses of the gold $= q_{400} = \frac{(27)(28)(29)+3\times27(-6))}{3} = \frac{24}{3}$
Sum migration level factor of the masses of the gold $= q_{400} = 7146$
Sum migration step factor of the masses of the gold $= w_n = \frac{(a-1)(a)(a+1)+3(n-m)(n-m+1)}{6}$

Sum migration step factor of the masses of the gold $= w_{400} = \frac{(27-1)(27)(27+1)+3(400-379)(400-379+1)}{6}$
Sum migration step factor of the masses of the gold $= w_{400} = \frac{(26)(27)(28)+3(21)(22)}{6}$
Sum migration step factor of the masses of the gold $= w_{400} = 3507$
$S_n = k(q_n) + i(w_n) + nf$
$S_{400} = k(q_{400}) + i(w_{400}) + 400\ \times f$
Since $i = -2g\ and\ f = 5g$
Sum of the masses of the first four hundred terms of the gold manufacture $= S_{400} = k \times (7146) + (-2)(3507) + 400 \times 5 = 16424g$
$k \times (7146) = 16424 - 400 \times 5 + 2 \times 3507$
$7146k = 21438$
$k = \frac{21438}{7146}$
$k = 3g$
Migration level value of the masses of gold $= \mathrm{k} = 3g$

(ii) Since migration level value $= k = 3g$, migration step value $= i = -2g$ and the masses of the first term of the gold manufacture $= f = 5g$, then the Kifilideen's Matrix Structural Framework for the sequence of the first three levels of gold manufacture is given in Table 6.

Table 6. Kifilideen's Matrix Structural Framework for the sequence of question (d)

$level, l$		
l_1	l_2	l_3
$5g$		
	$8g$	
	$6g$	$11g$
		$9g$
		$7g$

From the Table 6, the value of the masses of the gold in level 1 of step 1 is $5g$. The value of the masses of gold in level 2 of steps 2 and 3 are $8g$ and $6g$ respectively. More so, the value of the masses of gold in level 3 of steps 3, 4 and 5 are $11g$, $9g$ and $7g$ respectively. The difference in value of the masses of gold in last step in one level and the last step in the previous level is equivalent to the sum of the migration level value, k and the migration step value, i. For this design, the difference in value of the masses of gold in last step in one level and the last step in the previous level is $1g$ (this is the difference in value of the masses of gold in last step in one level and the last step in the previous level $k + i = 3 + (-2) = 1g$).

4.0 Conclusion

This study introduces Kifilideen's Sum Formula for infinite Matrix Progression Series, a novel summation approach that efficiently compute structured numerical sequences. The limitations of existing summation techniques in handling hierarchical matrix-based progressions were identified, highlighting the need for a systematic and computationally efficient method. Through mathematical induction, sum formulas for bi-number product progression series were established, serving as the foundation for deriving Kifilideen's Sum Formula. The application of the proposed formula in real-world scenarios including manufacturing, financial modeling, and resource allocation, demonstrated its practical utility. The formula significantly reduces computational complexity while maintaining accuracy, making it a powerful tool for industries that rely on structured numerical aggregation. The case studies presented validate its effectiveness in optimizing decision-making processes in production forecasting, investment planning, and large-scale distribution systems. By introducting a structured and efficient framework for summing infinite matrix progression series, this study contributes to mathematical advancements in structured summation techniques. Future research can explore further refinements of the formula, its integration into computational algorithms, and its application in broader scientific and engineering fields.

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Numerical and Experimental Investigation on Combustion of Briquettes Made from Sawdust

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Abstract

The study reports on the numerical and experimental investigation of the combustion of briquettes made from sawdust. The stoichiometric air required for complete combustion was calculated and three excess air factors (10, 20, 30%) were considered. The numerical simulation was carried out using ANSYS 19R3 and the outputs monitored were the adiabatic flame temperature and volume fractions of the combustion products (CO_2, O_2, CO, SO_2, and NO). The combustion was experimentally studied using the residential charcoal combustor. A Tetso 330 flue gas analyzer was used to measure the gas emission. The maximum flue gas temperature was recorded for all the briquette samples during ambient air conditions, while the least was recorded at 30% excess air. High amounts of CO_2 and low amounts of oxygen were recorded at ambient and as the amount of air supplied was increased, the amount of CO_2 and CO was reduced. A good agreement between the experimental data and Computational Fluid Dynamics (CFD) results was observed, which suggests that CFD can be a convenient tool for investigating emissions during the burning of briquettes. The SO_2 and NO recorded were far below the OSHA standard, indicating that the briquettes will be environmentally friendly.

Keywords: Numerical, Briquettes, Combustion, Emissions

1.0 Introduction

The significant environmental impact surrounding fossil fuels has been a great concern. The mitigation of the effects of burning fossil fuels involves substituting them with renewable energy sources (Alonge and Obayopo, 2023b; Malat'ák *et al.*, 2020). Biomass briquette has been recognized as a viable replacement for coal and other fossil fuels used in several applications, including cooking, heating, boiler combustion, power production, and more (Alonge and Obayopo, 2023a; Jia *et al.*, 2020). Biomass briquette fuel is very efficient, clean, easy to ignite, and emits near-zero CO_2.

Generally, burning fuel emits volatile organic matter, a sulphur compound, nitrogen oxides, carbon monoxide, particulates, and trace elements, depending on the content of the fuel and the degree of combustion. The emission of gases during the combustion of solid fuels is related to the elemental composition of the fuel (carbon, hydrogen, oxygen, sulphur, and nitrogen). Most biomass only contains a minor amount of nitrogen and sulfur, the main constituents are carbon, oxygen, and hydrogen. Gases that were mostly measured during the combustion of solid fuel are O_2, CO_2, CO, NO, NO_2, and SO_2 (Muraina *et al.*, 2017; Pilusa *et al.*, 2013). Although, O_2, CO, NO, NO_2, and SO_2 are measured electrochemically by using a gas analyzer, CO_2 and NO_x are calculated by a gas analyzer. Nitrogen and sulphur have been the most significant in the formation of harmful emissions and affect reactions forming ash. One of the most dangerous pollutants emitted by the burning of solid fuels is nitrogen oxide, which contributes to the creation of photochemical smog, acid rain, the greenhouse effect, and stratospheric ozone depletion (Tibor *et al.*, 2018). There are three main reasons for NO_x formation during biomass combustion which are prompt NO_x (formed at the flame front), thermal NOx (formed from atmospheric nitrogen, above 1300 ^oC), and the fuel-NO_x (formed from elemental nitrogen contents of the fuel). Fuel-NOx emissions can be reduced by producing volatile nitrogen in an oxygen-deficient atmosphere (staged combustion).

Literature has also reported the emission of CO during combustion which may be the result of low combustion temperature, insufficient oxygen, poor mixing of fuel with the combustion air, and/or too short residence time of the combustion gases (González *et al.*, 2020; Tissari *et al.*, 2009). Theoretical analysis of air required to achieve complete combustion is necessary using stoichiometric calculation with fuel ultimate and proximate analysis data. Mohon Roy and Corscadden (2012) researched the burning and emissions of biomass briquettes in a home wood stove, and it was reported that grassy briquettes showed less average carbon-monoxide emissions than woody briquettes while NO_x emissions recorded were higher than woody briquettes but SO_2 emissions are similar for both briquettes. Gálvez *et al.* (2010) prepared a catalytic briquette using a low-rank coal carbon precursor and vanadium compounds. Briquettes produced showed considerable activity in the selective catalytic reduction of NO in a wide temperature range (75–350 ^oC) and high selectivity towards N_2. The catalytic briquettes' structural-chemical, mechanical, and catalytic capabilities are all impacted by the various stages that go into making them, as well as how well they reduce NO selectively. Occupational Safety and Health Agency has a standard occupational emission that should also be considered and followed when combusting solid fuel (OSHA, 2019).

Hence, the combustion of the briquettes made from low- and high-density sawdust has been carried out in this study using numerical and experimental approaches to know the volume of gases the burning process of the briquettes will emit.

2.0 Materials and Method

2.1 Materials

Fig. 1 shows the briquettes investigated, made from low-density sawdust (***Ceiba Pentandra***) and high-density sawdust (***Nauclea diderichii***).

(a) (b)

Fig. 1. Briquettes made from (a) *Ceiba Pentandra* (b) *Nauclea diderichii.*

2.2 Elemental Analysis of the Briquettes

Ultimate and proximate analyses of the briquettes are presented in Table 1. The higher fixed carbon content recorded for the *Ceiba Pentandra* briquette implies that it will retain more heat than the *Nauclea diderichii* briquette. The fuel ratio which shows how easily fuel will ignite and burn out was also determined. The higher the fuel ratio, the more challenging to ignite the fuel (Chukwu *et al.*, 2016). The fuel ratio result shows that the *Nauclea diderichii* briquette will ignite easily. Higher ash content recorded for the *Ceiba Pentandra* briquette shows the possibility of lesser efficiency during burning. However, the ash contents recorded for the two samples are within an acceptable range according to the recommendation by Hashan *et al.,* (2013).

Table 1: Proximate and Ultimate Analysis of Briquettes made from *Nauclea diderichii and Ceiba Pentandra.*

S/N	Sample	V.M %	ASH %	F.C %	Fuel Ratio	C %	H %	N %	O %	S %	HHV (MJ/Kg)
1	ND	82.23	0.64	17.13	0.21	48.33	5.92	0.95	43.70	0.46	18.83
2	CP	71.53	0.92	27.63	0.39	50.15	5.93	1.12	41.21	0.67	21.55

ND: *Nauclea diderichii,* CP: *Ceiba Pentandra*

2.3 Experimental Investigation of the Combustion Process

The combustion was carried out using the residential charcoal combustor (as shown in Fig. 2). The experimental apparatus comprises a 12 V D.C. fan for combustion air supply, a 12 V battery, and a speed controller. A gas analyzer with a multipurpose probe for continuous gas analysis was installed. The produced briquettes of known masses were ignited and combusted in the rig. The combustion air to achieve complete combustion and excess air were followed as calculated in the stoichiometric calculation shown in Table 2. A Tetso 330 flue gas analyzer was used to measure the gas emission, and the response time of this analyzer was 10s for all the gases. The measurement range and accuracy are ±0.2 vol.% for O_2 and CO_2 and ±10% for CO at the concentrations observed in these experiments.

Fig. 2. Combustion process of the briquettes.

Table 2. Stoichiometric Calculation for the Theoretical Amount of Air for the Combustion.

S/N	**Proportion**	**Theoretical Air (m^3/Kg)**	**Average Mass of a Briquette (Kg)**	**Theoretical Air for a Briquette (m^3/kg)**	**Fuel flow rate (Kg/s)**	**Air flow rate (m^3/s)**	**Excess Actual Air (m^3/s)**		
							10%	20%	30%
1	ND	4.44	0.032±0.0012	0.142±0.0053	0.032	0.0045	0.0051	0.0055	0.0060
2	CP	4.69	0.091±0.0036	0.427±0.0169	0.091	0.0389	0.0428	0.0467	0.0506

ND: *Nauclea diderichii,* CP: *Ceiba Pentandra*

2.4 Numerical Method

ANSYS 19R was used to simulate the validation of the combustion process of the briquette. A non-premixed model of the combustion process was developed utilizing mixed fraction theory. This combustion model was chosen because the solid fuel could be described as an empirical stream therefore, the solid fuels were only specified as data from the ultimate analysis. The governing equations employed and solved were the continuity equation for the continuous phase as expressed in Eq. 1, the dispersed phase in Eq. 2 and Eq. 3, and the momentum equation as expressed by Eq. 4, which were all solved under steady-state conditions (Baloyi, 2017).

$$\nabla . (\rho \bar{v}) = -S_m . \tag{1}$$

$$\nabla . (\rho \bar{v} . \bar{f}) = \nabla . \left[\frac{\mu_t}{\sigma_t} \nabla \bar{f}\right] + s_m . \tag{2}$$

$$\nabla . \left(\rho \vec{v} \overline{f'^2}\right) = \nabla . \left(\frac{\mu_t}{\sigma_t} \nabla \overline{f'^2}\right) + C_g \mu_t \left(\nabla \bar{f}\right)^2 - 2.0 \rho \frac{\varepsilon}{k} \overline{f'^2}. \tag{3}$$

$$\nabla.(\rho\vec{v}\vec{v}) = -\nabla_{\varrho} + \nabla.(\bar{\bar{\tau}}) + \rho\vec{g} + \vec{F}. \tag{4}$$

The stress tensor is given by Eq. 5 (Baloyi, 2017).

$$\bar{\bar{\tau}} = \mu\left[(\nabla\vec{v} + \nabla\vec{v}^{T}) - \frac{2}{3}\nabla.\vec{v}\hat{\imath}\right]. \tag{5}$$

Where μ is the molecular viscosity of the continuous phase, $\vec{F}$ is the interactive body forces between the dispersed and the continuous phases, s_m is the source term accounting for the mass transfer from the solid phase to the gas phase and $\hat{\imath}$ Is a unit vector. $\bar{f}$ and $\overline{f'^2}$ are the mixture fraction and its variance. The energy for the non-premixed combustion model is expressed by Eq. 6 (Baloyi, 2017):

$$\nabla.(\rho\vec{v}H) = \nabla.\left(\frac{K_t}{c_p}\nabla H\right) + S_h. \tag{6}$$

The total Enthalpy is given by H is given by Eq. 7.

$$H = \sum_{j=1}^{m} Y_j\left(\int_{T_{ref,j}}^{T} C_{p,j}\,dT + h_j^0\,(T_{ref,j})\right). \tag{7}$$

Where Y_j is the mass fraction, $C_{p,j}$ is the specific heat and constant pressure and $h_j^0\,(T_{ref,j})$ is the enthalpy of the formation of the J^{th} species. S_h is the source term due to viscous dissipation. The use of the combustion model requires the use of a turbulent model because the combustion model is a mixture model. The $k-\varepsilon$ turbulent model with enhanced wall function was chosen as the turbulence model for all the simulations and the turbulence energy is given in Eq. 8 (Baloyi, 2017), while the turbulence dissipation is given in Eq. 9 and Eq. 10 (Baloyi, 2017). The radiation was modeled using the P1 model included. The pressure was solved using the PRESTO method and continuity, energy, turbulence, and mass fraction were solved using a second-order upwind scheme.

$$\frac{\delta}{\delta x_i}(\rho k u_i) = \frac{\delta}{\delta x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\delta k}{\delta x_j}\right] + G_k + G_b - \rho\varepsilon - Y_M\,. \tag{8}$$

$$\frac{\delta}{\delta x_i}(\rho\varepsilon u_i) = \frac{\delta}{\delta x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\delta\varepsilon}{\delta x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}\,. \tag{9}$$

$$\mu_t = \rho C_\mu\frac{K^2}{\varepsilon}\,. \tag{10}$$

Where i, j, K equal 1,2,3; G_k is the generation of turbulence kinetic energy due to mean velocity gradients, G_b is the generation of turbulence kinetic energy due to buoyancy; Y_m is the generation of turbulence kinetic energy due to fluctuation dilation in compressible turbulence to the overall dissipation rate; $C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$ and C_μ are constant. σ_k is the turbulent Prandt number for the turbulence kinetic energy, σ_ε is the turbulent Prandtl number for the turbulence dissipation rate, μ_t is the turbulent viscosity.

2.5 Model description and meshing

The combustor was modeled as shown in Fig. 3. It has a fuel inlet and an air inlet. The fuel flow rate and the airflow rate were input for each run of the simulation as specified in Table 3. A mesh independence study was done to reduce simulation costs and eliminate numerical effects on the results. A mesh size of 3,064 was chosen from the study. The outcome of the meshing process is shown in Fig. 4. The inlet temperature of the fuel inlet was set at the devolatilization temperature obtained from the thermogravimetric analysis reported by Alonge and Obayopo, (2023b). The inlet air temperature was set at 300 K. The fuel and air mass flow rates were input as calculated in Table 2. The wall of the combustor was set to be adiabatic. A Presto method and a second-order upwind scheme were combined with a pressure-based solver to calculate continuity, momentum, turbulence, and turbulence terms. The outputs monitored were the adiabatic flame temperature and volume fractions of the combustion products, namely: CO_2, O_2, CO, SO_2, and NO.

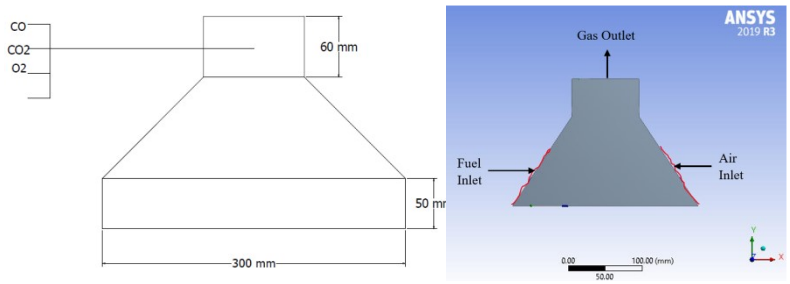


Fig. 3. Combustion Rig Model.

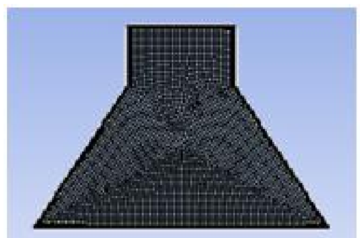


Fig. 4. Meshing Outcome.

3. Result and Discussion

The gases emitted during the experimental combustion of the briquettes are reported in Table 3 - 6. In this study, CO, CO_2, and O_2 emitted from burning were determined. The OSHA was used as a benchmark in this study.

Table 3. Emission of Gases from Burning of Briquettes made from *Nauclea diderrichii* at Different Air Supply.

Samples	**Variables**	**FT °C**	**Time (min.)**	**O_2 (%)**		**CO (%)**		**CO_2 (%)**	
				Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
ND	Amb.	49.9 – 413.6	41	14.4	20.2	0.1	2.8	1.14	6.51
	Stio.	56.4 – 306.1	13	18.5	20.9	0.1	0.4	1.29	2.47
	10% EA	41.9 – 280.5	14	18.9	20.7	0.1	0.2	1.16	1.75
	20% EA	53.1 – 234.7	13	19.2	20.8	0.1	0.2	1.10	1.25
	30% EA	45.3 – 223.1	12	19.7	20.8	0.1	0.1	1.04	1.10

ND: *Nauclea diderrichii,* FT: Flame temperature

Table 4. Emission of Gases from Burning of Briquettes made from *Ceiba pentandra* at Different Air Supply.

Samples	Variables	FT	Time	O_2 (%)		CO (%)		CO_2 (%)	
		°C	(min)	Min	Max	Min	Max	Min	Max
CP	Amb.	53.7 - 544.1	27	13.9	20.8	0.1	0.4	1.22	12.49
	Stio	52.7 - 137.4	15	17.8	20.7	0.1	0.3	1.08	3.96
	10% EA	60.2 – 209.1	15	18.2	20.9	0.1	0.3	1.16	2.55
	20% EA	51.2 – 142.4	13	18.9	20.9	0.1	0.2	1.12	2.39
	30% EA	51.0 -144.5	13	19.4	20.8	0.1	0.1	-	2.24

CP: *Ceiba pentandra*, FT: Flame Temperature

3.1 Flue gas temperature

The flue gas temperature varied throughout the experiment for the briquettes and was recorded in ranges. The variation was due to the airflow behavior in the burning chamber and the intensity at which the briquette was burning. The higher the excess air, the lesser the maximum flue gas temperature recorded. This shows that as the airflow increases, the sensible heat has been driven from the combustion chamber towards the outlet. As the flue gas temperature decreased with an increase in airflows, the emission of CO and CO_2 also decreased, while the flue gas cooling and dilution were done by combustion air. Maximum flue gas temperature was recorded for the two briquette samples during ambient air conditions (ranging between 413.6 and 544.1 °C), while the least was recorded at 0.3 excess air factor (ranging between 144.5 and 223.1 °C). Knigawka *et al.*, (2022) reported that the amount of flue gas produced and the temperature of flue gases (the difference between the temperature of flue gases and laboratory temperature) are directly related to the loss of combustion products through sensible heat. The flue gas temperature values of the briquettes indicate their potential use as solid fuel. It was also observed that as the airflow increased, the shorter time it took the briquette to burn out. *Nauclea diderrichii* briquettes burned out more quickly than *Ceiba pentandra* briquettes. This can be attributed to the higher fixed carbon possessed by the *Ceiba pentandra* briquettes.

3.2 CO_2 Emission

The CO_2 emission was recorded as shown in Tables 3 and 4. The maximum amount of CO_2 recorded ranged between 1.10 - 6.51% for *Nauclea diderrichii* briquette, while for raw *Ceiba pentandra* briquette, it ranged between 1.24 - 12.49%. From the above result, *Nauclea diderrichii* briquette showed more excellent combustion characteristics than the *Ceiba pentandra* briquette briquettes. The highest amount of CO_2 was seen to be associated with intense flame temperature and as the flame intensity reduced, a decrease in CO_2 concentration coupled with low combustion temperature was observed. High amounts of carbon dioxide and low amounts of oxygen were recorded at ambient and as the amount of air supplied was increased, the amount of carbon dioxide was reduced. At excess air above 20%, no change in the emission of CO_2 was observed.

According to (Obernberger *et al.*, 2006), briquettes that are not burned completely generate unburned carbon-based pollutants like carbon monoxide, hydrocarbons, polycyclic aromatic hydrocarbons, and soot. Therefore, the reduction in CO_2 emission as more air was being supplied shows the closeness of the burning process to complete combustion. High emission of CO_2 was recorded at ambient and could be probably caused by inadequate air supply and insufficient fuel-air mixing (Obernberger *et al.*, 2006). For each of the samples, high carbon dioxide was recorded which indicates complete combustion resulting in carbon monoxide being oxidized to carbon dioxide which is more of a greenhouse gas. The comparison between gas emissions from briquettes in this study and those recorded in previous works done using different combustion systems are reported in Table 5. It can be seen that the emission of CO_2 varies significantly from one biomass briquette to another. The CO_2 measured in this study was higher than the OSHA standard and those reported in previous works. The variation also depends on the combustion technology used and the organic composition of the briquettes. Low CO_2 emission (average) of 2900 ppm (0.29%) and 929 – 2180 ppm (0.09 - 0.2%) for anthracite and spent coffee grounds briquettes were measured in a boiler by Kim *et al.* (2021) and 453 – 565 ppm (0.05 - 0.06%) for water hyacinth briquette were measured in a conventional charcoal stove by Okia *et al.* (2017), whereas a high CO_2 emission (Avg.) of 21332 ppm (2.13%) for corn stover briquette were measured in a combustion system by (Pilusa *et al.*, 2013).

Table 5: Comparison of the Emission of CO_2 and CO of Briquettes Produced and that of Previous Studies under Ambient Air Condition

Combustion Rig	Briquette	Max. CO_2 (%)	Avg. CO_2 (%)	Max. CO (%)	Avg. CO (%)
P.S	Raw ND 100	6.51	2.85 (28,500 ppm)	3.1	0.37 (3,700 ppm)
P.S	Raw CP 100	12.49	3.38 (33,800 ppm)	0.4	0.12 (1,200 ppm)
Boiler (Yeongu *et al.*, 2022)	Anthracite	-	2900 ppm (0.29%)	-	995 ppm (0.1%)
	Spent Coffee Grounds		929-2180 ppm (0.09-0.2%)		8 – 48 ppm
Combustion System (Pilusa *et al.*, 2013)	Corn stover		21332 ppm (2.13%)		73.78 ppm (0.007%)
Okia *et al.*, 2017	Water Hyacinth		453-565 ppm (0.05-0.06%)		29-62 ppm
Anna *et al.*, 2021 (Convectional multi-fuel stove)	Torrefied Olive	5000-6000 ppm (0.1-0.6%)		11000-12000 ppm (0.35-1.2%)	
(Wang *et al.*, 2017) (Biomass furnace)	Corn Straw Biochar				104.06 mg/m^3 (0.01%)
	Paper				1162 ppm (0.12%)
Meng *et al.*, 2018 (Commercial Stove)	Ekolog wood				957 ppm (0.096%)
	Coal				1163 ppm (0.12%)
Combustion system (Pilusa *et al.*, 2013)	Natural Gas		10-12 %		70-110 ppm
	Coal		10.6%		5579 ppm
	Fuel Oil		12-14%		-
OSHA Limit			5000 ppm (0.5%)		50-200 ppm

3.3 CO emission

The maximum amount of CO recorded for *Nauclea diderrichii* briquette ranged between 0.1 – 2.8%, while for *Ceiba pentandra* briquette, it ranged between 0.2 - 0.4%. This shows that emissions of CO in the flue gas were lower for the *Ceiba pentandra* briquette than *Nauclea diderrichii* briquette and implies that the *Ceiba pentandra* briquette will be more environmentally friendly. Generally, a high amount of CO was recorded at ambient and as the amount of air supplied was increasing, the amount of CO was reduced. No significant change was observed in CO emitted for the stoichiometric air and excess air factors. According to Tawil (2021), the reactivity of the fuel, fineness, and particle size of the fuel, fuel/air mixing efficiency, surplus air available for complete combustion, residence time, and temperature profile inside the boiler are all important elements that influence the complete combustion of carbon. No evident relationship was observed between CO emission parameters and flue gas temperatures. CO emissions are reduced by burning the fuel at a high furnace temperature and a lengthy residence period (Vakkilainen, 2017). There is no direct relationship between fuel properties like volatile matter and CO emission variables. Above 20% excess air, no significant increase in emission was observed. Hence, 20% excess air will be recommended for the burning of the briquettes. Table 5 shows the comparison between CO emissions from briquettes in this study and those recorded in previous works. It can be seen that the emission of CO varies significantly from one biomass briquette to another and the variation also depends on the combustion technology used and the organic composition of the briquette. As can be seen in Table 5, a low CO emission (average) of 995 ppm (0.1%) for anthracite briquettes was measured in a boiler by Yeongu *et al.* (2022), 29-62 ppm (0.003-0.0062%) for water hyacinth briquettes were measured in a conventional charcoal stove by Okia *et al.* (2017), and 1162 ppm (0.12%), 957 ppm (0.096%), 1163 ppm(0.12%) for corn straw biochar briquette, paper briquette, ekolog wood briquette, respectively were measured in a conventional stove whereas a high CO emission of 11000 - 12000 ppm (1.1-1.2%) for torrefied olive briquettes was measured in a domestic solid-fuel stove by Trubetskaya *et al.*, (2021).

3.4 Numerical Validation of Gases Emission

During the simulation process, four emitted gases (CO, CO_2, SO_2, and NO) were monitored while CO and CO_2 at different air velocities were only compared with experimental results for validation. Table 6 and Table 7 show the comparisons between the simulation results and experimental data of the emission of gases from the burning of the briquettes at different air supplies. Generally, a good agreement between the experimental data and CFD results was observed, which suggests that CFD can be a convenient tool for investigating emissions during the burning of briquettes and can provide guidance for the design and optimization of briquette burning. The emission contours of CO, CO_2, SO_2, and NO are shown in Fig. 5 -13.

Table 6: Comparisons between CFD Results and Experimental Data of Emission of Gases from Burning of Briquettes made from *Nauclea diderichii* at Different Air Supply

Sample	**Variables**	**CO (%)**		**CO_2**		**SO_2 (x10^5)**	**NO**
		Exp.	**CFD**	**Exp.**	**CFD**	**CFD**	**CFD**
ND	Amb.	2.8	3.02	6.51	5.50	12.70	6.59 x10^-22
	Stio.	0.4	0.53	2.47	4.46	11.50	8.59 x10^-20
	10% EA	0.2	0.32	1.75	3.40	6.20	1.32x10^-11
	20% EA	0.2	0.31	1.25	3.57	12.2	2.76 x10^-16
	30% EA	0.1	0.30	1.10	3.50	7.88	9.36 x10^-19

ND: *Nauclea diderrichii,* CFD: Computational Fluid Dynamics, Amb.: Ambient, Stio.: Stoichiometric, EA: Excess Air.

Table 7: Comparisons between CFD Results and Experimental Data of Emission of Gases from Burning of Briquettes made from *Ceiba pentandra* at Different Air Supply

Sample	Variables	CO (%)		CO_2 (%)		SO_2 (%) (10^-5)	NO (%)
		EXP.	CFD	EXP.	CFD	CFD	CFD
CP	Amb.	2.1	1.8	12.49	13.50	6.75	7.64 x10^-33
	Stio	0.3	0.567	3.96	4.49	4.63	9.64 x10^-31
	10% EA	0.3	0.476	2.55	4.24	4.15	6.25 x10^-30
	20% EA	0.2	0.409	2.39	3.78	4.03	2.83 x10^-29
	30% EA	0.1	0.341	2.24	3.76	3.27	1.71 x10^-27

ND: *Nauclea diderrichii,* CP: *Ceiba pentandra*, Exp: Experimental, CFD: Computational Fluid Dynamics, Amb.: Ambient, Stio.: Stoichiometric, EA: Excess Air

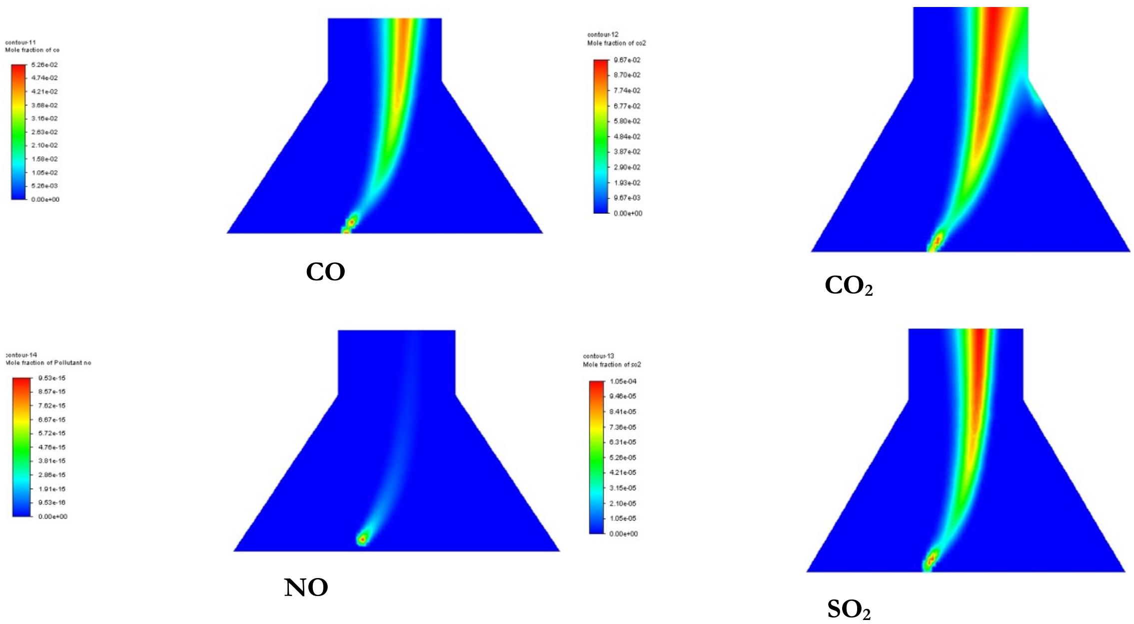


Fig. 5. Contours of Gases Emitted during the Combustion of Nauclea Diderrichi Briquettes at Ambient

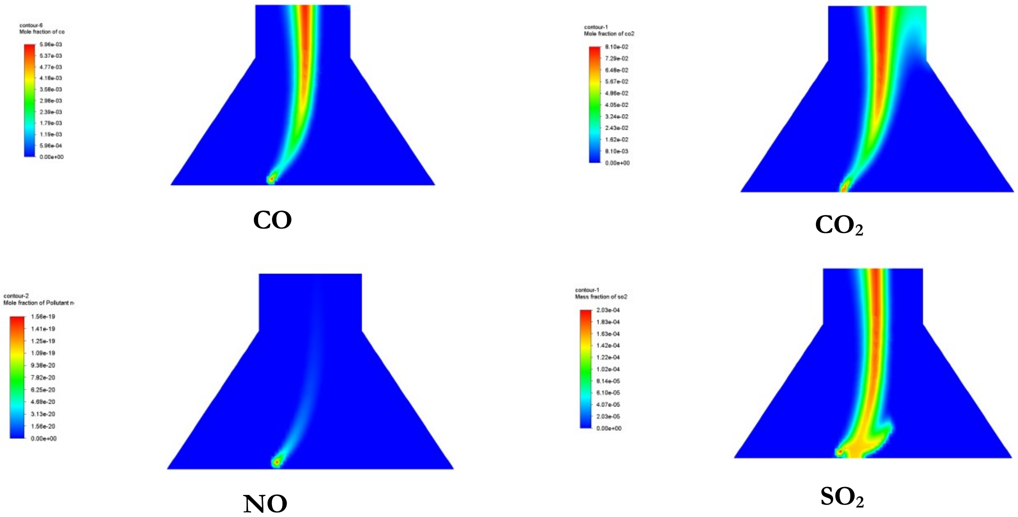


Fig. 6. Contours of Gases Emitted during the Combustion of Nauclea Diderrichi Briquettes at Stoichiometric Air Flow

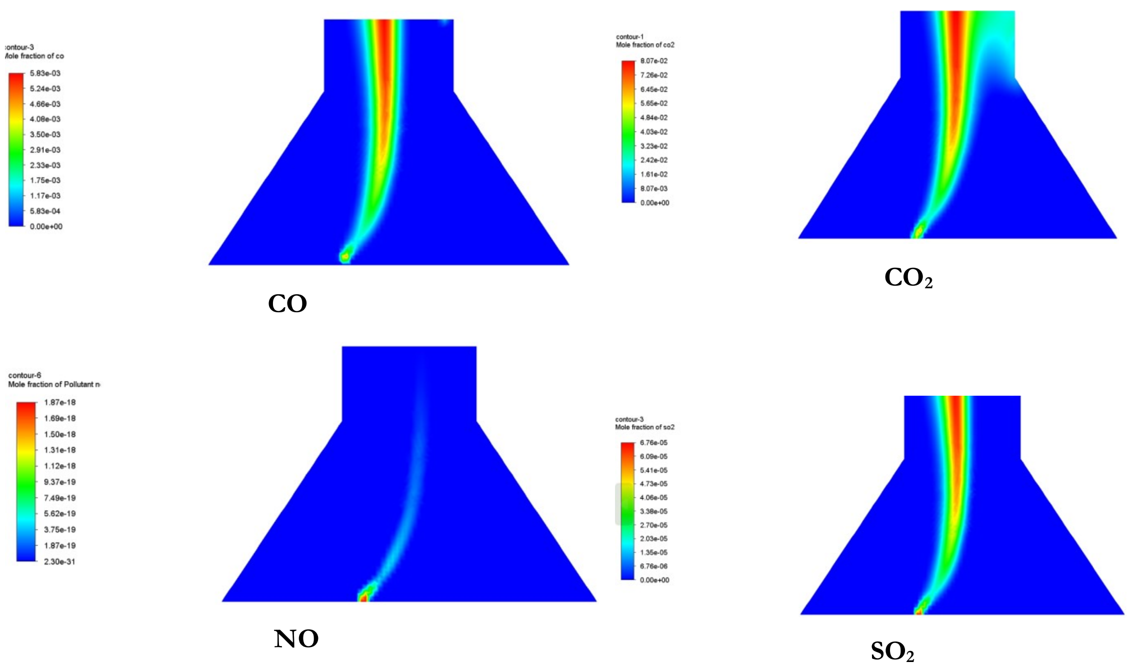


Fig. 7. Contours of Gases Emitted during the Combustion of Nauclea Diderrichi Briquettes at 10% Excess Air.

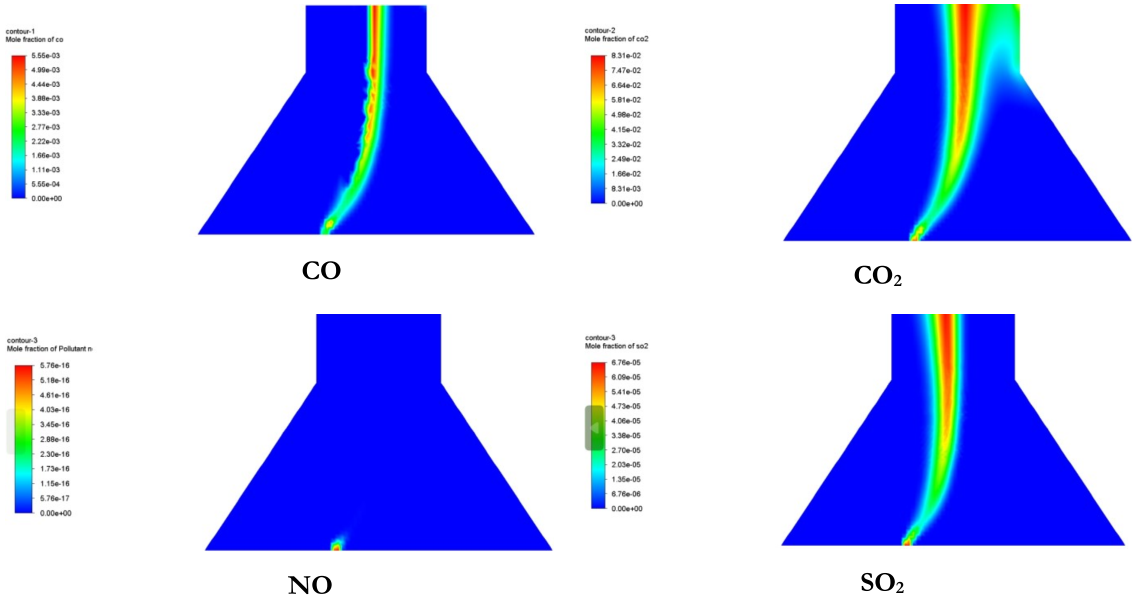


Fig. 8. Contours of Gases Emitted during the Combustion of Nauclea Diderrichi Raw Briquettes at 20% Excess Air.

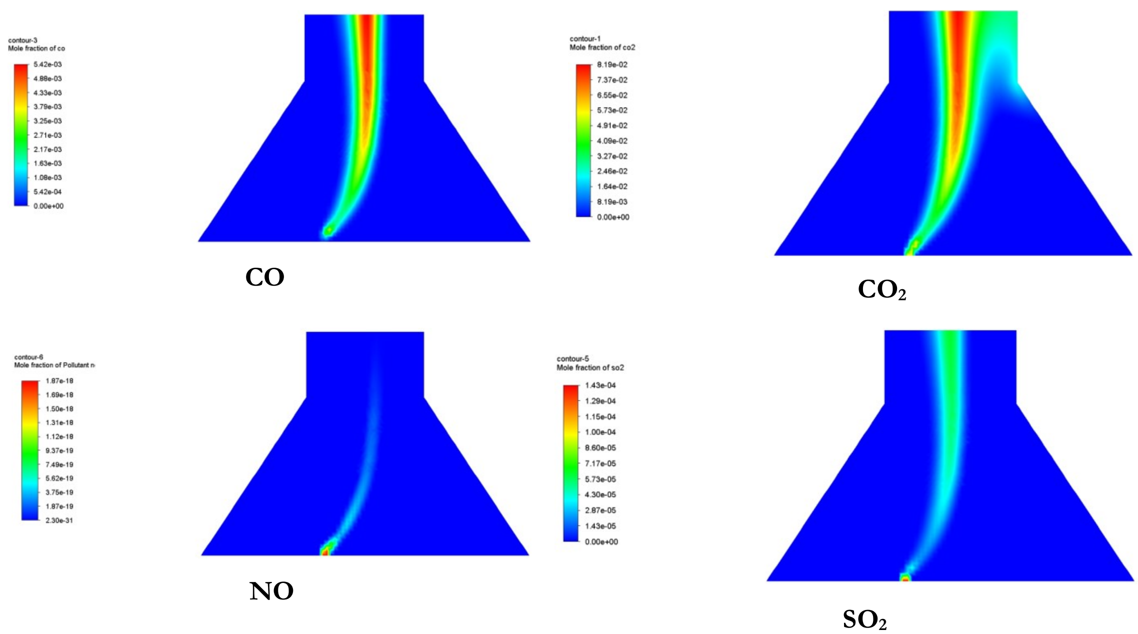
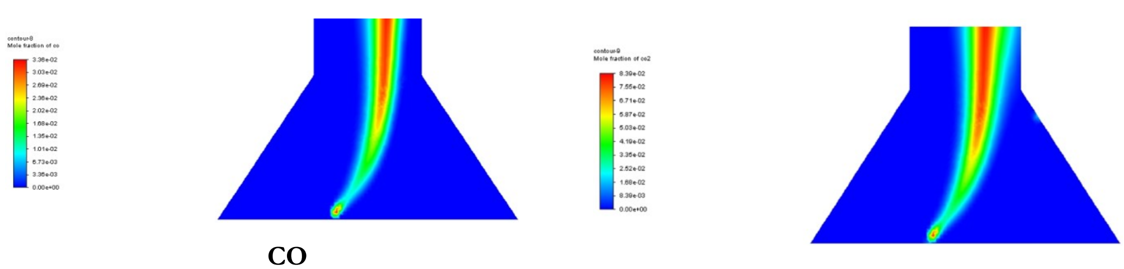


Fig. 9. Contours of Gases Emitted during the Combustion of ND Briquettes at 30% Excess Air.



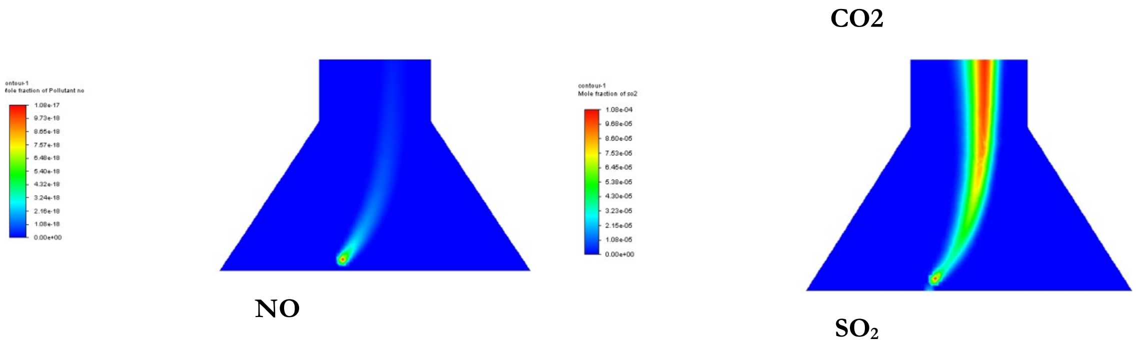


Fig. 10. Contours of Gases Emitted during the Combustion of CP Briquettes at Ambient.

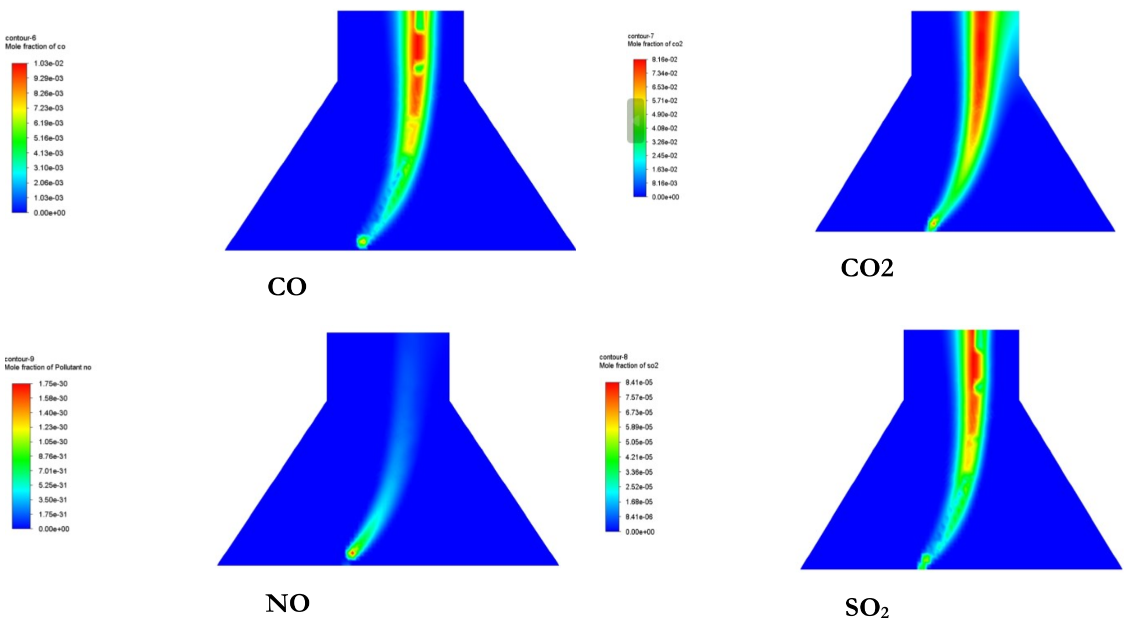
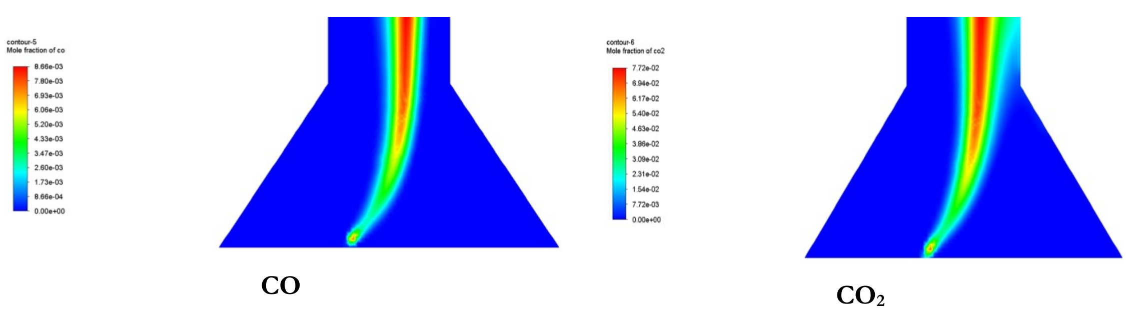
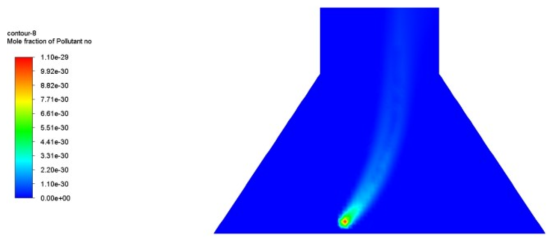
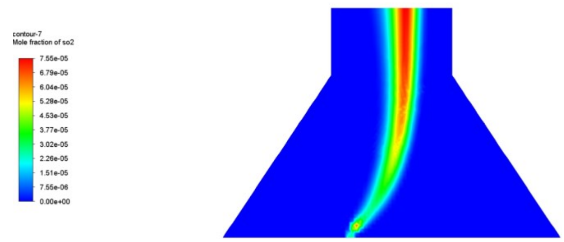


Fig. 11. Contours of Gases Emitted during the Combustion of CP Briquettes at Stoichiometric Air Flow.

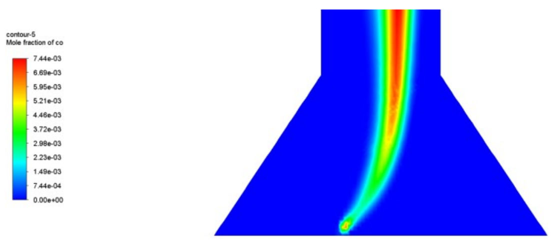


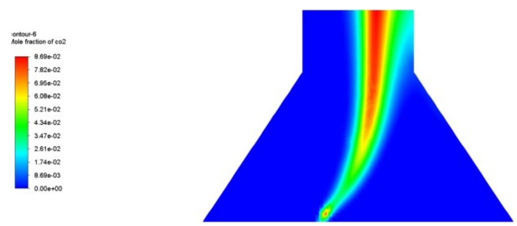




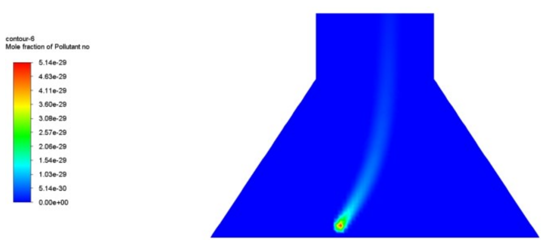
NO **SO_2**

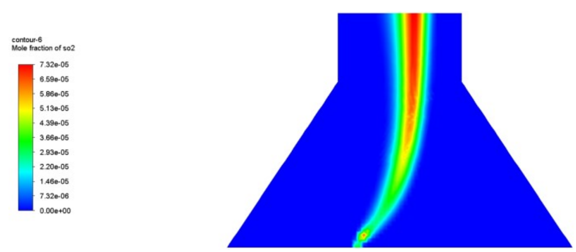
Fig. 11. Contours of Gases Emitted during the Combustion of CP Briquettes at 10% Excess Air.





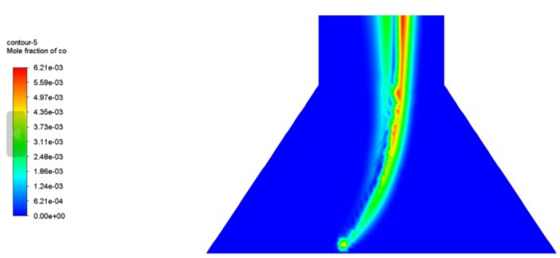
CO **CO_2**

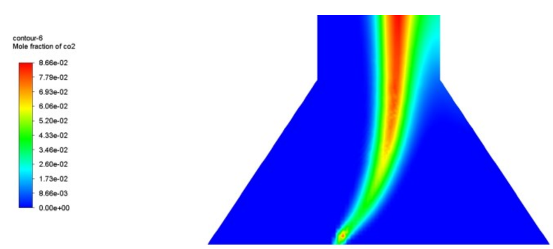




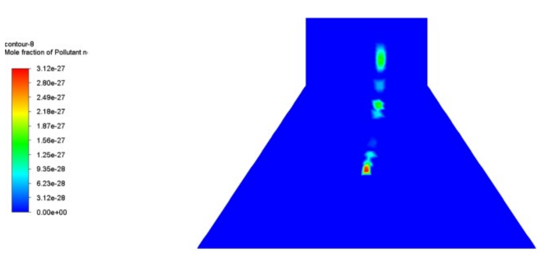
NO **SO_2**

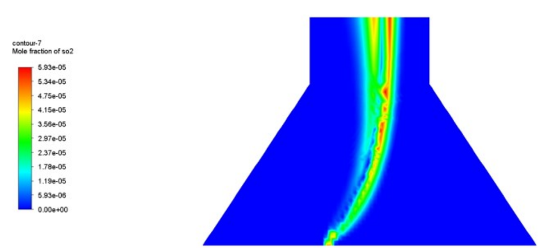
Fig. 12. Contours of Gases Emitted during the Combustion of CP Briquettes at 20% Excess Air.





CO **CO2**





NO **SO_2**

Fig. 13. Contours of Gases Emitted during the Combustion of CP Briquettes at 30% Excess Air.

3.5 Comparison of CO Obtained from CFD and Experimental Investigation

Similar to the relationship observed between air supply and CO emission in the experimental results, the CO emission also decreased with an increase in air supply in the CFD result for both samples. Generally, the measured CO concentration is lesser in the experimental rig than in the CFD simulation. An over-prediction was observed by the CFD model, and this could either be the result of assumptions in the formulation of the employed model or due to experimental lapses. Similar discrepancies were reported by Levy *et al.* (2018) and Perpignan *et al.* (2018). The deviation between the experimental and CFD results ranged between 0.11 and 0.22% for *Nauclea diderrichii* briquette, and it ranged between 0.17 and 0.30% for *Ceiba pentandra* briquette. The deviation in prediction for *Ceiba pentandra* was much higher than *Nauclea diderrichii.*

3.6 Comparison of CO_2 Obtained from CFD and Experimental Investigation

The trend observed in the relationship between air supply and CO_2 emission was also like that of the experimental results. CO_2 emission decreases with an increase in air supply. However, there are a few cases where the CO_2 predicted for 20% excess air was higher than the prediction for stoichiometric air supply. Generally, the measured CO_2 concentration was lesser in the experimental rig than in the simulation. The deviation between the experimental and the simulation results ranged between 1.01 and 2.40% for *Nauclea diderrichii* briquette, and it ranged between 1.01 and 1.69% for *Ceiba pentandra* briquette.

3.7 NO and SO_2 emission

The sulphur that is bonded to the fuel produces sulfur dioxide emissions. The predominant form of sulfur released during combustion is H_2S, which is then oxidized to produce SO_2, and then partially recovered in the produced ash and contributes to SO_2 emissions (Emil Vainio, 2014). Generally, raw biomass has negligible sulphur content, its combustion does not contribute significantly to sulphur emission. In this study, the initial sulphur content determined for the briquette ranged between 0.46 – 0.71%. The SO_2 emissions obtained from the CFD were low in the order of exponential minus five (10^{-5}) as they ranged between 6.20 x 10^{-5} and 12.70 x 10^{-5} % at different air supplies for *Nauclea diderichii* briquette. It ranged between 3.27 x 10^{-5} and 6.75 x 10^{-5} % for *Ceiba pentandra. Ceiba pentandra* had the least amount of SO_2 emitted, followed by *Nauclea diderrichii* briquette. Generally, the highest amount of sulfur dioxide was recorded at ambient, while the least was recorded at 30% excess air. The SO_2 recorded is far below the OSHA standard. This implies that the briquettes will be environmentally friendly in terms of SO_2 emission.

Nitrogen oxide (NO) emission also originates from fuel-bound nitrogen and the N_2 in the combustion air. The nitrogen in the fuel and that of the combustion are oxidized to nitric oxide during combustion and give two sources of nitric oxide (thermal NOx and fuel NOx). Temperature and the amount of oxygen present in the combustion zone affect how quickly NOx forms. Thermal NOx is lowered by lowering the flame temperature and surplus air, while fuel NOx is decreased by lowering the oxygen availability in the combustion zone. The initial nitrogen content determined for the sample briquette ranged between 0.82 – 1.20 %. Generally, the NO recorded for all the samples was very low in the order equal and less than exponential minus 11 (10^{-11} to 10^{-36}). The low value of NO recorded could be the result of low flame temperature which was less than 500 ^{o}C. This shows that the burning of briquettes made from sawdust in a traditional household rig produces an insignificant amount of NO. The NO recorded is far below the OSHA standard. This implies that the briquettes will be environmentally friendly in terms of NO emissions.

Conclusions

Generally, the amounts of gases emitted were within the acceptable range and made the briquette suitable for use without environmental issues. Emissions of CO, NO and SO_2 were lower for the *Ceiba pentandra* briquette than for the *Nauclea dedirrichii* briquette. Although, *Nauclea dedirrichii* shows good burning potential and in cases where high energy content is required, it would be preferred over *Ceiba pentandra.* CFD predictions and experimental measurements showed reasonable agreement which shows that the CFD is capable of predicting gas emission during the combustion of briquette. The model also provides a useful basis for further work. No further increase in CO and CO_2 was observed at excess air above 20% hence, 20% excess air will be recommended for the combustion of the briquettes. The environmental impacts have been assessed by analyzing the composition of emission gases produced during the combustion of briquettes combustion. The knowledge will help in developing cleaner and more environmentally friendly technologies. The study has explored combustion behaviour, and emissions characteristics of briquettes produced from wood sawdust.

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Assessment and Distribution of Heavy Metals in Existing Dumpsites in Urban and Peri-Urban Area of Kano State

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Abstract

Improper management of waste disposal presents significant environmental challenges. In the absence of leachate systems at dumpsite facilities, leachate contaminates the surrounding with toxic heavy metals. This study evaluates the distribution of heavy metals in existing dumpsites within the urban and peri-urban areas of Kano State and assessed the soil's pollution and contamination indices. Three active dumpsites were selected in the Kano metropolis, Nigeria for this study. Both surface and sub-surface samples, at depths of approximately 0 – 10 cm, were collected. Six soil samples were collected and stored in a cool place pending analysis. The pH and heavy metals concentrations of the samples were taken at different points. Agilent 4100 Microwave Plasma–Atomic Emission Spectrometer was used to obtain heavy metals concentrations. The following concentrations (Pb-0.37mg/kg, Cr-5.61 mg/kg, Fe-67.75 mg/kg, Cu-0.49 mg/kg and Zn mg/kg respectively) are obtained for heavy metals. The mCd obtained (12.50 and 19.27) from sites CR-1 and CR-2 indicate a high level of contamination. These indicate that heavy metals have a major impact on the soil, requiring prompt attention and potential remediation method while the mCd values at other sites, KB-1, KB-2, RR-1, and RR-2 are 0.87, 1.29, 2.46, and 1.54, respectively. For both KB-1 and RR-2, a mCd value below 1.5 indicates low contamination, indicating little human influence and metal concentrations close to natural levels. On the other hand, KB-2 and RR-1 show moderate levels of contamination, with mCd somewhat over 1.5. While CR-1 and CR-2 are more serious than these sites. The PLI for the sites CR-1, CR-2, KB-1, KB-2, RR-1, and RR-2 have been recorded at 1.82, 2.08, 0.68, 1.24, 1.22, and 0.80 in that order. These PLI data emphasize the necessity for intervention measures to mitigate immediate and future environmental implications.

Keywords: Heavy metals, Dumpsite, PLI, Contamination index remediation, Solid waste.

Introduction

Improper management of solid wastes leads to environmental challenges (World Bank, 2020). Due to the absence of a leachate collection system in dumpsite facilities, the leachate migrates and contaminates the soil within the vicinity of the dumpsite, especially with toxic heavy metals such as lead, chromium, cadmium, copper, arsenic, iron, manganese, and zinc (Clément et al, 2015). In Kano Metropolis and most developing cities in Africa where there are increase in population and industrial activities are being experienced uncontrolled solid waste disposal management. On the other hand, urbanization, migrations and economic development, has led to indiscriminate dumping of solid wastes of various sources in and around any available large expanse of land either under fallow or abandoned land. Research carried out on lands close to dumpsites at Zaria city and other areas showed that most land around dumpsites are well contaminated with heavy metals (Olayiwola *et al.,* 2017). Soil contamination by toxic metals poses significant issues due to their non-biodegradability.

Salami and Popoola (2023) highlight the escalating environmental, health and management. Addressing this is crucial for sustainable living. Urbanization and economic growth lea to solid waste production, with urban municipal solid waste (MSW) from anthropogenic activities being a major contributor (Verge and Rowe, 2013). These hazardous waste discharge contaminates soil worldwide, with plants absorbing heavy metals through various pathways (Akinbile and Yusoff, 2012). Numerous studies had reported high metal levels around dumpsites but often do not evaluate contamination indices. At four different e-waste management activity sites in Lagos, Nigeria, where e-waste was being burned openly, disposed of, and kept, (Osibanjo, 2023) conducted heavy metals assessments. Samples were frequently collected from each site during the dry and rainy seasons for a period of two years. After being digested in aqua regia, the samples were analyzed with an atomic absorption spectrometer to look for particular metals. During the wet season, the mean values (mg/kg) of the following metal concentrations were found in the soil at the open burning site: Cd - 24.80, Cr - 69.30, Ni - 108.00, Zn - 4380.00, Pb - 15200.00, and Cu - 41700.00.

The remarkable contamination factor values were greater than six for the open burning site indicated exceptionally high levels of Pb and Cu contamination.

Amos-tauta et al. (2013) assessed PB, Cd, and Cr levels, as well as physicochemical properties, samples from a Yenagoa dumpsite and a control site. Samples from 0 - 10cm and 10 - 20cm depth showed the dumpsite had over 80% sand, less clay, with varied pH between 4.89 - 7.60 respectively. However, total nitrogen and organic matter were good and may be rehabilitated to farmland without remediation. Osakwe (2014) investigated heavy metal contamination and physicochemical properties of soils in Abraka, Delta State, Nigeria. Samples from various depths (0 - 45cm) and a control site showed pH values of 3.6 - 6.7. The total organic carbon content ranged from 29.56% to 77.76%. Heavy metals were found in mean value; Fe - 40.05mg/kg, Zn - 16.74mg/kg, Mn - 34.39 mg/kg, and Cu - 0.66mg/kg.

Ogbemudia & Mbong (2013) examined heavy metal levels in plants and soil from Uyo, Nigeria dumpsites . Soil samples showed heavy metals presence, with Mn and Fe the most prevalent while Cd was least abundant. Consumption of vegetables from the vicinity of contamination poses health risks due to elevated heavy metal levels, highlighting potential health hazards. Therefore, managing and disposing of MSW properly is a crucial environmental and public health issue, especially in developing countries like Nigeria. The traditional method of dealing with this environmental problem open dump of mixed MSW in open dumpsites and landfills which are largely unregulated. These methods are popular because they are easy, cheap, and do not require much technology.

Landfills and open dumpsites are often located near residential areas, groundwater recharge zones, and areas with high-water tables during some seasons. Unfortunately, many of these landfills and open dumpsites do not have proper planning and do not follow the best practices. Moreover, MSWs are frequently disposed of in an unregulated way, and many of these sites do not have systems for treating and collecting leachate (liquid that seeps through the waste) and greenhouse gases. This study seeks to generate data on the level of heavy metal contamination status of soil in the existing dumpsites in urban and peri-urban area of Kano state, Nigeria, which can be used by chemical engineers, environmental engineers, geologists, scientists and other users of such materials to improve their work since soil analysis plays a pivotal role in environmental protection, health preservation, and sustainable land use. It underpins decision-making, clean-up efforts, and ecosystem safeguarding, making it a crucial process in environmental management. Therefore, a holistic solution is needed to tackle this issue as a necessary step for achieving a sustainable and healthy lifestyle (Ahmad, 2013).

1. Materials and Methods

Sample Area Description

Kano metropolis is the administrative centre of Kano state and the third largest city in Nigeria after Lagos and Ibadan. Kano metropolis is located between latitudes 11˚52'N and 12˚07'N and longitudes 8˚24'E and 8˚38'E. It is relatively at the centre of Kano state (Figure 1.0). According to the most recent figures, Kano State, Nigeria, had a population totaling 9,401,288 as of the 2006 census and is currently estimated to be above 15 million. The demographic expansion of Kano was as a result of its good fertile landscape, commercial city, as well as its accessibility and hospitality.

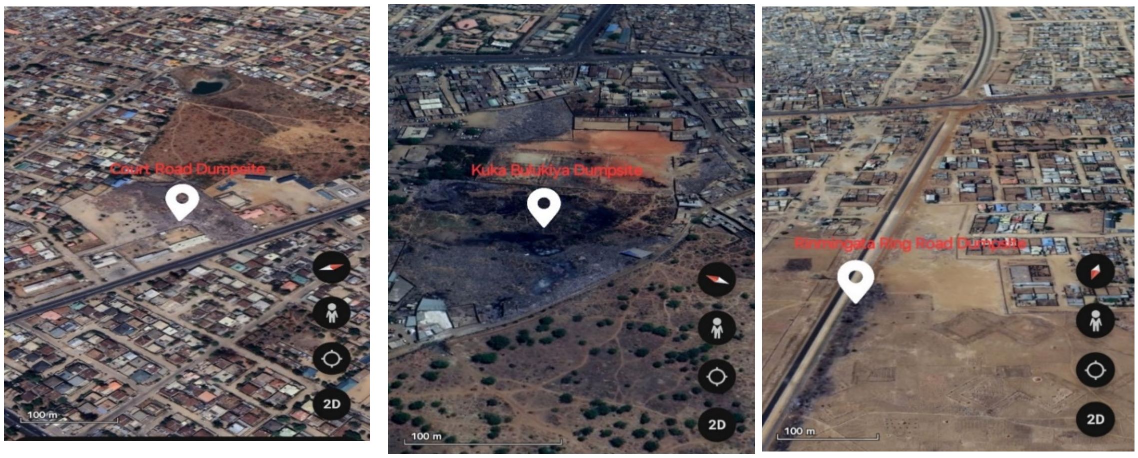

Fig 1.0 Satellite pictures of sampling points.

Below are the Geo-Referenced Position of Each Sampling Point and their Identification Respective to the Dumpsites.

Table 1: The Sampling Locations of the Dumpsites

Sample Code	Lat. (O N)	Long. (O E)	Vicinity	Elevation
CR-1	11.96773	8.54212	Residential area	481.23m
CR-2	11.96773	8.54212	Residential area	481.20m
KB-1	12.00910	8.50314	Residential area	480.53m
KB-2	12.00910	8.50314	Residential area	480.82m
RR-1	12.015070	8.439103	Residential area and farm	480.72m
RR-2	12.015070	8.439103	Residential area and farm	481.70m

2.1 Sampling

Soil samples were collected from three different dumpsites. One sample was taken from the surface soil, while another was obtained at a depth of 10 cm using a sampling spoon. Specifically: Two samples were collected from the dumpsite at Court Road Tarauni LGA and labeled as CR-1 and CR-2, respectively. Two samples were obtained from the dumpsite at Kuka Bulikiya, Dala LGA and labeled as KB-1 and KB-2, respectively. Lastly, two samples were collected from the dumpsite along Rimingata Ring Road, Ungogo LGA and labeled as RR-1 and RR-2, respectively. The GPS of sampling locations are presented in Table 1.0 below. The samples were collected in plastic containers. The figure 2 below shows the sampling and sampling preparations.

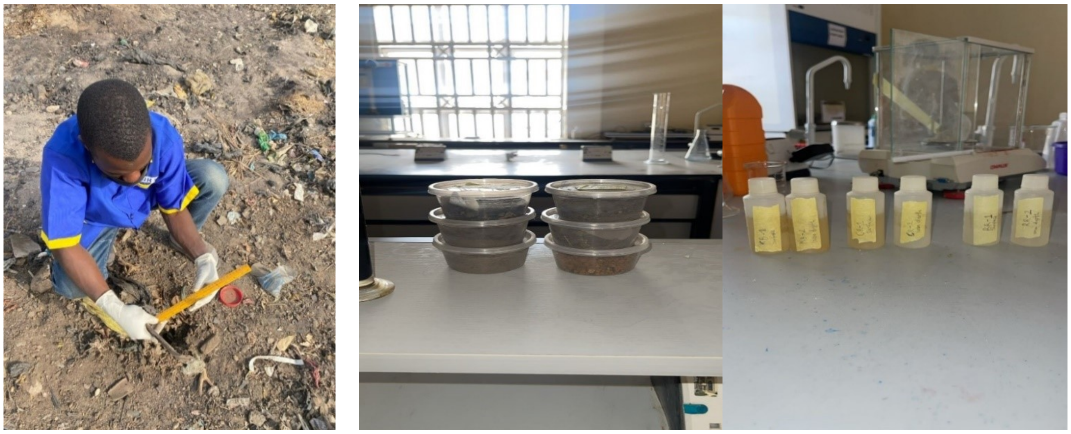

Fig. 2 Sampling and laboratory procedures

2.2 Preparation Analysis

The samples were air dried for three days, ground and sieved through a 2 mm sieve. These were stored in labelled plastic containers and were taken to the laboratory for analysis. After which, 1.00 g of each sample was digested with 20 mL aqua regia (HCl/HNO3 3:1) in a beaker (open-beaker digestion) on a thermostatically controlled hot plate. The digested samples were heated to near dryness and cooled to ambient temperature. Then 5.0 mL of hydrogen peroxide was added in parts to complete the digestion and the resulting mixture heated again to near dryness in a fume cupboard. The beaker walls were washed with 10 mL of de-ionized water and 5 mL HCl were added, mixed and heated again. The resulting digest was allowed to cool and transferred into a 50 mL standard flask and made up to the mark with de-ionized water. Pb, Fe, Cu, Zn, and Cr heavy metal elements were then analyzed by direct aspiration of the sample solution into a MP-AES.

2. Results and Discussion

Results of the heavy metals assessments are presented below. The results are presented with the following characterizations: the pH; Heavy Metal Concentration and Contamination of Samples; Geo-accumulation Index; Contamination Factor and Modified Degree of Contamination and Pollution Load Index.

3.1 The pH and Metal Concentration of Samples

The pH of the samples in this study ranged between 4.76 and 6.0 with KB-1 and RR-2 having the lowest and highest values respectively (as shown in Table 1). The pH of the soil samples in this study are slightly acidic to moderately acidic indicating that the area falls within acceptable ranges for plant growth and may not impact human living.

Table 1: The Standard Values for Metal Concentrations of the Soil Samples in mg/kg

Parameters	CR-1 (mg/kg)	CR-2 (mg/kg)	KB-1 (mg/kg)	KB-2 (mg/kg)	RR-1 (mg/kg)	RR-2 (mg/kg)	NESREA	WHO	DPR
pH	5.14	6.13	4.76	5.94	5.98	6.00			
Cr	3.61	5.61	0.13	0.23	0.54	0.35	0.05	0.05	100
Cu	0.48	0.47	0.23	0.49	0.41	0.18	1.0	-	36
Pb	0.28	0.28	0.19	0.37	0.18	0.14	1.0	-	85
Zn	2.45	3.00	1.52	1.02	1.58	0.39	-	-	140
Fe	40.97	52.88	26.32	46.11	38.07	67.75	20	30	

Table 2: Geo-Accumulation Index of Soil Samples in the Selected Areas of Study.

S/N	Heavy metals	Geo-Accumulation Index (Igeo)					
		CR-1	**CR-2**	**KB-1**	**KB-2**	**RR-1**	**RR-2**
1	Cr	5.59	6.23	0.80	1.62	2.85	2.22
2	Cu	-1.65	-1.68	-6.03	-1.62	-1.87	-7.04
3	Pb	-8.06	-8.06	-9.93	-6.70	-7.04	-11.4
4	Zn	-	-	-	-	-	-
5	Fe	0.45	0.82	-0.52	0.71	0.34	1.17

Table 3: Contamination Factor of Soil Samples from the Selected Areas of Study.

S/N	Heavy Metals	Contamination Factor					
		CR-1	**CR-2**	**KB-1**	**KB-2**	**RR-1**	**RR-2**
1	Cr	72.20	112.20	2.60	4.60	10.80	7.00
2	Cu	0.48	0.47	0.23	0.49	0.41	0.18
3	Pb	0.28	0.28	0.19	0.37	0.18	0.14
4	Zn	-	-	-	-	-	-
5	Fe	20.49		1.32	2.31	3.39	1.90

Table 4: Pollution Load Index and Modified Degree of Contamination of Soil Samples from the Selected Areas of Study.

S/N	Sample Points	PLI	mC_d
1	CR-1	1.82	12.50
2	CR-2	2.08	19.27
3	KB-1	0.68	0.87
4	KB-2	1.14	1.29
5	RR-1	1.22	2.46
6	RR-2	0.80	1.54

Lead in soil poses significant health risks. This study found levels between 0.14 and 0.37mg/kg, within NESREA's 1.0mg/kg limit. Iron, an essential plant nutrient, recorded 26.32-67.75mg/kg, exceeding NESREA and who limits of 20 and 30mg/kg. Chromium levels ranged from 0.13 to 5.61mg/kg, within acceptable limits. Copper, essential for plants, ranged from 0.18 to 0.49mg/kg, below NESREA's 1mg/kg limit. Zinc, crucial for many bodily functions, ranged from 0.39 to 3.0mg/kg, well within DPR and WHO limits.

3.2 Geo-accumulation Index (Igeo)

Table 2 represents the geo-accumulation index (Igeo) for samples from CR-1, CR-2, KB-1, KB-2, RR-1, RR-2. Pb and Cu Igeo values were below zero, indicating no contamination. However, chromium showed moderate to strong contamination at CR-1 (5.59) and CR-2 (6.23). KB-2, RR-1, and RR-2 indicated moderate contamination and values of 1.62, 2.85, and 2.22, respectively. Fe values ranged from 0.713 to 1.174, suggesting a transition from uncontaminated to moderately contaminated. Elevated iron levels could still be of concern.

3.3 Contamination Factor

Table 3 shows contamination factors (CF) for the samples analyzed. At CR-1 and CR-2, Cr shows severe contamination (>50CF), while Cu - 0.48 CF and Pb - 0.28 CF are below threshold levels. Fe concentration indicates moderate contamination of 2.0485 CF at CR-1 and 2.644 CF at CR-2). KB-1 and KB-2 reveal moderate to high Cr contamination (2.6 CF at KB-1, 4.6 CF at KB-2), moderate Fe contamination (1.316 CF at KB-1, 2.3055 CF at KB-2), and low Cu and Pb levels. These findings highlight chromium as the primary contaminant needing environmental intervention.

3.4 Modified Degree of Contamination and Pollution Load Index

The mCd values for samples show different contamination. CR-1 and CR-2 have high contaminations 12.50 and 19.27 respectively. Therefore, needing immediate remediation. KB-1, KB-2, RR-1, and RR-2 show lower mCd values ranging from 0.87 to 2.46 indicating low to moderate contamination. PLI values in all sampling points are above 1, this reflects significant soil quality deterioration, necessitating urgent remediation.

3. Conclusions

This study carefully assessed the levels of heavy metals in several dumpsites located in Kano's urban and peri-urban areas, and then compared the results to international guidelines established by NASEREA and the WHO. The findings show a variety of soil conditions: some have extremely high levels of iron and chromium pollution, while other places show low human impact and are safe for lead and copper poisoning. These metals have reached levels that indicate a severe environmental state, especially at sites CR-1 and CR-2, with contamination indices pointing to the urgent need for intervention. The Modified Degree of Contamination and Pollution Load Index are indicators of the condition of the soil, illustrating an ecological imbalance that threatens the basic basis of terrestrial life. While the mild findings at KB-2 and RR-1 necessitate continued monitoring and assessment, the significant pollution CR-1 and CR-2 demand a quick response.

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Comparative Performance of Derived Organic Coagulants for Water Treatment

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Abstract

"Water is life" is a known saying likewise "health is wealth". Without clean potable water, a lot of people would be having health challenges and this could lead to death. Therefore, with clean water comes good health. This research was done to determine the effectiveness of tamarind and baobab seeds as natural coagulants and disinfectants in treating a river water located in the heart of Kano State, Nigeria. The research was conducted at Chalawa Water Treatment Facility, in Chalawa, Kumbutso Local Government Area of Kano, Kano State, Nigeria in the year 2024. Turbidity and pH value of water were determined to know the effectiveness of Tamarind and Baobab seed extracts as coagulants. Also, the Escherichia coli (E. coli) and total coliform counts were determined to know the effectiveness of Tamarind and Baobab seed extracts as disinfectants. Jar test analysis was done to know the optimum coagulant dosage which was used in conducting the tests for E. coli, total coliform counts and biological oxygen demand of the raw river water samples. Both seed extracts were found to be more effective as disinfectants than as coagulants because the values of E. coli, total coliform and biological oxygen demand conformed to the standards set by Nigerian Standard for Drinking Water Quality (NSDWQ) while the turbidity though reduced significantly from the initial raw water value, but not in conformity with the standard set by NSDWQ. Tamarind and Baobab seeds could be used as disinfectants in place of the more expensive calcium hypochlorite that is mostly been used. Even though the turbidity value was not up to standards, the decreasing values showed that they have potential in serving as coagulants to wastewater with lesser turbidity values.

Keywords: Coagulant, Water treatment, Disinfectants, Seed extracts, Tamarind and Baobab Seed.

Introduction

Water is a substance composed of the chemical elements hydrogen and oxygen and existing in gaseous, liquid, and solid states and one of the most plentiful and essential of compounds. It acts as a solvent for many substances and processes. Indeed, the versatility of water as a solvent is essential to living organisms. Water also exists on other planets and moons both within and beyond the solar system. In small quantities, water appears colourless, but water actually has an intrinsic blue colour caused by slight absorption of light at red wavelengths. Water is a basic human need including food, shelter and clothing. Thus, the water humans' drink is an essential ingredient for their wellbeing and a healthy life. Water is important for human being and other living things. Water is vital to life and development all over the globe. Its supply in adequate terms of both quality and quantity is very essential to human (KiliÇ, 2021). Water (H_2O) is a polar inorganic compound. At room temperature it is tasteless and odourless liquid, nearly colourless with a hint of blue. Water covers about 71% of the Earth's surface, with seas and oceans making up most of the water volume ~ 96.5%. Water plays an important role in the world economy.

Approximately 70% of the freshwater used by humans goes to agriculture. Water pollution is any chemical, physical or biological change in the quality of water that has a harmful effect on any living thing that drinks or uses or lives in it. When humans drink polluted water, it often has serious effects on their health (Lin, *et al.*, 2022; Singh *et al.*, 2022). Rapid growth of population, urbanization and industrial as well as agricultural activities have increased water contamination and pollution, particularly in recent years. Due to all these activities the demand for clean and safe water is increasing. Water treatment industry is among the most important industries in many countries (Singh *et al.*, 2022; Younas and Younas, 2022). In many rural communities of developing countries water treatment methods like flocculation, coagulation, sedimentation and disinfection are often impractical because of the high cost of equipment and low availability of chemical coagulants (Kurniawan et al., 2020). Indigenous knowledge indicates that there are several plant species that can be used as a coagulant and disinfectant (Omotesho *et al.*, 2013; Salim, 2018; Amran, 2021). The coagulation process aims to remove particles and organic matter dissolved in natural water, in order to improve aesthetics and health aspects of water (Buenano *et al.*, 2019; Dilipkumar and Souvik, 2020).

The use of natural coagulant in water purification have had a growing interest due to their advantages over chemical coagulants, such as low toxicity, biodegradability, low cost, abundant sources of production and elimination of the toxicity risk to human (Benalia *et al*., 2023). The ingestion of the commonly use coagulant (aluminium sulphide) affects the liver, heart, brain, etc. and is related to Alzheimer's degeneration (Buenaño *et al*., 2019). Also, its utilization is reducing the water pH which affects the natural alkalinity, reduces coagulation efficiency and deposition of sludge during water purification (Edogbanya and Ocholi, 2016). Tables 1 and 2 present some standards requirements for drinkable water according to Nigeria Standard for Drinking Water Quality (NSDWQ). Nowadays, one of the ultimate needs in Nigeria is to provide access to clean drinking water by cost effective means, particularly to the rural population who are not capable to afford effective water treatment process. This research was aimed at investigating water treatment using Baobab and Tamarind Seeds to produced bio coagulants for local water treatment.

Table 1. Some Inorganic Constituents (NSDWQ, 2017)

Parameter	**Unit**	**Maximum Permitted**	**Health Impact**
Aluminum (Al)	mg/L	0.2	Potential neuro-degenerative disorders
Arsenic (As)	mg/L	0.01	Cancer
Barium	mg/L	0.7	Hypertension
Cadmium (Cd)	mg/L	0.003	Toxic to the kidney
Chloride (Cl)	mg/L	250	None
Chromium ($Cr6^{+}$)	mg/L	0.05	Cancer
Copper (Cu^{2+})	mg/L	1	Gastrointestinal disorder,
Cyanide (CN^{-})	mg/L	0.01	Very toxic to the thyroid and the nervous system
Fluoride (F^{-})	mg/L	1.5	Fluorosis, skeletal tissue (bones and teeth) morbidity
Hardness (as $CaCO_3$)	mg/L	150	None
Lead (Pb)	mg/L	0.01	Cancer, interference with Vitamin D metabolism, affect mental development in infants, toxic to the central and peripheral nervous systems
Manganese (Mn^{2+})	mg/L	0.2	Neurological disorder
Mercury (Hg)	mg/L	0.001	Affects the kidney and central nervous system
Nickel (Ni)	mg/L	0.02	Possible carcinogenic
Nitrate (NO_3)	mg/L	50	Cyanosis, and asphyxia ('blue-baby syndrome") in infants under 3 months syndrome") in infants under 3 months
pH	-	6.5-8.5	None
Sodium (Na)	mg/L	200	None
Sulphate (SO_4)	mg/L	100	None
Total Dissolved Solids	mg/L	500	None

Table 2: Physical/Organoleptic Parameters (NSDWQ, 2017)

Parameter	Unit	Maximum Permitted Levels	Health Impact
Colour	TCU	15	None
Odour	-	Unobjectionable	None
Taste	-	Unobjectionable	None
Temperature	C	Ambient	None
Turbidity	NTU	5	None

Materials and Methods

Collection of water sample

Raw water samples were collected on the same day to ensure the parameters of interest of the water is not alter according to the standard methods. The containers for samples were first washed, emptied and rinsed with specific water sample that was collected. Raw Samples were obtained from River Chalawa, Kano, Nigeria and was analyzed to know the basis of the parameters and to be able to distinguish whether the coagulants and disinfectants had any effect on the raw water samples.

Materials

The list of apparatus is presented in the Table 3 below.

Table 3. List of Apparatus/ Equipment

Equipment/Apparatus	Manufacturer	Specification
Digital Weighing Balance	Explorer-Pro, Switzerland	Digital
Filter paper	Whatt-man	1 μm
Electric oven	Venus, England	500^0 C Capacity
Digital pH meter	Jenway, Switzerland	Digital
Turbidity meter	Lovibond, India	Digital
Conductivity meter	Jenway, Switzerland	Digital
Magnetic stirrer	Gallenkamp, India	
Sieve Shaker		

Collection and preparation of Tamarind and Baobab seeds

Dried fruits of Baobab (*Adansonia digitata*) seeds were collected from local market in Kano, Kano State, Nigeria. The fruits were opened and seeds were removed, washed with distilled water and oven dried at 105 °C for thirty minutes. They were crushed using mortar and pestle and then sieved using a sieve machine of size 0.4 mm. Oil extraction was done using a Soxhlet Extractor to remove the oil in the seeds to avoid contamination of the water with ethanol as the solvent. The residue was then heated at low temperature to evaporate the remaining ethanol on the cake residue. Thereafter, 30 g of the dried powdered seed was measured to be used for the experiment.

Dried Tamarind (*Tamarindus Indica*) fruits were selected from the pulp purchase from the local market in Kano, Kano state, Nigeria. The seeds were collected and sun-dried. Then it was grounded to powder with a grinding machine. A sieve analysis machine was used to separate the sizes and the 0.4 mm size was used. Oil extraction was done using a Soxhlet Extractor to remove the oil in the seeds to avoid contamination of the water with ethanol as the solvent. The residue was then heated at low temperature to evaporate the remaining ethanol on the cake residue. Thereafter, 30 g of the dried powdered seed was measured to be used for the experiment.

Figure 1: Rotary Dryer

Figure 2: Soxhlet Extractor

Figure 3: Jar Test

Preparation of *Escherichia Coli* culture

Some 13 g of nutrient broth was dissolved in 1000 ml of distilled water by heating. This mixture was sterilized for 15 minutes in an autoclave at a temperature of 130 °C, then cooled and used to prepare

Escherichia Coli culture. The culture was standardized to 1:5000 using normal saline and used for the disinfection experiment.

Disinfection experiment

To prepare the disinfectant, 150 mg/L of the extract was added to different tubes containing 10 ml of *Escherichia coli* suspension and incubated without agitation for 24 hours. Cell survival was assessed by making dilution series of bacteria suspension on Muller Hinton agar dishes and incubated for 24 hours at 37 °C. Triplicates were made for both assay and colonies were counted dishes and the cell survival ratio was estimated by comparing it to a control sample (no added extract). The bio-coagulation and disinfection studies were performed in Chalawa Water Treatment Plant in Kano, Kano State, Nigeria.

Results and Discussion

Determination of raw water samples properties

The results of laboratory analysis performed on the raw water are presented in Table 4. According to the Nigerian standard for drinking water quality (NSDWQ, 2017) given in Tables 1 and 2, the maximum permitted level for *E.coli* is 0 cfu/100mL and that of total bacterial count is 10 cfu/mL. Also, the pH should range from 6.50-8.50 and the turbidity should be 5 NTU. However, the results obtained from the raw water sampled analysis (Table 4) revealed that none of the parameters conforms to NSDWQ (2017) admissible limits except pH, thereby making the raw water unsafe for drinking.

Table 4: The Raw Water Analysis

Water properties indicator	Results
Appearance	Cloudy
Turbidity (NTU)	290
pH	7.00
Total Bacterial Count	85
E.Coli	7

Analysis of Dosages of Derived Tamarind Seed Powder Extract added to Raw Water

Different dosages (by weight) of 0.05, 0.10, 0.15 and 0.20 mg of tamarind seed powder was added to the beaker and 500 ml of raw water sample was also added. The jar test was run for 30 minutes, the results obtained were presented in Table 5.

Table 5: Results of Water Treatment with Derived Tamarind Powder Extract

Water Properties Indicator	Dosages			
	0.05 mg	**0.10 mg**	**0.15 mg**	**0.20 mg**
Appearance	Cloudy	Less Cloudy	Clear	Clear
Turbidity (NTU)	283	274	238	266
pH	7.00	7.00	7.00	7.00
Total Bacterial Count	-	-	-	-
E. coli	-	-	-	-

Analysis of Dosages of Derived Baobab Seed Powder Extract added to Raw Water

The Baobab Seed Powder Extract in doses of 0.05, 0.10, 0.15 and 0.20 mg were added to the beaker with 500 ml of raw water sample. A jar test was run for 30 minutes, the results shown in Table 6 were obtained, a reduction in turbidity was observed accompanied by a less cloudy appearance compared to that of raw water. The pH is within permissible range as provided by NSDWQ (2017).

Table 6: Results of Water Treatment with Derived Baobab Powder Extract

Water Properties Indicator	Dosages			
	0.05 mg	**0.10 mg**	**0.15 mg**	**0.20 mg**
Appearance	Less Cloudy	Less Cloudy	Less Cloudy	Clear
Turbidity (NTU)	276	260	260	238
pH	7.30	7.30	7.30	7.30
Total Bacterial Count	-	-	-	-
E. coli	-	-	-	-

Microbial Analysis of Baobab and Tamarind Seed Powder Extracts

The 0.15 mg dosage of Tamarind Seed Powder Extract and 0.20 mg dosage of Baobab Seed Powder Extract were taken as selected dosages for further determination of the disinfectant properties of the seeds. The microbial analysis (total coliform and *E. coli*). The fecal coliform and *E. coli* for both treatment with Tamarind and Baobab Seed Powder Extracts counted 0, meaning that they both conform to the Nigerian Standard and also indicates that both could serve as disinfectants in killing some bacteria found in wastewater. In addition, the Nigerian drinking water standard of 10 cfu/mL was not exceeded by the total bacterial count or total coliform, which also meant that the use of Tamarind and Baobab Seed Powder Extracts are good disinfectants in killing bacterial properties in water.

The analysis results on dissolve oxygen (DO) and BOD for the selected 0.15 mg dosage of Tamarind Seed Powder Extract and 0.20 mg dosage of Baobab Seed Powder Extract are presented in Tables 7 and 8. The difference between the two DO levels represents the amount of oxygen required for the decomposition of any organic materials in the sample. A high BOD indicates that there are lots of microorganisms in water that need oxygen to break down organic materials while a low BOD indicates lesser microorganism in the water sample. And from the result obtained from both, the BOD value is low as presented in Tables 7 and 8, respectively. The BOD should be lower than the DO because the BOD measures the required amount of oxygen microorganisms require to decompose organic matter in water.

Table 7: The Analysis of Raw Water with 0.15 mg Dosage of Derived Baobab Powder Extract

Water Properties Indicator	Results	Comment
Dissolved Oxygen (before)	8.20 mg/L	High value
Dissolved Oxygen (5 days)	4.30 mg/ L	Within specified value
BOD	3.90 mg/ L	Within specified value
Total Bacterial Count	4 cfu/m L	Within specified value
E.Coli, viable count	0 cfu 100/ml	In agreement with the NSDWQ (2017)

Table 8: The Analysis of Raw Water with 0.20 mg Dosage of Derived Baobab Powder Extract

Water Properties Indicator	Results	Comment
Dissolved Oxygen (before)	7.90 mg/ L	High value
Dissolved Oxygen (5 days)	4.50 mg/ L	Within specified value
BOD	3.40 mg/ L	Within specified value
Total bacterial count	3 cfu/m L	Within specified value
E.Coli, viable count	0 cfu/100ml	In agreement with the NSDWQ (2017)

Comparing the results above, the Baobab seed powder showed more effectiveness in disinfecting and coagulating raw water than the Tamarind seed powder. The total bacterial count of Baobab was lesser than that of Tamarind seed showing more effectiveness of the Baobab in that aspect. Both seeds are in the range limit set by the Nigerian standard for drinking water quality as referenced above.

Conclusions

Water treatment is an essential process for producing portable water. After raw water sample treatment with Tamarind and Baobab, the turbidity of the seeds showed a decrease in their values despite the fact that they fell short of the Nigerian standard for drinking water quality values. The bacterial count and *E. coli* values were within range of the standard set by the NSDWQ thereby making the seeds good disinfectants. Though Baobab showed more effectiveness in total bacterial count of the raw water, both seeds treatment for *E. coli* where the same. For the BOD, the value for the Baobab seed was less than that of the Tamarind seed. Meaning that the Baobab seed is more effective in disinfecting raw water than Tamarind seed. For turbidity, increase in dosage of the seeds resulted in decrease in the turbidity value of the raw water with that of Baobab showing more decrease compared to Tamarind seed whilst maintaining the same pH value. It can be inferred from results obtained after analyses in this study that Tamarind and Baobab possess disinfection properties for application as disinfectants in water treatment. Therefore, they can be used as alternatives to commercial coagulants and disinfectants used in water treatment.

Furthermore, Tamarind and Baobab can be employed as coagulants and disinfectants specifically for treatment of water with low turbidity and high contamination.

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Green area encroachment impact on urban temperature: the case study of Federal Capital City Abuja, Nigeria

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Abstract

Urbanization and green space encroachment are significantly altering the microclimate of cities worldwide. This study investigates the impact of green area encroachment on urban temperature in Abuja, Nigeria's Federal Capital City. Using remote sensing and GIS techniques, we analyzed land use/land cover changes and temperature variations between 2000 and 2015. Our results show a significant decline in green areas (−23.4%) and a corresponding increase in built-up areas (+45.6%), leading to a rise in urban temperature (+1.8°C). We identified areas with high temperature anomalies and heat islands, primarily correlated with reduced green spaces. Our findings underscore the importance of preserving green infrastructure in mitigating urban heat island effects and promoting sustainable urban planning in Abuja and similar tropical cities.

Keywords: green area encroachment, urban temperature, Abuja, Nigeria, urban heat island, sustainable urban planning.

1.0 INTRODUCTION

Urban green space can be broadly defined as any land predominantly covered with vegetation that is situated within an urban area. This space can include parks, gardens, playing fields, children's play areas and also derelict and vacant land. Green space is often considered to be an essential type of urban land use that can benefit urban dwellers by making their everyday life more pleasant, livable and healthy. Many areas of green space within or adjacent to cities are experiencing pressures and threats resulting from the processes of urban growth and redevelopment that are occurring in cities in all parts of the world. There is thus a widespread concern that the rapid expansion and internal restructuring of urban areas in many countries can isolate urban dwellers from direct contact with nature (Wilson, 1984; Miller, 2005; Fuller et al., 2007). These concerns appear to be particularly strong in developing countries, where there is evidence that urban green spaces are often being lost or degraded at alarming rates (Kuchelmeister and Braatz, 1993; Yaakup et al., 2004).

As urban areas expand, it sometimes poses threats to the built environment in the whole planet (Mayer, 1986; Munson, 1993; and Jones, 1994). Jafari and Wall (1994) have therefore suggested that urban development should aim to be more self-sufficient in its use of resources rather than depleting resources drawn from areas outside the city. There is thus a growing interest in reducing the ecological footprint of cities (Rees and Wackernagel, 1996), thereby making cities more sustainable and self-sustaining. From various perspectives, there is an emerging understanding that sustainability needs to be given greater priority in considering the growth of cities both in terms of their impact on the physical environment and with respect to how the latter interacts with society.

This implies that the urban landscape should be developed in a manner that takes into account the physical character of the original natural environment on which the city is built. Within this context, it can be argued that green spaces should not be seen as merely the "left-over" spaces that have not yet been developed within an urban area, but as spaces which function as part of the life-support system of the city and which benefit the urban dwellers through providing them with better surroundings in which to live and work and hence to enjoy a better quality of life. In Europe and North America, an effective and comprehensive system for planning the protection and development of urban green spaces is now widely seen as essential to ensure the preceding environmental and social benefits can be maintained as urban growth continues. By making cities more attractive and healthy places to live, work and visit, such provision should also have social and economic benefits.

The designers of the original Abuja Master Plan made provisions for the development of adequate recreational open spaces, green areas, parks, gardens and other incidental open spaces in line with the idea of a capital city. Incidentally, as the rapid development of the new capital city of Abuja progressed, these open spaces became a subject of abuse and were subsequently taken over by developers who converted some of these open spaces to other land uses, leading to the distortion of the original Abuja Master Plan. However, in 2003 the Federal Government through the former Minister of the Federal Capital Territory embarked on a massive restoration of these green areas and open spaces. The restoration and reclamation of these open spaces and green areas led to the re-establishment of urban parks and open spaces in the capital city of Abuja (Jubril, 2010).

Replacement of natural vegetation with impervious surfaces reduces the moisture content of the environment. With low moisture available for latent heat transfer, the majority of the surface energy is dissipated as sensible heat. Sensible heat transfer induces a change in temperature of the involved media. Without moisture, surfaces directly transfer heat energy to the atmosphere by radiation. This elevates the temperature of the atmosphere as the surface cools. Geometry of urban structures plays a key role through increasing the surface area and changing the surface roughness. The large surface area in the street corridors forms urban canyons that is not fully open to the atmosphere and thus is prevented from radiating into the atmosphere. Increased surface roughness affects the local aerodynamics and may reduce air movement impacting the convective cooling. Finally, anthropomorphic activities in populated areas encourage elevated temperatures, although it has been shown that the effects can be very slight in the urban center or even negligible in the residential suburban regions (Taha, 1997).

Moreover, heavy traffic in high populated areas also generates greenhouse gases and thermal discomfort and air quality. Increased nighttime temperatures do prolong thermal discomfort as experienced during the daytime and this encourages increased energy consumption through extended use of air conditioning units. Increased generation of electricity to power cities contributes to greenhouse gases and other air pollutants that affect city air quality. Sustained high temperatures also elevate the creation of ground-level ozone, which typically occurs during hot weather.

Table 1: Planning Standard of Open Green Spaces

Open Space Category	Provision
Regional open space	No standard
District open space	10ha per 100,000 persons (i.e 1m^2/person
Local open space	10ha per 100,000 persons (i.e 1m^2/person

Source: Architectural Services Department, Universal Accessibility for External Areas, Open Spaces & Green Spaces (2007)

1.1 Aim and Objectives

The aim of the study is to examine the impact of green area encroachment on urban temperature of Abuja and to understand the nature, diversity and value of green spaces in Abuja. The following objectives will be achieved:

(i) Examine the trend in green area encroachment over a period of fifteen (15) years in Abuja;
(ii) Examine the trends in the temperature changes over the same period of fifteen years;
(iii) Identify the major development land use activities in the area;
(iv) Correlate the green area changes with the temperature changes to find the effect; and
(v) Analyze the impact of the changes.

2.0 Materials and Methods

The primary data utilized for this research was gathered through surveys intended to gain data on the impact of green area encroachment on the Federal Capital city Abuja. The primary data are the information or data gathered from the field by the researcher. The primary data was sourced through reconnaissance survey, and direct observation. In the course of this study, the reconnaissance survey entails visiting some of the parks and green areas in the Federal capital city, Abuja and GPS was used to capture geographical coordinates for pre satellite image analysis.

While at the secondary level information were sourced from relevant literature materials which include periodicals' maps on geographical, political and historical setting. secondary data includes both hard and soft copy materials relevant to the subject matter, data was collected from offices such as Abuja geographic information system (AGIS), Abuja municipal area council (AMAC) and (NIMET) Nigeria metrological agency's climate data, this also include the collection of relevant fact and information from text book, and internet publication remote sensing data and land sat ETM imagery of 2000, land sat ETM 2005, land sat ETM 2010 and land sat ETM 2015 were insect to examine the trend in green area encroachment Abuja data on rainfall and temperature of federal capital city collected and shaved in.

Table 2.1 Satellites images Acquired for the study

S/no	Sensors	Year Acquired	Resolution	Source
1	Land sat TM	2000	30M	GCLF
2	Land sat ETM	2005	30M	GCLF
3	Land sat ETM+	2010	30M	GCLM
4	Land sat ETM+	2015	30M	GCLM

Source: Author's Compilation, 2024

2.1 Method of Ground Thruting and Field Survey

Field reconnaissance survey and physical observation during the pre-satellite image analysis and use of GPS to capture geographical coordinates existing green areas coordination for training sites and for accuracy were carried out, a total of six point of green areas were taken.

2.2 Classification of Land Sat Imagery

The images were imported into Idrisi 32 for classification i.e. the process of extraction of different classes or theme from raw remotely sensed digital satellite data each cluster of observation is a class. A class occupies its own area in the feature space i.e a specific part of the feature space corresponds to a specific class. Classes to be distinguished in an image classification need to have different spectral characteristic, which can be analyzed by comparing spectra reflectance cure. The only limitation of image classification is that if classes do not have distinct clusters in the feature space. Such image classification does not give reliable result.

Table 2.2 Geographical Coordinated Planned Green Areas in Abuja

Location	Northing	Easting	Description
Central Area	302819	978463	Millennium Garden
Wuye	307676	976465	Abuja Wonderland Park
Maitama	304297	977546	Abuja Zoological Park
Wuse 1	303486	986754	Abuja Amusement Park
Utako	300612	977958	Adigdas General Garden

Source Authors field survey, 2024

Training sites were generated on the images by on-screen digitizing for each land cover classes derived from image of different band combination. A supervised (Full Gaussian) maximum likelihood classification was implemented for the four images. This was due to the fact that the researcher has familiarized herself with the study area though dedication field observation, whereby the spectra characteristics of the classes in the sampled area have been identified. Ground truth information was used to assess the accuracy of the classification.

Table 2.3 Classification Scheme Used

Category	Land Use Types
0.	Built-up area/settlement
1.	Bare Land
2.	Recreation Open Space
3.	Vegetation/Vegetated Surface (natural)
4.	Water Bodies
5.	Cultivated Land/Farm Land

Source: Anderson, 1979

2.3 Examination of temperature changes over the same period of fifteen years

The method of correlation analysis in moment product of correlation through the use of computer software, SPSS was used to correlative between the climate indicator and also to know the strength of relationship.

The correlation, r is determined by the expression:

$$R = \frac{n\sum xy - [\sum x]\,[\sum y]}{n\sum x2 - [\sum y]^2}$$

Where,

r = correlation coefficient
x = Humility and Temperature
N = No of year data available
$\sum$ = Summation of Value

2.4 Multiple Regressions

In statistics, regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (or 'predictors').n More specifically, regression analysis helps one understand how the typical value of the dependent variable (or 'criterion variable') changes when any one of the independent variables is varied, while the other independent variables are held fixed. Regression gram will be plotted to give visual relationship.

$y = a_1 + b_1 x_1 + b_2 x_2$

x_1 = Humility

x_2 = Temperature

3.0 RESULTS AND DISCUSSIONS

The first result presented involves the delineation of green areas in the study area and examination of trend in their encroachment. Secondly, temperature changes over the study period were identified and trend examined, followed by an assessment of the spatial pattern of land use/cover change in the area over the study period. Finally, the green area changes with the temperature changes were correlated and their impacts analysed. These are in line with the aim and objectives of the research study.

3.1. Green Area Encroachment

Figure 3.1 Original Master plan of Abuja Municipal Area Council (left), Master plan showing encroached green areas (right)

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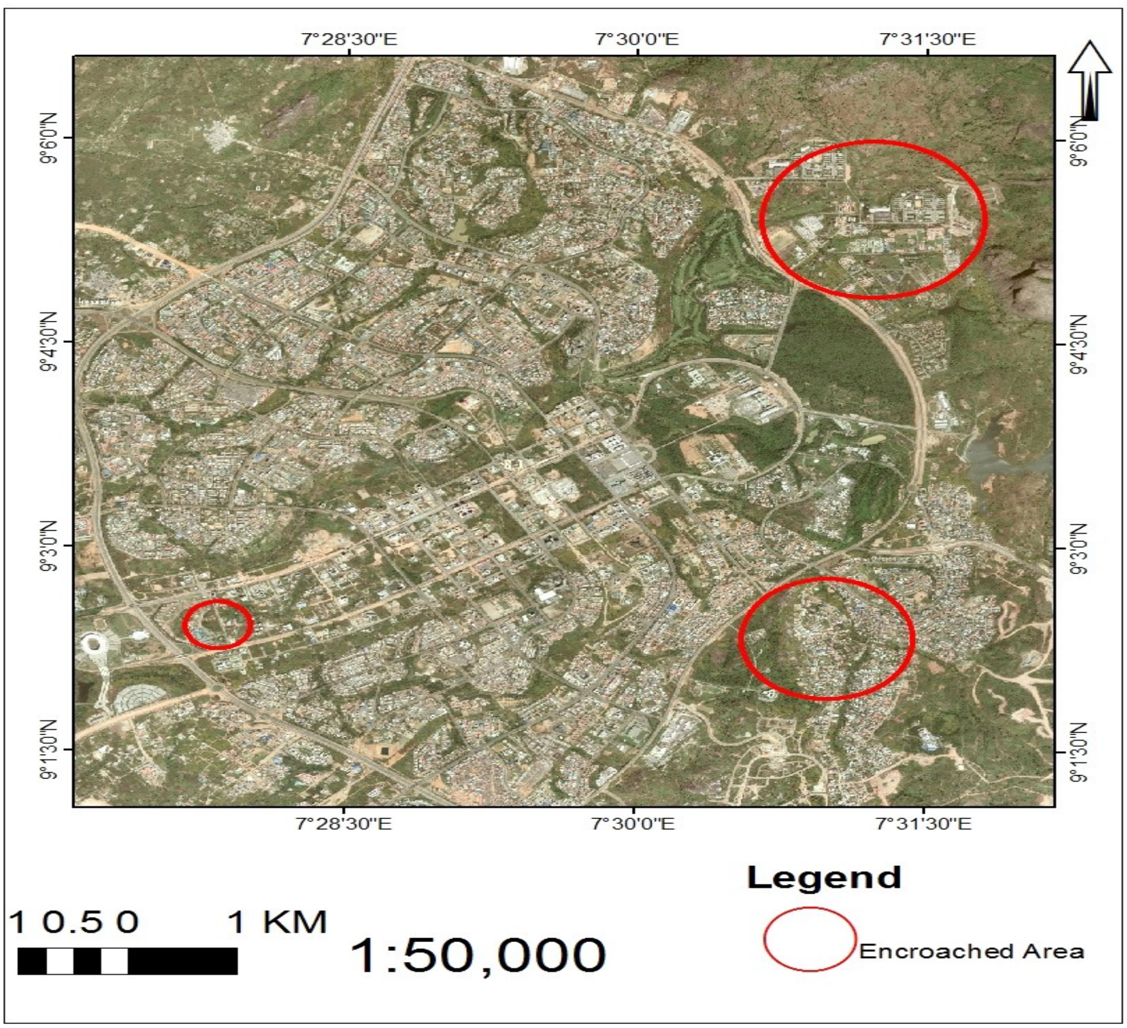

Figure 3.2: Satellite Imagery showing encroached Green Areas.

In assessing the level of green area encroachment in the study area, the original master plan of Abuja Municipal Area Council (Figure 4.1) was overlaid with a high resolution quickbird satellite imagery and green areas that where encroached were identified. The encroached green areas identified are presented in figure 4.2. As seen from the map, there is an increasing trend of built-up area in the study area. The development occurs in the form of densification in the central part of the study area. Moreover, extensive development of new residential areas is taking place in the western and south eastern part of the area under study.

This situation has led to the encroachment of the green areas and thus leading to their reduction. This factor in turn has been considered to be the main causes of urban warming. The implication of this green area destruction for residential and other commercial purpose is critical as it plays a fundamental role in determining the variation in temperature and other related climatic elements. Urban heat island is also one of the direct effect of the temperature increase arising from the destruction of green areas. Another major consequence is the reduction in the level of evapotranspiration. This is a process that cools down a place via transfer of heat. Research has shown that every gram of water evaporated or transpired carries 600 calories of heat away from the source. Hence, the lack of evaporation & transpiration will result in the absorbed solar energy staying at the source of absorption, i.e. in the buildings, roads, pavements, parking lots, etc. resulting to cities with little vegetation being hotter than those that are well planned with green areas.

3.2 Spatial Trend in Temperature Changes

Table 4.2, 4.3 and 4.4 presents the minimum and maximum temperature of the study area for the period under study. The data gotten from the Nigerian Meteorological Agency (NIMET) were analysed and the results presented in table 4.1 and Figures 4.3. For the overall period, minimum temperature has a range of 16.5 ^{o} C – 25.7 ^{o} C, 28.1 ^{o} C - 37.9 ^{o} C for the maximum temperature, and 27.15 ^{o} C – 28.1 ^{o} C for the average temperature (Table 4.1). The lowest values for the minimum, maximum and average temperature occur 2011, 2007 and 2011. Meanwhile the highest value for the minimum, maximum and average temperature occurred in 2010, 2007, and 2010 respectively.

Table 3.1: Average and mean monthly temperature from 2000 -2015

Minimum ^{o}C			**Maximum ^{o}C**		
Year	**Total**	**Mean**	**Total**	**Mean**	**Average**
2000	255.5	21.3	398.7	33.2	27.25
2001	259.9	21.7	399.2	33.3	27.5
2002	264.3	22	397.7	33.1	27.55
2003	228.9	22.3	401.6	33.5	27.9
2004	223.3	21.9	396.1	33	27.45
2005	272.4	22.7	393.7	32.8	27.75
2006	270	22.5	403.6	33.6	28.05
2007	263.8	22	396.3	33	27.5
2008	266.4	22.2	399.9	33.3	27.75
2009	266	22.2	394.3	32.9	27.55
2010	278.2	23.2	395.4	33	28.1
2011	255.3	21.3	396.1	33	27.15
2012	267.5	22.3	388.6	32.4	27.35
2013	254.9	21.2	389.8	32.5	26.85
2014	252.4	21	389.4	32.5	26.75
2015	249.9	20.8	394.3	32.9	26.85

Source: NIMET, Abuja

In general, the mean temperature values show a fluctuating (increase/decrease) trend from year to year. Despite the slight decrease in maximum temperature from 2003 to 2005 and more significant decrease in 2012, the overall maximum mean temperature still shows an increasing trend.

In addition to the overall trend, there are also significant differences in the annual average temperature value for the period of 2000 - 2015 as presented in Figure 4.3. The result of the average annual temperature shows that it has a range of 27.15 ° C – 28.1 ° C

Average temperature was 27.7 ° C in 2000 which declined to 27.5 ° C in 2001 and later rose back to 27.55 ° C and 27.9 ° C in 2002 and 2003 respectively. There was slight decrease in 2004 to 27.4 ° C but in 2005, it went up to 27.75 ° C which subsequently increased again to 28.05 ° C in 2006. After dropping to 27.7 ° C in 2007, the average temperature increased significantly to 28.1 ° C in 2010. This increase is not unconnected to the continuous increase in population and encroachment into the green areas and destruction of the natural vegetal cover in the study area. The value then fluctuated up and down for four (4) years consecutively (2011, 2012, 2013 and 2014), before starting to rise in 2015(26.85 ° C).

3.3 Spatial pattern of land use/cover changes

The results of the changes in land use in the study area are analyzed and presented below with regards to the spatial coverage of land use distributions and proportions for 2000, 2005, 2010 and 2015. Figures 4.4, 4.6 and 4.8 show the result of the land use map generated based on four major classes of land use/cover categorization (Built-up Area, Rock/Bare Surface, Shrub/Agricultural Area, Vegetation and Water body). The process of categorization is wholly a combination of visual image interpretation of colours, shapes, size, textures and patterns in identifying homogenous group of pixels thus putting them into classes.

3.3.1 Land use Distribution 2000

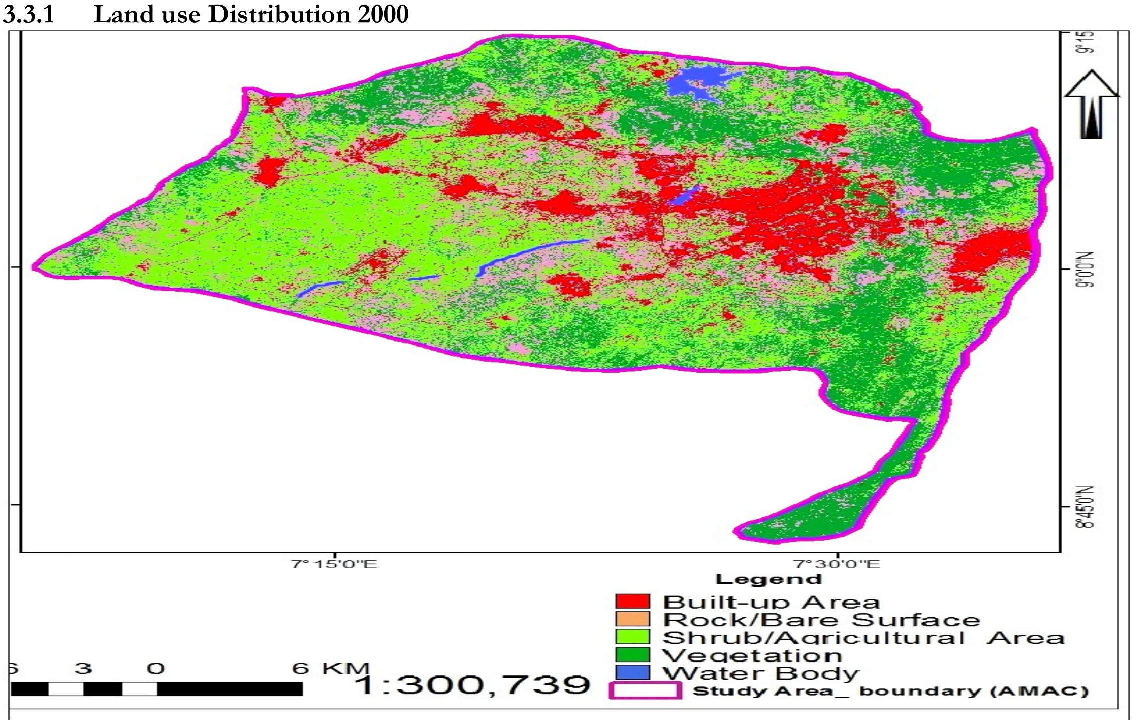

Figure 3.3 Map of Land use Categories 2000
Source: Derived from Interpreted Remotely Sensed data

The land use classification for 2000 derived from the Landsat ETM satellite image (Figures 3.3, 3.4) showed that a majority of the study area was under Shrub/Agricultural Area with 40.73%. These are concentrated to the north, south east and north western portions of the study area. The next higher land use is vegetation which has an area coverage of (24.27%) and is scattered to the west, south and across the south eastern parts with small patches towards the northern part of the study area. Rock/Bare Surface is the next in area coverage with (20.36%) located mainly to the central and eastern portion with small patches to the eastern part of the study area. Built up Area next occupies (14.06%) and it has an area coverage located mainly to the north, running through the central and finding its way to the southern part of the study area.

Table 3.2: land Use Area (hectares) in 2000

Land Use	Area (Hectares)	Percentage (%)
Built up Area	22374.12	14.06
Rock/Bare Surface	32399.51	20.36
Shrub/Agricultural Area	64814.93	40.73
Vegetation	38621.61	24.27
Water body	922.97	0.58
	Total: 159133.14	

3.3.2 Land use Distribution 2005

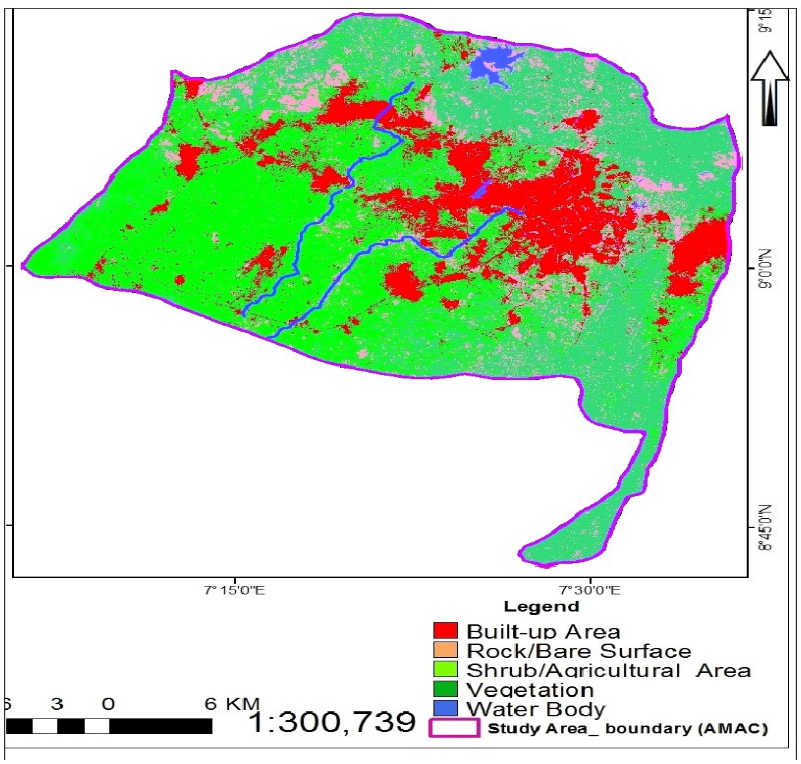

Figure 3.4 Map of Landuse Categories 2005
Source: Derived from Interpreted Remotely Sensed data

The spatial extent of the 2005 land use yielded Shrub/Agricultural Area occupying the largest area coverage with (36.07%) as compared to other land use classes. This is largely concentrated across the west and southern portion with patches around the eastern and northern part of the study area (figure 3.4). Vegetation covers an area of (30.53%) and it is concentrated along the north east and north western portion. Built up Area occupies a coverage of (16.95%) and is mainly concentrated along the central part extending towards the east and western portion of the entire study area. Rock/Bare Surface with an area of (15.53%) concentrates to the North east and eastern portion of the map Water body with (0.92%) is concentrated within the reservoir and are majorly found in the north and southern portion. This period witnessed gradual migration and urban expansion in terms of physical changes with improvements in water supply, physical roads, residential, commercial and institutional facilities as well as essential services. Settlements were gradually expanding and becoming more clustered partly due to migration and population increase. The beginning of such change in land use was strongly attributed to human activities.

Table 3.3: land Use Area (hectares) in 2005

Land Use	Area (Hectares)	Percentage (%)
Built up Area	26973.07	16.95
Rock/Bare Surface	24713.38	15.53
Shrub/Agricultural Area	57399.32	36.07
Vegetation	48583.35	30.53
Water body	1464.02	0.92
	Total: 159133.14	

3.3.3 Land use Distribution 2010

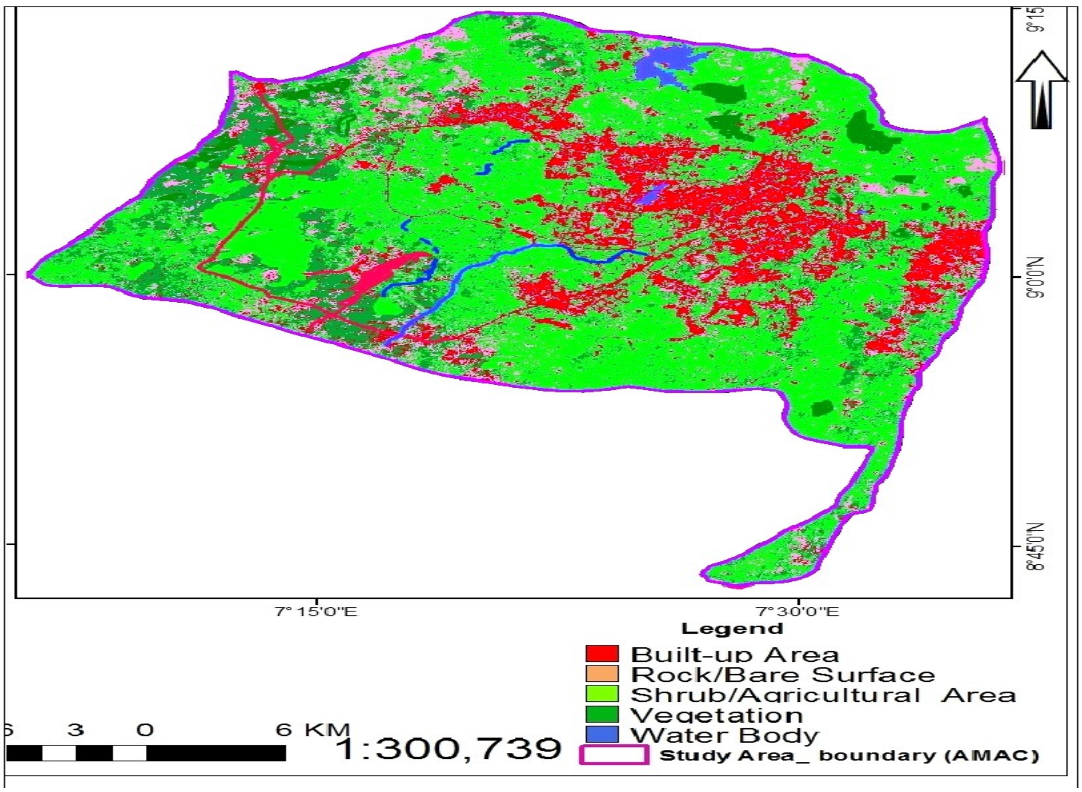

Figure 3.5 Map of Landuse Categories 2010
Source: Derived from Interpreted Remotely Sensed data

Furthermore, the land use distribution of 2010 yielded a land use map (figure 3.5) with Shrub/Agricultural Area occupying the largest area coverage of (40.53%) which is concentrated to the west south eastern and northern portions of the study area. vegetation accounts for (26.5%) and is dominated around the west and south western parts of the study area. Built up Area occupying an area of (18.61%) has become more clustered and are expanding in size compared with the past years. This is concentrated to the central portion and extending strongly to the east, south and north western part of the study area. Water body with 0.66% (figure 3.5) experienced a drop compared to the previous epoch, with its concentration remaining at the northern part of the study area .This period envisaged a population increase causing more pressure on urban infrastructure, increased cultivation and migration thereby leading to de-vegetation and encroachment of green areas, while also witnessing unplanned developments and the presence of squatter settlements. Under this circumstance human activities were on the rise.

Table 3.4: land Use Area (hectares) in 2010

Land Use	Area (Hectares)	Percentage (%)
Built up Area	29614.68	18.61
Rock/Bare Surface	21801.24	13.7
Shrub/Agricultural Area	64496.66	40.53
Vegetation	42170.28	26.5
Water body	1050.28	0.66
	Total: 159133.14	

3.3.5 Land use Distribution 2015

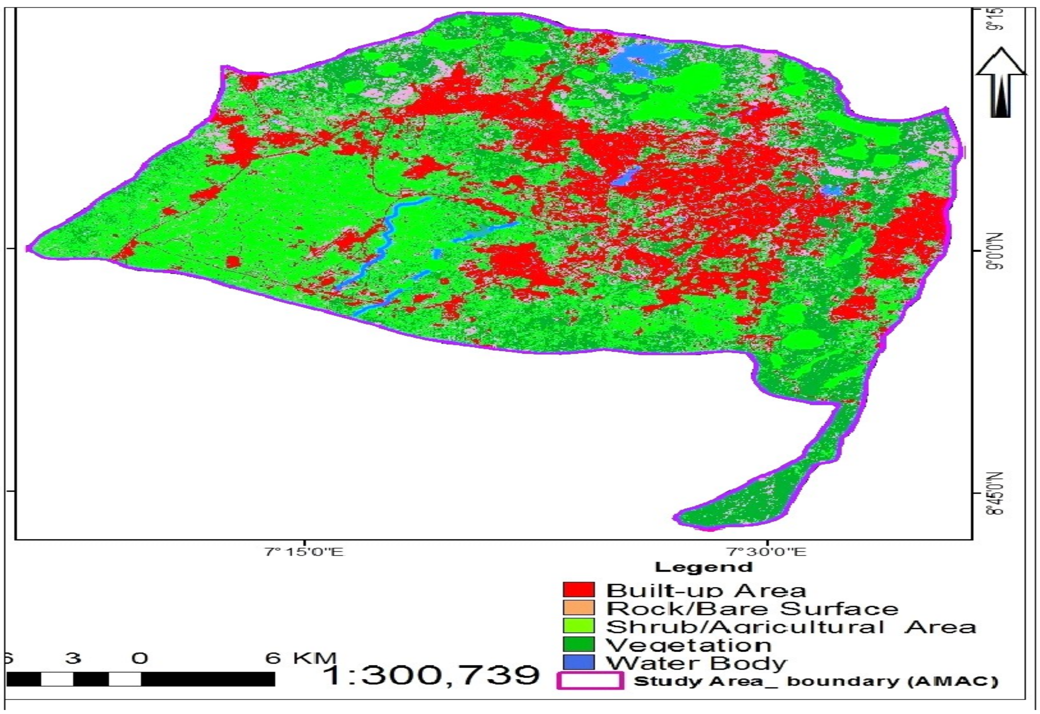

Figure 3.6 Map of Landuse Categories 2015
Source: Derived from Interpreted Remotely Sensed data

Finally, in 2015 land use distribution yielded a classification with Shrub/Agricultural Area occupying the highest coverage of the study area with 41.38% (figure 3.6) and were covering extensive areas mainly centered to the North western and south eastern with a major patches in other parts of the study area. Built up Area experienced a drastic increase compared to the other epochs covering an area of 24.9% (figure 3.6) and is mainly concentrated at the center with its density fully experienced at the eastern, southern and western part of the entire study area with patches all around.

Vegetation amounted to (21.23%) and is concentrated to the north east, east and scattered in patches to the southern parts of the study area. Rock/Bare Surface occupies 11.86% and is dominant in the north eastern and north western part with patches all around. Water body having (0.63%) is mainly gradually experiencing decrease with concentrated within the reservoir in the north and southern portion. This period witnessed increase in population, increase in physical developments majorly from the government and real estate developers. The implication of this transformation is the continuous damage to green areas and vegetal cover caused by the drive to satisfy the housing demand arising from population increase.

The result of the analysis as seen from table 3.5 shows that Built up area were getting higher on the average moving from 14.06 % in 2000 to 16.95% in 2005, and then continued to 18.61% in 2010 which further went up to 24.9% as at 2015. The reason of the continuous increase in built up area is primarily linked to the influx of people into the area brining about population explosion and further leading to the conversion of areas to build up.

Table 3.5: land Use Area from 2000-2015

Year	**Built up Area**	**Rock/Bare Surface**	**Shrub/Agricultural Area**	**Vegetation**	**Water body**
2000	14.06	20.36	40.73	24.27	0.58
2005	16.95	15.53	36.07	30.53	0.92
2010	18.61	13.7	40.53	26.5	0.66
2015	24.9	11.86	41.38	21.23	0.63

Rock/Bare Surface on the other hand was high as at 2000 (20.36%) relative to the preceding years. in 2005 it declined to 15.53% of the entire study area and further went down to 13.7% the following period and continue to drop to 11.86% in 2015. The reason for this constant decline is not far from the fact that rocks are fundamental raw materials for the construction industries thus its blasting is inevitable.

Shrub/Agricultural Area experienced a coverage of 40.73% in 2000 before dropping to 36.07% in 2005. This drop in coverage is seen to be as a result on increase in built up areas which is associated to the increase in population. However in 2010 it went up to 40.53% and further increase again to 41.38% in 2015.

Vegetation on one hand experienced an increase from 24.27% in 2000 to 30.53% in 2005. This increase is traced to the effort of the then government which was concerned on preserving the Abuja Master plan and conserving the environment. However in 2010 the coverage dropped to 26.5% and further went down to 21.23%. The level of Water body coverage is seen to fluctuate between the range of 0.58% to 0.92% for the study period.

3.4. Correlation between Green Area Changes with Temperature Changes

Table: 3.6: Variation in Green Area and Temperature.

Year	Green Area	Temperature
2000	65	27.7
2005	66.6	27.75
2010	67.03	28.1
2015	62.61	26.85

As presented from the result of the analysis in table 3.6, Green Area experienced a significant increase from 2000 to 2010 moving from 65% to 67.03%. This increase is basically due to the pressure of the then government to return and maintain the design of Abuja Master plan and creating policies that lead to the establishment of recreation parks and gardens. e.g. Millennium Park, which is the biggest amongst others. However, in 2015 the level of green area started witnessing backward trend in its coverage, bringing about sharp decrease to 62.61% and this can be tied to the increase in residential estates and proliferation of industries.

The behavior of the Temperature change is seen to be increasing despite the increase in green area from 2005 -2010. it moved from 27.27 ^{o} C to 27.75 ^{o} C in 2005 and 28.1 ^{o} C in 2010 respectively. This flow in increase is associated to heat island resulting from strong urbanization within the city center and continuous increase in the proliferation of estates and industries.

3.5 Summary of Findings

The findings of the study indicate that the study area has been growing to a relatively compact urban agglomeration. The concentration of built-up area at the central part of the study area has been getting bigger and more aggregated. However, the urban expansion has also happen extensively in urban fringes, converting agricultural to built-up areas. The built-up areas have mainly occurred in the central, south western and eastern part of the study area with a lot of development of new residential areas and infrastructures.

The land cover trend of the study area from the period of 2000-2015 shows dramatic changes for the dominant land cover types , which are shrubs/ agricultural area, built-up and vegetation. Built-up area has increased by 10.84% (from 14.06% in 2000 to 24.9% in2015).

The area has experienced rapid growth in the last few years with built-up area increasing by 6.29% from 2010 to 2015. On the contrary, vegetation has decrease by 3.04% from 24.27% in 2000 to 21.23% in 2015. Green spaces in the urban fringe areas in the north, east and central part of the study area have been getting smaller, indicating the conversion of reserved fields into agricultural and built-up areas.

The land cover changes have an impact on the temperature in the study area. The increasing trend of built-up and decreasing trend of vegetated area over the years have led to the overall increase in temperature within the area under study.

It is evident in the study that the study area is experiencing significant temperature changes as a result of the series of activities particularly construction of mass housing and industrial estates within it. This is impacting seriously on its physical environment and causing serious devastation of the green areas and natural resources. Of course the construction is not the only cause of change but is evidently the most important. Other anthropic activities include farming, grazing and bush burning. Also in recent times, the study area is experiencing heavy influx of people thus leading to increase in human population which has further increased growth in infrastructural development and expansion of housing estate, which consequently have negative influence on the natural environment.

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Effect of Size on Drying Rate and Kinetics of Smoke-Dried Snail

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Abstract
Snail meat is highly perishable, spoilage begins within few hours of post-harvest, which poses a significant challenge to stakeholders. In this study, the effect of size on drying rate and kinetics of snails, Archachatina marginata was investigated using the NSPRI smoking kiln. A portion of the snail used was cut (half-sliced), while the other portion was left uncut. The experimental data generated was converted to moisture ratio and fitted in seven drying models. The moisture content of the snail was reduced from 247.253% to 6.683 and 10.531% for whole and cut samples respectively. The drying rate of the whole and half-cut samples were 0.0106±0.0068 and 0.0069±0.0027 kg/h respectively; while their respective drying time were 7 and 5 hours. The drying temperature range attained was 72 to 120 ℃. All the models performed very well, however, Midilli et al. model gave the best fit for thewhole snail with R^2 of 0.9975 and RMSE of 0.0151, while half-cut was best described by Wang and Sing with the highest value of R^2 (0.9986) and least value of RMSE (0.0117). NSPRI smoking kiln is an efficient value addition equipment that could be used to add value to snail to enhance its quality and extend its shelf-life.

Keywords: *Archachatina marginata,* Drying, Experimental moisture ratio, Modelling, Shelf-life

1.0 Introduction

Snails are soft-bodied shell-bearing invertebrates of the phylum Mollusca and the second largest animal group after arthropods (Achaglinkame *et al*., 2020). Typically, they are wholly or partly enclosed in a calcium carbonate shell secreted by a soft mantle covering the body (Parden, 2011; Solomon, 2013). Snail meat is a delicacy in tropical region and relatively affordable. It is rich in protein with about 80.9 - 89.92% of its dry weight, and it has low level of fat and cholesterol (Achaglinkame *et al.,* 2020; Egbe *et al*., 2021); hence, it is of importance to individuals that are mindful of their health. The snail meat is characteristically tender with flexible or springy texture when chewed. These qualities make snail meat not only a nutritious food choice but also a suitable option for preventing vascular-related illnesses such as heart attacks, cardiac arrest, hypertension and strokes (Emelue and Dododawa, 2017; Achaglinkame *et al*., 2020).

Despite its nutritional value, snails have limitations due to their perishability and seasonality (Engmann *et al.,* 2012). It is reported that the fresh meat of snailsbarely lasts for a day before decaying due torapid deterioration caused by exposure to different kinds of bacteria and pollutants when they crawl on the soil (Onwubuche e*t al.,* 2019). Snail meat is highly perishable, spoilage begins within one to two hours of post-harvest, which presents a significant challenge for farmers, processors, and consumers. To address this, effective preservation techniques are paramount. Common methods of preservation include convectional drying, smoking, sun-drying, and the use of artificial or natural preservatives (Adeyeye *et al.,* 2020). Smoke-drying is a reliable method of extending the shelf-life of perishable foods such as fish, meat, and snails, which also enhances their flavour and prevents microbial spoilage (Olayemi, 2012). Smoke-drying involves the removal of moisture, which is essential in reducing the risk of microbial growth and spoilage. This study, therefore, explored the drying kinetics of snails of varying sizes using the Nigerian Stored Products Research Institute (NSPRI) smoking kiln® to provide insights into optimizing the drying processes of the product.

The NSPRI smoking kiln® is an equipment designed to improve the quality and storage stability of smoked agricultural products. It was initiallydesigned to address the challenges of smoking fish, with its competitive advantages ensuring consistent heat distribution, controlled smoking conditions, and reduced exposure to environmental contaminants. It has been adapted for some food items, including snails. The smoking kiln's design allows for better control of some drying parameters, which are critical factors that influence the drying kinetics and final product quality (Omodara *et al.,* 2016). It is therefore essentialto understand the drying behaviour of snails in the NSPRI smoking kiln® to optimize the drying process. Drying kinetics refers to the rate and form in which moisture removal occurs during the drying operation. This depends on the product's properties (size, shape, internal structure and initial moisture content); drying conditions (temperature, relative humidity and airflow); and the type of dryer used. The study of drying kinetics helps to determine the optimal drying conditions that minimize drying time while also preserving the nutritional and sensory qualities of the snails. This can lead to more efficient energy use, cost savings, and higher-quality dried products delivery (Ojediran and Raji, 2011; Raji and Olanrewaju, 2015; Aremu and Akintola, 2016; Ajao *et al.,* 2021).

Previous studies of drying kinetics focused on different agricultural products using a series of drying equipment, NSPRI smoking kiln® inclusive. Specifically, the kiln has been successfully utilisedfor drying fish (Omodara *et al.,* 2016; Oyewole *et al.,* 2021), which, therefore, demonstrates the potential of using similar drying technology for snails. However, snails' unique composition and tissue structure require a tailored approach to drying. Applying the NSPRI smoking kiln® for snail drying presents an opportunity to investigate how this method affects the drying rate, moisture diffusivity, and quality of the final product. Additionally, the findings from this study could contribute to developing standardiseddrying protocols that can be adopted by small-scale snail farmers and processors, ultimately reducing post-harvest losses and improving food safety in Nigeria. Therefore, this study investigated the effect of slice thickness and drying temperature on the drying kinetics of snails using NSPRI smoking kiln®.

2.0 Methodology

2.1 *Collection of Snails (Archachatina marginata)*

Sixty whole pieces of *Archachatina marginata* (African giant snails) were gotten from *Oje* market (7˚23'19' N, 3˚54'30'E), Ibadan, Oyo State, Nigeria. The snails were placed in plastic containers and afterwards transported for processing at Nigerian Stored Products Research Institute, Ibadan zonal office.

2.2 Description of NSPRI smoking kiln®

Model B NSPRI smoking kiln® was used, and it consists of the smoking chamber, drying racks and trays, combustion chamber and oil collector. The smoking chamber is cuboid in shape and is made of a double wall of metal effectively insulated with polyurethane. The chamber, positioned on a set of metal wheels, possesses an access door in the front and vents at the top. The racks are welded to the inner wall of the chamber. The drying trays are constructed with square pipe and expanded wire mesh which are rectangular in shape and are placed on the racks for support, easy loading and unloading of products. The trays are arranged on five different levels in the smoking chamber. The combustion chamber is positioned at the rear end of the smoking chamber and is fabricated of a double-wall metal insulated with polyurethane. It is a detachable component that houses the charcoal box and ash tray. Lastly is the oil collection component made of stainless steel plate and pipe. It is directly positioned beneath the drying trays. It gathers the oil removed from the product during smoke-drying and channels it to the side for collection (Figure 1).

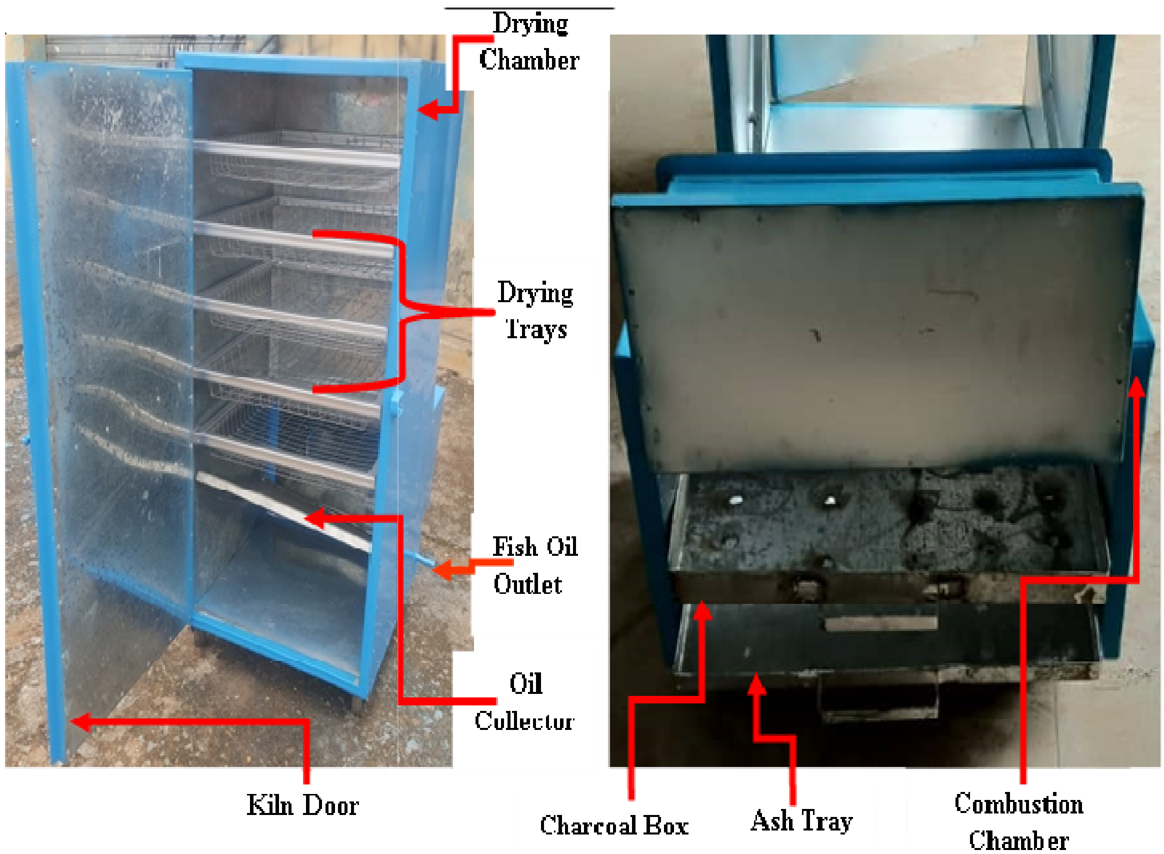

Fig. 1. The pictorial view of NSPRI smoking kiln® (Model B)

2.3 *Preparation of snail samples*

The snails were cracked, degutted, cut, washed and rinsed in potable water thoroughly to remove all adhering shell pieces, slime and dirt, following the method of Oyewole *et al.* (2024) (Figure 2). A portion was cut (half-sliced) while the other portion was left uncut. The intention of the cutting was to determine the effect of size reduction on drying rate and kinetics of the snail. Thereafter, brining was carried out by putting the snail samples into salt solutions (10 g of salt – 1 cm³ of water – 1 kg of snail meat) (Oyewole *et al.,* 2024). A total weight of about 5.9 kg of fresh cleaned snail meat samples were arranged on the trays and loaded into the smoking kiln and dried to achieve safe moisture content (Figure 3). The temperature of the kiln was monitored using a temperature logger (TEKCOPLUS THTK–6 K-Type 4-channels SD thermocouple). Specific snail samples were marked for the purpose of the study of drying kinetics and the representative samples were taken at different levels of the drying chamber for moisture loss monitoring at an interval of 30 minutes.

2.4 *Analysis of drying data*

2.4.1 *Drying kinetics of the smoke-dried snail*

The dry matter was determined by oven drying at 130°C for 10 hours according to standard (ASABE, 2021) and data obtained was used to determine the initial moisture content using the expression in Equation 1.

$$M_0 = \frac{W_0 - W_d}{W_d} \qquad 1$$

Where: W_0 denotes the initial weight of the sample; W_d denotes the weight of the dry solid.

After the initial moisture content had been established, the moisture content (dry basis) of the sample was estimated by the percentage equivalent of the ratio of the weight of water to the total weight of the dry material (Equation 2).

$$\text{Moisture Content (MC), db } = \frac{M}{S} \times 100 \qquad 2$$

Where: M is the content of moisture and S is the content of solid

The MC conversion to dimensionless moisture ratio (MR) was done by application of the non-exponential portion of the expressions considered as shown in Equation 3 (Raji and Olanrewaju, 2015; Ajao *et al.*, 2023).

$$MR = \frac{M - M_e}{M_o - M_e}$$

Where, M denotes moisture content at time t (% db), M_o denotes initial moisture content (% db), M_e denotes equilibrium moisture content (% db), MR denotes moisture ratio and t is the drying time (hr).

2.4.2 Drying rate

The drying rates of the samples were calculated using Equation 4 (Hada *et al.*, 2017; Ajao *et al.,* 2023; Oyewole *et al.,* 2023). The calculated drying rates were plotted against drying time to produce the respective drying curves for the sizes of snail considered in the study.

$$dr = \frac{M_t - M_{t+\Delta t}}{\Delta t} \qquad 4$$

Where; M_t is the initial weight of the sample (kg), $M_{t+\Delta t}$ is the weight of the dried sample at time, $t + \Delta t$, Δt is the drying time (hour).

Fig. 2. Flowchart for production of smoke-dried snail

Fig. 3. The smoking kiln loaded with snail

2.4.3 *Modelling of the drying process*

Experimental data obtained were fitted into seven drying models (Table 1) that have been used in literature for the study of the drying kinetics of several agricultural crops (Sacilik, 2007; Hada *et al.*, 2017). These models require the calculation of dimensionless moisture ratio expressed in Equation 3.

Table 1. Mathematical models applied to the drying curves of smoke-dried snails

S/N	Model Name	Model	Sources
1	Newton/Lewis	$MR = exp\ (-kt)$	Liu and Bakker – Arkema (2001)
2	Logarithmic	$MR = exp\ (-kt) + c$	Yaldiz *et al.* (2001)
3	Two-term	$MR = aexp\ (-k_0t) + bexp(-k_1t)$	Zielinska and Markowski (2010)
4	Modified Henderson and Pabis	$MR = aexp\ (-kt) + bexp(-gt) + cexp(-ht)$	Karathanos (1999)
5	Approximation of diffusion	$MR = aexp\ (-kt) + (1-a)exp(-kt)$	Amendola and Queiroz (2007)
6	Midilli *et al.*	$MR = aexp(-ktn) + bt$	Midilli *et al.* (2002)
7	Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh (1978)

2.4.4 *Performance Evaluation of Models*

The primary measures used in the selection of the best model to describe the drying kinetics of smoke-dried snail were coefficient of determination (R^2) and root mean square error (RMSE). They both depict the adequacy and goodness of fit for the models according to Ertekin and Yaldiz (2004), Ndukwu *et al.* (2018) and Oyewole *et al.* (2023). The higher the value of R^2 and the lower the value of RMSE, the better the goodness of the fit (Oke and Workneh, 2014; Ajao *et al.,* 2023; Oyewole *et al.,* 2023) for thesamples.R^2 and RMSE were calculated using the expressions in Equations 5 and 6.

$$R^2 = [1 - \frac{\sum(MR_{exp,i} - MR_{pre,i})^2]}{\sum(MR_{exp,mean} - MR_{pre,i})^2]}] \quad 5$$

$$\text{RMSE} = [\frac{1}{N}\sum(MR_{pre,i} - MR_{exp,i})^2]^{\frac{1}{2}} \quad 6$$

3.0 Results and Discussion

3.1 *Initial and final moisture contents of the smoke-dried snail*

The result in Table 2 shows the initial and final moisture contents of the smoke-dried snail. The initial moisture content of the fresh snail was 247.253±4.366%, while the final moisture contents of the dried whole and cut snail were 6.683±1.386 and 10.531±2.203%db respectively. The drying time for reducing moisture content in whole snail samples from the initial moisture content to final moisture content of 6.683±1.386 was 7 hours. However, result shows that 5 hours was used to reduce initial moisture in cut samples to 10.531±2.203%. However, longer time was spent in drying of the whole sample, but its final moisture content was significantly lower than that of the cut dried snail ($P<0.05$). This longer period could be responsible for the significant variation in the moisture contents of the two finished products. If the drying of the two samples were terminated the same time, it is expected that the cut sample would have lower moisture content because of more surface area that was available for moisture removal during the drying process.

Table 2. Initial and final moisture contents of the smoke-dried snail

Sample ID	Average moisture content (% MC, db)	
	Whole	**Half-cut**
Fresh Snail	247.253±4.366	247.253±4.366
Dried Snail	6.683±1.386[a]	10.531±2.203[b]

Values are expressed as mean ± standard deviation of triplicate determination. Means with the same letters along the same row are not significantly different ($p<0.05$)

3.2 *Drying behaviour of smoke-dried snail*

3.2.1 *Influence of slice thickness on drying rate and time*

The drying temperature range attained in the NSPRI smoking kiln for smoke-drying of the snail was 72 to 120 ℃ (Figure 4). The drying rate of the smoke-dried snail for both whole and half-cut samples were 0.0106±0.0068 and 0.0069±0.0027 kg/h respectively (Table 3). The drying rate of the whole snail was significantly different from that of the sliced sample. The drying of the whole snail sample was completed in 7 hours, while the half-cut sample lasted for 5 hours before attaining safe moisture content (Figure 5). The difference in the drying time used for both snail samples logically explains the effect of slice size on the drying rate of the dried products. The reduction of moisture content of the samples depends on both the slice size and drying temperature. The drying took place in the falling rate period which is the usual behaviour of most agricultural produce (Sacilik, 2007; Ojediran and Raji, 2010; Omodara *et al.*, 2016; Oyewole *et al.,* 2023).

Table 3. Drying rate of the smoke-dried snail

Sample ID	Drying rate (kg/h)	
	Whole	**Half-cut**
Snail	0.0106±0.0068[a]	0.0069±0.0027[b]

Values are expressed as mean ± standard deviation of triplicate determination. Means with the same letters along the same row are not significantly different ($p<0.05$)

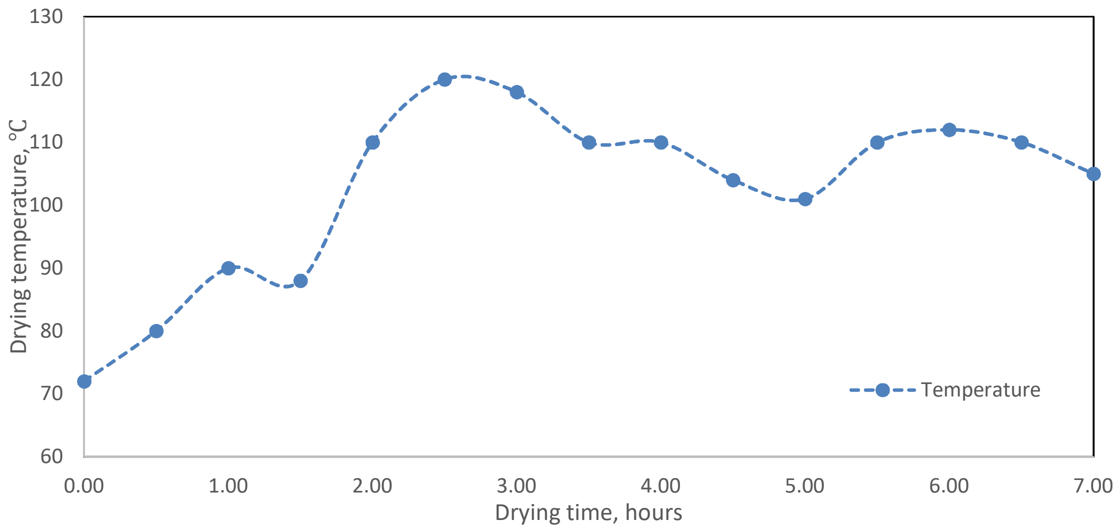

Figure 4: Drying temperature versus drying time of snail in NSPRI smoking kiln

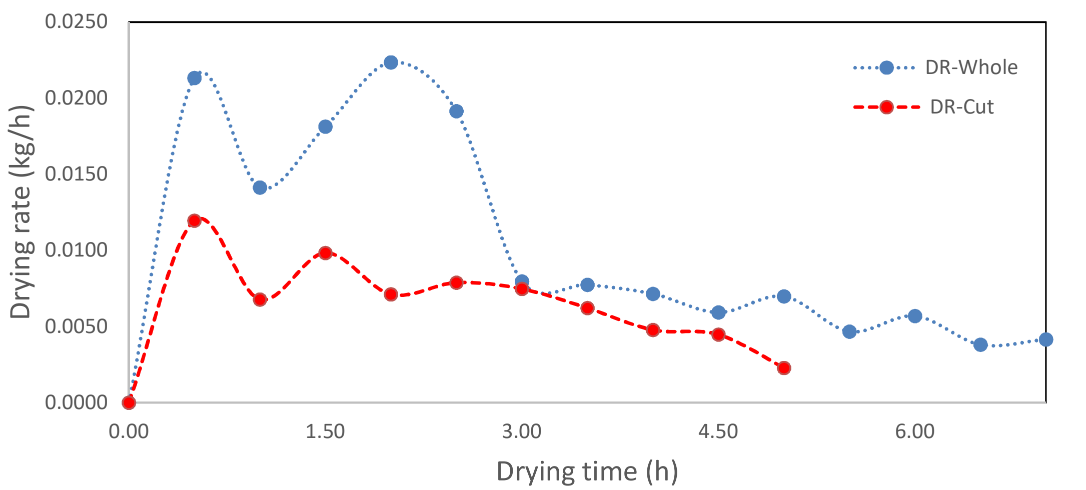

Figure 5: Drying rate versus time curve of smoke-dried snail samples

3.2.2 Modelling of the drying kinetics of smoke-dried snail

Modelling of the drying process of the snails is paramount in explaining the drying kinetics of both whole and half-cut snail samples. The experimental data on moisture ratio versus drying time obtained from smoke-drying of snail *(Archachatina marginata)* is illustrated in Figure 6. Thereafter, this was thus fitted into the seven mathematical models earlier selected (Newton/Lewis, Logarithmic, Two-term, Modified Henderson and Pabis, Approximation of diffusion, Midilli *et al.*, and Wang and Singh) and they were evaluated for both whole and half-cut snails in Figures 7 and 8 respectively. The mass transfer during the drying period was entirely as a result of liquid diffusion or capillary flow. This result is in line with findings from previous studies on drying of agricultural products (Ojediran and Raji, 2010; Raji and Olanrewaju, 2015; Ajao *et al.,* 2024).

The best fit model was selected based on results of R^2 and RMSE (Table 4). The model that gave the best description of drying behaviour of the half-cut snail dried in the kiln was Wang and Sing with the highest value of R^2 (0.9986) and least value of RMSE (0.0117). Midilli *et al.* model gave the best fit for smoke-dried whole snail because it yielded the highest R^2 of 0.9975 with the lowest RMSE value of 0.0151. This implies that drying temperature has the most significant effect in the drying rate since the coefficients of the Midilli *et al.* model is dependent on the drying air temperature. This result is in line with the finding of a study on drying of poplar wood particles (Arabi *et al.,* 2016), which reported that Midili, Kucuk and Yapar, and Henderson and Pabis models among eleven models gave the best result for describing the drying behaviour of the wood particle. Also, a study on drying kinetics of ginger showed that Midilli model was discovered to be the best in describing the pulse microwave drying behaviour of ginger (Nema *et al.*, 2013). The Midili-Kucuk model with four model constants was found to be the best model for some products (Kucuk *et al.,* 2014). Finally, Hada *et al.* (2017) validated three models to describe the convection oven drying kinetics of *E. longifolia,* and discovered that Midilli *et al.* model gave the best prediction. However, Wang and Sing model gave the best for half-cut smoke-dried snail.

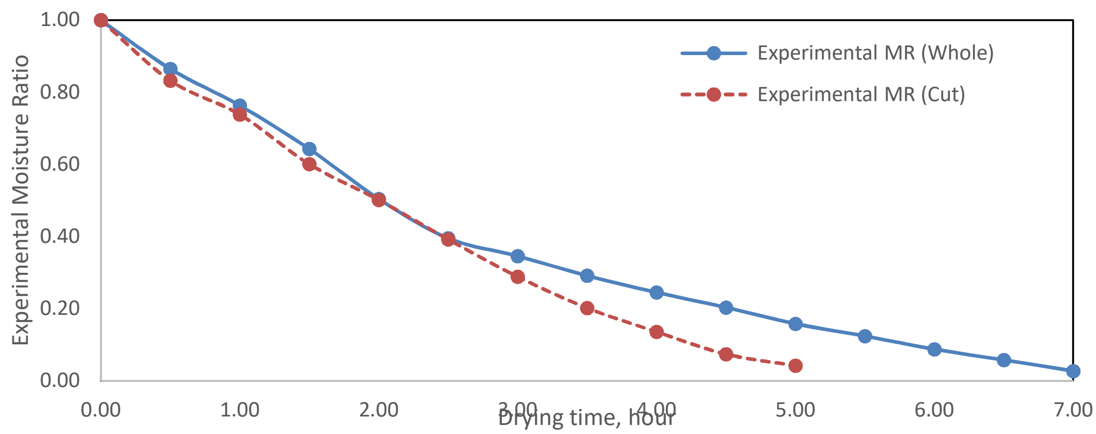

Fig. 6. Experimental moisture ratio curve for smoke-dried snails

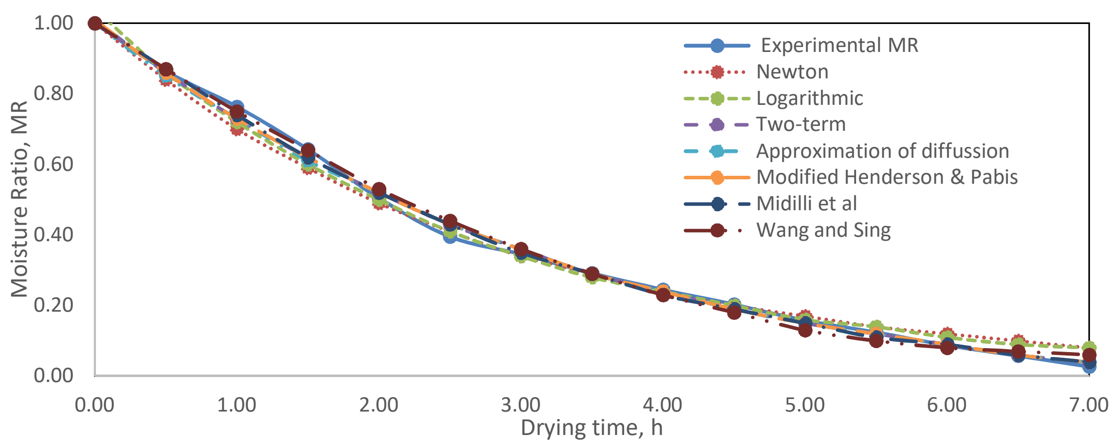

Fig. 7. Moisture ratio fittings of whole smoke-dried snails

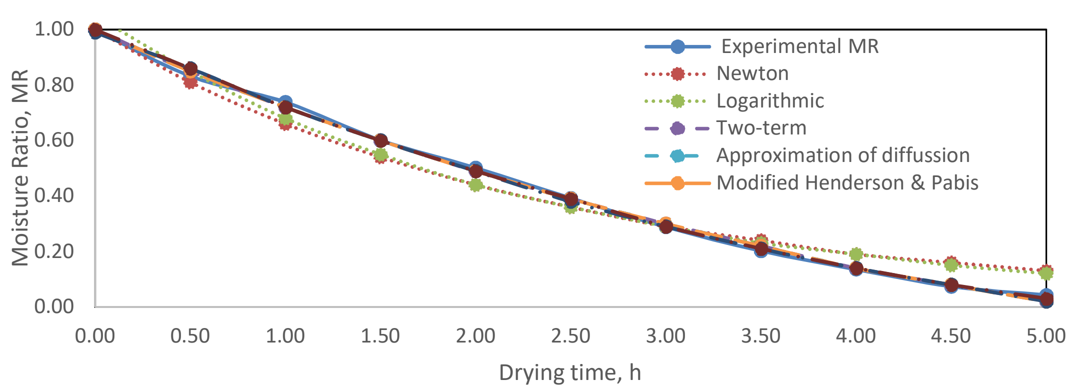

Fig. 8. Moisture ratio fittings of half-cut smoke-dried snails

Table 4. Estimated parameters and statistical criteria for models used for smoke-drying of snails

		Models						
Sample ID	**Estimated parameters and statistical criteria**	**Newton**	**Logarithmic**	**Two-term**	**Approximation of Diffusion**	**Modified Henderson and Pabis**	**Midilli *et al.***	**Wang and Sing**
Whole	a		1.040	5.709	34.780	0.180	1.002	-0.272
	k	0.356	0.370		0.190	0.180	0.299	
	n						1.098	
	k_o			0.209				
	b			-4.697	0.981	4.032	-0.005	0.2000
	c					-0.615		
	g					0.215		
	h					0.180		
	k_1			0.186				
	RMSE	0.0305	0.0263	0.016	0.0174	0.0161	0.0151	0.020
	R^2	0.9942	0.9931	0.9972	0.9970	0.9972	0.9975	0.9952
Half-cut	a		1.052	10.263	20.077	14.760	0.990	-0.297
	k	0.412	0.434		0.122	0.108	0.265	
	n						1.120	
	k_o			0.126				
	b			-9.264	0.919		-0.35	0.21
	c					0.003		
	g					0.121		
	h					27.914		
	k_1			0.106				
	RMSE	0.0562	0.051	0.0128	0.012	0.0128	0.0138	0.0117
	R^2	0.9968	0.9754	0.9983	0.9982	0.9983	0.9981	0.9986

4.0 Conclusion

The effect of size and temperature on the drying rate and kinetics of smoke-dried snails was studied. The findings revealed that size significantly affects the drying rate and kinetics of smoke-dried snails. Drying of snails predominantly occurred in the falling rate period. At all conditions, all seven models that were validated for the description of smoke-drying of snails gave good predictions. However, Midilli *et al.* model gave the best fit for smoke-dried whole snails, while Wang and Sing's model gave the best fit for half-cut smoke-dried snails. The NSPRI smoking kiln has the potential to efficiently and effectively smoke-dry snails to safe moisture content, thereby making it shelf-stable.

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Mathematical Modeling and Drying Kinetics of Catfish Smoked in NSPRI Smoking Kiln®

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Abstract

Fish is a major source of animal protein worldwide, with catfish (Clarias gariepinus) being particularly popular due to its taste and nutritional benefits. However, catfish is highly perishable and requires effective preservation methods to extend its shelf-life. This study explored the mathematical modelling and drying kinetics of catfish using NSPRI smoking kiln®, to optimise drying parameters and enhance quality preservation efficiency. The kiln was independently powered with charcoal and gas. Initial moisture content of the fish used ranged from 183.97±0.01 to 225.53±0.004% (db). Four drying models, Newton, Modified Page, Two-Term and Wang, were employed to analyse drying kinetics. Drying rates were monitored for different fish parts: whole, head, middle, and tail. Statistical criteria, such as the coefficient of determination (R^2) and Root Mean Square Error (RMSE) were used to evaluate model performance. Results showed that the NSPRI smoking kiln effectively reduced moisture content to levels between 6.37 and 24.67% (db), with drying rates varying significantly among fish parts. The drying kinetics of fish samples and model performance evaluation were characterised by high R^2 and low RMSE values. The Two-Term model gave the best prediction with the exemption of whole fish and head part dried in charcoal-powered kiln and gas-powered kiln, respectively, that Newton and Modified page models performed better in predicting their drying behaviour. The NSPRI smoking kiln proved effective in drying catfish, and the models adequately described the drying kinetics. This study provides insights into optimising drying parameters and improving preservation methods, potentially reducing post-harvest losses, enhancing the quality of dried catfish and advancing the technology of fish preservation.

Keywords: Catfish, drying parameters, drying rate, mathematical models, smoking kiln

Introduction

Fish is a major source of animal protein, providing a significant portion of the protein intake in the diets of man (Ikutegbe and Sikoki, 2014; Adeyeye and Oyewole, 2016; Peter and Coolborn, 2019). In Nigeria, fish is consumed fresh after being cooked, preserved or processed to gain quality stability in storage, and it forms a much-cherished delicacy that cuts across socio-economic, age, religious and educational barriers (Peter and Coolborn, 2019). It has nutrients such as omega-3 long chain polyunsaturated fatty acids (n-3 LC-PUFAs), calcium, iodine, vitamin D, zinc and iron. Catfish (*Clarias gariepinus*) is popular and widely sought-after as a delicacy in America, Europe, Asia and Africa, particularly in Nigeria due to palatability and good taste (Adeparusi *et al.,* 2010). Despite its nutritional benefits, catfish is highly perishable and susceptible to microbial attacks if not adequately preserved. Effective preservation methods are essential to maintain its quality and extend its shelf-life. Reducing the moisture content of fresh fish through drying to a low water activity level that is unfavorable to microbial proliferations is one of the oldest and most effective processing and preservation methods (Ajao *et al*., 2024; Oyewole *et al*., 2024). Drying has been practiced since ancient times and remains a crucial method for food preservation till date (Rodríguez *et al*., 2014).

It involves the removal of moisture due to heat and mass transfer between the biological product and drying air by evaporation, and usually caused by temperature and air convection forces (Aremu and Akintola, 2016; Ajao *et al.,* 2024). Also, it reduces the bulkiness of fish thereby leading to decreased costs of packaging, storage and transportation (Patel and Kar, 2012; Ajao *et al.,* 2024). In order to dry fish to a reasonable level that will be able to retain the nutritional composition of the product during drying and as well sustain it beyond the process, it is very important to understand the drying process with respect to its behaviour using a particular drying facility such as the kiln**.**

Mathematical modeling of drying process is an inevitable part of design, development and optimisation of a dryer (Dhalsamant, 2021, Ajao *et al.,* 2021). It mainly involves elaborative study of drying kinetics, which describes the mechanisms and influence that certain process variables exert on moisture transfer (Mutuli, 2020). It can be used to study the drying variables, evaluate the drying kinetics and optimise the drying parameters and conditions (Yun *et al*., 2013; Senadeera *et al*., 2020). A proper dryer design requires knowledge of the characteristics of the material to be dried and the drying kinetics (Kannan and Subramanian, 2008). Drying kinetics is a phenomenon that has gained popularity in food drying in recent times, it was defined by Simal *et al.* (2005) as the description of variations in the moisture content of the material during drying. It describes the macroscopic and microscopic mechanisms of heat and mass transfer that occur during food drying (Feng *et al*., 2012). This kinetics can be represented as drying rate curves (Aremu and Akintola, 2016). Understanding drying kinetics is crucial for predicting and determining the drying behaviour of food materials and optimising food drying parameters. Numerous kinetic models have been developed to predict these drying curves (Inyang *et al.,* 2018).

Many models have been used to describe the drying kinetics for various food products, ranging from models that are based on the laws of diffusion to thin-layer designs, which can be grouped into theoretical, semi-theoretical or empirical (Doymaz, 2007). The reliable modelling of drying processes requires a thorough knowledge of the physicochemical behaviour of food and water removal mechanisms, partially expressed through the drying kinetics. The various mathematical models developed to represent food drying kinetics are mainly empirical, due to the complexity of the various phenomena involved. Different drying models are usually analyszed and the one that shows the best model that predicts moisture loss and thus suits the drying kinetics of the product under consideration is selected. The appropriate model is important not only for the type of equipment, but also for the level of experimental data available and the type of results required to deliver a more effective and efficient facility (Ismail *et al*., 2020). Drying facilities such as smoking kilns are not exemptions from delivering good quality value-added fish products.

The evolution of smoking kilns has been driven by the need to increase drying efficiency, improve the quality of smoked fish, and enhance performance. Early improvements in smoking techniques focused on better uniformity of smoke exposure and temperature control (Omodara *et al*., 2016). Over time, these kilns have incorporated additional features to address various drying operational concerns. The Nigerian Stored Products Research Institute (NSPRI) smoking kiln is composed of a smoking chamber, drying trays, an oil collector, a separate combustion chamber attached to the kiln's rear end, well-distributed vertical arrangement of trays along the kiln walls, and vents for moisture exit (Oyewole *et al*., 2021). These features ensure consistent heat distribution, controlled smoking conditions, and reduced exposure to environmental contaminants.

The NSPRI smoking kiln® represents a significant advancement over traditional smoking methods, addressing many problems identified in the hot-smoking process, which stem from the low technological level of smoking equipment. A practical model is essential for process design, optimisation, energy integration, and control. This study therefore, aimed to explore the mathematical modelling and drying kinetics of catfish using the NSPRI smoking kiln®. By understanding the drying process and evaluating various drying models, the study sought to optimise drying parameters and conditions, ultimately enhancing the efficiency of the kiln and the quality of dried catfish.

Materials and Methods

Description of the NSPRI Smoking Kiln®

The model of NSPRI smoking kiln® used for the study comprises the smoke-drying chamber, drying racks and trays, combustion chamber and oil collection mechanism. The smoke-drying chamber is a cuboid cabinet fabricated of double-wall metal adequately insulated with polyurethane. The chamber is provided with access door in the front, vents at the top, and positioned on a set of metal wheels. The racks are welded to the inner wall of the chamber. The drying trays constructed of square pipe and expanded wire mesh are rectangular in shape and are placed on the racks for support, easy loading and unloading of products. The combustion chamber positioned at the rear end of the drying chamber is also fabricated of double wall metal insulated with polyurethane. It is a detachable component that houses the charcoal box and ash tray. The fourth component is the oil collection mechanism constructed of stainless-steel plate and pipe. It is directly positioned beneath the drying trays. It collects the oil from the fish during smoke-drying and channels it to the side it could be collected outside the smoking chamber. The particular kiln used is a 25 kg capacity and it is referred to as Model B Type I (Figure 1).

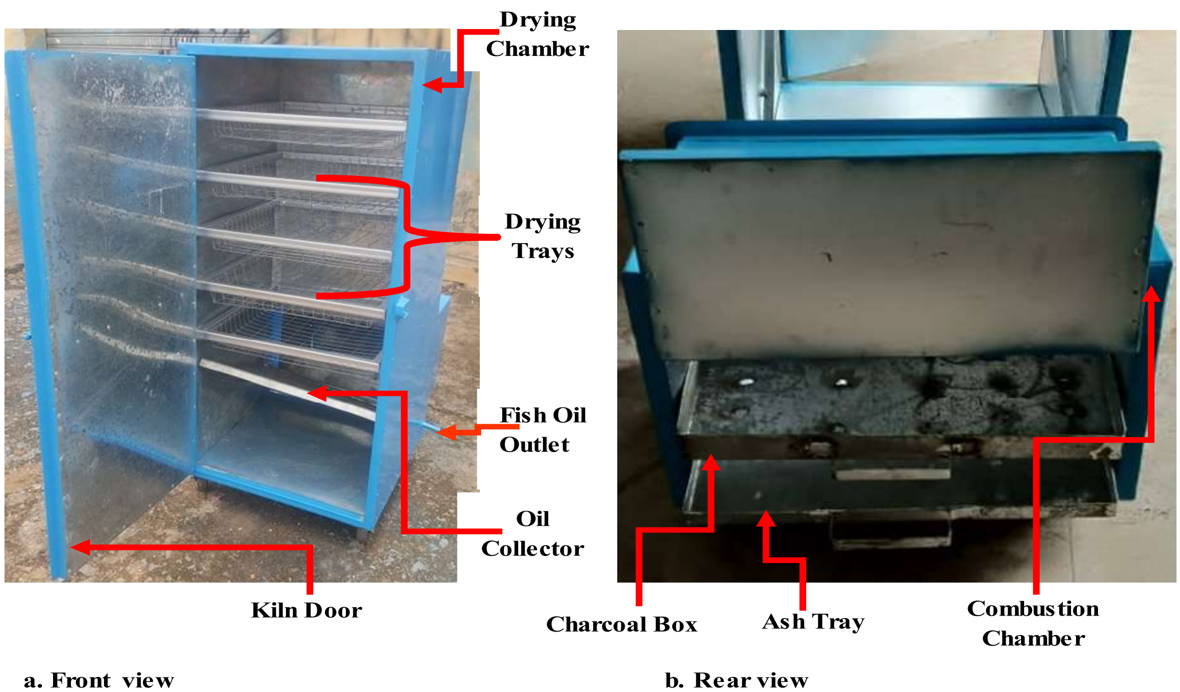


Fig. 1. The pictorial view of NSPRI smoking kiln® (Model B).

Collection and Preparation of Fresh Catfish for Smoking

The quantity of fish used for the research work was 25 kg and it was procured from a catfish farmer at Eleyele, Ibadan, Nigeria. The fishes were washed, sorted and degutted to remove the gills and offal organs. They were processed using the method described by Omodara *et al.* (2016). The fishes were cut into different parts (head, middle and tail) while some were folded as whole fish. They were soaked in brine solution (250 g of salt in 25 litres of water for 25 kg of fish) for 30 minutes (to enhance the taste of the dried fish product). The fishes were then drained and properly arranged on drying trays to ensure the removal of surface water before putting them into the dryer. The details of preparatory procedure used are presented in Figure 2. The pictorial view of the kiln showing the interior loaded with fish during the experiment is shown in Figure 3. The temperature of the kiln was monitored using a temperature logger (TEKCOPLUS THTK– 6 K-Type 4-channels SD thermocouple). Individual fish samples were marked for this purpose and the samples were taken at different levels of the drying chamber for moisture loss monitoring at an interval of one hour.

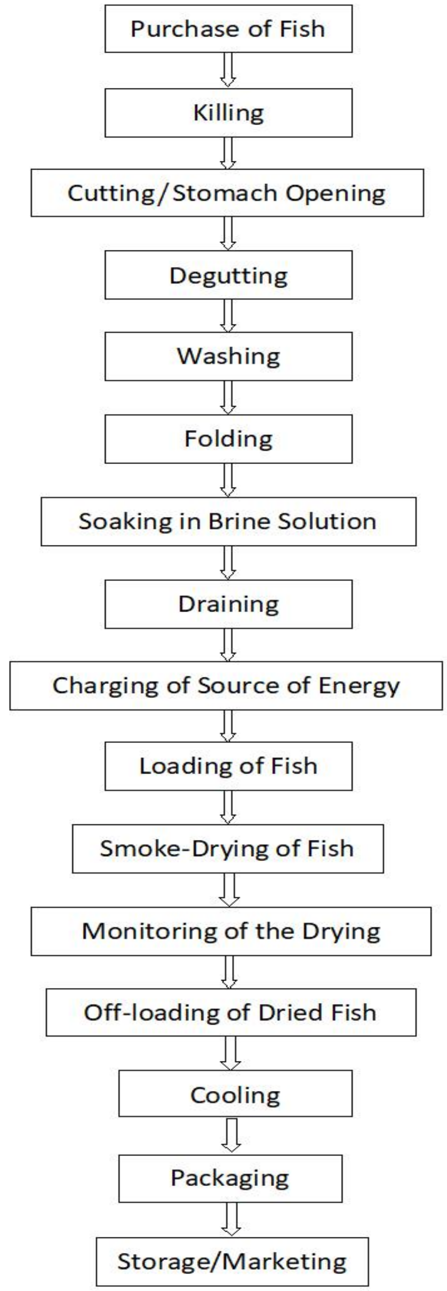


Fig. 2. Flow Chart for Smoking of Fish

Fig. 3. Interior view of the loaded smoking kiln

Drying Kinetics and Modeling

The dry matter and initial moisture content were determined by oven drying at 130°C for 10 hours according to standard (ASABE, 2021). After the initial moisture content has been established, weight loss was applied in estimating the moisture content as expressed in Equation 1 (Ajao *et al.*, 2023; Oyewole *et al.*, 2023).

$$M_t = \frac{M_i m_i - w_i}{m_i - w_i} \quad 1$$

Where: M_t denotes moisture content (MC) at time t, (% w.b.); M_i denotes MC at initial point (% w.b); m_i denotes weight at initial point (g) and w_i is the weight loss at any time, t (g).

The MC conversion to dimensionless moisture ratio (MR) was done by application of the non-exponential portion of the expressions considered as shown in Equation 2 (Raji and Olanrewaju, 2015; Ajao *et al.*, 2023).

$$MR = \frac{M - M_e}{M_o - M_e} \quad 2$$

Where: M denotes moisture content at time t (% db), M_o denotes initial moisture content (% db), M_e denotes equilibrium moisture content (% db), MR denotes moisture ratio and t is the drying time (hr).

Drying rate (dr) was determined using Equation 3.

$$dr = \frac{M_t - M_{t+\Delta t}}{\Delta t} \quad 3$$

Where: M_t is the initial weight of the sample (g), $M_{t+\Delta t}$ is the weight of the dried sample at time, $t + \Delta t$, Δt is the drying time (min).

The models considered for the study were four and they are presented in Table 1.

Table 1. Mathematical models applied to the drying curves

Model	Name of Model	Sources
$MR = \exp(-kt)$	Newton	Tiris *et al.* (1994); Liu and Bakker-Arkema (1997)
$MR = \exp[-(kt)^n]$	Modified Page	Panchariya *et al.* (2002); Demir *et al.* (2004)
$MR = a\exp(-k_0 t) + b exp(k_1 t)$	Two-Term	Soponronnarit *et al.* (2001); Dandamrongrak *et al.* (2002)
$MR = 1 + at + bt^2$	Wang and Sing	Wang and Singh (1978); Chen and Wu (2001); Panchariya *et al.* (2002)

Performance Evaluation of Models

The coefficient of determination (R^2) and Root Mean Square Error (RMSE) were the statistical tools used as primary criteria for adequacy and goodness of fit for the models according to Ertekin and Yaldiz (2004), Raji and Olanrewaju (2015); Ndukwu *et al.* (2018) and Oyewole *et al.* (2023). Hence, the curve with the highest R^2 and lowest RMSE value was selected as the best-fit model for predicting the drying characteristics of catfish using the NSPRI Smoking Kiln®. R^2 and RMSE were calculated using the expressions in Equations 4 and 5.

$$R^2 = [1 - \frac{\sum(MR_{exp,i} - MR_{pre,i})^2]}{\sum(MR_{exp,mean} - MR_{pre,i})^2]}] \quad 4$$

$$\text{RMSE} = [\frac{1}{N}\sum(MR_{pre,i} - MR_{exp,i})^2]^{\frac{1}{2}} \quad 5$$

Results and Discussion

Initial and Final Moisture Contents of the Fish Dried in Charcoal and Gas-Powered Kilns

Table 2 shows the results of the initial and final moisture contents of the fish dried in the charcoal-powered smoking kiln. The initial moisture content of the fresh fish ranged from 183.97±0.01 to 184.72±0.01%db. The initial moisture content recorded in the tail was significantly different from other components and whole fish, with a slight increase ($P<0.05$). At the point of termination of the experiment, the moisture content of the middle part was significantly higher than others. This is an indication that the middle part took longer time to dry when compared with other treatments. In the case of fish dried in the gas-powered kiln, the initial moisture content of the head was significantly different from that of the middle, while the tail and whole fish were neither different from the head nor the middle (Table 3). The moisture contents of all fish parts and whole fish dried in the gas-powered kiln were significantly the same at the point of termination of the experiment. The reduction in moisture content from initial values of all samples of fish to final levels, underscores the kiln's efficiency to achieve significant moisture removal essential for extending the shelf-life and enhancing the quality of catfish.

Table 2. Initial and final moisture contents of the fish dried in charcoal powered smoking kiln

	Average moisture content (% MC, db)			
	Whole	**Head**	**Middle**	**Tail**
Fresh Fish	183.97 ± 0.01^a	184.02 ± 0.09^a	183.97 ± 0.004^a	184.72 ± 0.66^b
Dried Fish	6.3697 ± 7.02^a	8.0872 ± 7.13^a	24.6741 ± 4.72^b	8.1625 ± 7.02^a

Values are expressed as mean ± standard deviation of triplicate determination. Means with the same letters along the same row are not significantly different ($p<0.05$)

Table 3. Initial and final moisture contents of the fish dried in gas powered smoking kiln

	Average moisture content (% MC, db)			
	Whole	**Head**	**Middle**	**Tail**
Fresh Fish	225.50±0.01[ab]	225.47±0.09[a]	225.53±0.004[b]	225.51±0.06[ab]
Dried Fish	2.2476±1.25[a]	3.8191±3.12[a]	4.8377±2.45[a]	1.7020±1.26[a]

Values are expressed as mean ± standard deviation of triplicate determination. Means with the same letters along the same row are not significantly different ($p<0.05$)

Drying Behaviour of Smoke-Dried Fish

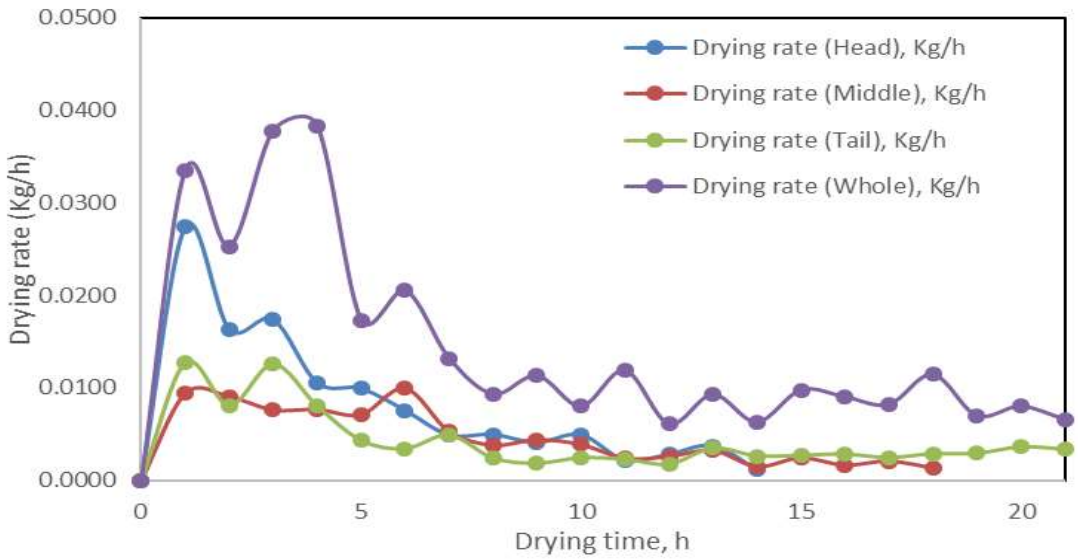
Drying rate

The drying rate represents the rate of change of moisture content (% db) over a period of time. Factors affecting drying rate are numerous and these include initial moisture content, size (thickness of sample), surface area, and nature of the sample, among others. The drying rate based on different parts of whole, head, middle and tail of fish using the NSPRI smoking kiln powered with charcoal were 0.0147±0.0104, 0.0084±0.0074, 0.0048±0.0029 and 0.0044±0.0032 kg/h respectively; while 0.0106±0.0100, 0.0081±0.0072, 0.0040±0.0037 and 0.0042±0.0013 were recorded in the kiln powered with gas for whole, head, middle and tail respectively (Table 4). Under the two drying conditions of using charcoal and gas, the middle and tail dried at the same rate ($P<0.05$). The highest drying rates were recorded in the whole fish samples, and these were significantly higher than any of the drying rates recorded in other parts of the fish irrespective of the source of energy. This could be attributed to the wider surface area available in the whole fish for moisture removal. Despite the quantity of flesh present in the head, the drying rates recorded under the two conditions were higher than those obtained in the middle and tail. This could also be attributed to the size of the head and the removal of gills and guts earlier carried out during the preparatory stage of the experiment. This variation in drying rates highlights the impact of sample size and thickness on the efficiency of the drying process. It was further observed that in all cases of fish parts and whole fish, the drying rates under charcoal-powered operation were higher than the corresponding rates recorded when powered with gas. This could be due to the higher temperature recorded in the charcoal-powered kiln. The drying rate curves are presented in Figure 4. Drying rates for all samples occurred in the falling rate period which implies that drying took place by diffusion. Similar results have been reported in several food products during drying (Ojediran and Raji, 2010; Omodara *et al.*, 2016; Olayemi *et al.,* 2017; Oyewole *et al*., 2022; Ajao *et al*., 2023).

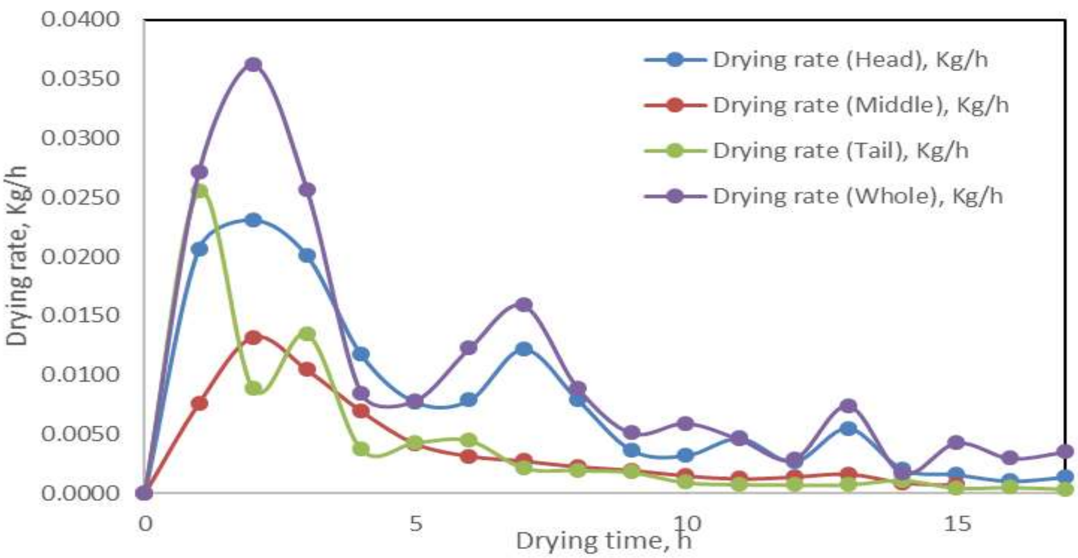
Table 4. Drying rate of the different parts of catfish smoke-dried in the kilns independently powered with charcoal and gas

		Drying rate (kg/h)		
Sample ID	**Head**	**Middle**	**Tail**	**Whole**
Charcoal	0.0084±0.0074[b]	0.0048±0.0029[a]	0.0044±0.0032[a]	0.0147±0.0104[c]
Gas	0.0081±0.0072[b]	0.0040±0.0037[a]	0.0042±0.0013[a]	0.0106±0.0100[c]

Values are expressed as mean ± standard deviation of triplicate determination. Means with the same letters along the same row are not significantly different ($p<0.05$)



a



b

Figure 4a: Drying rate of fish smoke-dried in the kiln powered with charcoal

b: Drying rate of fish smoke-dried in the kiln powered with gas

Drying Kinetics and Model fitting

The experimental data for all samples showing the moisture ratio variations and drying time at all conditions and dried using both charcoal and gas respectively are represented in Figures 5 – 6. The experimental moisture ratio was fitted accordingly into Newton, Modified Page, Two-term models and Wang models (Figures 7 – 8). The models were evaluated and compared using statistical tools and the results are shown in Tables 5 and 6. Results indicate that fish samples behaved differently, perhaps peculiar to their cuts. For whole fish dried with charcoal, Newton and Modified page models gave the best prediction while for fish parts (Head, Middle, and Tail) dried with charcoal, Two-term model gave the best prediction. Furthermore, for whole fish, middle and tail cuts dried using gas powered kiln, Two-term model gave the best prediction, while Newton and Modified page models gave the best prediction for head-cut dried under the same condition. Irrespective of the source of energy used to dried the middle and tail parts, the Two-Term model gave the best description of the drying behaviour of the two fish parts. This is an indication that the two fish parts reacted to heat treatment via drying process the same way, and this is evident in the results of the drying rates of the two parts that show no significance difference in their mean. However, the whole fish and head part behaved differently under the two conditions of energy sources. Despite this, head dried in the kiln powered with charcoal and whole fish dried in the kiln powered with gas were best predicted by the Two-Term model, and this shows that they equally reacted to drying process in the kiln the same manner the middle and tail parts did. On the contrary, the whole fish dried in charcoal powered kiln behaved the same way the head dried in the gas powered kiln did with Newton and Modified page models being their best predictive models.

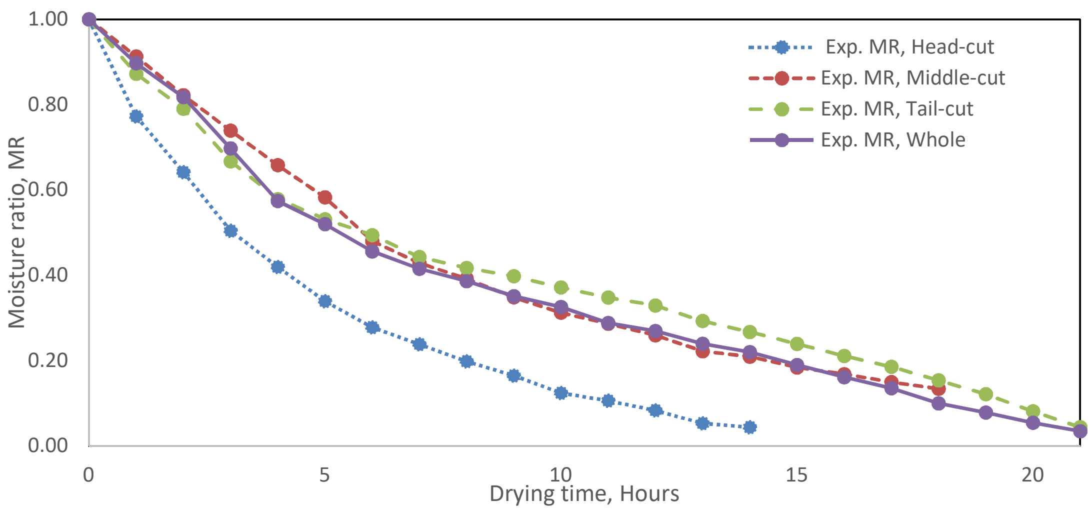


Fig. 5. Experimental moisture ratio curve for different fish parts dried with charcoal

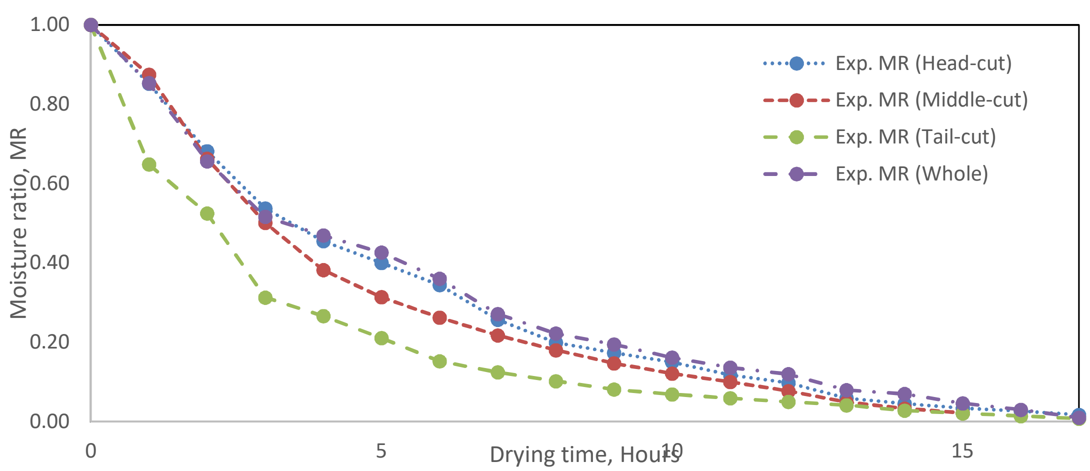


Fig. 6. Experimental moisture ratio curve for different fish parts dried with gas

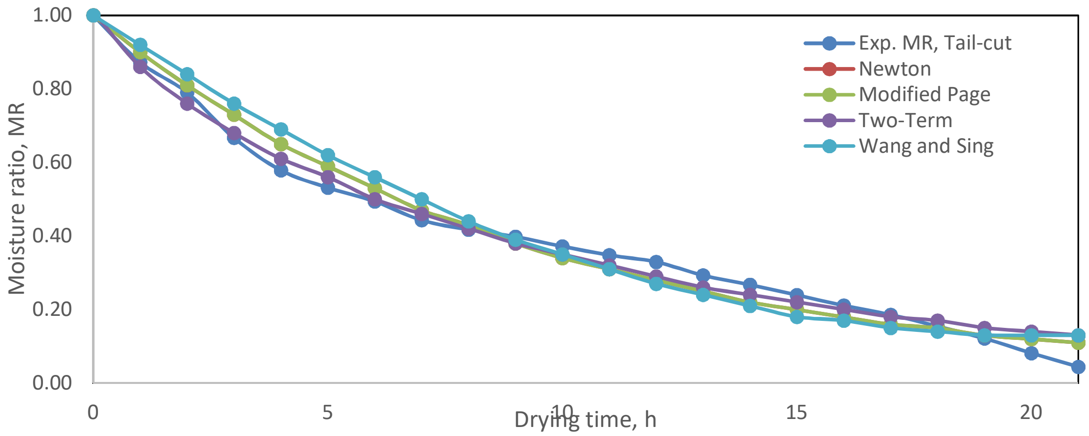


Fig. 7a. Drying curve of Dried Whole Catfish (Kiln powered with charcoal)

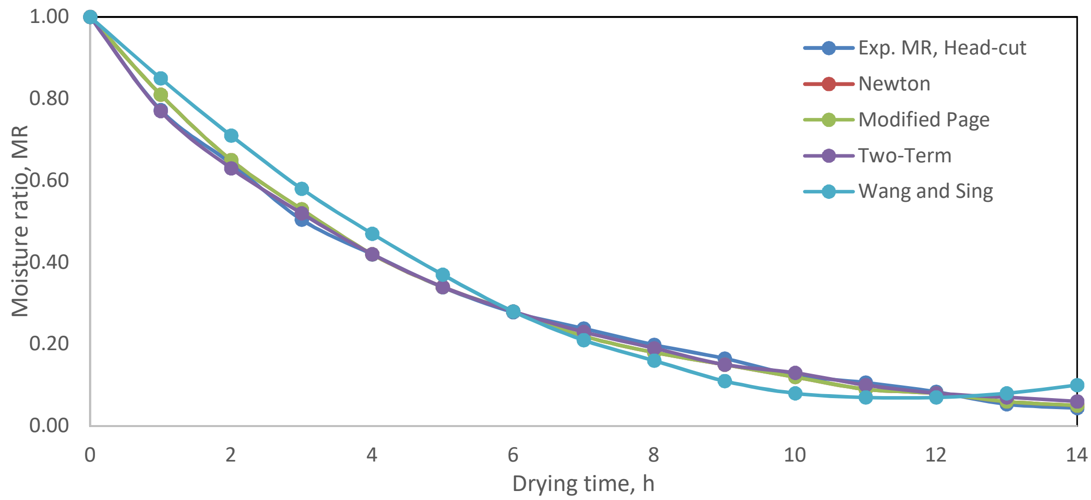


Fig. 7b. Drying curve of Dried Head-cut Catfish (Kiln powered with charcoal)

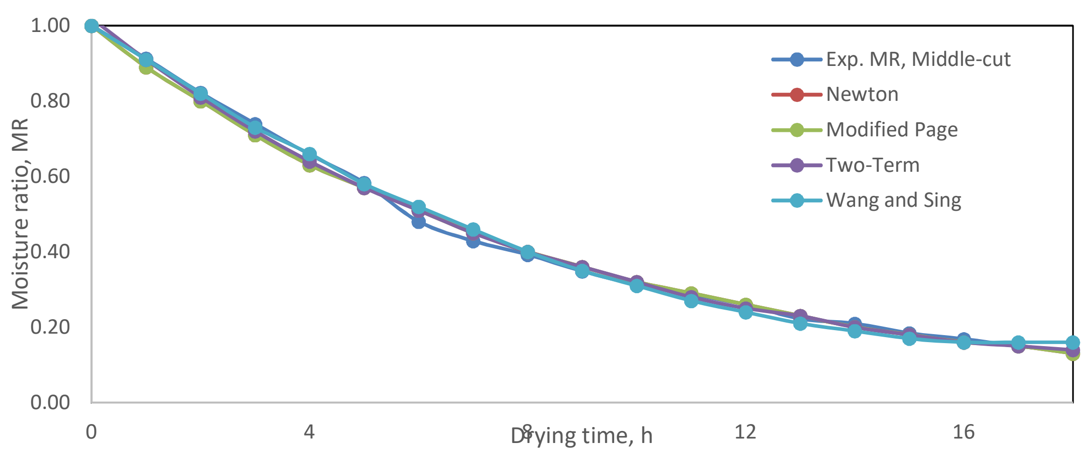


Fig. 7c. Drying curve of Dried Middle-cut Catfish (Kiln powered with charcoal)

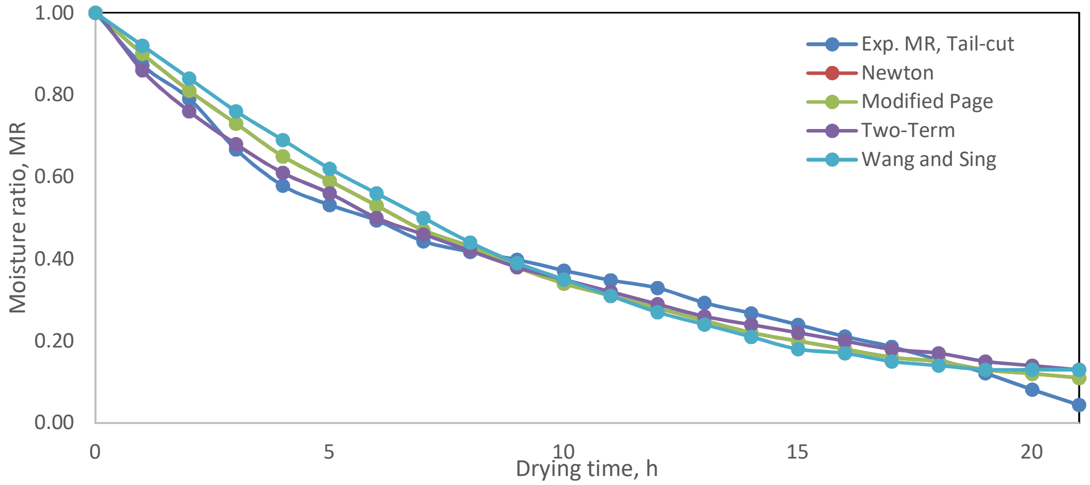


Fig. 7d. Drying curve of Dried Tail-cut Catfish (Kiln powered with charcoal)

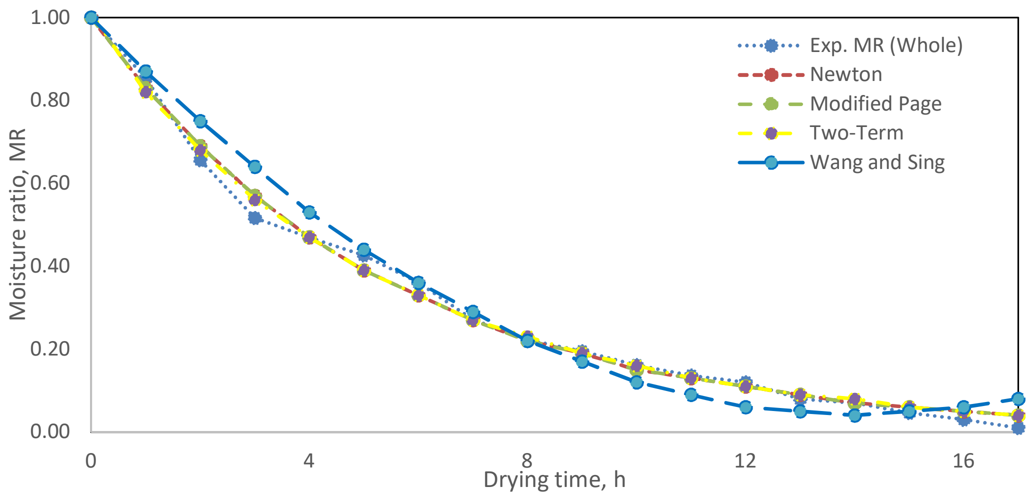


Fig. 8a. Drying curve of Dried Whole Catfish (Kiln powered with gas)

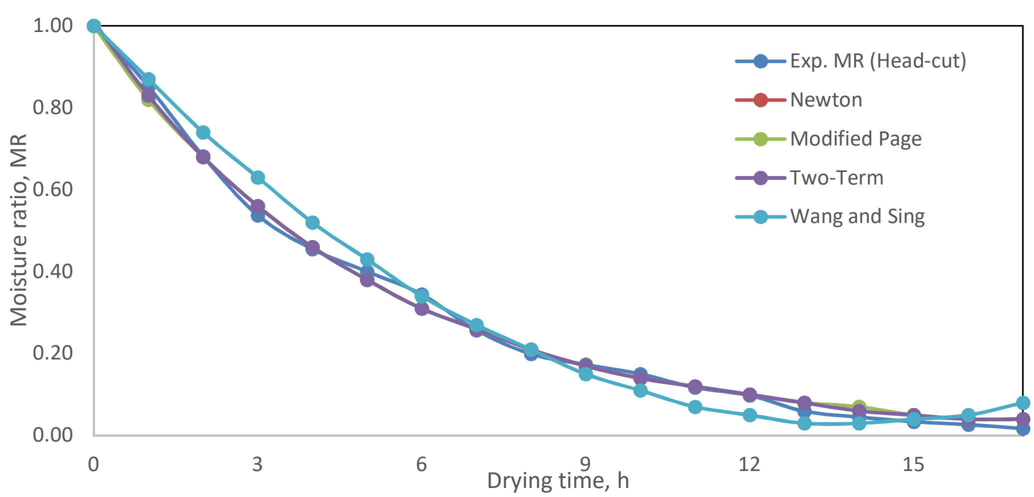


Fig. 8b. Drying curve of Dried Head-cut Catfish (Kiln powered with gas)

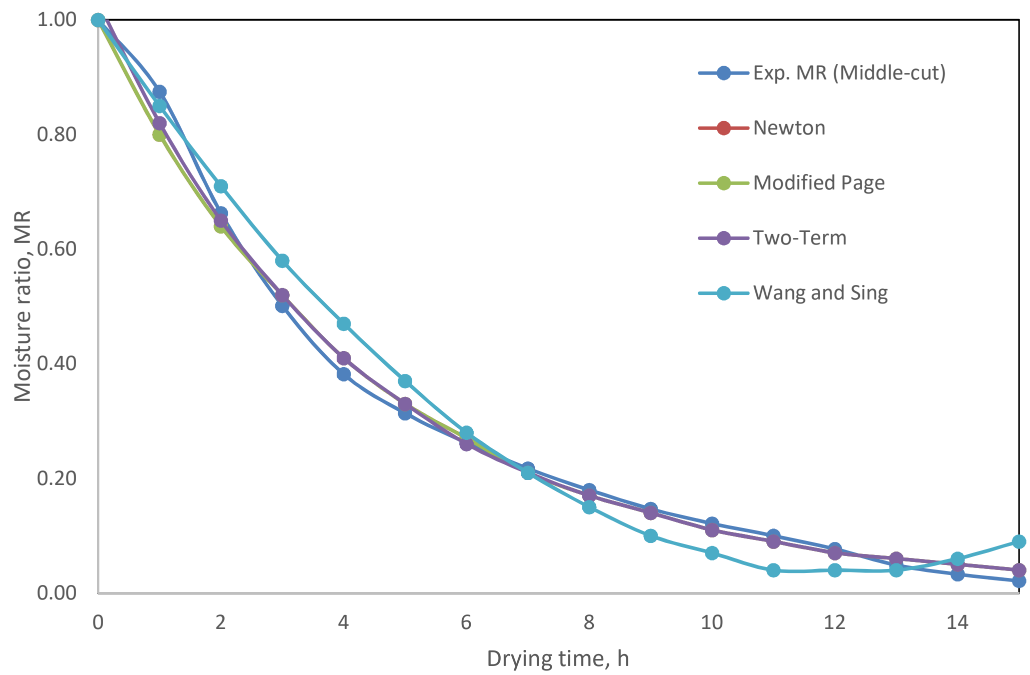


Fig. 8c. Drying curve of Dried Middle-cut Catfish (Kiln powered with gas)

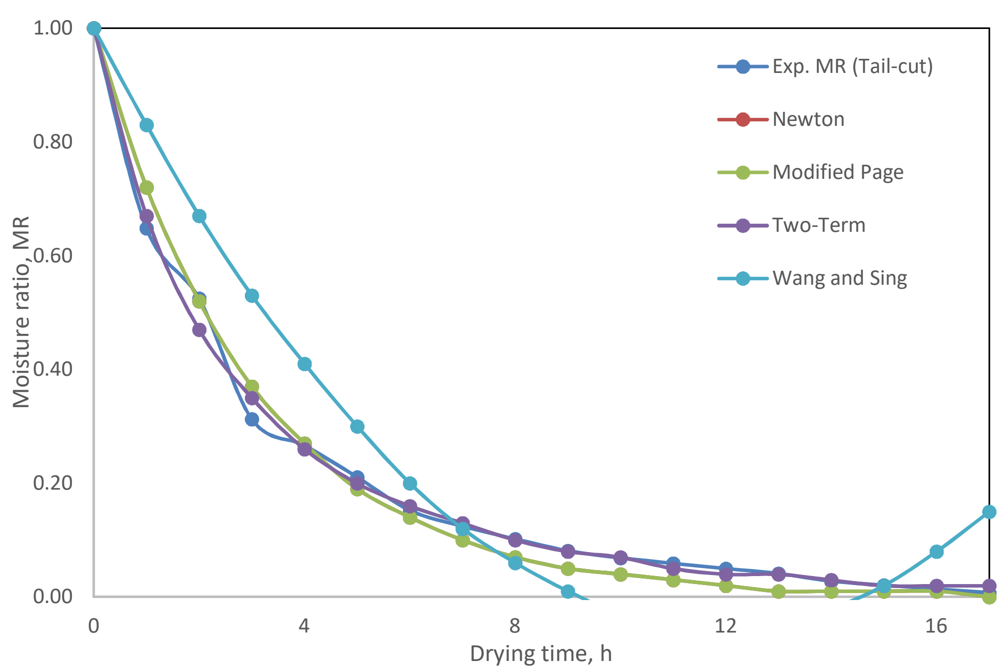


Fig. 8d. Drying curve of Dried Tail-cut Catfish (Kiln powered with gas)

Table 5. Estimated parameters and statistical criteria for models used for smoke-drying of catfish samples in the kilns powered with charcoal

Catfish sample	Estimated parameters and statistical criteria	Models Newton	Modified Page	Two-Term	Wang and Sing
Whole	a			0.052	0.093
	k	0.119	0.185		
	n		0.645		
	k_0			0.479	
	b			0.961	0.002
	k_1			0.115	
	RMSE	0.0250	0.0250	0.0257	0.0446
	R_2	0.9916	0.9916	0.9912	0.9782
Head	a			0.057	-0.160
	k	0.214	0.178		
	n		1.203		
	k_0			23.844	
	b			0.943	0.007
	k_1			0.201	
	RMSE	0.0151	0.0151	0.0096	0.0022
	R_2	0.9979	0.9979	0.9988	0.9823
Middle	a			0.0001	-0.097
	k	0.114	2.225		
	n		0.051		
	k_0			-0.229	
	b			1.021	0.003
	k_1			0.118	
	RMSE	0.0157	0.0157	0.0130	0.0162
	R_2	0.9971	0.9971	0.9975	0.9964
Tail	a			0.877	-0.807
	k	0.107	2.004		
	n		0.053		
	k_0			0.937	
	b			0.129	0.002

	k_1			0.690	
	RMSE	0.0394	0.0394	0.0398	0.1150
	R_2	0.9797	0.9797	0.9851	0.9652

Table 6: Estimated parameters and statistical criteria for models used for smoke-drying of catfish samples in the kilns powered with gas

		Models			
Catfish sample	Estimated parameters and statistical criteria	Newton	Modified Page	Two-Term	Wang and Sing
Whole	a			0.033	-0.135
	k	0.187	0.877	1.022	
	n		0.213		
	k_0				
	b			0.973	0.005
	k_1			0.182	
	RMSE	0.0220	0.0220	0.0209	0.0496
	R^2	0.9940	0.9940	0.9947	0.9779
Head	a			0.164	-0.139
	k	0.194	3.095		
	n		0.063		
	k_0			0.196	
	b				0.005
	k_1			0.196	
	RMSE	0.0174	0.0174	0.0160	0.0408
	R^2	0.9979	0.9979	0.9973	0.9856
Middle	a			0.793	-0.159
	k	0.221	2.067		
	n		0.085		
	k_0			0.249	
	b			0.236	0.007
	k_1			0.170	
	RMSE	0.0224	0.0224	0.0204	0.0478
	R^2	0.9946	0.9946	0.9952	0.9771
Tail	a			0.506	-0.178

k	0.330	4.846		
n		0.068		
k_0			0.616	
b			0.490	0.008
k_1			0.202	
RMSE	0.0295	0.0295	0.0175	0.1065
R^2	0.9926	0.9926	0.9955	0.9111

Conclusion

This study has successfully demonstrated the NSPRI smoking kiln's effectiveness in drying and preserving catfish quality. The drying rates varied notably among different parts of the fish, with whole fish exhibiting the fastest drying rate compared to the head, middle, and tail sections. The variation in drying rates highlights the impact of sample size, part and thickness on the efficiency of the drying process. The observation that drying predominantly occurred in the falling rate period indicates that diffusion was the main mechanism driving moisture removal. The drying kinetics of fish samples and evaluation of model performance were characterized by high coefficient of determination (R_2) and low Root Mean Square Error (RMSE) values. In all, Two-term model gave the best prediction with exemption of whole fish and head part dried in charcoal powered kiln and gas- powered kiln respectively, that Newton and Modified page models performed better in predicting their drying behaviour. This finding confirms the suitability of the models for predicting the drying behaviour of catfish using the NSPRI smoking kiln.

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Micro-Grids Development: The Solution to Nigeria Energy Problem

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Abstract

Electrical energy is fundamental for socio-economic development, global communication and poverty reduction. According to world energy council (WEC 2021), it was reported that 44% of Nigerians lack access to the national grid because of various issues, thus firewood and diesel generator (DG) are used and results in rising cost and environmental degradation. However, an alternative means of producing electricity across Nigeria becomes crucial and hence, the use of micro-generation referred to as micro-grid (MG) has been proposed. This technology has been developed for many years and proved to be reliable, efficient and secured approach in power system. This paper explains the potential utilization of micro-grid to solve the problem of energy system in Nigeria, most especially for rural dwellers that are remote form the utility grid. The potential of solar PV and wind in many cities in Nigeria is investigated. Epileptic power supply is the order of the day in Nigeria, despite the potential of fossil fuels and other conventional sources. Electricity access in Nigeria is estimated as 60% of which 55% lives in the urban areas. The prospect of MG is presented in this paper as a solution to energy challenges in Nigeria.

Keywords: Renewable Energy, Micro-Grids, Sustainable Development, Energy Management System

1. Introduction:

Electricity generation throughout the world using fossil fuel has three main challenges, availability, fuel costs and greenhouse gas emission (GHS) which degrades the environment by depleting the ozone layer. To sustain the environment, there is a need to embark on power generation techniques that would be environmental friendly as well as meeting the load demand. Orovwode, (2014) employed non convectional and renewable energy source (RES) at distribution voltage level. Individual generations do not benefit from the economies of scale offered by a central generating scheme. The expectations of the researchers on the use of renewable energy sources to take over from fossil fuel are not realizable, as energy fuel like bio-fuels have proved to be uneconomical (Pimentel & Patzek, 2008). Furthermore, technologies like fuel cells and hydrogen energy have not been widely applied (they are still in research labs) and are not anticipated to have a significant influence on the energy landscape for some time (Orovwode, 2014). To utilize available resources efficiently, all power generations which run on fossil fuel need to be pulled together to form a MG. Micro-grids are small-scale energy systems that can function independently or in tandem with the larger grid. They frequently incorporate renewable energy sources (RES) including solar power, wind power, and energy storage devices.

They have potential to improve resilience, sustainability and energy security in areas with unreliable power supply. It is a self-sufficient energy system that serves a specific area such as a neighbourhood, a campus, a business district or rural community. By using this strategy, power plants will operate for shorter periods of time, last longer, use less fuel, and emit less greenhouse gases.

2. Micro-grid Concept

A micro-grid (MG) is a small power system with low voltage that is connected to a distribution grid via a point of common connection. It is made up of interconnected load and energy storage sources as well as distributed energy resources (DERs) like solar photovoltaic (PV), wind turbines, fuel cells, among others. Oladejo (2019) used cooperative game theory to study MG's energy management. It can function in two modes: islanded (when not linked to the main grid) or grid-connected (when connected to the main grid). Its use of low-carbon sources and potential for application in remote local environments are advantages. These include the potential to postpone the need for transmission facilities and the accompanying expenses.

Figure 1 displays the distribution energy resources (DERs), which include conventional and renewable energy sources, smart homes, and energy storage systems. Through a point of common coupling (PCC), MG is connected to the main grid. The voltage at the micro-grid's point of common coupling is determined by the main grid. (Zia, *et al*., 2018; Wang, *et al.,* 2023; Devi, *et al*., 2023). Each DER needs to have the power electronic interface (PEI) in both the grid-connected and islanded mode in order to achieve the appropriate control, protection, and metering with plug-and-play features. There is energy trading with the electric grid when in grid-connected mode. Nonetheless, the micro-grid can be isolated and function independently to manage its own resources to improve system stability when upstream problems arise in the main grid. In this instance, load shedding, demand response, and integration of the distribution energy resources can all be used to protect the critical loads (Zia, *et al*., 2018). (Li, & Nejabatkham, 2014). The local controllers (LCs) and the micro-grid central controller (MGCC) work together as a mediator to oversee and manage the micro-grid's overall operations. System performance and the micro-grid's sustainable development are improved by efficient DER management and coordination (Zia, *et al.,* 2018).

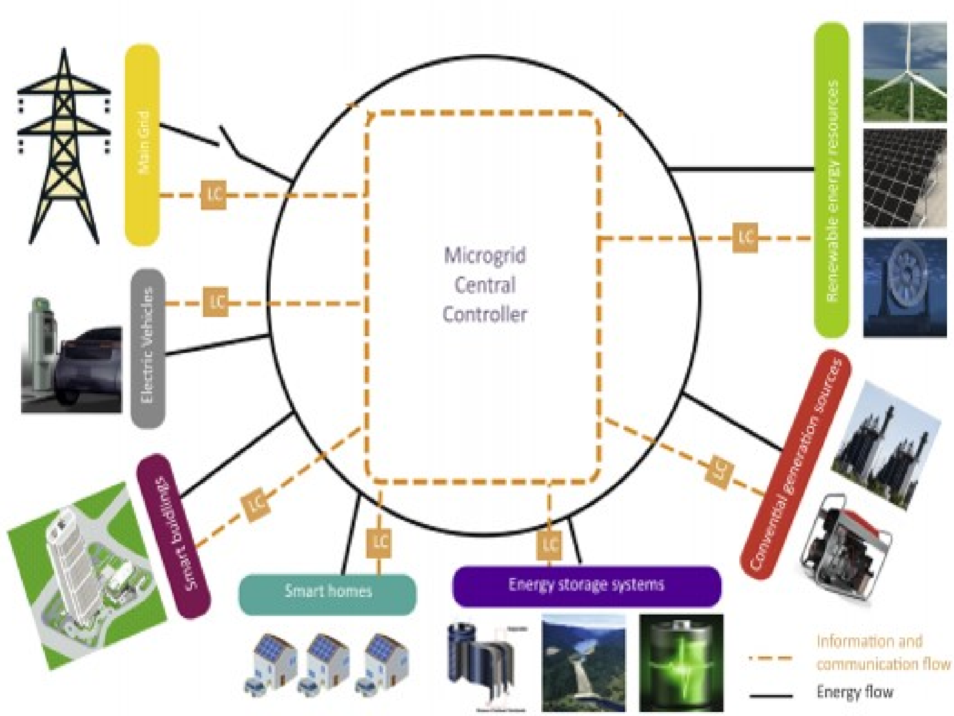


Figure 1: Micro-grid Architecture (Zia, *et al.,* 2018).

Micro-grids, which comprise DERs like solar PV, wind turbines, diesel generators, etc., and energy systems that use local heat waste like biomass, co-generation plants, etc., were introduced as a result of greenhouse gas emissions from conventional energy resources, increased awareness of climate change, and the need to preserve the environment (Li, *et al.,* 2016; Oladejo, *et al*., 2024). In this instance, the MG energy management system (MG EMS), which is accomplished by this energy system's optimization, handles the decision-making processes. The distinction between the MG and the traditional main grid was emphasized in Table 1. In order to promote sustainable development, it is important to take into account techniques that lower power consumption, improve system reliability, minimize losses, mitigate greenhouse gas emissions, and expand the energy system.

3. Micro-grid Energy Management

Energy management, according to (IEAC, 2005), is the use of computers to make sure that costs are kept to a minimum or profits are increased while maintaining a sufficient level of energy supply security. To guarantee that the facilities for electrical generation and transmission are run efficiently, it uses a software platform that offers some functional applications in addition to basic support services. By guaranteeing that the generation, load,

Table 1: Difference between the conventional grid and micro-grid

S/N	Micro-grid	Conventional utility grid
1	Localized power generation and distribution	Centralized power generation and distribution
2	Can operate in isolation (island mode) or grid-connected mode	Transmission and substations for long distance energy transport.
3	Typically serve a small-defined area (campus, community or building)	Serve a large wide-spread area (cities, regions)
4	Often incorporates renewable energy sources (solar, wind)	Typically reliant on fossil fuels and large power plants
5	Response to emergency is very fast	Emergency response is slow
6	Energy storage systems (batteries) for reliability and resilience.	Limited energy storage capability
7	Can provide backup power during outages	More vulnerability to widespread power outages
8	Make use of bi-directional communication in real time	Make use of uni-directional communication
9	Many sensors and monitors are incorporated	Limited number of sensors are incorporated
10	Volumes of data involved are very large	Limited data in used
11	Protection is quite adaptive	Disruptions of the system required human attention
12	Recovery and control are automatic	Recovery and control are manual
13	Control system is quite extensive	Control system is quite limited

and storage units receive an optimal decision, the energy management system (EMS) decision-making is effectively implemented through the use of modules of load forecasting, DERs, human-machine interface (HMI), supervisory control and data acquisition (SCADA), among others. (Chen, *et al.,* 2011). The analysis, tracking, and forecasting of DER generated electricity, energy market prices, and other tasks are among the MG EMS services that support optimization and the fulfillment of relevant restrictions.

There are two types of micro-grid EMS control architectures: decentralized energy management and centralized energy management. In centralized EMS, data related to weather, cost functions, the generated power of distributed energy resources (DERs), and customer demand profiles are gathered and transmitted to the micro-grid central controller (MGCC). After that, the best way to schedule electricity in the micro-grid is decided, and all local controllers (LCs) are informed of the outcome. In contrast, the MGCC transmits and receives all information in real time to and from each local controller in the decentralized energy management system. Each LC processes the generation schedule, future demand, and current demand before sending it to the MGCC. The MGCC then determines the best energy scheduling and returns the information to the LC. There might be a difference of opinion about how the two are currently operating, so they bargain until an equilibrium is formed and the global goals are met. Unit-commitment and traditional economic dispatch are being replaced by micro-grid EMS with the emergence of DERs such as solar PV, wind turbines, and storage sources. The control of the stochastic character of renewable energy sources, loss minimization and outages, scheduling of loads and distributed energy resources (DERs), and the economical and dependable operation of micro-grids are further methods carried out by the micro-grid EMS.

4. Benefits of Micro-grids

The benefits accrued while utilizing MGs are:

(i) Power quality improvement: Frequency and voltage quality are at its best when implementing the MG. At this point there must be availability of DERs and energy storage system.

(ii) Reliability: The system is reliable when using MG. The utility grid power blackout can be eliminated in case of an upstream fault because of energy storage and availability of local generation (Soyoye & Ayinla, 2016). Redundancy would be created because of different available sources of electricity.

(iii) Demand response: One method for controlling energy use at the load sides is demand response. Because the system is managed as a single entity in MGs, this method is simpler to apply.

(iv) Integrate renewable energy sources: It might be difficult to directly integrate renewable energy sources into the utility grid system because of their variability. An electrical barrier, or point of common coupling, exists between MG and the utility grid, allowing for the integration of renewable energy sources for the generation of power.

(v) Saving money: MG makes this feasible for power system operation and initial installation.The saving is gotten because of elimination of transmission and distribution infrastructures that represent cost saving in an installation. When using renewable energy sources in MG, fuel cost is totally eliminated.

(vi) Energy arbitrage: If MG has excess energy, the utility grid can buy it from MG at a price greater than what it would cost to get the electricity.

(vii) Efficiency: Localized energy production minimizes energy losses that occur during long distance transmission and improves overall system efficiency.

(viii) Environmental sustainability: MG often incorporate RES, reducing GHG emission and contributing to a cleaner energy future.

5. Challenges in Micro-Grids Development in Nigeria

The following are the challenges accumulated while utilizing MGs:

(i) High initial cost: Initially development and installation can be expensive particularly for integrating renewable energy (RE) and storage technologies.

(ii) Regulatory barriers: Regulatory frameworks are still evolving to accommodate MGs and there can be legal and policy in their implementation.

(iii) Technical complexity: Designing, controlling and maintenance can be technically challenging when multiple energy sources and storage are integrating together.

6. Potentials of Micro-Grids in Nigeria

Micro-grids hold significant potential for addressing Nigerians energy challenges. The country faces critical issues such as unreliable power supply, insufficient grid coverage and a growing energy demand driven by rapid population growth and industrialization. In Nigeria, MGs may be a crucial, affordable, and ecologically friendly way to increase energy access, dependability, and sustainability. According to historical records, there are numerous advantages that this kind of micro-generation possesses over large-scale generations. For instance, transmission of power over vast distances in large-scale generation results in losses along the line, which can be avoided in micro-generation .Some of the potentials of MG are describe below.

6.1 Diesel Generator

The diesel generator is one of the contemporary energy sources that shows to be reliable and adaptable in supplying energy to the rural community. The diesel generator shows itself to be dependable and consistent. When it comes to delivering the essential backup generator for homes, businesses, and schools, it is incredibly effective. Diesel generators are particularly popular because of their high power-to-weight ratio and great reliability (Arun, 2008; Heinz, 2014). According to Barretts and Fathoni (1991), diesel generator fuel is very common and has a high weight and volumetric, meaning it may be found in quite big quantities. When used for off-grid electrification in rural areas, it has certain disadvantages, too, as it might be very costly or difficult to get. Because it is difficult to transmit energy to remote locations, the cost may be considerable. Maintenance could be difficult if there is a shortage of diesel generator spare parts.

6.2 Hydro-power

All hydroelectricity schemes below 30 MW are classified as small hydro, mini below 1 MW, micro below 100 kW, and pico below 7 kW by the renewable energy master plan (Wikipedia, 2018). About 40% of Nigeria's total electricity supply comes from hydro-power (WEO, 1999), and as more hydro-power projects are put into service, that percentage will rise. Nigeria's principal rivers and waterfalls have a substantial amount of hydroelectric potential. The numerous river flows in Nigeria, especially the Niger, Benue, and Kuna rivers, as well as numerous smaller ones in the states of Ogun, Osun, and Oji, offer some opportunities for the investigation of small-scale hydropower projects in the different states of the country.

6.3 Solar Photovoltaic (PV*)*

With almost endless potential, solar energy is the most promising renewable energy source. Around 3.8 x 1023 kW of energy are emitted by the sun every second. One renewable energy source with a high rate of development is solar photovoltaic. Even while installed solar PV has a somewhat lower global capacity than wind power (roughly 50%), its growth is outpacing that of wind power (Wikipedia, 2018), Based on available statistics (Adewuyi *et al.,* 2020), the estimated capacity of solar power in Nigeria is approximately 43,000MW, of which only a small percentage has been put to use thus far. Figure 2 shows the distribution of energy resources and socio-economic zones on a map of Nigeria. The Federal Government of Nigeria made a 20 billion US dollar investment in solar projects in 2017, while Kaduna state's privately held 30 MW solar farm project is currently undergoing planning (Ayemba, 2017).

6.4 Wind Energy:

Wind energy is a natural phenomenon relating to air mass movement that is mostly brought on by the surface of the planet being heated differently by the sun. The strength and direction of the wind are influenced by variations in solar energy received throughout the year. The simplicity with which aero turbines convert air movement energy into rotary mechanical energy raises the possibility of converting wind energy into electricity through electrical devices. For many years, grain mills and water pumps have both been powered by wind energy.

6.5 Biomass Electricity:

Photosynthesis, the process by which green plants transform sunlight into plant material, is the source of biomass energy. The most common method for generating thermal and electrical energy from boilers powered by biomass is called biomass co-generation. Involvement of bio-energy based renewable in the fuel mix is a good indication of progress and strategy for attaining sustainable energy development. Energy from biomass can be used for various purposes such as cooking, heating and generating electricity.

Other untapped energy resources include hydro (small and large), fuel-wood, coal and ignite, and waste from bio-agricultural output. Table 2 also demonstrates the under-utilization of several of these energy resources near the Nigerian border. Therefore, adding these energy sources to MG is advantageous. A sufficient infrastructure for the reliable provision of power is lacking in many developing nations. Therefore, the MG can be added to these countries' electric power systems without requiring the removal of already-existing infrastructure.

7. Nigeria and Sub-Saharan Africa's energy poverty and demand for energy justice

In Sub-Saharan Africa, energy poverty is quite high, this is because of low income level and high cost of modern energy technology (Adewuyi, et al., 2020). In 2017, approximately 1.1billion of people all over the world were living with no access to clean energy. The worst- case scenario is sub-Saharan Africa, in which only one in every individuals are connected directly to clean and affordable form of energy. Small population experiences unreliable services, which short-change their daily energy, which are connected to the grid (Lee & Callaway, 2018), (Adewuyi, et al., 2020). In 2014, Sub-Saharan Africa with a population of about 860million residents, minus South Africa, has a total energy quoted to be 28 gigawatts (Adewuyi, et al., 2020).

Energy poverty analysis is surrounded by a number of factors, including the degree of mass illiteracy and the socioeconomic position of the populace. In this instance, given the significant differences in per capita energy availability that now exist worldwide, it is necessary to design energy policies that would solve a nation's energy-related issues. The average electricity per person in Sub-Saharan Africa is roughly 36.6 watts per hour per person. In contrast to what is happening in other regions of the world, as seen in Figure 3, this illustrates the extreme instance of energy poverty (CAs, 2018). Most houses and businesses in sub-Saharan Africa use tiny diesel or gasoline generators for their private energy generation due to the region's lack of social infrastructure and energy imbalance. The immediate environment and public health are negatively impacted by this (Avila, *et al.,* 2017).

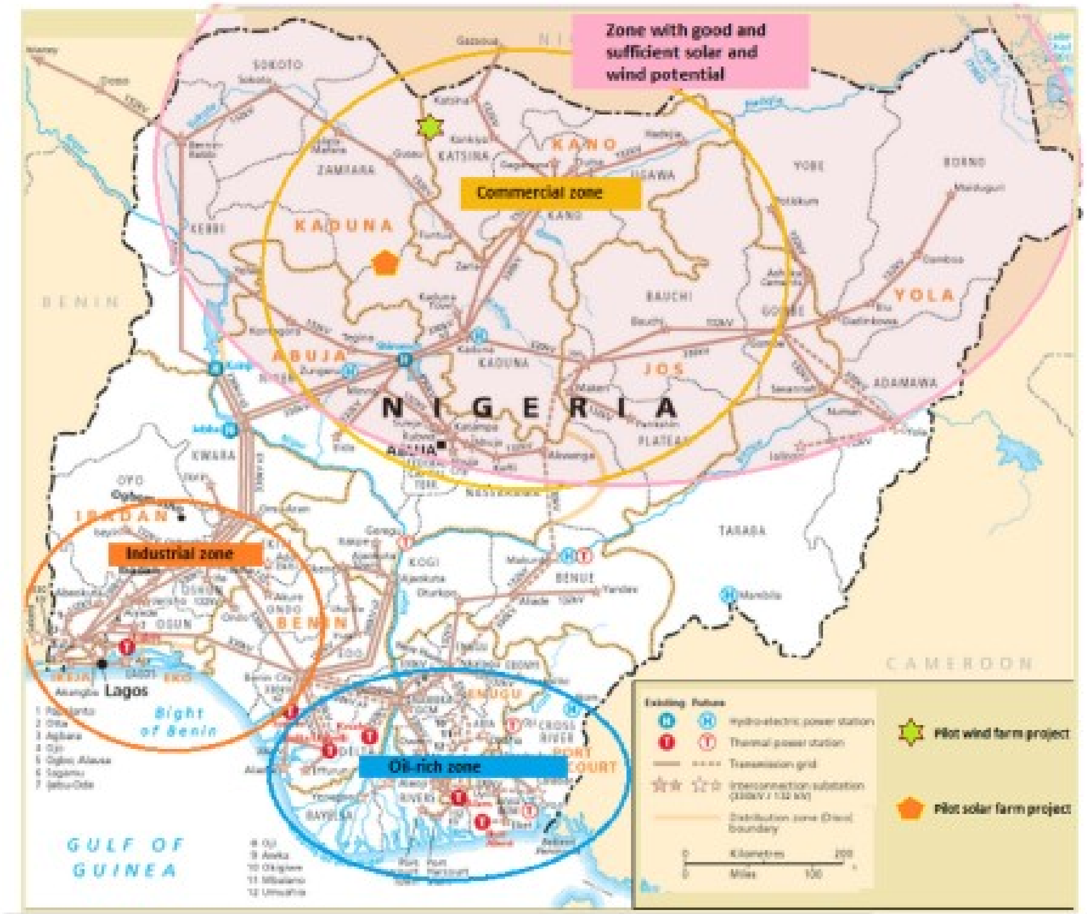
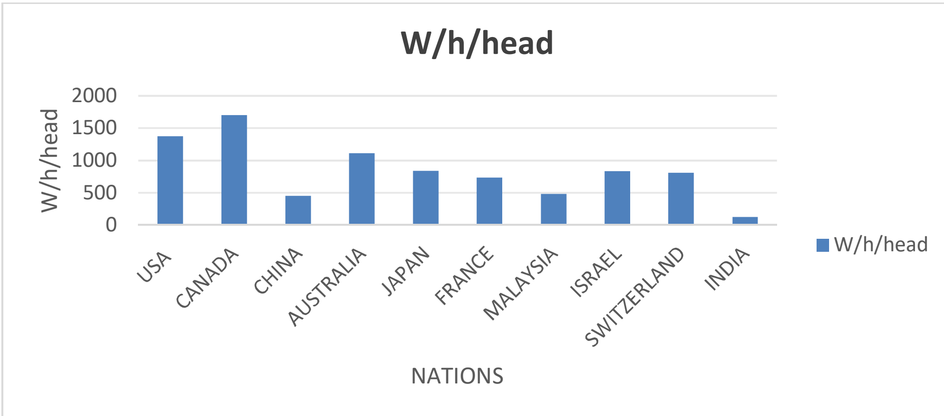


Figure 2: Nigerian Map Showing Socio-economic Zones and the Distribution of Energy Resources (Adewuyi, *et al.*, 2020)

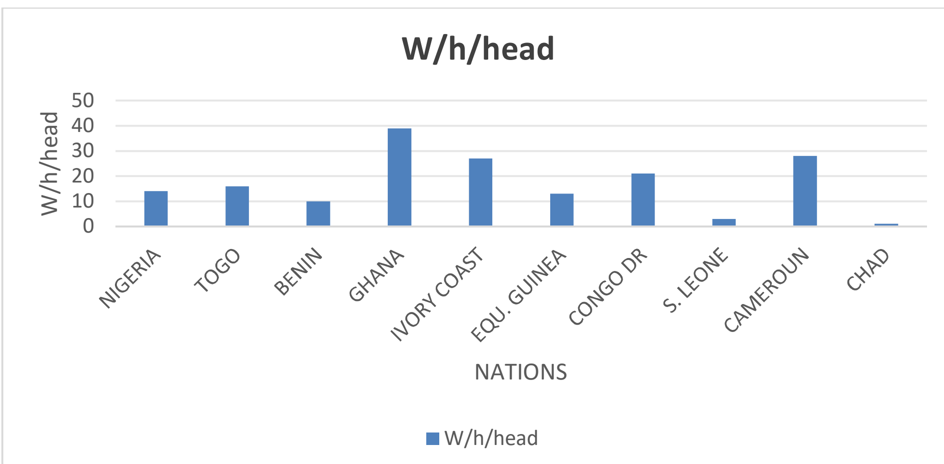
Table 2: Nigerian Energy Resources (Adewuyi, *et al.*, 2020)

Resources	**Quantification**	**Utilization characterization**
Wind	2.0-4.0 m/s at 10m height	Negligible utilization
Solar	3.5-7.0 kWh/m_2/day	27% capacity factor; negligible utilization
Small Hydro	3,500 MW	64 MW (2% utilized)
Large Hydro	11,250 MW	1938MW (17% utilized)
Crude oil	37.062 billion barrels	22% utilization of refineries
Natural gas	182.3 trillion standard cubic foot	18% indiscriminately flared
Tar sands	31 billion barrels of oil equivalent	Negligible usage
Coal and Ignite	2.7 billion tonnes	7% contribution to net GDP
Municipal waste	30 million tonnes/year	0.5kg/capita/day
Biomass (Fuel wood)	11 million hectares of forest	43.4 million tonnes/yr of consumption
Energy crop	28.2 million hectares of arable land	8.5% cultivated
Animal waste	1.05 tonnes/day	Negligible utilization
Agriculture residues	91.4 million tonnes/yr. produced	Negligible utilization

Globally, policies are being developed to facilitate the penetration of affordable and sustainable alternative energy sources, hence promoting a diverse energy mix. Meeting Nigeria's enormous energy shortfall and that of the entire Sub-Saharan area, however, is difficult (Adewuyi, et al., 2020), (CAs, 2018).



(a) Developed Nations



(b) Developing Nations

Figure 3: Power per capital average for a few chosen (a) developed and (b) developing nations (CAs, 2018)

8. Conclusion

The need to provide affordable energy services to Nigerians, in a sustainable manner, should be treated as a national priority. While there are several doable steps that may be taken to accomplish energy development that is sustainable, the creation of MG is the most important. The chosen energy source of the present and the future is micro-grid. It works, and has been used worldwide both in developing and developed countries.

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Use of vacuum pressure to accelerate anaerobic digestion of lignocellulose materials

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Abstract

Cattail is a lignocellulose plant in nature with an abundance of cellulose, hemicelluloses, and lignin. These fiber portions limit their potential in anaerobic digestion. However, the stability of anaerobic digestions system and processes to generate gas depends on the substrate characteristic, its degradation efficiency, and anaerobic conditions. Although various methods have been explored to digest lignocellulose material under different conditions and pre-treatment the configuration of anaerobic digester may have more influence in gas generation than other controlling factors. The study evaluates correlations between built-in pressure and gas volume produced in anaerobic conversion of lignocellulose material. Two factors considered were anaerobic digestions in vacuum and non-vacuum. Each factor was replicated five times. Higher digestion efficiency was observed in a vacuum system while non-vacuum indicates lower efficiency. The maximum gas volume was obtained in a system operate under vacuum with the highest volume of 186 ml/g. Non-vacuum produces the lowest gas volume 17 ml/g for the same quantity of biomass and hydraulic retention time. It was also observed there are strong correlations between build-in pressured and gas volume generated. Therefore, this technology will be served as a method of digestion lignocellulose material and enhance gas generation.

Keywords: Vacuum pressure, Anaerobic digestion, Lignocellulose, Biomass;

1. Introduction

Energy demands are a critical reason for extensive climate change, resource exploitation, and also restrict the living standard of humans (Li et al., 2007 and Li et al., 2009). Many of the rural communities in developing countries are forced to rely on traditional energy such as firewood, cow dung, and crop residue, among others. These traditional methods have consequences negative effects on the environment, health, and some time on agricultural productivity. In Nigeria, women and children spend many hours in the bush collecting firewood for cooking. These activities prevent some of the children from going to school and increase the number of children out of school in the country. Cooking accounts for 90% of energy consumptions in the household of most developing countries (Regendran et al., 2012), and access to electricity in rural areas is relatively scarce (Luijten et al., 2011). However, anaerobic digesters help to manage different waste, crop residues, grasses, and many other biomaterials to produce clean energy that can be used for domestic or industrial use.

Biogas is a substitute to firewood that can meet the energy needs of the rural population (Bhattacharya et al., 2000, Xiaohua and Jingfei, 2005). Biogas is a renewable source of energy that can be used as a substitute for natural gas or liquefied petroleum gas (Martins et al., 2009). Its production can be carried out in a small or bigger reactor at a laboratory or ambient condition. Anaerobic digestion depends on several different parameters for optimum performance. Different groups of microorganisms are involved in methane production and suitable conditions have to be established to keep all the microorganisms in balance. Some of these parameters are pH, temperature, mixing, substrate, C/N ratio, hydraulic retention time (HRT), and type of the digesters. Under the conventional method, the digestion processed is slow and take sometimes for microorganisms to adapt to a new condition.

The application for rural and urban biogas production is widely spread. It is a challenge for engineers and scientists to build an efficient digester with the material available at the same time taking the local and economical consideration into account. Although many digesters have been built with different configurations such as Chinese, Indian, and bags types however, there is still needs for improvement of these digesters to digest a wide variety of lignocelluloses materials. Most of the previous researches were tailor toward increasing digestion efficiency using various pretreatment and inclusion of cellulose-degrading microorganism. This research explored the use of vacuum pressure to improve the digestion efficiency of lignocellulose materials.

2. Materials and Methods

2.1 Sample collections

Typha grass was obtained from a biological pond experimental field at the University of Maryland United States. The mature plant was considered and harvested at dry matter content (DM) of 16%. The plant was chopped with a shredder, sundry, and milled with Wiley milling machine to 1 mm particles.

Plate 1: Harvested typha samples

2.2 Experimental Method

2.2.1 Experimental factors and treatment

The experiment was evaluated with a single factor vacuum and non-vacuum system. A total of ten (10) treatments were considered. Each system was replicated five times.

2.2.2 Data analysis

Data generated were analyzed using simple descriptive statistics with Microsoft excel.

2.2.3 Experimental procedures

The anaerobic digester was developed with a 20 ml glass tube and covered with a rubber stopper. The tube was perfectly sealed with film to make the system anaerobic. A working volume of 15 ml sample was prepared: 5 g of Typha biomass and 10 ml of media were mixed. After mixing the samples, carbon dioxide was used to purge the air and then, the digesters were moved to an incubator at a temperature between 35- 39 ^{o}C. Observations lasted for three weeks and volumes of gas produced from each system were measured three times a week with a 50-ml glass syringe. pH was tested with pH meter and litmus paper at certain intervals. Plate 2 and 3 shows some digesters samples

Plate 3: Vacuum system

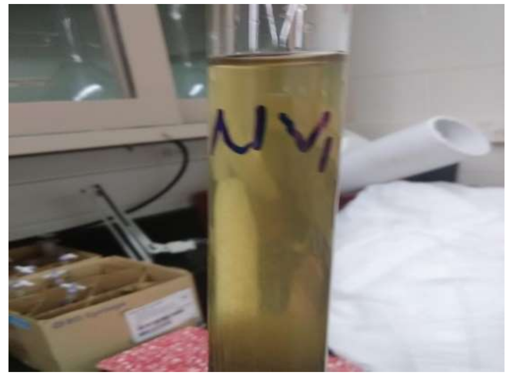

Plate 4: Non-vacuum system

3. Results and Discussion

3.1 Cumulative volume of gas generated

Figure 1 showed the mean volume of gas produced from the two systems vacuum and non-vacuum. It was observed the maximum gas production was obtained with the system operated under vacuum (181.04 ml) while the minimum volume recorded at the non-vacuum system. This may be due to the slow activity of microorganisms especially at the hydrolysis stage which causes low degradation of volatile fatty acid (VFA). This inhibits gas generation by affecting the growth and activity of microorganisms especially methanogen which is responsible for methane production. However, vacuum systems help in rapid VFA degradation. The substrate of methanogens comes from the breakdown of VFA to forms hydrogen, carbon dioxide, and acetate which are further breakdown into methane and carbon dioxide from the activity of methanogens.

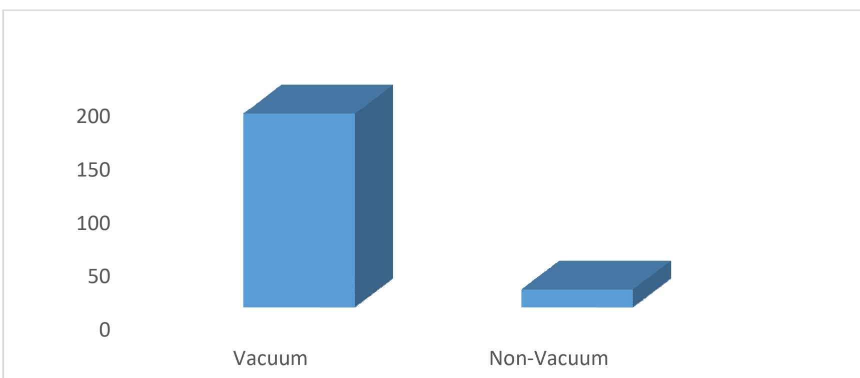

Figure 1: mean volume of gas generation

3.2 Effect of vacuum on gas production

The trend of gas generation from the two different systems indicated in Figures 2 and 3 below. The System operated under vacuum showed maximum gas productions after 20 days while non-vacuum showed its maximum second day after seeding of the digester. The possible reason for obtaining maximum gas after the second day with the non-vacuum system will be due to the media used in the system which produces higher CO_2. Furthermore, only a few hydrolyzing and fermenting microorganisms are growing due to the accumulation of VFA. Higher concentrations of VFA inhibit the growth and activities of microorganisms which in turn reduce the gas production. Gas volumes from the non-vacuum system continue to decrease from the second day after seeding to the last day of the experiment. This showed a decrease in the activity of a different group of microorganisms that are responsible for breakdown biomaterial. However, this may be the reason the vacuum system produced gas volume 3 times the non-vacuum. When the data were subjected to statistical analysis it indicates that the vacuum system is statistically significant with non-vacuum at 5% probability level table 1 showed the ANOVA.

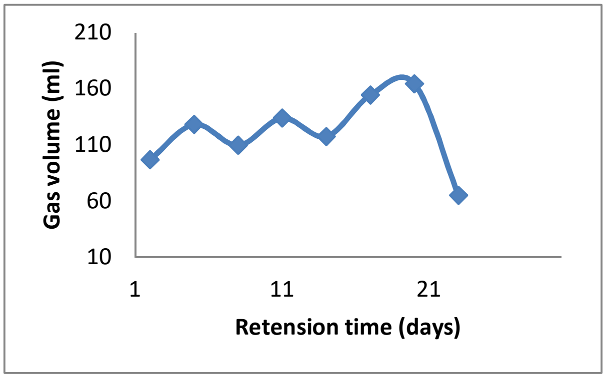

Figure 2: Gas generation with the Vacuum system

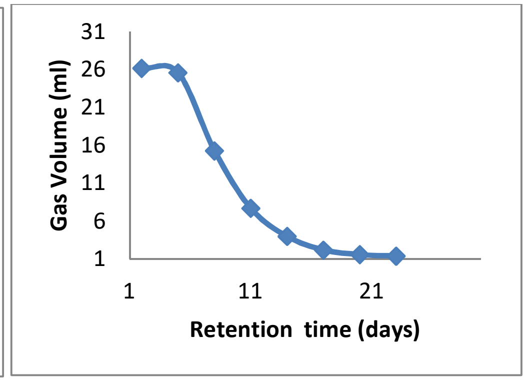

Figure 3: Gas generation with non-vacuum system

Table 1: ANOVA showing the comparison of two different systems

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F- crit.***
Vacuum X Non- Vacuum	49084.4	1	49084.4	87.22156418	2.16357×10^{-7}	4.60011
Within Groups	7878.575	14	562.7554			
Total	56962.98	15				

4. Conclusions

Correlation between build-in pressure and gas volume of batch type digesters has been investigated at laboratory conditions. The system operates with a vacuum produced a higher volume of gas compared to the non-vacuum system. Vacuum systems increased gas volume more than three times than non-vacuum. An anaerobic reactor that can be built to operate under vacuum to accelerate the digestion of lignocellulose material will be a promising technology for the enhancement of gas generation.

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Quantitative Assessment of Television White Space Spectrum Availability in Osun State, Nigeria.

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Abstract
This research aimed at the detection of Television white space for opportunistic secondary uses. Energy detection measurement approach was employed in this study. Measurements were taken at six distinct places at Osun State University, Osogbo (namely: Engineering Complex, Health sciences, Library, Auditorium, Administrative and URP building) spanning the frequency bands 470 MHz to 870 MHz using Agilent N9342C Spectrum Analyser. The number of available channels was determined and the results showed that there is 78% Television white space, equating 312 MHz TV white space (TVWS), spectrum availability. The available TVWS of 160 MHz as obtained can be used to exploit new wireless technologies in the future.

Keywords: Radio frequency, spectrum, channel, TV white space.

1. Introduction

The Radio Frequency (RF) spectrum refers to the range of radio frequencies that specify the channels that can be used for specific radio transmission systems. The radio spectrum is a portion of the electromagnetic spectrum ranging from 3 kHz to 300 GHz. Fig. 1 shows the schematic illustration of partition of radio spectrum and ranges (Mustapha *et al.*, 2015).

In wireless communication system, the radio frequency (RF) spectrum is a finite, scarce but non-exhaustible resources. The rapid growth of new wireless communication applications and services, on the other hand, is putting a lot of pressure on the utilization of these scarce spectrum resources. The spectrum or frequency band can be licensed or unlicensed. A certain amount of money is to be paid to have access to licensed band, which ensures exclusivity and the absence of interference from other wireless users. The local regulating authority is in charge of managing the radio spectrum and collecting funds from licensed band auctions. Unlicensed bands, on the other hand, do not require any licenses or payments to use the spectrum, but they are prone to interference because of the limited number of unlicensed bands and the growing number of users competing for access to those open bands (Coll, 2012).

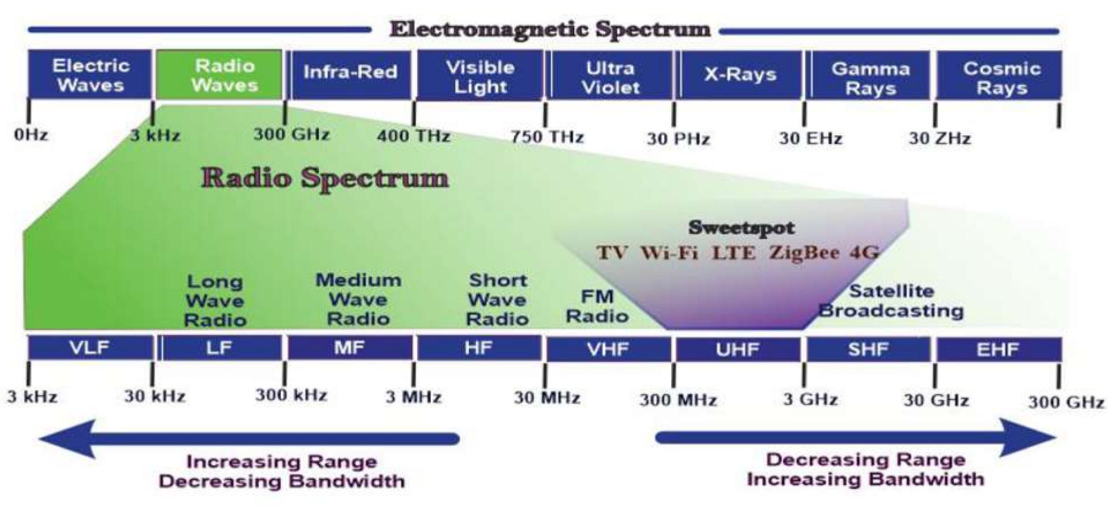

Fig. 1: Schematic illustration of partition of Radio Spectrum and Ranges

However, the increase in the request for spectrum as compelled numerous scholars around the universe to measure and study the utilization of spectrum in various nations. These measurements suggest that apart from the bands allotted to services such as cellular technology and the industrial, scientific and medical (ISM) bands, the vast majority of the assigned bands are underutilized (Naik *et al*., 2014). The underutilization of the spectrum occurs when Primary Users (PU) are not completely utilizing the spectrum at all the time and in all locations. Furthermore, the current spectrum allocation mechanism, which pre-allocates spectrum to authorized users, has resulted in some bands seeing tremendous traffic while others remain underutilized, resulting in a massive waste of spectrum resources. Many research efforts, by academia, scientist and telecommunication engineers, on the improvement of the bandwidth and many researchers had documented efficient use of the available ones.

Conducting a rigorous spectrum utilization measurement campaign is one of the most important ways to offer foundation data of existing and anticipated spectrum usage information to regulators, researchers, and engineers so that the corresponding white spaces that are not being used can be readily identified. This is to enable exploitation of the vacant band of the licensed user for unlicensed access to facilitate low powered White Space Devices (WSD) utilization of this spectrum deprived of interference to the licensed user. The unexploited broadcast TV channels differ barely from one locality to another.

White Spaces (WS) are unused electromagnetic spectrum bands, while Television White Spaces (TVWS) are WS that fall within the electromagnetic spectrum bands utilised by television broadcasting services (Brown *et al*., 2014). Using fixed site monitoring, Ufoaroh and Abu, (2019) employed an RF explorer 3G Combo model equipped with other devices to assess the TV white space availability in Ugbowo, Benin City, a Southern Nigeria. Kumar *et al.* (2013) used an RF Explorer model WSUB1G to take 24-hour long spectrum measurements from 240 MHz to 960 MHz at three different places in India. "Power level cumulative distribution" and "maximum contiguous bandwidth available" were two metrics used to liken the results at different geographical locations. NARDA SRM-3006 spectrum analyser was used by Bedogni *et al.* (2014) to carry out indoor spectrum measurement in the 470MHz – 798MHz band for the reception of TV white space in Turin, Italy. Jayavalan *et al.* (2014) analyses the presence of white spaces in UHF TV bands 470MHz – 798MHz in Malaysia. The measurement was carried out at the College of Information Technology (COIT), Universiti Tenaga Nasional (UNITEN), Selangor, Malaysia, using an Advantest U3741 spectrum analyser, with the focus on spectrum use in the cellular and UHF TV broadcasting bands. Result showed that virtually all the assigned TV bands recorded less than 15% occupancy.

Naik *et al.* (2014) focused on the quantitative assessment of TVWS availability within UHF TV band in India. Two methods were employed in quantifying the existing TVWS; the protection and pollution viewpoints, and practical requirement by the FCC. Result revealed that over 100MHz spectrum was, on the average, present as TV white space within the band, even though real spectrum measurement was not carried out. Adediran *et al.* (2014) presented the evaluation of the amount of TVWS within UHF bands in Nigeria. Here, the existing TVWS was quantified using geo-spatial approach. In this approach, a protection viewpoint was used from which the spectrum sharing model was established. The results showed that about 368MHz of spectrum available can be assessed by secondary users. Nevertheless, the model employed decreases the opportunity of extracting all the white space.

Kurnaz, Engiz, and Albayrak (2016) worked on the determination of TVWS spectrum availability in Samsun city centre, Turkey. The measurements were implemented in the 470MHz – 790MHz band, at ten sites. A software based RTL2832U-R820T frequency analyser was used in carrying out the measurement spatially in six of the locations and temporally in the remaining four locations, with all locations separated from TV transmitter stations. Results revealed that the existing TVWS is 37.5% in Samsun city centre.

Ufoaroh and Abu, (2019) concentrated on the assessment of TVWS existence in Ugbowo, Benin City, Southern Nigeria. An RF explorer 3G Combo Model was used to collect some feasibility-oriented parameters of TV Stations situated in Ovia North, Ugbowo, Edo state. UHF TV band 470MHz – 870MHz was considered and the spectral analysis for frequency span 470MHz – 570MHz, 570MHz – 670MHz, 670MHz – 770MHZ and 770MHz – 870MHz was plotted. Results showed that the available

TVWS was 58% corresponding to 232 MHz in the dense area of Benin City which indicate that reasonable percentage of the TV band is unused, even without digitization.

In this research work, real-time spectrum measurements of TV bands were carried out by employing energy detection techniques using spectrum analyser. The spectrum utilization of the examined bands was qualitatively and quantitatively analysed and the corresponding TV white spaces availability within the UHF bands were also quantified for future deployment by secondary users.

2. Materials and Methods

2.1. Measurement location

Spectrum utilization varies depending on the environments and as such measurements were carried out at six different locations in Osun State University, Osogbo Campus Osogbo (namely: Engineering Complex, Health sciences, Library, Auditorium, Administrative and URP building) to attribute a wide view to the spectrum occupancy. Fig. 2 shows the Google map of the measurement sites.

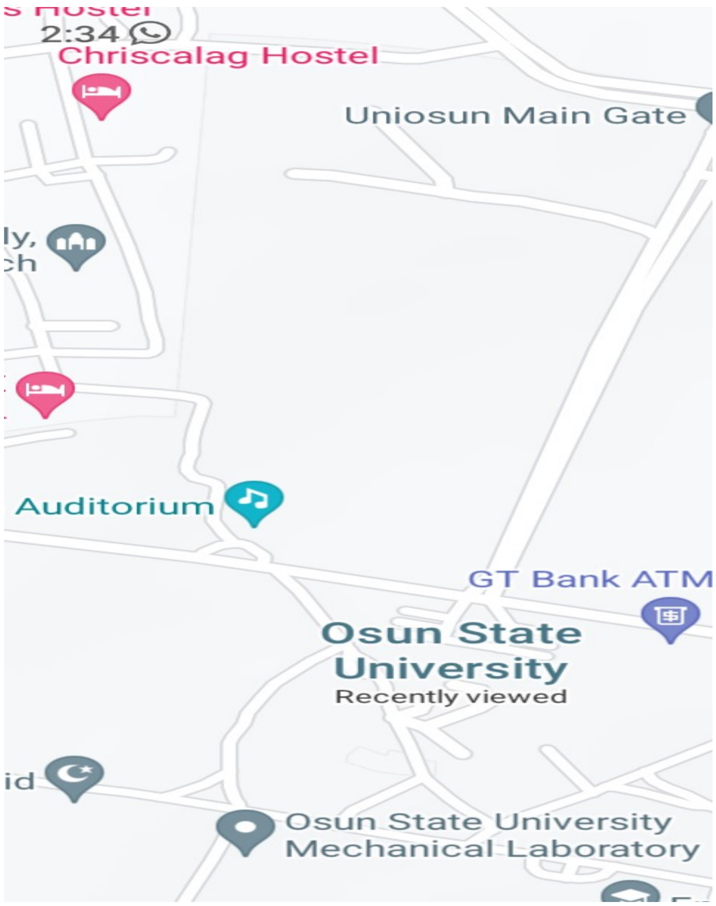

Fig. 2. Google map of the study area

2.2. Measurement setup

Fig. 3 shows the measurement equipment setup at the locations. The measurement setup consists majorly of Agilent N9342C Handheld Spectrum Analyser, a RH799 wide band antenna and data storage device.

Fig. 3. Measurement setup

2.2.1. Agilent N9342C Handheld Spectrum Analyser:
This analyser is capable of measuring from 100 KHz to 7GHz. The device uses energy detection to directly measures received signal level in dBm. It is capable of displaying the spectrogram of signals being received. This energy detector also has in-built Global Positioning System (GPS) for location features, and an external GPS connected to it for improved location accuracy.

2.2.2. RH799 wide band antenna
This is a telescopic whip antenna capable of detecting signals from 70MHz – 1GHz, with 180 degrees' tilt angle adjustable. It is capable of transferring higher data rates as well as magnifying distant objects.

2.2.3. Data storage device
Used to save the log files generated by spectrum analyser in real-time. A 16GB Universal Serial Bus (USB) flash drive was used as the data storage device for the measurement. The accuracy of the measurement result is closely connected to the measurement parameter settings. Hence, the spectrum analyser's parameters were configured according to the values presented in Table 1.

Table 1. Spectrum Analyser Configuration

Parameter	Value
Resolution Bandwidth (RBW)	3 MHz (Automatically set by the SA)
Video Bandwidth (VBW)	3 MHz (Automatically set by the SA)
Sweep Time	20.40ms (Automatically set by the SA)
Sweep Type	Continuous
Reference Level	-50 dBm
Preamplifier	ON
Impedance	50Ω

2.3. Data collection, processing and analysis

Measurements were taken several times at different hours of the day and in different periods of time in order to account for potential daily temporal patterns. The measured signal strengths were generated in comma-separated value (csv) file format and saved in the data storage device. A total of 1500 frames were received into the analyser per band per location, with 461 number of time slots (N) measured per received frame. Table 2 presents the licensed TV stations that can be received within the studied area and their parameter.

Table 2. TV Stations parameter in Osun State.

TV Stations	Channel	Frequency
OSBC TV, Osogbo	32	559.25 MHz
New Dawn TV (NDTV), Ibokun	22	479.25 MHz
NTA, Ile-Ife	39	622.25 MHz
NTA, Osogbo	49	690 MHz
AIT, Osogbo	26	514 MHz
Freedom TV, Ilesa	34	578 MHz
Reality Radiovision Services, Iwo	66	835 MHz

The signals received from the spectrum analyser were processed in a laptop using Microsoft excel. Five analysis metrics were employed for assessing the utilisation of the spectrum.

2.3.1 Noise floor:

Calculating the noise floor is very essential in order to determine the lowest possible signal that can be measured. It helps to eliminate noise and to quantify the utilization accurately. Noise floor is determined by averaging the measured instantaneous power of each location as given in equation (1):

$$N_f = \frac{1}{N}\sum_{r=1}^{N} P_r \quad (1)$$

where N_f is the average power of specific frequency point, N is the number of time slot of the received frequency power, and P_r is the power of specific frequency in a given time slot.

2.3.2 Decision threshold:

The threshold is a value at the receiver input that defines if a channel is occupied. The occupancy that results is highly dependent on the threshold. In order to ensure a reliable estimation of spectrum usage, the M-dB criteria was employed and the threshold value $(\propto)$ was set using equation (2):

$$\propto \; = N_f + M \quad (2)$$

where M is a margin chosen as 5dB according to ITU-R handbook for spectrum monitoring.

However, the value of $\propto$ should not be too low to avoid overestimated spectrum occupancy i.e. high probability of false alarm (P_{fa}) and should not be too high to avoid underestimated spectrum occupancy i.e. low probability of detection (P_d).

2.3.3 Spectrum occupancy rate:

This is the most important metrics to measure the utilisation of spectrum. It is generally defined as the chance that the signal strength of a specific frequency band is occupied using the energy detection method, which means that the signal is occupied when its signal power exceeds a certain fixed decision threshold. Calculating the occupancies of all frequency sampling points in the band yielded the spectrum occupancy. Spectrum occupancy illustrates the degree to which the allocated frequency bands is being utilised. The statistics of spectrum occupancy is important for the spectrum regulatory body of any country.

Let $\mathbf{S}_{(f_r,\, t_r)}$ be the spectrum occupancy in each measurement frequencies as seen in equation (3):

$$\mathbf{S}_{(f_r,\, t_r)} = \begin{Bmatrix} \mathbf{0}, & \boldsymbol{P_r} < \propto \\ \mathbf{1}, & \boldsymbol{P_r} \geq \propto \end{Bmatrix} \tag{3}$$

where P_r is the received power spectral density in dBm, measured in frequency point f_r and at time index t_r and $\propto$ is the decision threshold.

2.3.4 Duty cycle:

Duty cycle gives valuable information on spectrum availability by frequency band, time and location. It is delineated as the percentage of time a frequency band or channel is occupied over a given period. The duty cycle analysis is useful for determining how much time the band is utilized in a certain period. It is expressed mathematical as shown in equation (4):

$$\ddot{Y} = \sum_{i=1}^{N} \frac{\mathbf{S}_{(f_r,\, t_r)}}{N} \tag{4}$$

where $\ddot{Y}$ represent the duty cycle for specific frequency of a given location at specific time, N is the total number of time samples for a frequency point.

2.3.5 Channel Occupancy:

In order to explore the unoccupied spectrum, the percentage channel occupancy must be determined. Equations 5 and 6 show the mathematical expression for determining the percentage channel occupancy and the corresponding white space channels respectively.

$$\text{Channel Occupancy (\%)} = \frac{\textit{Number of occupied c annels}}{\textit{Total number of c annels investigated}} \times 100\ \% \tag{5}$$

$$\text{White Space Channel (\%)} = 100\% - \text{Channel Occupancy (\%)} \tag{6}$$

With the known investigated frequency span, then the total amount of TV white space availability was calculated using equation (7).

$$\underset{\text{(in frequency)}}{\text{Amount of TVWS}} = \text{White Space Channel (\%)} \times \text{Frequency Span} \tag{7}$$

3. Results and Discussion

During the measurement, the spectrum analyser was able to receive the signal strength of all the 50 UHF channels (21 through 70) corresponding to the measured spectrum band 470MHz – 870MHz. Fig. 4 shows the spectogram view of the measured TV Band.

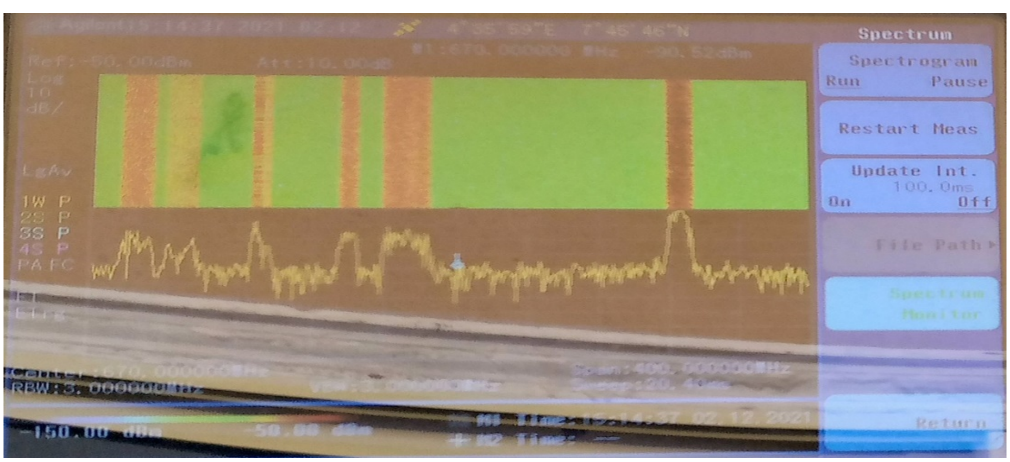

Fig. 4. Spectogram view of the measured 470 MHz – 870 MHz TV Band

The analysis of the result obtained showed the UHF channels and the corresponding occupancy status. Tables 3 and 4 depict the channels occupied by the frequency band and the status of its utilization.

Table 3: Frequency band (Channel 21 – 50) occupancy status

Frequency Span (MHz)	Channel Number	Status
470 – 478	21	Unoccupied
479 – 486	22	Unoccupied
487 – 494	23	Unoccupied
495 – 502	24	Occupied
503 – 510	25	Unoccupied
511 – 518	26	Fairly occupied
519 – 526	27	Occupied
527 – 534	28	Unoccupied
535 – 542	29	Unoccupied
543 – 550	30	Unoccupied
551 – 558	31	Unoccupied
559 – 566	32	Occupied
567 – 574	33	Unoccupied
575 – 582	34	Unoccupied
583 – 590	35	Unoccupied
591 – 598	36	Unoccupied
599 – 606	37	Unoccupied
607 – 614	38	Occupied
615 – 622	39	Unoccupied
623 – 630	40	Unoccupied
631 – 638	41	Occupied
639 –646	42	Occupied
647 – 654	43	Occupied
655 – 662	44	Unoccupied
663 – 670	45	Unoccupied
671 – 678	46	Unoccupied
679 – 686	47	Unoccupied
687 – 694	48	Unoccupied
694 – 702	49	Unoccupied
703 – 710	50	Unoccupied

Table 4: Frequency band (Channels 51 – 70) occupancy status

Frequency Span (MHz)	Channel Number	Status
711 – 718	51	Unoccupied
719 – 726	52	Unoccupied
727 – 734	53	Unoccupied
735 – 742	54	Unoccupied
743 – 750	55	Unoccupied
751 – 758	56	Unoccupied
759 – 766	57	Unoccupied
767 – 774	58	Unoccupied
775 – 782	59	Unoccupied
783 – 790	60	Occupied
791 – 798	61	Occupied
799 – 806	62	Occupied
807 – 814	63	Unoccupied

815 – 822	64	Unoccupied
823 – 830	65	Unoccupied
831 – 838	66	Unoccupied
839 – 846	67	Unoccupied
847 – 854	68	Unoccupied
855 – 862	69	Unoccupied
863 – 868	70	Unoccupied

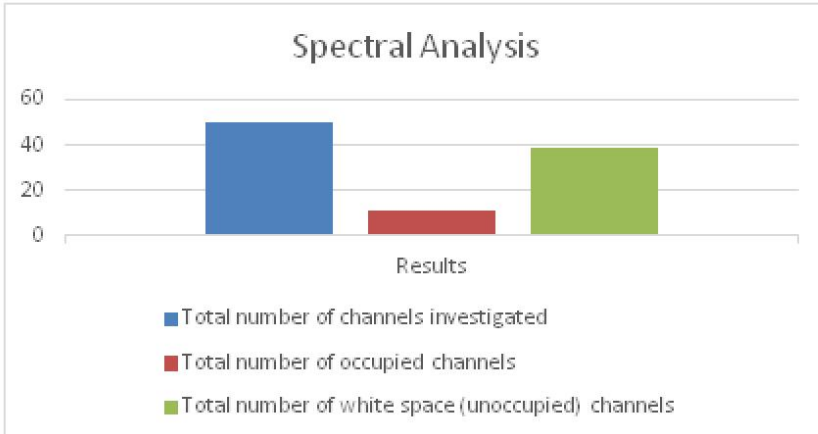

Figure 5. Overview of the spectral analysis

From Tables 3 and 4, the total number of channels investigated is 50. It was revealed that the total number of occupied channels were 11, while those of unoccupied (i.e white space) channels were 39. This analysis is illustrated by Fig. 5.

Also, it can be seen from equations (5) and (6) that 22% of the channels were occupied while 78% of the channels were free i.e. white space channels. More so, it follows from equation (7) that, with 400MHz frequency span considered, the total amount of the available TV white spaces spectrum is 312 MHz. This implies that, this quantity of TVWS spectrum is existing in the investigated frequency bands which may be reallocated by the spectrum regulator agency of the country. Table 5 is the summary of the results from the spectral analysis. This analysis showed that an abundance of free spectrum is available in the studied area, which can be utilized for broadband connectivity at Osun State University main campus, Osogbo and its environs.

Table 5: Summary of results obtained from spectral analysis

Investigation/Analysis	Results
Total number of channels investigated	50
Total number of occupied channels	11
Total number of white space (unoccupied) channels	39
Percentage of occupied channels	22%
Percentage of white space channels	78%
Total free spectrum (TVWS)	312 MHz

4. Conclusions

In this paper, spectrum utilization was investigated based on energy detection measurement technique. Measurements, spanning from frequency band 470 MHz to 870 MHz, were conducted at six different locations in Osun State University main campus, Osogbo at the busiest hours of the day.

Based on spatial measurement, number of available channels were detected. It is seen from the results that:

(i) Available TV white space is 78% which amounts to 312 MHz TV white spaces spectrum availability. This is an indication that a very large part of the spectrum is underutilized and thus, will be a good prospect for campus broadband services.
(ii) Considering that each TV channels uses 8MHz of channel spacing or bandwidth; then the available TVWS of 160 MHz which was determined for the densest case could be reused by new wireless technology applications.

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Effect of Stone dust as a Stabilizer on Plasticity and Compaction Characteristics of lateritic soil in Pavement Construction

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Abstract
Stone dust (SD) is a byproduct generated from the rock crushing activity and is readily available in abundance. Approximately, each crushing plant generated up to 15%-20% stone dust which is being referred to as a leftover. However, research has shown that stone dust possesses both pozzolanic and coarser properties, and the use of it as a stabilizing material for poor lateritic soil will solve the issue of discarding it into environment which stances various geoenvironmental glitches like landfill disposal, environmental and health dangers. This study assessed the influence of stone dust on plasticity and Compaction characteristics by utilising the British Standard Light (BSL) method of compacting lateritic soil. The soil sample was treated with stone dust at 0-30% by weight substitution. Index properties, compaction, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS) tests were conducted on the lateritic soil in both stabilized and unstabilized state. Oxide composition test was carried out on the stone dust. Results shows decrease in the liquid limit, plastic limit and plasticity index of the soil to a minimum value of 43%, 30% and 12% respectively at 15% stone dust addition. There was an Increment in the dry density from 1740 kg/m³ to 1896 kg/m³, and reduction in water content from 17.40% at 0% to 14.05%, unsoaked CBR increased from 29.81% at 0% to 63.19%, soaked CBR increased from 12.54% at 0% to 35.10% and UCS improved from 134.45 kN/m² at 0% to 331.39 kN/m². All this increase was recorded at 15% SD addition. This shows that incorporating stone dust in lateritic soil would be an effective stabilizer in improving the soil's properties as a pavement material.

Keywords: British Standard Light, Laterite soil, Plasticity, Stabilization, Stone dust.

1.0 Introduction

Road pavement is a form of durable hard surface constructed from resilient materials designed to support automobile or pedestrian traffic. It distributes the applied vehicle loads to the subgrade, which consists primarily of naturally compacted lateritic soil. Its strength is the key determinant of the pavement's thickness (Haseeb, 2017).

Laterites, classified as a soil class rather than engineered materials, are normally located in the leaching soils of the tropical humid regions, where initially examined. They are soil types that developed in tropical region and are high in aluminum and iron (Alexander and Olukorede, 2023). Because iron oxides are present, the majority of laterites have a rusty-red colour. They develop due to prolonged and extensive weathering of the parent rock beneath (Ameen *et al.,* 2023).

Lateritic soil is a conventional material that assumes a crucial function in the construction of road pavement. However, its capacity and stability cannot be ascertained under load since it contains high proportion of clay in its natural state which makes it to swell significantly when in contact with water (Er-jing *et al.,* 2022). Numerous damages and failures have been reported of various roads constructed on the soil thereby reducing its lifetime due to its highly expansive behavior and the durability of such road is greatly impacted by the properties of the underlying soil (You *et al.,* 2024). Thus, there is need for stabilizing the soil with readily available material to enhance its load carrying capacity and increase its overall strength.
Soil stabilization is a method employed in improving the durability and stability of soil, mostly in area with weak and unstable soil condition. It enhances the soil's ability to support structures coming on it (Samwel *et al.,* 2024). Generally, lime, bitumen, cement is the stabilizing material that are applied widely in soft clay soil improvement. They are easy to apply and their usage is not determined by the mineral composition of the soil. However, unfortunately, their usage has economic and environmental disadvantages most especially cement (Ogunribido *et al.,* 2022). Being a conventional and key material in construction work, they are comparatively costly, particularly in underdeveloped nations. Also, the harmful emissions resulting from their production procedure, together with the higher concentration of heavy metals in cement, shows they have a detrimental influence on the atmosphere (Vamsi *et al.,* 2023).

Therefore, the utilisation of environmentally sustainable materials as a replacement for the conventional ones are necessary so as to lessen (if not eradicate) the disadvantages. Stone dust is another material that can serve as a substitute for the natural soil stabilizer. It is a by-product generated from rock crushing, and they are generally regarded as waste (Ameen *et al.,* 2023). It has been mentioned that it possesses both pozzolanic and coarser properties with high silica content which will help in enhancing the soil's properties (Magdalena *et al.,* 2023).

Amit *et al.* (2015) stated that stone dust has numerous practical applications; the most prevalent is as a setting bed or base layer for stone paver laying. Previous research also showed that about 20% stone dust addition is capable of using as a cement replacement in concrete. Aishwara *et al. (* 2022) established that stone dust is capable of replacing fine aggregate in the production of sandcrete block. Moreover, other researchers (Raffaele *et. al.,* 2021; Muhammad *et al.,* 2023 and Ketan and Preetpal, 2024) also examined the application of ashes from some waste product like bamboo leaf, recycled glass powder and rice husk with chicken bone respectively as a stabilizer for laterite in road pavements.

However, investigating stone dust addition as the replacement for the conventional stabilizing material for lateritic soil as a pavement material need to be done. Therefore, this work aimed at determining the contribution of SD on the plasticity and compaction characteristic of lateritic soil in pavement construction.

2.0 Materials and Method

2.1 Materials

The lateritic soil material was taken along Abeere-Owode road (7º43'02"N; 4º30'58"E) in osun state. It was dried under laboratory condition to get rid of the moisture, then sieved with BS sieve No 200 and No 4 based on the tests carried out. The stone dust used was taken from stone quarrying facility in Awo (7º48'25"N; 5º26'37"E), Osun State. it was also processed under laboratory condition to get rid of the moisture. It was mixed with the soil sample at the percentages of 5% to 30% by weight of the soil.

2.2 Methods

X-ray Fluorescence (XRF) test on stone dust

This analysis test was done to established and quantified the various oxide present in the stone dust. It was carried out as stated in the ASTM E1621-21 standard practice for XRF.

Soil classification test

For classification purpose, Natural Moisture Content (NMC), particle size analysis and Specific Gravity (SG) of the soil were analysed as stated in ASTM D2216-19, ASTM D6913M-17 and ASTM D854-23 standard respectively.

Atterberg limit test

The essence of atterberg limits (liquid limit (LL), plastic limit (PL) and plasticity index (PI)) is to ascertain the consistency of the soil. It establishes the percentage of water at which the uniformity of the soil changed. LL, PL and PI were carried out as specified in BS 1377 (1990).

Compaction

This experiment was under taken to find out the vapor-density correlation of both unstabilized and stabilized soil in compliance with BS 1377 (1990) and BS 1924 (1990), respectively. The British Standard Light (BSL) compacting method was utilised for this study. The process involves the use of 1000 cm^3 cylindrical metal mould (Proctor mould) and a 2.5kg rammer. The sample was compressed in three strata inside the mould with the rammer at 27 blows per layer dropping at a height of 300 mm. Samples for water content were obtained from the mould's lower and upper surfaces. The water level that gives the optimum dried density was considered the Optimum Moisture Content (OMC).

California Bearing Ratio

California Bearing Ratio (CBR) test assesses the soil's load bearing ability, stability, and rigidity. It was conducted in compliance ASTM D1883 (2021) standard. Both unsoaked and soaked CBR was analysed to replicate the field status. Test's samples were prepared with the obtained water content of BSL compactive effort.

Unconfined compressive strength

The test measures the soil's compressive strength without lateral confinement. It was carried out as stipulated in BS 1377:1990 testing method. The samples were prepared with the obtained water content of BSL compactive effort.

3.0 Results and Discussion

3.1 Oxide Compositions

The oxide compositions of the stone dust using X-Ray Flourescence as obtained from previous study (Ameen et al., 2023) revealed that the main elements (expressed as oxide) in the stone dust are SiO_2 (silica) (67.29%), Al_2O_3 (12%) and Fe_2O_3 (6.06) which indicates its pozzolanic characteristics which tend to advance the engineering characteristics of the natural soil sample. This is in line with the work of Ahmed and Alaa (2020). Classification according to ASTM C 618(2023) shows that the stone dust is a class F pozzolanic material which are effective and beneficial in the production of high strength soil. Table 1 present the analysis of the XRF result.

Table 1: XRF result of the Stone dust

Oxide	Composition(%)
SiO_2	67.29
Al_2O_3	12.16
Fe_2O_3	6.06
CaO	5.12
P_2O_5	0.08
K_2O	6.11
MnO	0.00
SO_3	1.05
TiO	1.08
CuO	0.01
ZnO	0.02
Cr_2O_3	0.03
NiO	0.01
Cl	0.55
V_2O_5	0.10
MgO	1.58
	SiO_2+Al_2O_3+Fe_2O_3=85.51%

3.2 Preliminary test results

Table 2 shows an overview of the index parameters and the soil's particle distribution in its natural state as reported previously by (Ameen *et al.,* 2023). The NMC of the soil is 17.06 with SG of 2.43. This is an indication that the soil contains larger clay fraction in it and also related closely with the mineralogy (kaolinite) of the soil as stated by Antonio (2018). The soil was grouped as A–7–5 (silt-clayey soil) with group index of 9 and MH (elastic silt) based on AASHTO (with more than 35% passing through sieve No 200) and USCS (greater than 50% passed through No 200 sieve) respectively. The results of the preliminary tests carried out on the natural soil sample shows that the soil cannot be used in its natural state, hence, the need for modification.

Table 2: Characteristics of the unstabilized soil

Properties	Quantity
Natural moisture content (%)	17.06
Liquid limit (%)	55.65
Plastic limit (%)	39.01
Plasticity Index (%)	17.05
Specific Gravity	2.43
% Passing BS Sieve No. 200	56.41
% Passing BS Sieve No. 4	99
Maximum dry density (kg/m^3)	1743
Optimum moisture content (%)	17.40
USCS Classification	MH
AASHTO Classification	A–7–5 (9)
Unconfined Compressive Strength (kN/m^2)	134.45
Califonia Bearing Ratio (Soaked)	15.54
Califonia Bearing Ratio (unsoaked)	29.81
Colour	Reddish-brown
Dominant clay mineral	Kaolinite

3.3 Atterberg Limits

The Atterberg limits results of the unstabilized and stabilized soil are presented in Figures 1-3. At the natural state, the LL. PL and PI were 56%, 39% and 17%, respectively. As stated by Yamusa (2019), soils characterised by a liquid limit below 35% are considered to have small plasticity rate, those between 35 to 50% exhibit medium plasticity, between 50 and 70% are considered to have high plasticity rate, 70 to 90%, has higher plastic rate and the plasticity rate is exceptionally high when it is more than 90%. Based on this, the soil belongs to group of high plasticity soil which means that it is not suitable for use in its natural state. The plasticity index result also shows that the soil contains plasticity clay as stated by Bello (2013).

Upon stabilization, LL, PL and PI of the soil reduced to 42%, 29% and 11%, respectively which shows that stone addition caused changes in the plasticity rate of the soil. All these can be attributed to the coarser and pozzolanic properties of the stone dust which reduced the soil's affinity for water and gives it more strength, thereby increases the soil's effectiveness as highway material (Alexander and Olukorede, 2023). This is related to the work of Nermin *et al.* (2017).

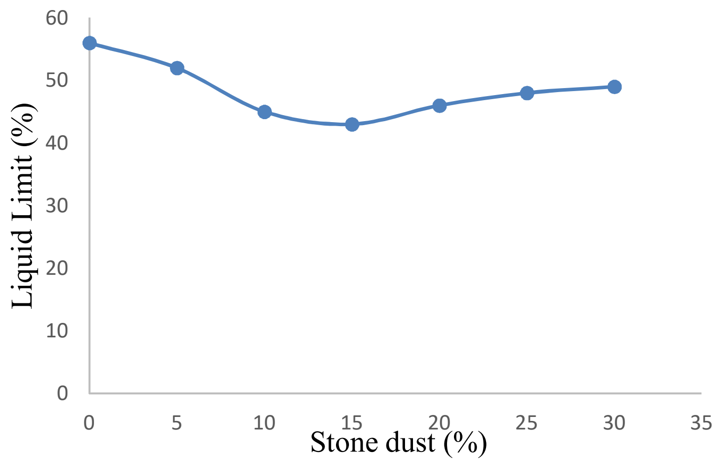

Figure 1. Liquid limit of the soil with addition of stone dust

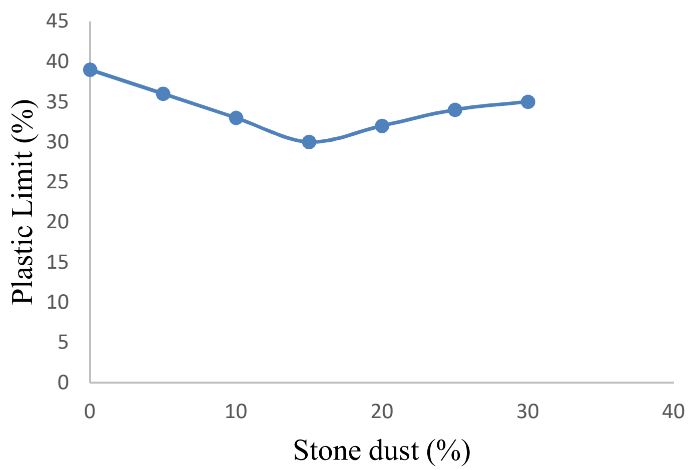

Figure 2. Plastic limit of the soil with percentage of stone dust

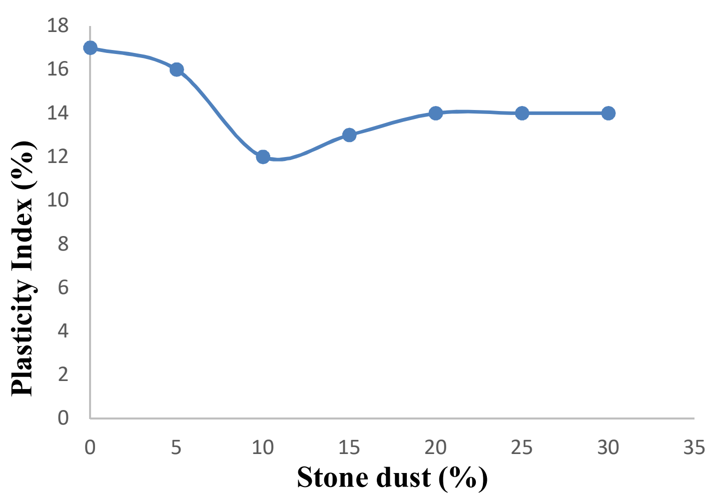

Figure 3. PI of the soil with addition of stone dust

3.4 Compaction

Maximum Dry Density and Optimum Moisture Content

Incorporation of stone dust led to an appreciable boost in the strength of the soil as shown in the MDD result (Figure 4). The value increased from 1740 kg/m³ at 0% to an optimum value of 1896 kg/m³ at 15% and decrease in value was observed beyond 15% addition. This correspond with that of Ahmed and Alaa (2020). The upsurge in the dry density can be connected to the action of silica on the soil, which allows the soil's particle to agglomerate and flocculate due to exchange of ion. Also, the subsequent reduction in the MDD after the optimum can be ascribed to the continuing and increasing addition of heavy particles stone dust in large amount which causes segregation and thereby reduces the soil's resilience (Woelandari *et al.* 2021).

Incorporating stone dust also led to reduction in the OMC (Figure 5) of the soil. It decreases from 18.00% at natural state to 14.00%. This shows that adding stone dust reduces the soil's affinity for water, which resulted to increase in MDD.

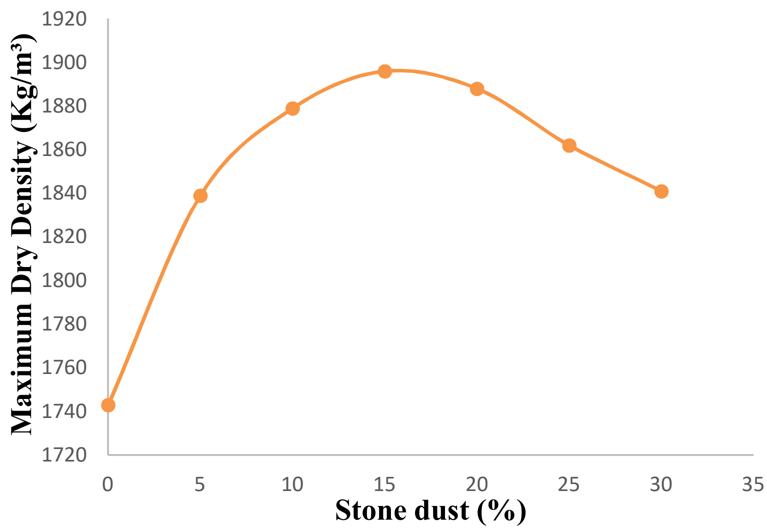

Figure 4: MDD with the addition of stone dust

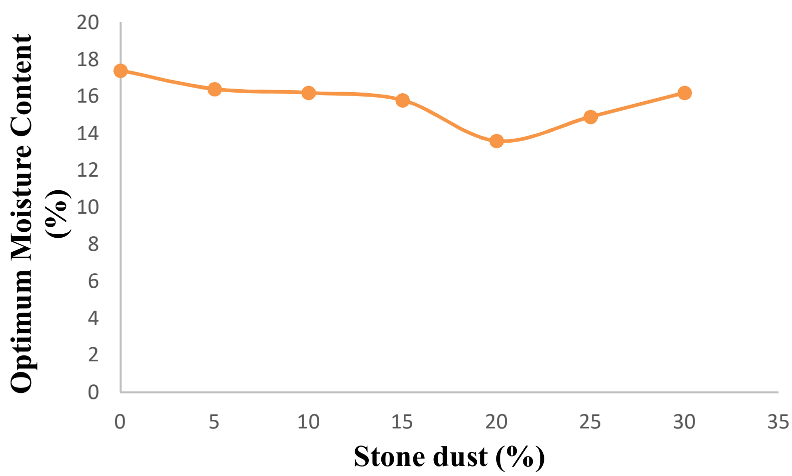

Figure 5: OMC with the addition of stone dust

3.5 California Bearing Ratio (CBR)

The test specifies the resilience requirements of materials for subgrade, subbase, and base in pavement construction. Increase in CBR was observed with the addition of stone dust to the mix. Increment in stone dust stabilizer from 0 to 15% causes an upsurge in the unsoaked CBR (Figure 6) from 29.81 to 63.19% respectively, while the soaked CBR (Figure 7) increased from 12.54% at 0% to 35.10%. As expected, CBR values of the soaked stabilized samples is not as high as that of unsoaked one. This results from intake of water at the soaked state which the reduced soil's resilience. The increase in the CBR values can be ascribed to the incorporation of hydration material which filled the existing voids within the mix, resulting to increase in CBR, thereby enhanced the soil's ability to carry load (Nermin *et al.*, 2017). This correspond with the work of Ibrahim *et al.* (2024).

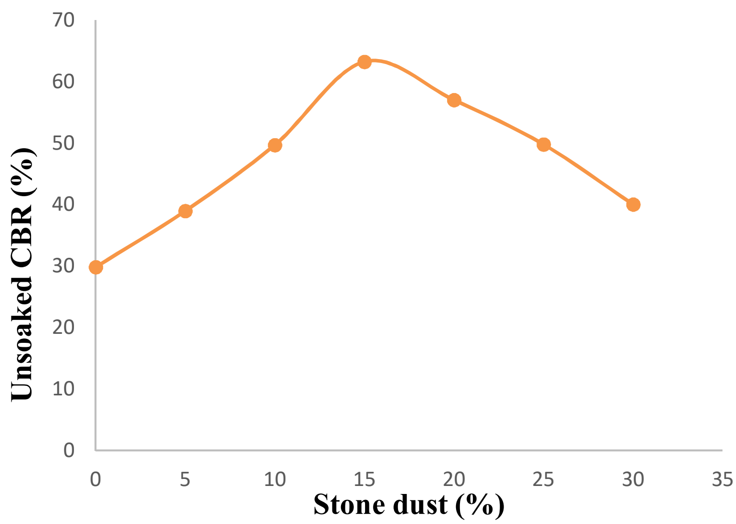

Figure 6: Unsoaked CBR with the percentage of stone dust

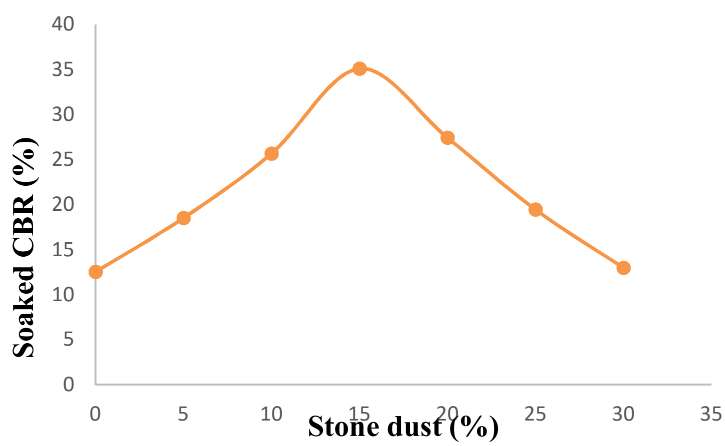

Figure 7: Soaked CBR with the percentage of stone dust

3.6 Unconfined Compressive Strength (UCS)

The UCS result (Figure 8) shows enhancement in the compressive strength of the soil from 5–15% stone dust addition, further increase in the stone dust addition beyond the optimum resulted to decrease in the strength. The value increased from 134.45 kN/m² at unstabized state to a peak value of 331.39 kN/m² at

15% stone dust addition. This agrees to the work of Ketan and Preetpal (2024). This increase could be as a result of both the coarser and pozzolanic activity of the stone dust on the soil (Alexander and Olukorede, 2023).

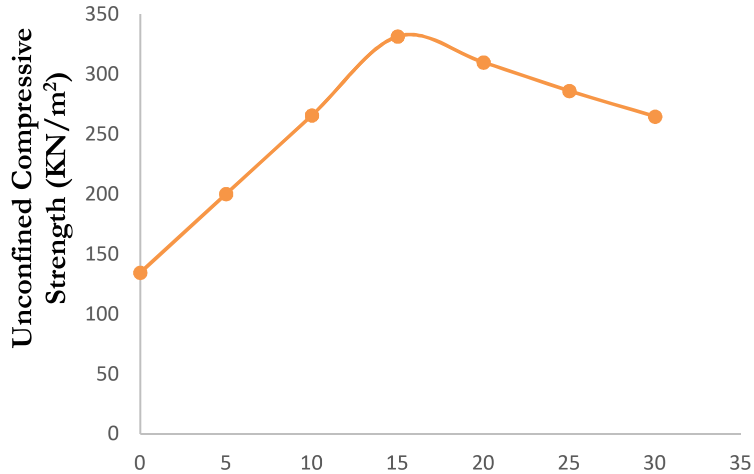

Figure 8: Uncompressive strength with the percentage of stone dust

CONCLUSION

Conclusion drawn from this work is that stone dust is capable of replacing the conventional stabilizing used for pliable and expansive soil due to high amount of silica present in it. This is proved by the outcome of plasticity and strength tests. Treating the soil with 15% Stone dust effectively advanced the plasticity of the soil to 42%, 29% and 11% from 56%, 39% and 17% respectively for liquid limit, plastic limit and plasticity index. There was also increment in MDD from 1740 kg/m^3 to 1896 kg/m^3, the UCS better from 134.4 kN/m^2 to 331.39 kN/m^2 at 15% stone dust addition thereby reducing the swelling possibility of the soil.

RECOMENDATION

Based on the results, 15% stone dust addition gives better results and is referred to as the best quantity for improving and enhancing the lateritic soil in pavement construction utilising the British Standard Light compactive energy.

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EXAMINATION OF FACTORS GOVERNING THE CHOICE OF SELECTING TENANTS IN ỌLỌRUNDÁ LOCAL GOVERNMENT AREA, OSOGBO

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Abstract

The aim of the paper is to provide an examination into the factors governing the choice of selecting tenants in Olorunda local government area that regulate the choice of tenant that are adopted by the registered real estate firms in Ọlọrunda local government, Osogbo. The objective of the research includes examination of tenant selection process and the factors governing the choice of tenant selection in respect to rental housing market with a view of enhancing better tenant selection in the study area. The study adopt a questionnaire survey and it was administered to 19 registered estate surveying and valuation firms in the study area out of which 16 questionnaire were retrieve, data gathered were analyzed using descriptive statistics tools. The finding from the study reveals that all the identified tenant selection factors are important and income status is the most important tenant selection requirement and the study recommended an equalization and uniformity of other factors that governs the choice of selecting tenants.

Keywords: Residential Property, Factors Governing, Choice, Selection, Tenants.

Introduction

According to Oni (2011), the ultimate focus of investing in private rental property is to generate acceptable returns, which can only be done by carefully choosing the tenants. Also, specified list of requirements for selecting a potential tenant, including stable sources of income, job possibilities, a responsible physical appearance, and social standing. Additional factors include tribe, age, the maximum number of children and their ages, religion, the number of cars allowed, and marital status. Some of these requirements, including career prospects and physical appearance, aren't actually relevant to the majority of the Nigerian real estate market. Without first asking the applicant about his or her occupation, it is uncommon to initially provide the applicant a place in an apartment. In the research, one of the characteristics evaluated while selecting tenants is affordability, according to JCHSHU (2008) and Bello (2008), the cost of renting is a key element in determining investment in rental properties in the majority of developing countries. This has nothing to do with the tenant's reputation. Non-payment of rent is seen by (Oni, 2010) as a serious violation of the lease agreement, regardless of the tenant's financial situation. This is typically prevented by making clear demands for affordable proof, criminal history, a police report, and references and guarantees of significant worth. The circumstances of the potential tenant may also be taken into consideration while setting criteria. According to Carter (2008), a single parent (lone parent) who has low income or a single parent due to death, divorce, or separation will not be able to afford the rent for acceptable housing in the private market and will not have the money to get around any potential entrance barriers (for example, bonds and rent in advance). In light of the unique challenges they experience, it may be acceptable to give single-parent families extra consideration when it comes to housing availability.

According to Sweet (2009), the importance of planned or limited competition, protection from unfair competition from new tenants, and restrictions on the introduction of new product lines by current tenants are also significant. The author claims that consumers do not desire businesses and are overly pushy or unconventional in their merchandising strategies. In other words, choosing a tenant depends on the history and suggested uses of the flat or other place that is being sought after. Yet, this relates to commercial lease in particular. In addition, other factors considered include the public interest (impact), legal issues, and innovator which historically has been perceived as a worrisome element (Sweet, 2009). The type of tenant, in terms of authority and position, is frequently taken into consideration while picking a tenant (Brzowski, 2008; Ojo, 2003). This usually takes the form of a person's age, history of involvement in the community, and potential consequences on the structure. The current tenancy status is one of the elements Saaty emphasized (2001). This includes the number of children in the family, the existing occupancy and demands, and the duration of the current lease.

The rental housing sector plays a significant role in the housing market. Due to the constant rural-urban migration experienced in the majority of developing nations, owning a home has become more difficult due to the high cost of real estate development, thus they are left with little choice but to rent out other people's homes in order to meet their housing needs. As a result, the landlord class and the tenant class are now two distinct groups of urban dwellers, in accordance with this arrangement, the tenant pays the landlord a specified sum of money in exchange for the right to occupy the owner's dwelling unit; this sum is referred to as rent (Olatoye, 2005) (Akomolede, 2006) (Francis, 2011). Nigeria is experiencing one of the world's greatest housing crises, urban drift, over population of moving from rural to urban areas, all has resulted in dangerously congested cities and a crushing demand for land and homes, which the government has been unable to handle, this brought about Landlord and tenants relationship which cater for the housing demands in the urban area. The aim of the study is to provide information into the factors governing the choice of selecting tenants in Olorunda local government area that regulate the choice of tenant in Ọlọrundá Local Government Area, Osogbo, in respect to rental housing market with a view to enhancing better tenant selection in the study area. The importance of this study is to both the body of knowledge and to the professionals in the real estate practices .In terms of the study relevance to the professionals in the real estate field, the study will provide information on how to handle problematic tenants in the rental market taking into consideration the criteria for tenant selection, it's also saves the property managers and client from unending litigation process which can be time consuming and frustrating.

Materials and Methods

The study is conducted in Osogbo, the focus group for the research work is the practicing firms of estate surveyors and valuers who are custodians of properties and are often involved in management of landed properties found in the study area. They are the real estate consultants professionally recognized in Nigeria to conduct property management activities. The study adopted a questionnaire survey method. Structured questionnaires are administered to the practicing estate surveying and valuation firms registered with the Nigerian Institution of Estate Surveyors and Valuers (NIESV). However, this does not overrule the fact that there are quacks (unregistered agents) in the market. In this study, the professional opinion is considered superior to that of non-professional. Presentation and analysis of data is done using Frequency and percentage distribution and Mean Score, Mean Deviation. The study concentrated on Estate surveyor and valuer firms that act as letting agents for landlords when renting out apartments and other properties. According to the records of the Nigerian Institution of Estate Surveyors and Valuers (NIESV), Osun state section of the year 2023, there are 19 registered estate surveyors and valuers firms in osogbo stated by the NIESV. The sample for the study is the registered estate firms in Osogbo, and according to the NIESV's dictionary, there are nineteen (19) registered estate surveyors and valuers working in osogbo. Questionnaires will be given to the 19 real estate firms companies in order to gather data.

Results and Discussion

A total of 19 copies questionnaire were distributed to estate surveying and valuation firms in Osogbo, 16 copies of the distributed questionnaire to these firms were retrieved due to unforeseen circumstances.

Factors Governing the Choice of Tenant

From survey of literature, it can be deduced that the choice of selecting tenant is backed up by some essential and this is in variation vary from across the world, Furthermore no single set of criteria may be imposed as a they all work together to ensure that the tenant is fit into the desire choice of tenant. However, survey of estate surveyors in the study area showed the common criteria which are: financial soundness ,level of income, occupation and types of employer, marital status, tribe, job prospects, marital status, physical appearance, religion, sex, and number of children.

The table below (Table 1) shows comprehensive data obtain, the respondents was requested to indicate their criteria for selecting tenants in order of importance. Out of 20 questionnaires administered, 16 were returned and found useful for analysis. The respondents stated and ranked the criteria identified in literature and it's found relevant to them. The table above indicate the survey 8 (50.0%) of a family size and its show that family size is one of the essential criteria to be put in place in the choice of selecting the prospective tenants, this is because the size of the family will have either positive or negative effect on the useful life of the property. Likewise the level of marital status indicated above shows is an important tool for tenant selection, this is because the property owners are willingly to give lease out their property to the married individuals as they are seen as matured and responsible individuals who can keep the contract with the property owner. The financial soundness/ tenant income, of the prospective tenants was established according to the survey as optimum because this will depicts how well the prospect will be able to pay for rent in the long run of the tenant years of leases as shown in the tables above the survey for the prospective tenant shows 14(87.5%), therefore this shows the tenant must be sound enough to financially pay all through the time of lease.

Findings from the study 7(43.8% show the occupation level as an important criteria in tenant selection process this is because the occupation of will show the prospective tenant approved for the contract, finding from the study show of the age importance in selection of tenants 5(31.3%) and other 3(18.8%) at this depicts the liberty of given to individual for occupancy. The survey 7(43.8%) find criminality records as important in the quest for leasing a property to the prospect tenant this is because letting out a property to a tenant who has criminal records can diminish the value of the property. More so the religion 5(31.3%), tribe 8(50.0%), socio-status (56.3%), findings as seen in the table above are seen relevant in the selection process of a tenant.

The survey shows that both 6(37.5%) disability, gender, numbers of cars 6(37.5%) and physical appearance 5(31.3%) are seen relevant in the tenant selection process, some tenant may not dressed up to the standard of they looking wealthy or influential and also the survey study show that health status, profession , 9(56.3%) ascertain that credit report is of high relevance ,quality of guarantor show the position of their relevance in the selecting a tenant, likewise records on the previous tenant reports 6(37.5%) agree that this criteria is extremely significant, level of education 6(37.5%) agree that its not important in tenant selection criteria because with the current economy of the country you can have a degree and still don't have a reputable job to do with it, social status, compatibility with neighbors ,potential value to the building and community impact use of the tenant in selection is shown as part of the standards to be put in order to get the right tenants for the property. The tenant income level as shown in the table above show that 12(75%) agree that tenant income is extremely important and crucial aspect of tenancy. The property owner lends out the property with the sole purpose of getting maximum return of the investment. According to the similar study of Oni (2010) the study agrees with relevant criteria that estate surveyors used in selecting tenant, having a significant importance in choosing a prospective tenant which will aid the profitability and the successful impact in the management of the property.

TENANT SELECTION PROCESS

Tenant selection process are the step and procedures the property manager followed to choose a suitable tenant for the rental property and it involves assessing and evaluating potential tenants based on several factors to determine their eligibility and suitability, such factors include: tenant interview and behavioral test, physical appearance, tenant socio status, application screening.

From the Literature review tenant selection is seen as crucial deciding whether a property owner should accept the first applicant who respond to advertisement or choosing from the pool of applicant, as well as what grounds the property owner may use to reject a tenant as what precaution taken to avoid leasing the property to undesirable tenant

Table 1: Factor governing the choice of tenant selection using: Extremely important (5), very important (4), just important (3) less important (2), not important (1)

CRITERIA FOR SELECTING TENANT	1	2	3	4	5	6
Family size	2 (12.5%)	3 (18.8%)	2 (12.5%)	1 (6.3%)	8 (50.0%)	16 (100%)
Marital status	3(18.8%)	2(12.5%)	1(6.3%)	6(37.5%)	4(25.0%)	16 (100%)
Financial soundness	1(6.3%)		1(6.3%)		14(87.5)	16 (100%)
Occupation	5(31.3%)	2(12.5%)		2(12.5%)	7(43.8)	16 (100%)
Age	3(18.8%)	2(12.5%)	3(18.8%)	5(31.3%)	3(18.8%)	16 (100%)
Criminal records	3(18.8%)	1(6.3%)	3(18.8%)	2(12.5%)	7(43.8%)	16 (100%)
Religion	2(12.5%)	4(25.0%)	5(31.3%)	4(25.0%)	1(6.3%)	16 (100%)
Tribe	2(12.5%)	1(6.3%)	8(50.0%)	5(31.3%)		16 (100%)
Socio-status	2(12.5%)		9(56.3%)	2(12.5%)	3(18.8%)	16 (100%)
Disability	4(25.0%)	2(12.5%)	6(37.5%)	3(18.8%)	1 (6.3%)	16 (100%)
Gender	3(18.8%)	3(18.8%)	4(25.0%)	3(18.8%)	3(18.8%)	16 (100%)
Numbers of Cars	3(18.8%)	3(18.8%)	3(18.8%)	6(37.5%)	1 (6.3%)	16 (100%)
Physical appearance	5(31.3%)	4(25.0%)	1 (6.3%)	5(31.3%)	1 (6.3%)	16 (100%)
Size of income	1 (6.3%)	1 (6.3%)	1 (6.3%)	2(12.5%)	11(68.8%)	16 (100%)
Health Status	3(18.8%)	2(12.5%)	3(18.8%)	3(18.8%)		16 (100%)
Profession		3(18.8%)	3(18.8%)	3(18.8%)	7(43.8%)	16 (100%)
Credit report	1 (6.3%)	2(12.5%)	1 (6.3%)	3(18.8%)	9(56.3%)	16 (100%)
Quality of guarantor	3(18.8%)	1 (6.3%)	1 (6.3%)	3(18.8%)	8(50.0%)	16 (100%)
Report on previous tenancy	4(25.0%)	2(12.5%)	3(18.8%)	1 (6.3%)	6(37.5%)	16 (100%)
Tenant income				4(25.0%)	12(75%)	16 (100%)
Level of education	6(37.5%)	3(18.8%)	3(18.8%)	1 (6.3%)	3(18.8%)	16 (100%)
Compatibility with neighbors	2(12.5%)	5(31.3%)	3(18.8%)	3(18.8%)	3(18.8%)	16 (100%)
Potential value to the building	1 (6.3%)	3(18.8%)	4(25.0%)	3(18.8%)	5(31.3% t)	16 (100%)
Community impact use	4(25.0%)	2(12.5%)	2(12.5%)	3(18.8%)	5(31.3%)	16 (100%)

Table 2: Below are Tenant selection process using: Always used (1), rarely used (2), often use (3) Sometimes used (4), Never in use (5)

TENANT SELECTION PROCESS	1	2	3	4	5	6
Application submission	0	0	16 (100%)		0	16 (100%)
Landlord preference	8(50.0%)	3(18.8%)	0	5(31.3%)	0	16 (100%)
Tenant interviews / behavioral test	16 (100%)	0	0	0	0	16 (100%)
Tenant social status	5(31.3%)	2(12.5%)	3(18.8%)	6(37.5%)	0	16 (100%)
Tenant level of income	16 (100%)	0	0	0	0	16 (100%)
Physical appearance	8(50.0%)	0	8(50.0%)	0	0	16 (100%)
Lease agreement	9(56.3%)	0	6(37.5%)	1(6.3%)	0	16 (100%)
Guarantor's prestige	6(37.5%)	0	5(31.3%)	5(31.3%)	0	16 (100%)
Advertising the property	7(43.8%)	0	5(31.3%)	4(25.0%)	0	16 (100%)
Established relationship	0	16 (100%)	0	0	0	16 (100%)
Application screening	10(52.5%)		6(37.5%)		0	16 (100%)

The Table 2 above shows comprehensive data obtain, the respondents were requested to indicate the tenant selection processes, which are commonly administered in selection process. As presented in table 2, result analysis shows that 16 (100%) of the respondent often maximize application submission as one of the process of selecting tenant. Table 2 analyses the Landlords' preference 8(50.0%) indicated as always use, 3(18.8%) say they rarely used landlord preference, 5(31.3%) often used, it shows that majority of the respondent adopt landlord preference in the process. This survey established that the landlord preference has significant effects in the tenant selection as property manager carry out their choice of whom to lease their property. Furthermore the survey depicts that 16 (100%) of the respondent adopt tenant interviews and behavioral test in the selection of tenant. The property manager may whom to choose from the pool of applicant who came for interview after examining their behavior alongside, this is in the view of the landlord choices. Table 2 the survey on the tenant social status in the considering the selection process shows that 5(31.3%) evaluate tenant with this 2(12.5%) rarely consider this process, 3(18.8%) adopt this process often and 6(37.5%) sometimes consider this process. More so the analyses establishes that 16 (100%) of the respondent take the tenant level of income important in occupying a suitable tenant, this is because the tenant is the source of income for a rented property, thus their capacity to pay rent and uphold other covenants in the tenancy agreement are crucial.

Table 2 show the satisfaction of respondent in respect to Physical appearance of the tenant when it comes to choosing prospective tenant 8(50.0%) consider this always and 8(50.0%) consider this sometimes due to in most cases someone physical appearance may not necessary be relevant but it can be decisive as physical appearance don't judge if the suitable tenant has a good character or financially buoyant. Table 2 above shows that 9(56.3%) of the respondent consider lease agreement and 6(37.5%) of the respondent and 1(6.3%) apply this process sometimes in the searching for a suitable tenant. Lease agreement outline the terms and condition of tenancy this is taken into consider to ensure if the prospective tenant willing to adhere to the terms of lease, payment of rent and caution deposits. Table 2 above depicts 6(37.5%) adopt the guarantors prestige as a means of evaluation and 5(31.3%) of the respondent are indifferent in considering the prestige of the tenant guarantor, more so 7(43.8%) of the respondent agree that they adopt advertising of their property always, 5(31.3%) consider it often and 4(25.0%) sometimes, this is to the end that the property attract potential tenants. Furthermore 16 (100%)

rarely use established relationship as a yardstick for selecting potential tenants, this should be or an arms-length transaction. The survey about show that 10(52.5%) of the respondent consider application submission of the interested tenants to provide personal and financial information. This finding corroborates with the tenant selection plan established in accordance with compliance with the Department of Housing and Urban Development (HUD) Handbook 4350.3, REV-1.

Conclusions

The study concludes that there are various criteria for selecting tenant are significant and they are mostly dependent on each other. To produce a positive result and to unmitigated flow of returns on investment especially the property located in urban areas the various criteria will need to work dependently on each other, it's observed that tenant selection is the most successful part of property management, without proper tenant selection criteria, the landlord and or property manager can find themselves stuck with potentially bad tenant which may not only cost lots of money, but also endless frustrations. It was noted that the occupation of tenants isn't excluded, and the bulk of these tenants are self-employed and between the ages of 31 and 40. This indicates that the majority of the Christians and Muslims that live in Olorunda are currently self-employed, particularly at the time of acceptance.

Tenant selection process in the study area which established various process used in assessing a prospective tenants through various process such as: tenant interview and behavioral test, physical appearance, tenant socio status, application screening. A tenant's physical appearance, socioeconomic status, tenant interview, behavioral test, and application screening are just a few of the criteria that are used to evaluate potential tenants as part of the tenant selection process in the study area. This study indicate six commonly used process in tenant selection that property managers (agents) consider in searching for prospective tenant and these process are ;Landlord preference, tenant interview and behavioral test and physical appearance, advertising the property application screening, and Lease agreement. These factors were selected to be mostly adopted in tenant selection process by the respondent; the replies were subjected to a range of importance analysis. This further demonstrates that the aforementioned eligibility and suitability determination process can help the property manager or owner make better tenant selections and ensure that the main goal obtaining the greatest possible return on the owner's investment is successfully attained.

The factors governing the choice of selecting tenants in the study area established various factors governing the choice of selecting tenant which are: financial soundness, profession, physical appearance, criminal record, religion, family size, number of cars, types of pet ethnicity, compatibility with neighbors, health status, marital status, gender and age. Furthermore there are numerous ways to screen potential tenants all of which work in hand to ensure that a wrong tenant is not picked during the tenant selection. According to this study, there are five main factors that property managers (agents) consider when choosing which residential leases and these are: family size, tenant's degree of income and financial stability, credit report, and quality of guarantor This criteria were selected to be mostly adopted in deducing the factors that govern the choice of selecting tenant by the respondent, the replies were subjected to a range of importance analysis.

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ASSESSMENT OF THE EFFECT OF SACHET WATER WASTE ON THE ENVIRONMENT IN WUSHISHI, NIGER STATE

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Abstract
This study aimed to assess the environmental effects of sachets water waste on the environment and to isolate and possibly identify bacteria that are likely connected to the sachet's biodegradation from degraded soil. Sachet water is packaged in polyethylene bags that are not biodegradable or decay, and when burned, produces oxides of carbon, nitrogen, and sulphur. It can also be found on streets, in drainage systems, and even in our water bodies, leading to pollution and ecological damage. The accumulation of sachet water waste blocks drainage system, increasing the risk of flooding during the rainy season. Questionnaire was used for data collection. This study have been able to establish that sachet water wastes have consumed 70% of the land in the study area, hinting at the possibility of the sachet water wastes in the study area affecting the ecological footprint of the town on one hand and causing health and safety challenges on the other; although safety was found 5th *in ranking to be the least consideration by the residents of Wushishi in the choice of sachet water that they consume. Similarly, the sachet water waste disposal methods in the study area were largely environmentally unfriendly and unsustainable. The study therefore recommends serious enlightenment on the need for adequate water consumption in line with established global standards; and a public-private partnership network aimed at creating sustainable waste disposal and management system for the town; creating designated waste collection/disposal and management spot which should be subjected to periodic fumigation to curb the development and spread of disease pathogens.*

Keywords: Environment, Effect, Sachet water waste

1.0 INTRODUCTION

Solid Waste disposal is a major issue not just for less developed countries but also for the developed countries. The most pressing issue is how to manage the enormous amount of waste that is produced all over the world in order to preserve the environment and ensure humanity's continued existence. The issues confronting less developed countries in the treatment of Metropolitan Solid waste are not difficult to solve however they need deliberate exertion from all parts of society. Any meaningful and long-lasting solution requires an all-encompassing approach (Orji, 2006). According to Akunyili (2003), the proliferation of so-called "pure water" producers in Nigeria is largely attributable to the government's inability to consistently provide sufficient potable water to the increasing population. Therefore, the solution for the shortage of potable water prompted the development of sachet.

Sachet water entails the packaging of drinking water in a non-biodegradable synthetic polyethylene (polythene). Sachet water, popularly called pure water in Nigeria has become an everyday intake for an average Nigerian. The evidence of this is seen in the amount of disposed sachets littering the streets and also the increased number of drainages blocked by 'blocks' of sachet water waste. Sachet water was introduced to the Nigerian markets around 1990 but its regulation by the National Agency for Food and Drug Administration and Control (NAFDAC). Sachet water gained much popularity in Nigeria because the product is convenient for use, affordable and economically viable. It brought 'potable' water to the doorsteps of many Nigerians (Akunyili, 2003).

The venture has also given employment to Nigerians which enables them to put food on their table. Notwithstanding the benefits accruing from sachet water production and consumption, the indiscriminate disposal of the waste in various undesired sites such as along the streets, gutters, motor parks, schools, markets, homes, and venues of social functions etc. poses a lot of threat on the environment. The sachets are made of non-biodegradable synthetic polyethylene (polythene) which does not decompose in the soil even after many years. The polythene even when subjected to burning produces carbon monoxide, nitrogen oxide, methane and sulphur. Sachet water waste disposal is a vast problem that needs to be tackled because of the implications it has on environment such as soil, vegetation air and water (Adenuga, 2006). According to Idiata and Iyasele (2014), several environmental impacts from sachet water waste includes obstruction of waterways, animals choking and soils and litters of pure water sachet on the landscape requires immediate attention. The effects include, Increase disease transmission, contamination of ground and surface water, generation of Greenhouse gas emissions and other air pollutants, damage to ecosystems, injury to people and properties.

Therefore no detailed study on the environmental problems of sachet water waste disposal on the environment in the study area; this is a research gap this study sets to fill.

Specifically, the study aims to assess the environmental problems associated with sachet water wastes disposal in the study area with a view to finding solutions to improve on the environmental quality.

1.1 Study Area

Wushishi local government area is domiciled in Niger state, North-central geopolitical zone of Nigeria. The headquarters of the LGA are in the town of Wushishi.

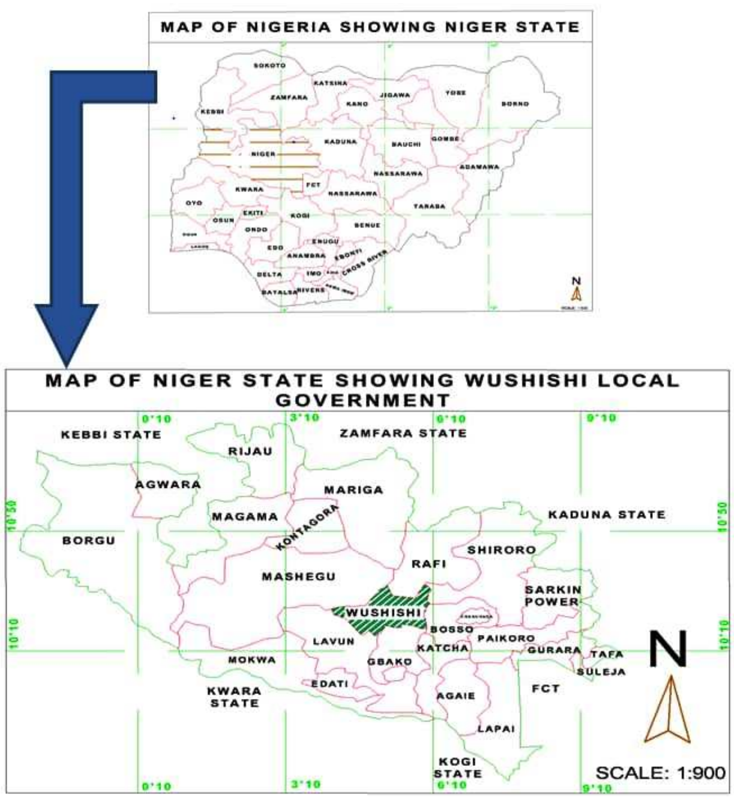

Figure 1: Location of Wushishi in Nigeria

Source: Nigeria Galleria (2023)

2.0 LITERATURE REVIEW

Sustainability of the environment is an important factor influencing sustainable socioeconomic development of any community. However, anthropogenic practices have contaminated the environment to such an extent that managing and maintaining healthy environmental conditions has become a worldwide problem. Rapid urbanization and population growth in the last half century have outpaced government efforts to maintain and expand potable water infrastructure in Nigeria, and the private sector has responded with an easy but environmentally threatening solution. Stoler, *et al.* (2015) in their study asserted that, Sachet water, known colloquially as *"pure water"* has out-competed nearly all alternatives to the unreliable government water infrastructure to become the country's cheap, mobile, and omnipresent answer to the country's urban water crisis.

Sachet bag is made from polyethene Sachet material which is non-biodegradable; it belongs to single-use Sachet (Temitope*, et al.*, 2015). Sachet bags can be recycled by crafting it to another thing, but unfortunately it mostly ends up on landfills or littering the ground after use. In Nigeria, the name of the producing company and the NAFDAC registration number will be printed on the bag. This number is what people (consumers) always look out for before buying the water as they have strong belief that such a company has passed all the NAFDAC specification. Any company with sachet bag that has no NAFDAC number can be reported and get charged to court. However, the creation and commercialization of sachet bags which are less controlled resulting into so many unregistered factory in the businesses. Some are filled up with tap water, untreated or from illicit drilling. In addition, serious hygiene issues occur because of the storage of the bag (unsanitary premises). Other noticeable problem is that, they are often left littering the ground and blocking the waterways which can lead to flooding (Akunyili, 2003).

The packaging of this sachet water is made of non-biodegradable synthetic polyethylene (polythene), which does not decay, decompose or corrode, and which when burnt, produces oxides of carbon, nitrogen and sulphur. However, the use of sachet water has become a menace, due to its negative long-term environmental consequences, namely the vast increase in polythene waste that needs to be degraded. When one walks around large metropolitan areas in Nigeria, the polythene wastes that constitute the majority of litter is unavoidable and also the used sachet water bags constitute an alarming portion (Tiwary, 2015).

Sachet water packaging, typically made of low-grade plastics, poses a severe threat to our environment. The lightweight nature of these sachets makes them prone to being carried by wind and water, resulting in widespread littering. Sachet water waste can be found on streets, in drainage systems, and even in our water bodies, leading to pollution and ecological damage. The accumulation of sachet water waste blocks drainage systems, increasing the risk of flooding during the rainy season. Moreover, the Sachet materials used in sachet water packaging take years to decompose, exacerbating the environmental impact (Orji, 2006).

The problem of solid waste disposal is alarming in urban centres of the country and is a major concern to the government. This problem of waste generation and disposal is worrisome in Borno state, where it is always on the increase because of increasing population pressure and socioeconomic factors. Several environmental impacts including blockage of waterways and choking of animals, soils and mosaic litters of pure water sachet in the landscape requires urgent attention. The effects include increase disease transmission, contamination of ground and surface water, generation of Greenhouse gas emissions and other air pollutants, damage to ecosystems, injury to people and properties (Idiata and Iyasele, 2014). Rapid urbanization, rural-urban migration, little or no town planning efforts coupled with attitudinal irresponsibility, lack of political will, ineptitude and graft have independently and collectively created environmental challenges in Nigeria resulting to human or solid waste decorating streets and public spaces everywhere in the country (Oyeniyi, 2011).

3.0 METHODOLOGY

This study used both primary and secondary data. The primary data were used to estimate the rate of sachet water consumption in the study area, the perception of the residents on the effects of sachet water wastes, the reasons for sachet water consumption and the methods of sachet water waste disposal in Wushishi. The primary data were collected with the aid of a structured questionnaire. Wushishi has a population of 140,200. Systematic random sampling technique was used to administer questionnaire to 280 residents of the study area after calculating the representative sample of the population using the Krejcie and Morgan's (1970) sampling size determination table.

The secondary data used for this study were obtained from published sources (journal articles, reports and online sources). Studies suggest that man requires between 1.89litres to 3.0litres of water for drinking daily (WHO, 2004; Tiwary, 2015; USEPA, 2016; Apeh, 2018). However, this figure is a little bit lesser in

Wushishi where the average daily sachet water consumption stood at five sachets per capita as presented in Table 1. Thus, daily average of five sachet water per capita will be adopted for this study to capture this peculiarity. In addition, it has been discovered that at least 70% of Nigerians depend on sachet water for their daily drinking water need (Edoga *et al.*, 2008). So, in conformity with established threshold, 70% sachet water dependency rate will be maintained. With regard to the average area covered by sachet water packs, Ibrahim *et al.* (2015) reported that each pack covers approximately 0.0211m², which is adopted for this study.

Descriptive statistics was used for the analysis of data collected and the data are presented in frequency tables. Microsoft Excel was used for the analysis of the data.

4.0 RESULTS AND DISCUSSION

4.1 Sachet Water Use

Sachet water usage in the study area is presented in Table 1. The result shows that all the respondents consume sachet water, thus qualifying them for inclusion in this study. Regarding the number of sachet water consumed daily, more than 7% and 19% reportedly consumed 1-2 and 3-4 sachets respectively. However, about 62% reportedly consumed 5-6 sachets daily; while more than 5% and 6% consumed 7-8 and more than 8 sachets of water respectively per day. Importantly, the mean daily water consumption in Wushishi is 5 sachets (or 2500ml) daily. This is a little below the 6 sachets or 3000ml reported for Liberia by Apeh (2018). This means that the daily drinking water requirement pegged at between 2.7litres and 3.7litres for adult men and women respectively by Sawka (2005) is not met in the study area, although it meets the WHO requirement of 1.89litres to 3.0litres (WHO, 2004). In addition, the residents reported seasonal variations in the rate of sachet water consumption, with most consumption occurring in hot season; while the greatest proportion of the residents preferred cold water for consumption.

Table 1: Sachet water use

Variable		Frequency	Percentage	Mean	Standard deviation
Sachet water consumption	Yes	280	100.0		
	No	0	0.0		
Number of sachet water consumed daily (50cl of 500ml)	1-2 sachets	21	7.5	5.0	67.31
	3-4 sachets	54	19.3		
	5-6 sachets	173	61.8		
	7-8 sachets	15	5.4		
	> 8 sachets	17	6.1		
Seasonal variations in daily sachet water intake	Yes	280	100.0		
	No	0	0.0		
Season with higher intake	Wet season	0	0.0		
	Hot season	280	100.0		
Preferred sachet water temperature for consumption	Normal	18	6.4		
	Mild	92	32.9		
	Cold	170	60.7		

Source: Authors' Field Survey (2024)

4.2 Sachet Water Generation in Wushishi

The rate of sachet water waste generation in Wushishi is presented in Table 2. As the result shows, the expected volume of sachet water consumption in the study area per day is 701,000. However, after adopting the 70% threshold of minimum number of sachet water consumers in Nigeria as reported by Edoga *et al.* (2008) on the one hand and adopting the five sachets mean found for this study as presented in Table 1, the observed number of sachet water consumption stood at 490,700. Therefore, considering the standard area of each sachet water pack which is approximately 0.0211m² (Ibrahim *et al.*, 2015), the average area covered by sachet water wastes in Wushishi is 10,353.77m². It is worrisome to note that if this trend is not curtailed, this will translate to sachet water wastes alone capable of affecting the ecological footprint of the town, and ultimately affecting its environmental sustainability.

Table 2: Sachet water waste generation in Wushishi

Population of Wushishi population	**Population**	**Expected volume of sachet water consumption (population x sachet water consumption per capita per day)**	**Observed sachet water consumption per day (70% of the population x five sachet waters per capita per day)**	**Average area of sachet water wastes (0.0211m² x 70% of the population x five)**
140,200		701,000	490,700	10,353.77

Source: Authors' Estimate (2024)

4.3 Residents' Perception of the Environmental Effects of Sachet Water Waste Disposal

Residents' perception of their environment is a very important step towards environmental stewardship. The perception of the residents of Wushishi on the environmental effects of sachet water waste disposal is presented in Table 3. The result suggests that blocking of drainage systems and littering of the environment ranked 1st and 2nd among the perceived effects of sachet water waste disposal with mean scores of 4.88 and 4.61 respectively. Clogging of drainage systems is a precursor to flood disaster. The perception of the residents that sachet water wastes constitutes possible toxins when used as play toys by children on the one hand, and causes soil pollution on the other ranked 3rd and 4th with mean scores of 4.09 and 4.01 respectively. Furthermore, ranking 5th and 6th on the list of the perceived effects of sachet water waste disposal in Wushishi are the perceptions that they create breeding ground for mosquitoes and create soil pollution. Mosquitoes are the primary cause of malaria which is responsible for millions of deaths in sub-Saharan Africa. Thus, sachet water wastes constitute health challenge to the residents of the study area. It was also reported that sachet water wastes constitute offensive odour when burnt, ranking 6th on Table 3 with a mean score of 3.82. This is in addition to the reports of causing accidental falls (ranking 7th with a mean score of 3.30). All of these are pointers to the need to address the issue of sachet water wastes in order to achieve a safe, aesthetically pleasing and sustainable urban environment.

Table 3: Residents' perception of the effects of sachet water waste disposal

	Effects	Strongly Agree		Agree		Disagree		Strongly Disagree		MEAN	Standard Deviation	Rank
		F	P	F	P	F	P	F	P			
A1	Blocking of drainages	108	38.6	152	54.3	14	5.0	6	2.1	4.88*	1.93	1st
A2	Environmental littering	120	42.9	158	56.4	2	0.7	0	0.0	4.61*	1.40	2nd
A3	Possible toxins when used as play toys	105	37.5	166	59.3	9	3.2	0	0.0	4.09*	1.91	3rd
A4	Causes soil pollution	79	28.2	181	64.6	19	6.8	1	0.4	4.01*	1.26	4th
A5	Helps breed mosquitoes	105	37.5	174	62.1	1	0.4	0	0.0	3.90*	1.29	5th
A6	Offensive odour when burnt	244	87.1	36	12.9	0	0.0	0	0.0	3.82*	1.42	6th
A7	Contributes to accidental falls	208	74.3	61	21.8	11	3.9	0	0.0	3.30*	1.30	7th
A8	Visual pollution	98	35.0	167	59.6	4	1.4	1	0.4	2.97	1.48	8th

A9	Pollution of ponds	65	23.2	119	45.5	96	34.3	0	0.0	2.95	1.50	9th
A10	Visual impairment for motorists	96	34.3	169	60.4	5	1.8	0	0.0	2.45	1.22	10th

NB: F = Frequency; P = Percentage
Source: Authors' Field Survey (2024)

4.4 Reasons for the Consumption of Sachet Water

The reasons for the consumption of sachet water in the study area are presented in Table 4. The highest ranking reason for the consumption of sachet water in the study area is its availability with a mean score or 4.11. Similar result was reported in the studies of sachet water consumption in urban areas of Nigeria and Liberia by Omalu *et al.* (2010) and Apeh (2018). This was closely followed by affordability as the second most important reason for sachet water consumption with a mean score of 3.93. In a similar study in Ogbomosho, Olaniyan *et al.* (2016) reported that people choose to consume sachet water because it is cheaper compared to other packaged potable water sources. Surprisingly, safety ranked 5th and lowest in the ranking of the reasons for the consumption of sachet water in the study area, implying that safety considerations played insignificant role in the choice of sachet water for the consumers.

Table 4: Reasons for the consumption of sachet water

Reason	Rank	Mean ()	Standard deviation
Availability	1st	4.11*	0.83
Affordability	4th	3.93*	1.22
Quality	3rd	3.78*	1.82
Accessibility	2nd	3.59*	1.60
Safety	5th	2.97	0.94

Source: Authors' Field Survey (2024)

4.5 Methods of Sachet Water Disposal Adopted

Owing to its considerable non-biodegradable nature, sachet water waste disposal methods are of utmost importance. The methods of sachet water waste disposal adopted in Wushishi is presented in Table 5. The result shows that the sachet water waste disposal methods Adopted in the study area are largely unsustainable because of their environmentally unfriendly nature. For instance, open dumping ranked 1st among the methods used in disposing sachet water wastes in the study area with a mean score of 4.12; dumping in waste bins ranked 2nd with a mean score of 3.99; open burning ranked 3rd with a mean score of 3.90; throwing inside bushed ranked 4th with a mean score of 3.43; dumping in gutters ranked 5th with a mean score of 3.08, and other dumping methods ranked 6th with a mean score of 3.05. Similar results were reported by Audu and Nuhu (2019) in their study of Potiskum, Nigeria. Sadly, all of these disposal methods are proven to be environmentally unfriendly and unsustainable.

Table 5: Methods of sachet water disposal adopted

Method	Rank	Mean	Standard deviation
Open dumping	1st	4.12*	1.34
Dumping in waste bins	2nd	3.99*	1.46
Open burning	3rd	3.90*	1.38
Throwing inside bushes	4th	3.43*	1.30
Dumping in gutters	5th	3.08*	1.40
Other dumping methods	6th	3.05*	1.28
Controlled incineration	7th	2.82	1.54
Burying in refuse pits	8th	2.61	1.57

Source: Authors' Field Survey (2024)

5.0 CONCLUSION AND RECOMMENDATIONS

Sachet water wastes constitute a considerable proportion of the total solid wastes generated in urban areas. Yet, studies that specifically address the issue of sachet water was in urban and suburban areas in North-Central Nigeria in general and Niger State in Particular are relatively scarce. This is particularly so in Wushishi where this study was conducted.

This study shows that, unlike elsewhere, the average sachet water consumption per capita per day in Wushishi is five sachets. This study have been able to establish that sachet water wastes have consumed a vast mass of land in the study area, and will continue to spread its limit if the problem of sachet water waste generation and management is not adequately addressed. In addition, the study hints at the possibility of the sachet water wastes in the study area affecting the ecological footprint of the town. Furthermore, the study shows that the residents of the town perceived sachet water wastes in the study area as capable of causing health and safety challenges. Surprisingly, the study shows that safety was the least reason considered by the residents of Wushishi in the choice of sachet water that they consume. Finally, the sachet water waste disposal methods in the study area were largely environmentally unfriendly and unsustainable.

The study therefore recommends that the residents should be enlightened on the need for adequate water consumption in line with established global standards and the effects of inadequate water consumption. Similarly, the study suggests that the local government authority, non-governmental organisations in the town and well-meaning individuals should form a public-private partnership network in order to create a sustainable waste disposal and management system for the town. The wastes in this designated location can be recycled in line with the waste to wealth and zero waste principles. In addition, the designated waste collection/disposal and management spot should be subjected to periodic fumigation to curb the development and spread of disease pathogens. Lastly, this study examined the effects of sachet water wastes on the environment. Further studies are required to establish the economic and social impacts of sachet water production on the one hand, and its waste on the other.

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EFFECTS OF ROCK BLASTING ON ENVIRONMENT AND HEALTH OF RESIDENTS IN OBAGUN AND ENVIRONS

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Abstract

The study examines the effect of rock blasting on surrounding residents of Obaagun and environs. The study examine the methods of mining and ore extraction are employed by miners in Obagun, examine the effects of these methods on the environment, assess the health effects of mining on the people living in the area, suggest measures in reducing the environmental and health effects of mining activities on the people

There is only one quarry site. Using Rasta map, the quarry site will be at the centre and four perimeter circular zones were established marking the ones that are 5km,10km, 15km and 20km radius close to the quarry site. The number of houses found within each of the four radii zones forms the size of sample for the questionnaire survey. The first sample in each radius was the first house after which other houses were selected at interval of 1. Hence a total of 120 houses were sampled and an adult representative responded to the questionnaire. Correlation analysis was used to test the relationship between quarry site proximity and residents' liveability. The research revealed that there are frequent rock blasting in the quarry site which causes both environmental and health effects. Environmental effects such as land degradation and pollution of various forms (that is, Air and noise), and vibration in the surrounding communities of Obaagun quarry site are associated with rock blasting from the site. Land degradation has resulted mainly from surface (open pit) mining with the use of heavy machines, toxic chemicals and creation of tailings dams. In order to minimize the effect of ground vibration, blasting parameters like burden, spacing, hole diameter, sub-drilling etc. must be properly designed. Blast design using proper delay patterns and proper powder factor must be chosen.

Keywords: *Rock blasting, Health, Residential, Environment*

1. Introduction

Suspended particulate matter may be affecting more people globally than any other pollutants on a continuous basis (Alloway and Ayres, 2015). Going by epidemiological studies, a dose-response relationship between exposure to PM10 and respiratory morbidity and mortality are established (Deborah, 2016). Likewise is the role of Particulate Matter (PM) in the causation of asthma, lung cancer, cardiovascular issues, and premature death. Even at relatively low concentration (not exceeding standard guideline of 150ug/m^3 for 24 hours), inhalable particulate matter (PM10) have adverse effects on human health. Indeed, an increase of 50mg/m3 in particulates levels is shown to induce increase death rate from 2 to 8 percent in several countries (Bart, 2013). Supporting this particulate level and health relationship, WHO (1994) indicated that daily mortality rates would increase by 20 percent with an increase of particulate level to 200mg/m3. A report by the Environmental Working Group in California showed that respiratory illnesses caused by particulate matter are responsible for more than 10,000 deaths and 16,000 hospital admissions. The health care cost of these illnesses was put at $132 million, in addition to millions of missed work days and school absences each year (Deborah, 2016; Douglas, 2016).

Moreover, it investigated the prevalent health problems suffered by quarry workers and residents of nearby communities. Finally, it assessed the awareness of the negative impacts of living in close proximity to quarry sites among the residents. The surface mining method involves removing the top soil up to the bedrock, which bears the gold. Heavy machines are used for this purpose. Concessions are therefore made bare and devoid of vegetation. The use of heavy machines and chemicals underground do not only cause instability within the earth crust but also underground water which serves as source of water to various waterbodies in the area are affected by infiltration of toxic materials (Dockery, 2014).

In addition, dynamite is used to blast the large rocks to aid excavation of the area where gold is extracted. The loud noise and the vibrations from the blasts have affected people within the surrounding communities very much. Buildings of the indigenes have cracked whereas those very close to the mining sites suffer much from breaking of glasses and other glasswares in their homes. Added to this is the shock being experienced by the inhabitants. Cyanide (potassium cyanide), a poisonous chemical, is used to recover gold from the ore, and in the process some spillages occur resulting in drainage (of cyanide) into the nearby streams. This causes aquatic life loss, as these chemicals are highly toxic. It also seeps down into the soil causing plant roots to die. For instance, there was a tailing treatment dam failure at Kokoteasua in 2005 alledged to have been caused by illegal activities of 'galamseyers' two years ago. This resulted in the spillage of tailings materials into the external environment, thereby, affecting surrounding downstream communities of Kokoteasua, Abompekrom and Nkamprom (Enger and Smith, 2012).

Undoubtedly, it is evident that streams and rivers where these chemicals and toxic materials drain into serve the villages and towns along them. Consequently, their drinking water is poisoned, causing morbidity and mortality conditions among residents. During 2005, according to the annual report of the company, 17,460 cases of malaria were reported amongst its employees, reflecting a malaria lost-time injury frequency rate (MLTIFR) of 721.7 per million man-hours (HEI, 2015). This was one of the indirect effects of the mining activities.

These environmental and health effects of mining activities have been attracting attention recently, hence, need to be addressed. Although, the mining company is believed to have made steps to improve health conditions of residents within the surrounding communities, however, the extent to which these efforts are reducing the negative environmental and health impacts is yet to be established. Therefore, this study assesses the impact of rock blasting on residents of Obaagun and environs

2. Aim and Objectives

The main of this study is to examine the effect of rock blasting on surrounding residents of Obaagun and environs. The objectives are

- To examine the locational characteristic of quarry in Obagun
- To examine the environmental effects of the quarry site
- To know the health effects of quarry site on the people living in the area
- To suggest measures in reducing the environmental and health effects of mining activities on the people

3. JUSTIFICATION AND SIGNIFICANCE OF THE STUDY

Mining activities are indispensable in the economic development of any country endowed with mineral resources. This is due to the economic benefits that are made available to countries that are involved in the extraction of mineral resources, both internal and external. Internally, there is the creation of employment and revenue generation. Externally, a substantial foreign exchange is available to such countries.

Acknowledging the economic contributions of mining, however, several economies lost sight of environmental and health effects associated with mining activities. Researches that have been undertaken lately to look into the environmental and health effects of mining have found mining activities to be more hazardous to economic development than a blessing. Accordingly, several mining companies in the country claim to have responded to this by instituting and implementing several measures to reduce the negative environmental and health effects of their activities on the people. Whether some of these measures have or are capable of reducing the negative health impacts of mining on the environment and surrounding communities is a matter of great concern.

The significance of this research work lies in the fact that it seeks to undertake a thorough and broader outlook into the environmental and health effects of mining on surrounding communities, both negative and positive, and recommend policy directives to reducing the rate of hazardous health effects of the mining activities that may be identified in Obagun and environ Findings and recommendations will serve as guide to other mining companies in the country.

4. Materials and Methods

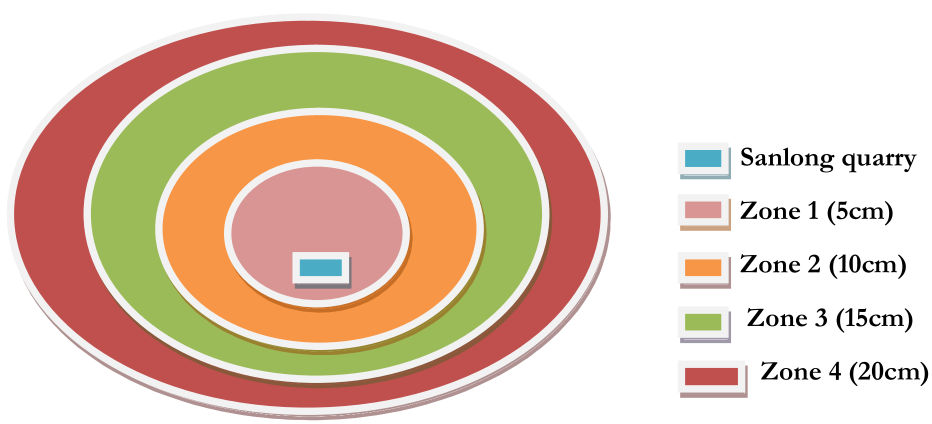
In Obaagun, there is only one quarry site. Using Rasta map, the quarry site will be at the centre and four perimeter circular zones were established marking the ones that are 5km, 15km and 20km radius close to the quarry site. The number of houses found within each of the four radii zones forms the size of sample for the questionnaire survey. The first sample in each radius was the first house after which other houses were selected at interval of 1. Hence a total of 120 houses were sampled and an adult representative responded to the questionnaire.

Table 1: Selected samples

Distances	Number of houses	Number of questionnaire
5cm	**33**	**33**
10cm	**36**	**36**
15cm	**31**	**31**
20cm	**20**	**20**
Total	**120**	**120**

Source: Author's Computation 2024

Figure 1: The demarcated radius for the questionnaire administration



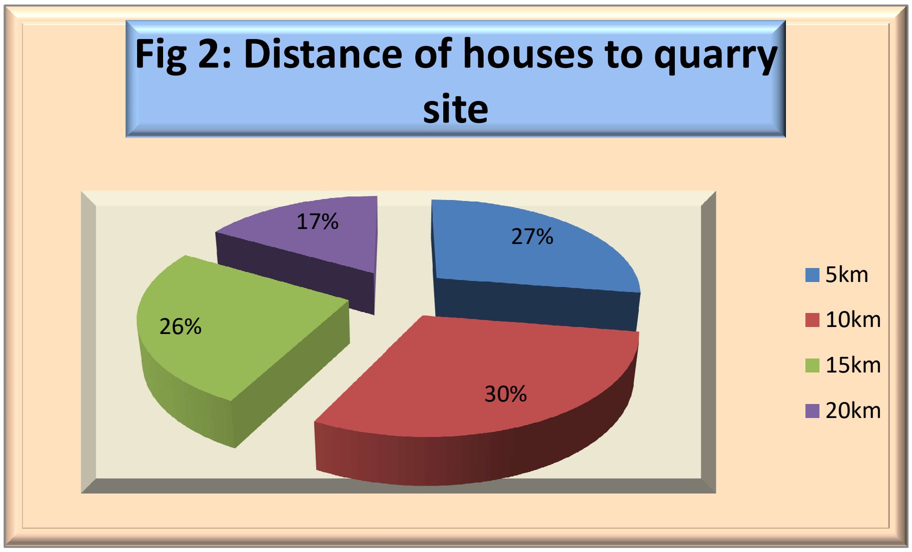
Source: Author's device (2024)

5. Results and Discussion

A. LOCATION CHARACTERISTICS

Distances of houses to quarry site

Fig 2 shows the distance of houses to quarry site and it shows that most of the houses are located very near to the quarry site. This means that they do not maintain the minimum standard setback as proposed by WHO. This implies that houses at closer range might be at risk.



Source: author fieldwork 2024

Table 1, presents the result of the chi square tests that explains the difference in location characteristics among the areas sampled. It can be seen here that there is significant difference between the distance of house of respondent, and area desirability of respondent to quarry site.

Table 1: X^2 Table of Difference in quarry Location Characteristics

Characteristics	X^2 value	P value	Remark
House distance to quarry	1.990	.000	Significant
Area desirability	2.525	.000	Significant

Source: author fieldwork 2024

B. Length of Stay in the Area

It is evident from table 2 that those who have stayed relatively longer period within the quarry area gave a hundred percent attestation that the quarry site affect the environment compared to those who have stayed for relatively shorter period

Table 2: Years of staying in the town

Years	Frequency	Percentage
1-4	33	27.5
5-8	18	15
8-12	32	26.6
Above 12 years	37	30.9

Source: author fieldwork 2024

C. Rock Blasting and Effects

Existence of problem

Table 3 shows that houses that are very close to quarry site are not secured from the noise generated and vibration from the site. This might therefore have some health related diseases attached to the noise intensity and vibration especially at night.

Table 3: existence of problem

Problem	Existence	Zones			
		5cm	**10cm**	**15cm**	**20cm**
Noise pollution	**Yes**	81.1	88.6	61.7	60.0
	No	18.9	11.4	38.3	40.0
Water contamination	**Yes**	92.5	87.1	48.9	45.2
	No	7.5	12.9	51.1	54.8
Vibration	**Yes**	84.9	70.0	34.0	38.7
	No	15.1	30.0	66.0	61.3
Flooding	**Yes**	96.2	97.1	83.0	45.2
	No	3.8	2.9	17.0	54.8
Accident	**Yes**	92.5	87.1	48.9	45.2
	No	7.5	12.9	51.1	54.8

Source: author fieldwork 2024

Problem from quarry site in relation to house distance

Table 4, presents the result of the chi square tests that explains the difference in the significance of problem among the zones. It can be seen here that there is significant difference between all the problems among the zones.

Table 4: X² of Significance of the Problem from quarry site In Relation To House Distances

Problem	T value	P value	Remark
Noise pollution	89.948	.000	Significant
Water contamination	74.759	.000	Significant
vibration	65.200	.000	Significant
flooding	73.140	.000	Significant

Source: author fieldwork 2024

Effects of rock blasting

Table 5 shows the scaled severity of disease and this was done by making use of likhert scale. The level of significance for each problem which was very significant, significant, just significant and not significant was rated 4,3,2,and 1 respectively for instance, very significant (4), significant (3), just significant (2), not significant (1). The rating was used to multiply the frequency of each problem and diseases according to each zone. It was deduced from the table that the higher the figure, the higher the higher the severity of the problem and diseases in the zones and the lower the figure, the lower the severity of the problems and diseases in the zone.

Table 5: Scaled severity of problem and diseases

Scaled severity of problems				
Problem	5cm	10cm	15cm	20cm
Noise	178	329	114	23
Water contamination	174	210	56	27
Vibration	125	144	62	30
Flooding	114	109	45	48
Health effect: Scaled Severity of diseases				
Disease	5km	10km	15km	20km
Asthma	91	124	83	29
Headache	215	186	116	37
Insomnia	228	168	112	56
Hearing loss	127	137	55	30
Water borne diseases	110	112	53	23
Hypertension	86	80	45	30
Cancer	97	154	95	32
Environmental effect: Scaled incidence of environmental problem				
Problem	5km	10km	15km	20km

Property value decline	210	190	100	54
Increased traffic	133	156	64	28
Community disruption	120	116	72	34
Loss of biodiversity	98	99	55	28

Source: author fieldwork 2024

Pearson Correlation of the Relationship between Resident's Health and Closeness to Mast

This is also used to test the hypothesis "there is no relationship between resident's closeness to quarry and their health" whether it is significant or not.

A Pearson correlation coefficient was used on thirteen variables relates to quarry and to find out whether there was any significant relation between the variables in each area. Probably, the relationship that commands the greatest attention is the length of stay with quarry, the distance of house from quarry and severity of diseases. The correlation shows that the relationship between % of respondent living with quarry between 11-15 yrs and severity of asthma is significant at 0.05 levels with P value 0.041. This implies that there is low +ve correlation between the length of stay and severity of asthma. Therefore, as the length of stay increases, asthma reduces. Also the correlation shows that the relationship between % of respondent living with quarry between 15 above and severity of asthma is significant at 0.05 levels with P value 0.016. This implies that there is little or no correlation between the length of stay and severity of asthma. Therefore, as the length of stay increases, asthma increases.

In summary, the multivariate analysis shows that there is strong relationship between the distance of quarry site, length of stay with quarry site and severity in diseases related with quarry site.

Table 6: Pearson correlation

A	I	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
X1	PC	1												
	PV													
X2	PC	.292	1											
	PV	.357												
X3	PC	.142	-.086	1										
	PV	.660	.790											
X4	PC	.102	.213	.902*	1									
	PV	.753	.506	.000										
X5	PC	-.385	-.523	.274	.320	1								
	PV	.217	.081	.388	.311									
X6	PC	-.228	.037	.423	.446	.058	1							

	PV	.476	.909	.171	.146	.857								
X7	PC	.103	.138	.301	.385	.140	.598*	1						
	PV	.751	.669	.342	.217	.665	.040							
X8	PC	.134	.465	.109	.153	.633*	.318		1					
	PV	.679	.128	.737	.634	.027	.313							
X9	PC	.304	.092	.762*	.730*	.137	.375	.531	.378	1				
	PV	336	.777	.004	.007	.671	.229	.076	.225					
X10	PC	.189	.038	.005	-.064	-.080	-.052	-.155	.231	.163	1			
	PV	.557	.907	.987	.843	.805	.872	.631	.470	.614				
X11	PC	.047	-.022	.178	.244	.325	-.090	.453	-.263	.150	-.675*	1		
	PV	.885	.947	.579	.445	.302	.780	.140	.409	.641	.016			
X12	PC	-.596*	.090	-.499	-.387	-.146	.059	-.387	.093	-.507	.015	-.602*	1	
	PV	.041	.780	.098	.214	.650	.855	.214	.774	.093	.964	.038		
X13	PC	.676*	-.155	.474	.241	-.294	.136	-.058	.086	.357	.121	-.155	-.508	1
	PV	.016	.631	.120	.450	.354	.674	.858	.791	.255	.708	.631	.092	

Where X1= severity of Asthma, X2= severity of Headache, X3= severity of Insomnia, X4= severity of hearing loss, X5= severity of water borne diseases, X6= severity of hypertension, X7= severity of cancer, X8= severity of respiratory diseases, X9= scaled house distance to quarry, X10= % respondent who stayed <5yrs with quarry, X11= % respondent who stayed 5-10yrs with quarry, X12= % respondent who stayed 11-15yrs with quarry, X13=% respondent who stayed >15yrs with quarry A= variable

Source: author fieldwork 2024

6. Summary of research findings

The research examined the rock blasting in quarry site of Obaagun and their environmental and health effects on the surrounding communities. The research revealed that there are frequent rock blasting in the quarry site which causes both environmental and health effects.

Environmental effects such as land degradation and pollution of various forms (that is, Air and noise), and vibration in the surrounding communities of Obaagun quarry site are associated with rock blasting from the site. Land degradation has resulted mainly from surface (open pit) mining with the use of heavy machines, toxic chemicals and creation of tailings dams.

Air pollution has emanated from emission of dust and other particles into the air, emission of chemicals such as carbon, sulphur, arsenic from processing plants. Noise and vibrations are essentially, the effects of blasting of rocks with explosives from both surface and underground mines.

Associated health effects of blasting activities are also remarkable. The research revealed that high prevalent rate of diseases such as high blood pressure, headache, and insomnia among residents were direct and indirect effects of blasting activities.

7. Conclusion

Ground vibration is one of the environmental challenges of blasting operation in quarries. Shock wave is the most common effect of ground vibration; its impact is felt in all the study.

Noise generated by ground vibration is perceived to be high in the study area. The occurrence of other issues such as: blown roof, wall crack, window shatter and landslide are generally low in all the study areas. Most of those who are seriously affected by the negative effects of ground vibration are those who reside less than 10km away from the quarry site.

8. Recommendations

In order to minimize the effect of ground vibration, blasting parameters like burden, spacing, hole diameter, sub-drilling etc. must be properly designed. Blast design using proper delay patterns and proper powder factor must be chosen. The impact of ground vibration will be reduced if blasting is carried out during periods of high local activity such as the noon hour, blasting during quiet periods should be avoided. Good public relation is also very important if the operator wants to live in harmony with neighbours. Government and appropriate regulatory bodies should formulate and implement policies on standard blasting practices and monitoring team should be commissioned to penalize defaulters.

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Compressive Strength of Slag-Based Geopolymer Concrete Incorporated with Nigeria Rice Husk Ash

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Abstract

This research investigates the compressive strength of slag-based geopolymer concrete incorporated with Rice husk ash as a sustainable construction material and in reducing Portland cement consumption. Geopolymer concrete will also reduce global warming due to emission of Carbon-monoxide during cement production process. The principal materials used were; Ground granulated blast furnace slag (GGBS) as base material and Rice husk ash (RHA) as supplementary cementitious material; sodium silicate gel (Na_2SiO_3) and sodium hydroxide (NaOH) solutions of 12 molar concentration as an alkaline activator. A designed mix of 50Mpa concrete was used in line with American Concrete Institute (ACI) guidelines. The substitution levels of 100, 75, 50, 25 and 0%(GGBS) and 0, 25, 50, 75 and 100% (RHA) were used to produce the geopolymer mixes, Thermal curing was done at a temperature of 60-80℃ in an oven for approximately 24hrs. After 7 and 28 days, the compressive strength of the hardened samples was the determined. The findings reveal an optimal substitution level of 50% GGBS and 50% RHA with compressive strength of 44.23 MPa, compared to the c control mix with measured strength of 43.48 MPa at 28days hydration period. Conclusively, the utilisation of GGBS-based geopolymer concrete is suitable for engineering construction and provide several benefits of improved strength and durability, better workability and reduced environmental impact.

Key words: Compressive Strength, geopolymer concrete, ground granulated blast furnace slag, Rice husk ash, sodium silicate gel and sodium hydroxide.

1.0 Introduction

Recent researches on utilisation of agricultural and industrial wastes have proven the feasibility of cement replacement by these wastes in concrete design (Buari et al., 2019). Geopolymer concrete (GPC) is one of the successful outcomes of blended concrete with reduction of cement consumption in concrete production (Yip et al., 2005; Yip et al., 2008; Ramani et al., 2015; Ismail et al., 2014). The term 'geo-polymer' is a compound of mineral binders that can be formed by the polymerization reaction of silicon (Si) and aluminum (Al) in an alkaline liquid source material. According to Davisovits (2011), these materials resemble zeolites chemically and have an amorphous microstructure. When geopolymer concrete is polymerized, a three-dimensional polymeric ring structure of Si-O-Al-O links is produced with a relatively quick chemical reaction. Materials sources determined the properties of Geopolymers. Various researchers have worked on best ways of producing concretes that are sustainable and can reduce environmental hazards and global warming. Buari et al., (2019), Olutoge et al., (2013), Ademola et al., 2013 designed different types of concretes with view of utilisation of Groundnut Shell Ash in reducing environmental hazard from continuous dumping of shells in the producing areas.

Prabu et al., (2014), Das et al., (2018) and Venkatesan and Pazhani (2016) designed geopolymer concretes with various cementitious materials. In their findings, geopolymer concrete is durable due to presence of cementitious paste made from alkaline solutions and geologically sourced materials which usually prevent concrete cracking and corrosion. In today's world, ground granulated blast furnace slag, or GGBS, is a very popular by-product that is frequently used as cementitious material. It is created by pouring molten slag straight from a blast furnace into a pit filled with steam or water, or both. This produces a glassy granular material that may be ground into a fine powder by quenching the slag (Prabu et al., 2014). Studies have shown that the incorporation of RHA in geopolymer concrete can result in flexural strength, compressive strength and splitting tensile strength increase. RHA can also improve the workability and reduce the setting time of the geopolymer concrete mixture. Das et al., (2018) explained in his finding that RHA is a suitable cementitious material in design of geopolymer concrete in addition to GGBS. The substitution levels adopted in this research was based on similar researches on design of geopolymer concrete by Prabu et al., (2014) and Das et al., (2018) with 10% - 20% of RHA replacement. Their findings indicated a retarding effect on the compressive strength of the specimen at 10% substitution level compared to control sample. However, at 20% substitution, the target strength of 50 MPa was exceeded at 28 days hydration period by 2%. It was also concluded that rice husk blended geopolymer concrete has lower workability at fresh state compared with fly ash replacement. Thus, rice husk ash has proven to have a very low workability and this is the reason for addition of chemical admixtures (such as plasticizer) which are commonly used to enhance concrete workability. Similarly, Venkatesan and Pazhani (2016) study GGBS blended geopolymer concrete with black rice husk ash (BRHA) substituted at 10, 20 and 30%. The results showed that an increase in curing temperature increased the strength of the geopolymer concrete. It was also found that with the addition of the BRHA beyond 10%, the strength development was stunted; though up to the 20% replacement levels, the strengths were seen to surpass the target. The compressive strength of PLC and GPC both depend on substitution level and hydration periods, mode of curing and environmental conditions. Concrete maximum strength development is usually attained at approximately 28 days hydration period with around 65-75% of concrete strength attained at 7 days hydration period, depending on the class of cementitious materials.

Hydration is an essential part of concrete development process and it allow the matrix of the concrete to crystalize for internal bonds development. The curing process for the attainment of optimum strength in blended concretes has been established to be different from conventional concrete. The findings of Kumar et al., (2014) and Singh et al. (2015), indicated that higher temperature is required to obtain optimum compressive strength of Geopolymer concrete. For above reasons, there is need to further studied the effects of RHA and its substitutions levels for optimum strength of slag-based geopolymer concrete. The main and justifiable reasons for this research also include the limited Literature on design of slag-based geopolymer concrete incorporated with Rice husk ash as Supplementary Cementitious Material and the Need to effectively utilize agricultural and industrial wastes incorporated geopolymer concrete for structural application in engineering in Nigeria

2.0 Method and Materials

Sodium hydroxide (NaOH), sodium silicate (Na2SiO3), aggregates, Portland limestone cement, ground granulated blast furnace slag, rice husk ash, and clean water for mixing and curing were the ingredients used in the experiment. The rice husk utilized in this study was procured from Yala in Cross River State. Rice husk was burned for three hours at 650 degrees Celsius in an electrical furnace to produce the ash that was used. Specimens of geopolymer concrete were thermally cured for around 24 hours at 60°C in an oven. The Department of Civil Engineering, Faculty of Technology, University of Ibadan, Nigeria's laboratory was used to conducted an experimental analysis on physical and chemical properties of RHA and GGBS samples, and aggregates were well graded. Tables 1.0, 2.0, and 3.0 display, respectively, the mix designs and the results of the physical and chemical properties of all the components utilized. For the experiment, pure river sand with a maximum diameter of 4.75 mm and granite stone with a maximum diameter of 19 mm that is devoid of harmful elements were utilized. By keeping aggregates from becoming overly moist, the rise in water content in the concrete mix was avoided. Portland limestone cement that conforms to type1 cement as specified by (BS 1881, 1983; BS12, 1978) were used as a major binder. Various trial mixes were performed until the target strength of 50MPa obtained. Standard methods were employed in determining all materials properties in this research.

Table 1.0: Materials Quantities used in mixes 1 – 5, per 100mm cube.

Sample Design.	Material Contents. [%]	Coarse Aggregates. [Kg]	Fine Aggregates. [Kg]	GGBS. [%]	RHA. [%]	GGBFS. [Kg]	RHA. [Kg]	NaOH. Solution. [ml]	Na_2SiO_3. Solution. [ml]
Mix 1	100% GGBS and 0% RHA	1	0.8	100	0	0.4	0	57	143
Mix 2	75% GGBS and 25% RHA	1	0.8	75	25	0.3	0.04	57	143
Mix 3	50% GGBS and 50% RHA	1	0.8	50	50	0.2	0.07	57	143
Mix 4	25% GGBS and 75% RHA	1	0.8	25	75	0.1	0.11	57	143
Mix 5	0% GGBS and 100% RHA	1	0.8	0	100	0	0.15	57	143

Source: Laboratory Analysis, 2023.

Table 2.0: Physical properties of materials used

Property	Coarse aggregate.	Fine aggregate.	GGBS.	OPC.
size (mm)	19.00	4.5	4.5	-
Water absorption (%)	0.39	1.14	0.21	-
Specific gravity	2.59	2.21	2.91	3.12
Fineness modulus	6.21	2.27	1.19	
Colour			Grey	Grey
Passed on a 45-µm (No. 325) sieve (%)			100	99

Source: Laboratory Analysis, 2023

Table 3.0: Chemical compositions of materials used for experimental work

Major Oxide. Composition.	%Composition. of OPC	%Composition. of GGBS
Ferrous oxide (Fe_2O_3)	3.89	0.40
Silica (SiO_2)	20. 70	35.44
Calcium Oxide (CaO)	62.84	40.49
Aluminum Oxide (Al_2O_3)	4.78	13.10
MagnesiumOxide (MgO)	2.08	8.00

Sodium Oxide (Na_2O)	0.37	……
Potassium Oxide (K_2O)	0.38	……
Mn2O3	……	0.63
Sulphite (SO_3-)	1.45	0.51
LOI	2.80	1.28

Source: Laboratory Analysis, 2023.

3.0 Result and Discussion

3.1 Compressive strength

The compressive strength determination was carried as specified by (ASTM C39-96 1998; Rathod and Mahure 2016) and the results of various hydration periods are presented in tables 4.0 and figures 1.0 below. The result of the compressive strength test after 7-days hydration periods on control mix of OPC based geo-polymer concrete indicate an average compressive strength of 33.08 MPa. The result of the compressive strength test on GPC mixes 1-5, the average compressive strengths obtained were 47.16 MPa, 40.61 MPa, 44.23 MPa, 34.05 MPa and 23.14 MPa, respectively after 28days hydration period. However, for 100% RHA concrete specimens, after a 72-hour resting period, the specimens collapsed upon demolding. In attempt to prevent this collapse, these 100% RHA specimens were thermally cured for approximately 48 hours before demolding, which was highly successful. Not only did the specimen bind fully, they achieved an average compressive strength of 23.14 MPa. Venkatesan et al. (2016) explained that the dry weather condition, wet atmospheric condition of 15°C increases the strength of geo-polymer concrete after 360day hydration period. Therefore, the hydration periods and environmental conditions to which the geo-polymer concrete is exposed, determined its compressive strength development. At the same time, the high rate of increase in compressive strength diminished with time (Das et al.,2018).The result in table 4.0 also revealed that the slag-rice husk ash-based geopolymer attained its optimum compressive strength at 50% RHA and 50% GGBS substitutions level. Therefore, a geopolymer concrete mix containing 50% RHA, 50% GGBS at 12M alkaline solution is the ideal mix design for the slag-based geo-polymer concrete production.

Table 4: Compressive Strength of Geopolymer concrete specimens

Samples	Samples composition.	Compressive Strength. [MPa]	
		7days	28days
Mix 1	100% GGBS and 0% RHA	33.08	47.16
Mix 2	75% GGBS and 25% RHA	30.27	40.61
Mix 3	50% GGBS and 50% RHA	30.17	44.23
Mix 4	25% GGBS and 75% RHA	21.81	34.05
Mix 5	0% GGBS and 100% RHA	15.67	23.14

Source: Laboratory Analysis, 2023.

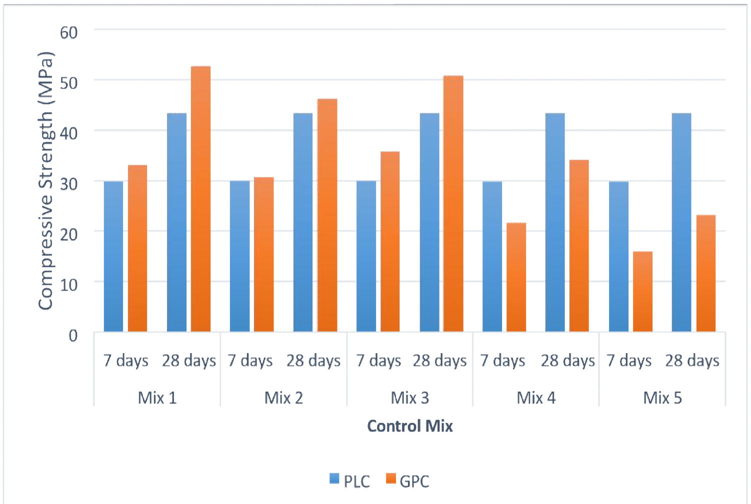

Fig. 1.0. Compressive Strengths of Control Mix & GPC Mixes the at 7 and 28 days

4.0 Conclusion

The results of this research after 28-day curing periods indicated that the compressive strength of control specimen was obtained to be 43.40 MPa whereas the geopolymer concrete mix had a compressive strength value of 44.23 MPa with 2.1% strength increase. This result was obtained at the optimal cementitious substitution levels of 50% GGBS – 50% RHA with the densities of all samples (modified and control) are within the range of 2200-2600kg/m^3. Thus, this leads to the conclusion that using a GGBS-based geopolymer concrete is suitable for engineering construction and provide several benefits of improved strength and durability, better workability and reduced environmental impact.

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Off-Site Construction Practices and Expansion Strategies for Sustainable Building Infrastructure in Lagos, Nigeria

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Abstract

Off-site construction offers scalable solutions to affordable, cleaner, more resilient building infrastructure. An active practice of off-site construction activities constitutes a construction sustainability approach to meet the rising building infrastructure demands in Nigeria. This study investigated the off-site construction activities that are applicable to building infrastructure delivery in Nigeria, particularly Lagos State; assessed the influence of the activities on infrastructure projects delivery; evaluated the factors that influence the practices; and examined the strategies for off-site-activities expansion for building infrastructure delivery. A questionnaire survey approach was adopted to obtain information from purposively sampled building professionals from construction firms that have hand-on experience on off-site construction. The data obtained was analyzed using descriptive and inferential statistics. Findings from the study established twenty-one off-site construction practices that are applicable to sustainable construction in Nigeria. Up to twenty (20) expansion strategies were statistically established to facilitate augmented practice of off-site construction in the country. The study contributes to the body of knowledge on the off-site construction practices that are applicable to construction sustainability for carbon footprint reduction, environmental impact reduction, and resource efficiency for building infrastructure delivery in Nigeria.

Keywords: Off-site Activities, Sustainable Development, Pre-fabrication, Waste Management, Energy Efficiency, Carbon reduction

1. Introduction

Nigeria is experiencing significant infrastructure expansion from rapid urbanization, particularly in Lagos (Owolabi, 2019). Increasing demand for timely and cost-effective delivery of building infrastructure projects has thus become intensified (Habitat for Humanity, 2022). Incorporating the innovative approach of off-site construction practices in the project delivery process is deemed significant in complementing the prevalent conventional delivery method, to meet the demands. Off-site construction (OC) is an established construction practice in the United Kingdom, the United States, Japan, and other Nordic countries, for delivering more efficient building infrastructure with improved quality, and at reduced construction waste generation (Hui & Li, 2021; Liu *et al.,* 2021). Up to 90% construction site waste reduction is achievable with OC practices when compared with the conventional practices (Nanyam *et al*., 2017).

Studies established the capacity of OC practices in producing building components, structures, and systems that are structurally sound, aesthetically appealing, environmentally friendly, and cost effective, for timely delivery of building infrastructure (Li *et al*., 2020; Weng & Lin, 2019). Liu *et al.* (2021) described OC as a process of constructing building components and structures at a separate location, i.e. a factory or workshop or other controlled setting, away from the construction site for improved quality control, efficiency, and waste reduction. Such OC practices include prefabrication, modular construction, off-site manufacturing, etc. (Ibem *et al*., 2020; Ogunsemi & Jagboro, 2015). Through the prefabrication process, building components like walls, floors, columns, beams, and steel truss are manufactured at a factory and transported to the construction site for installation (Filho et al., 2020; Weng & Lin, 2019). Pre-built modules are created by modular construction process, which when assembled on the constructure site produces an entire building structure (Burry & Burry, 2019). Similarly, 3D printing is an advanced off-site manufacturing technique for producing building components and building structures (Opawole *et al*, 2022). Thus, it is established that OC practices employ the integrated design, procurement and administration management system in delivering building projects on time, by using appropriate supply chain management techniques and materials in creating off-site components or panels (Khan *et al.,* 2021; Odeyinka *et al.,* 2020). Technological advancements with innovations from Building Information Modelling (BIM), for example, facilitate the integrated system approach of OC practices (Eastman *et al*., 2011).

While off-site construction is a modern construction method with vast capacity to facilitate construction sustainability in the accelerated delivery of greater quantity of building infrastructure in Nigeria, its active practice in the building sector cannot be overemphasized (Rahimian et al., 2017). Notwithstanding the derived benefits of sustainable development from the practice, entirely all stakeholders in the construction industry stand to benefit from the collective practice of OC in the country (Ohaneme & Agunanne, 2018). Several local studies have explored the techniques of OC and established its low level of practice in the country despite its sustainable, process-based, and objective-based benefits (Afolabi *et al*., 2021; Abanda *et al*., 2020; Adedeji *et al*., 2020; Odeyinka *et al*., 2020; Rahimian *et al.,* 2017; Ogunseimi & Jagboro, 2015). Limited empirical evidence was provided by the studies on the strategies to widely diffuse OC in the Nigerian construction industry. This study therefore sought to empirically bridge the gap and update literature on OC practices in the country. The study investigated the off-site construction activities that are applicable to building infrastructure delivery in Nigeria, particularly Lagos State; assessed the influence of the activities on infrastructure projects delivery; evaluated the factors that influence the practices; and examined the strategies for off-site activities expansion for construction sustainability of building infrastructure development.

2. Previous Research

The urgency in meeting the increasing demand for housing, commercial, and institutional buildings (over 14-16 million housing deficit) through an augmented supply of building infrastructure that is affordable, more resilient, and adaptable to climate change are drivers for the diffusion of off-site construction practices in the country (Habitat for Humanity, 2022; Ohaneme & Agunanne, 2018). Off-site construction accelerates project timeline, enhance cost effectiveness, ensure consistent quality control in the production of building frames, steel trusses, curtain walls and cladding, electrical system, plumbing and mechanical systems, and concrete foundation (Love *et al*., 2019; Guzowski & Lownik, 2018).

Cheng *et al*. (2019) asserted that the controlled environment for OC facilitates adopting eco-friendly technologies of energy integration and waste management systems, which align with the growing demand for environmentally conscious construction approaches. OC offers environmental and social benefits, by generating reduced Greenhouse Gas (GHG) than the conventional construction (Pervez *et al*., 2021). Abdallah *et al*. (2021) emphasized that OC generates less waste and offers improved environmental safety from activities carried out in controlled settings. Chang and Leiringer (2018), however, asserted that the key activities of OC are what maximize construction process efficiency, infuse higher quality standards, enhance greater productivity, and foster sustainability of construction development while minimizing any disruptions and on-site construction risks. Bryde *et al*. (2020) added that OC activities facilitate the reduction of construction time, cost of labour, and material waste. Said *et al*. (2014) revealed the Modular Building Institute, MBI, (2010) statistics, that about 30-50% construction time is saved with OC when compared with the conventional construction. The innovations of OC provide solutions to the challenges of traditional on-site construction regarding skills shortages, construction delays, safety hazards, and pollution (Cao *et al*., 2021; Adeniran *et al*., 2015).

Notwithstanding the opportunities from OC, studies indicated that a perceived high initial cost of OC and its extensive manufacturing capacity requirements are critical factors challenging the adoption of OC practices in India, New Zealand, and Nigeria (Rahimian *et al*., 2017). However, studies argued that cost savings are recorded from OC regarding reduced requirements for preliminaries and site overhead, reduced risk and cost certainty, reduced construction time, and maintenance cost (Gibb & Pendlebury, 2006). Lacking regulatory framework and infrastructure, reluctance to technological adoption, strong cultural affiliation to traditional on-site construction by professionals and other stakeholders, absence of building codes and standards, and limited local skill sets available for OC were identified as challenges to the adoption of OC in developing countries, particularly Nigeria (Drew, 2020; Adeleke *et al*., 2019). The inadequate market supply of off-site building components by few manufacturing companies in Nigeria also constitutes a significant hindrance to the widespread practices of OC in the country (Ayininuola *et al*., 2021).

Niu *et al*. (2021) and O'Brien *et al*. (2019) summarized the challenges of the OC to such needs regarding specialized equipment, skilled labour, transportation logistics, policy and regulatory framework, and upfront costs of establishing an off-site manufacturing factor, which discourage companies' investment in OC practices. Choi *et al*. (2020), Abanda *et al*. (2020), and Cheung and Chan (2021) attributed the challenges of OC to safety risks, quality control and logistic issues. According to them, the use of heavy equipment for OC activities exposes workers to safety threats; meeting the required specifications and standards to fabricate components requires repeated testing and monitoring; and transportation of resources from the factory to the construction site may cause a downtime. Bennett *et al*. (2021) therefore suggested the need to give serious consideration to the good working condition of equipment, security of the site, allowing only adequately trained personnel to operate the equipment, and properly coordinating transportation with scheduled activities for OC construction activities.

Huang *et al*. (2020) opined that effective planning, coordination, and monitoring contribute to an overall infrastructure construction success with OC. World Bank Group, WBG, (2019) suggested that a clear and streamlined regulatory framework for construction environment and ease of obtaining construction permit are strategies to facilitate the adoption and implementation of OC in Nigeria. An efficient regulatory framework and government support are expedient to reduce uncertainty and promote investment in OC (Yu *et al*., 2020; Smith & Davies, 2018). Developing local off-site facilities, investing in infrastructure, creating effective awareness, embracing advanced technologies and innovative solutions, and integrating digital tools and automation in off-site construction are strategies for enhanced OC practices (Ma *et al*., 2022; Fai *et al*., 2017). By aligning with accelerated project timelines, cost efficiency, and quality control, OC demonstrates significant relevance to enhanced construction delivery (Li *et al*, 2018; Chan *et al*., 2017; Smith *et al.,* 2015). OC supports construction sustainability by material waste reduction, energy consumption minimization, and resources' use optimization. Therefore, a transformative intervention from collective adoption of OC by construction stakeholders in Nigeria constitutes a key shift to accelerate the SDG progress on sustainable cities and communities (SDG 11) and climate change (SDG 13).

3. Methodology

Using a quantitative research method, the study adopted an open-ended questionnaire survey on off-site construction practices for sustainable building infrastructure delivery in Nigeria. The survey was conducted on building professionals in Lagos because the majority of the building infrastructure construction activities are carried out in the city centers, and Lagos outstands other cities in Nigeria, being known for the most bustling construction activities and the hub of commercial activities in the country (Olojede, 2024; Egbo, 2022). The questionnaire was structured into two sections, with the first section tailored to obtain the demographic information about the respondents, while the second section explored the objectives of the study. The reviewed literature informed the basis for establishing the examined variables on the study's objectives regarding the applicable OC for building infrastructure delivery in Nigeria, the influence of the OC activities on infrastructure project delivery, the factors that influence the practices, and the strategies for the expansion of OC for construction sustainability of building infrastructure development.

The building professionals from construction firms in Lagos State were the target population for the study's survey. The in-depth understanding of the professionals and their active state of involvement on the OC is significant in justifying the authenticity of the expert judgment on the research instrument (Alsabbagh, 2019). The sampling frame was therefore guided by the outcome of the pilot survey on the construction firms having executed OC in Lagos, which generated the production of 70 copies of questionnaires. The questionnaires were administered to architects, builders, engineers, and quantity surveyors at the piloted firms. Fifty-one copies of the administered questionnaires were retrieved, which gave a retrieval rate of 73% (approximate).

The data obtained were analyzed by descriptive and inferential statistical tools of the Statistical Package for Social Science (SPSS), that is, IBM SPSS version 22. Frequency, mean score, percentage, and standard deviation were utilized for the descriptive analysis. Analysis of Variance (ANOVA) was employed for the inferential statistical analysis for the study. This aids in the establishment of the statistically significant differences between the means of the sampled group of professionals on their expert judgment on the research variables (Field, 2009). A significant value of $p < 0.05$ implies that there is a statistically significant difference in the group means, but a $p > 0.05$ implies that there exists no statistically significant difference in the group means.

4. Results and Discussion

4.1 Respondents' profile information

Table 1 displayed the general profile information of the respondents, indicating their professional affiliations and membership, designations, and years of work experience, among others. Up to 15.7% of the respondents were CEO/MDs, 21.6% were directors, 27.5% were managers, and 35.3% were senior personnels. The professional representations of the respondents were quantity surveyors (45.1%), engineers (25.5%), builders (15.7%), and architects (13.7%). Over 55% of the respondents were Bachelor of Science (BSc)/Bachelor of Technology (B.Tech.) degree holders from the various building construction professional disciplines. All of the professionals were members of their respective professional institutional bodies in the State. The professionals had approximately 14 years of work experience in off-site construction for building infrastructure delivery in Lagos. The professional information about the respondents supports the credibility of their expert judgment on the research instruments for the study.

Table 1. General Profile Information of the Respondents

Profile	Frequency	Percentage
Designation of the Respondent		
CEO/MD	8	15.7
Director	11	21.6
Manager	14	27.5
Senior Personnel	18	35.3
Professional Designation of the Respondent		
Architects	7	13.7
Quantity Surveyors	23	45.1
Engineers	13	25.5
Builders	8	15.7
Years of work experience		
1 - 10 years	25	49.0
11 - 20 years	13	25.5
21 - 30 years	7	13.7
31 - 40 years	6	11.8
Highest Academic Qualification of the Respondent		
HND	4	7.8
PGD	3	5.9
BSc/B.Tech.	28	54.9

MSc/MBA	9	17.6
PhD/M.Phil.	7	13.7
Professional Membership of the Respondent		
MNIA	7	13.7
MNIQS	23	45.1
MNSE	13	25.5
MNIOB	8	15.7
Total	51	100

4.2 Influence of OC activities on the delivery of building infrastructure

Table 2 presents the mean score of the OC activities that are relevant for the delivery of building infrastructure projects in Lagos. The mean score (MS) value was calculated based on the expression: $MS = \Sigma(f \times s)/N$ (Cheung et al., 2012), were "s" is the score rating for the OC activities, "f" is the frequency, and "N" is the total number of the responses on OC activities. The overall top five (5) high-ranking OC activities were prefabrication of steel structures, such as trusses and frames (MS = 4.04), manufacture of off-site energy systems, such as solar panels or wind turbines (MS = 3.65), off-site fabrication of structural steel stairs and handrails (MS = 3.65), preassembly of fire protection systems, such as fire sprinklers or fire alarms (MS = 3.65), and fabrication of custom woodwork and cabinetry (MS = 3.65). The last ranked overall five (5) OC were production of prefabricated wall panels with integrated insulation (MS = 3.41), production of prefabricated bathrooms or kitchens (MS = 3.41), off-site construction of pre-engineered metal buildings (MS = 3.41), production of modular buildings or building sections (MS = 3.29), and manufacture of precast concrete foundations or footings (MS = 3.29).

Further inferential analysis conducted using ANOVA to indicated the existence of statistically significant difference in the ranking of the off-site activities' relevance between the groups of the professionals. The result revealed no statistically significant differences in up to 20 ranked OC activities by the professionals ($p > 0.05$). This implied that there was no statistically significant difference in the perception of professionals on the OC activities (20 nos.) relevant to the delivery of building infrastructure projects in Lagos, Nigeria. There was however a statistically significant difference in the ranking of 'production of pre-insulated piping for plumbing and HVAC' ($p < 0.05$).

The study revealed that all the examined OC activities (21 nos.) are very relevant to the delivery of building infrastructure in Nigeria. This corroborated the claim by Weng and Lin (2019) that various off-site activities have significant contribution for enhancing the efficiency and sustainability of building infrastructure construction. Notably, the prefabrication of steel structures such as trusses and frames emerged as a key off-site activity in delivering building construction projects.

Nonetheless, the diverse perceptions of off-site activities among professions regarding 'production of pre-insulated piping for plumbing and HVAC' are attributable to various factors.

Table 2. Off-site construction activities relevant to the delivery of building infrastructure in Lagos, Nigeria

Off-site Construction	Overall		Architect		Quantity Surveyor		Engineer		Builder		ANOVA
	MS	R	MS	R	MS	R	MS	R	MS	R	*p*
Prefabrication of steel structures, such as trusses and frames	4.04	1	4.33	1	3.87	1	3.69	1	4.25	1	0.28
Manufacture of off-site energy systems, such as solar panels	3.65	2	4.33	1	3.52	5	3.46	10	3.63	8	0.41
Off-site fabrication of structural steel stairs and handrails	3.65	2	4.00	7	3.52	5	3.54	5	3.35	6	0.73
Preassembly of fire protection systems, such as fire sprinkler or fire	3.63	4	4.00	7	3.43	9	3.46	10	4.00	3	0.37
Fabrication of custom woodwork and cabinet	3.63	4	3.83	15	3.30	3	3.38	13	3.63	8	0.11
Manufacture of precast concrete stairs and landings.	3.63	4	4.17	4	3.48	7	3.38	13	3.50	15	0.31
Manufacture of precast concrete elements, such as beams, columns,	3.59	7	4.00	7	3.65	4	3.31	18	3.50	15	0.80
Fabrication of pre-assembled exterior façades, such as brick panels or	3.55	8	4.00	7	3.22	15	3.54	5	4.00	3	0.25
Off-site production of Heating Ventilation, and Air Conditioning	3.53	9	3.67	17	3.48	7	3.54	5	3.50	15	0.98
Production of pre-insulated piping for plumbing and HVAC	3.51	10	4.00	7	3.04	18	3.62	3	4.13	2	0.04*
Preassembling mechanical, electrical, and plumbing systems off-site	3.51	10	3.83	15	3.25	14	3.62	3	3.63	8	0.56
Off-site production of curtain walls and cladding	3.49	12	4.00	7	3.43	9	3.38	13	3.50	15	0.71
Off-site construction of temporary or modular housing.	3.49	12	4.00	7	3.43	9	3.38	13	3.38	19	0.72
Pre-fabrication of building components, such as wall s, floors, and roofs.	3.49	12	3.33	20	3.87	1	3.08	21	3.13	21	0.28
Production of off-site-built modular data center	3.41	15	4.17	4	2.96	20	3.46	10	3.63	8	0.06
Fabrication of modular electrical switchgear and control panels	3.41	16	3.67	17	3.30	12	3.54	5	3.38	19	0.94
Production of prefabricated wall panels with integrated insulation	3.11	17	4.00	7	3.13	16	3.23	19	3.88	5	0.15
Production of prefabricated ballrooms or kitchens.	3.29	18	4.33	3	2.91	21	3.23	19	3.63	8	0.11
Off-site construction of pre-engineered metal buildings	3.41	19	3.67	18	3.26	13	3.54	5	3.63	8	0.69
Production of modular buildings or building sections.	3.41	19	4.17	4	3.09	17	3.38	13	3.35	6	0.26
Manufacture of precast concrete foundations or footings.	3.29	21	3.00	21	3.00	19	3.62	2	3.63	8	0.35

MS= Mean Score, *p* = significant difference, * = significant

These include distinct job roles, industry influences, skills gaps, networking needs, emerging trends, personal growth goals, organizational culture, location-based opportunities, career stages, and individual interests. These factors inform the professionals' views on the relevance of off-site activities (Olojede *et al.,* 2024; Adeleke *et al.*, 2019).

4.3 Influence of OC on Construction Sustainability of Building Infrastructure Project

Table 3 displays the level of influence of OC activities on the sustainable delivery of building infrastructure, as indicated by the mean score value rankings by the professionals. The mean score (MS) value was calculated based on the expression: $MS=\Sigma(f \times s)/N$ (Cheung et al., 2012). Where "s" is the score rating for the influence of OC, "f" is the frequency, and "N" is the total number of the responses on the influence of the OC on building delivery. The overall top (5) five rated influences of OC on building infrastructure delivery were technology integration (MS = 3.84), improved project schedule performance (MS = 3.84), accelerated project timelines (MS = 3.84), waste reduction and recycling (MS = 3.80), and optimized project delivery (MS = 3.80). Other last rankings of the influence of OC were the contribution to sustainable construction practices (MS = 3.69), efficient logistics management (MS = 3.69), design and engineering optimization (MS = 3.63), labor cost reduction (MS = 3.63), and cost efficiency (MS = 3.57).

Despite the variances in the rankings by the professionals on the influences of OC on sustainable building infrastructure delivery in Lagos, Nigeria (Table 3), there existed no statistically significant differences ($p > 0.05$) from the expert opinions between the groups of the professional on all the 23 examined variables. These findings agreed with the existing scholarly assertions on the influences of OC on building infrastructure delivery, and contextualized the construction sustainability strength of OC on building construction sustainability for all climes.

Table 3. Influence of OC on the sustainable delivery of building infrastructure project

Influence of Off-site Construction	Overall		Architect		Quantity Surveyor		Engineer		Builder		ANOVA
	MS	R	MS	R	MS	R	MS	R	MS	R	*p*
Technology integration	3.84	1	4.17	3	3.96	3	3.54	18	3.63	6	0.53
Improved project schedule performance	3.84	1	3.67	20	3.83	8	4.00	2	3.75	4	0.98
Accelerated project timelines	3.84	1	3.83	13	4.09	1	3.69	11	3.38	18	0.74
Waste reduction and recycling	3.80	4	4.00	11	3.78	11	3.92	3	3.30	14	0.86
Controlled environments	3.80	4	4.17	3	3.83	8	3.85	4	3.63	6	0.46
Optimized project delivery	3.80	4	4.50	1	3.91	5	3.62	15	3.50	15	0.20
Reduced on-site construction time	3.78	7	3.83	13	3.65	17	3.85	4	3.88	2	0.77
Streamlined construction processes	3.78	7	4.17	3	3.83	8	3.62	15	3.50	15	0.59
Enhanced project predictability	3.78	7	3.83	13	3.96	3	3.46	20	3.63	6	0.56
Flexibility and adaptability	3.76	10	3.67	20	4.00	2	3.69	11	3.13	23	0.27
Standardization in Construction	3.76	10	4.17	3	3.57	19	3.85	4	3.88	2	0.80
Enhanced quality control	3.75	12	3.83	13	3.78	11	3.34	21	4.00	1	0.80
Enhanced project outcomes	3.75	12	4.17	3	3.91	5	3.34	21	3.38	18	0.53
Reduced construction site disruption	3.73	14	3.83	13	3.87	7	3.34	21	3.63	6	0.80
Improved safety	3.73	14	3.50	23	3.78	11	3.77	7	3.63	6	0.99
Simultaneous construction activities On-site and offs	3.71	16	3.83	13	3.74	14	3.69	11	3.63	6	0.96
Environmentally conscious construction	3.71	16	4.17	3	3.61	18	3.69	11	3.63	6	0.86
Control over material usage	3.69	18	4.50	1	3.39	23	4.00	1	3.38	18	0.06
Contribution to sustainable construction practices	3.69	18	4.00	11	3.70	15	3.77	7	3.38	18	0.81
Efficient logistics management	3.69	18	4.17	3	3.70	15	3.54	18	3.50	15	0.83
Design and engineering optimization	3.63	21	4.17	3	3.52	20	3.77	7	3.63	6	0.11
Labour cost reduction	3.63	21	3.83	13	3.52	20	3.69	11	3.75	4	0.94
Cost efficiency	3.57	23	3.67	20	3.52	20	3.62	15	3.38	18	0.72

MS= Mean Score, *p* = significant difference.

4.4 Factors influencing OC practices for construction sustainability of building infrastructure in Nigeria

Several factors that influence the practices of OC for construction sustainability in the delivery of building infrastructure in Nigeria are indicated on Table 4. Based on the mean score value calculated as $MS = \Sigma(f \times s)/N$ (Cheung et al., 2012), where "s" is the score rating for the influencing factors, "f" is the frequency, and "N" is the total number of the responses on factors influencing OC, the ranking factors were established. The overall top five (5) high-ranked factors were improved construction quality (MS = 3.73), effective project management for off-site construction (MS = 3.67), stakeholder engagement and collaboration (MS = 3.65), efficient logistics and transportation of off-site construction components (MS = 3.63), and technical and technological advancements for off-site construction (MS = 3.63). Others last ranked factors that influence OC were cost competitiveness of off-site construction compared to traditional construction (MS = 3.43), industry culture and mindset towards off-site construction (MS = 3.43), market demand for off-site construction solutions (MS = 3.39), government policies and regulations for off-site construction (MS = 3.37), and cost of materials (MS = 3.29). The findings update existing literature. It agreed with Pan (2018) that improving construction quality is a central goal in off-site construction, as controlled off-site environments offer better quality control, reduced defects, and improved consistency. Likewise, Zhou et al. (2019) ascertained that effective project management plays a vital role in off-site construction, requiring a well-coordinated approach to align off-site manufacturing, transportation, and on-site assembly activities, thus mitigating potential disruptions.

About 21 factors were statistically inferred to influence the practice of OC in Nigeria, having no statistically significant differences ($p > 0.05$) in 20 ranked factors. This established an existing coherence in the expert judgment of the groups of professions on the factors

Table 4.3: Factors Influencing OC Practices for construction sustainability of building infrastructure in Nigeria

Off-site Construction	Overall		Architect		Quantity Surveyor		Engineer		Builder		ANOVA
	MS	R	MS	R	MS	R	MS	R	MS	R	*p*
Improved construction quality	3.73	1	3.83	12	3.70	9	3.69	1	3.63	1	0.80
Effective project management for off-site construction.	3.67	2	4.17	1	3.70	9	3.62	5	3.25	5	0.51
Stakeholder engagement and collaboration	3.65	3	4.00	8	3.91	1	3.62	5	3.00	17	0.06
Efficient logistics and transportation of off-site construction components.	3.63	4	3.67	18	3.78	5	3.69	1	3.25	5	0.43
Technical and technological advancements for off-site construction.	3.63	4	3.83	12	3.91	1	3.54	7	3.00	17	0.19
Availability of skilled labor for off-site construction.	3.63	4	4.00	8	3.78	5	3.23	21	3.50	2	0.65
Availability of suitable off-site manufacturing facilities.	3.61	7	4.17	4	3.70	9	3.46	12	3.50	2	0.13
Construction timelines	3.61	7	4.17	4	3.87	3	3.31	18	3.25	5	0.05*
Productivity and safety of construction	3.59	9	4.17	4	3.74	8	3.54	7	3.13	10	0.06
Project complexity and size	3.57	10	3.83	12	3.78	5	3.54	7	3.13	10	0.10
Appropriate project design and documentation for off-site construction.	3.55	11	3.83	12	3.52	17	3.69	1	3.38	4	0.68
Regulatory Environment	3.55	11	4.17	1	3.61	12	3.54	7	3.13	10	0.50
Construction sustainability	3.51	13	3.50	20	3.83	4	3.46	12	3.00	17	0.12
Cost efficiency	3.51	13	4.17	1	3.57	14	3.46	12	3.13	10	0.42
Labor cost and productivity	3.45	15	3.67	18	3.57	14	3.38	16	3.25	5	0.71
Market Demand and Industry Perception	3.45	15	4.00	8	3.57	14	3.38	16	3.12	16	0.16
Cost competitiveness of off-site construction compared to traditional construction	3.43	17	3.83	12	3.48	18	3.46	12	3.13	10	0.55
Industry culture and mindset towards off-site construction.	3.43	17	3.83	12	3.61	12	3.23	20	3.25	5	0.22
Market demand for off-site construction solutions.	3.39	19	4.17	4	3.39	19	3.54	7	2.88	21	0.11
Government policies and regulations for off-site construction.	3.37	20	4.00	8	3.30	20	3.31	18	3.13	10	0.63
Cost of Materials	3.29	21	3.00	21	3.30	20	3.69	1	3.00	17	0.46

MS= Mean Score, *p* = significant difference, * = significant influencing OC practices in the country. The factors were related with government enabling support, construction sustainability contents, cost efficiency, market readiness, and favourable acceptance by stakeholders in the construction industry. The existing statistically significant difference on the raked factors by the professional is exhibited in factors on ‘construction timeline’ only.

4.5 Strategies for the off-site construction expansion for construction sustainability of building infrastructure

Strategies for the expansion OC for sustainability of building infrastructure development are displayed in Table 5. The top (5) high-ranked strategies were implementation of Building Information Modelling (BIM) for collaboration and coordination (MS = 3.88), development of local off-site facilities (MS = 3.71), incorporation of digital tools and automation in off-site construction processes (MS = 3.71), awareness campaigns (MS = 3.69) and adoption of prefabrication and modular construction techniques (MS = 3.69). Other ranked strategies were government support through policy framework (MS = 3.57), financial incentives by the government (MS = 3.57), training and education for stakeholders (MS = 3.53), research and development support (MS = 3.53), and continuous innovation adoption (MS = 3.51).

The inferential analysis on the examined strategies using ANOVA indicated that there existed no statistically significant differences ($p > 0.05$) between the groups of the professionals on the examined strategies (20 nos.) for the expansion of OC for construction sustainability of building infrastructure projects in Lagos, Nigeria. The study’s findings corroborate the strategies for increased practices of OC in existing literature. The implementation of BIM for collaboration and coordination, and incorporation of digital tools and automation in offsite construction processes improved collaboration and coordination among project teams (Eastman *et al.,* 2011).

Table 5. Strategies for the OC expansion for construction sustainability

Strategies	Overall			Architect			Quantity Surveyor			Engineer			Builder			ANOVA
	MS	SD	R	MS	SD	R	MS	SD	R	MS	SD	R	MS	SD	R	*p*
Implementation of Building Information Modelling for collaboration & coordination	3.88	0.97	1	4.33	0.52	1	3.91	0.39	1	3.85	1.28	15	3.38	1.06	5	0.31
Development of local off-site facilities	3.71	0.99	2	3.83	0.35	8	3.87	0.87	2	3.46	1.20	10	3.50	1.20	3	0.88
Incorporation of digital tools &automation in off-site construction processes	3.71	1.08	3	4.00	0.89	6	3.78	0.95	7	3.54	1.45	1	3.50	1.07	2	0.36
Awareness campaign	3.69	0.93	4	4.00	0.63	2	3.30	0.88	12	3.77	1.09	7	3.38	1.06	6	0.31
Adoption of prefabrication and modular construction techniques	3.69	0.39	5	3.83	0.35	9	3.78	0.25	6	3.62	1.19	4	3.38	1.30	7	0.87
Effective stakeholders' collaboration	3.69	0.99	6	3.83	0.98	11	3.83	0.32	4	3.62	1.26	14	3.38	1.30	8	0.36
Adoption of advanced technologies and innovation solutions	3.67	0.91	7	3.50	0.84	20	3.30	0.37	10	3.77	0.93	13	3.50	1.41	4	0.95
Regulatory framework	3.65	1.02	8	4.00	0.63	3	3.74	0.81	8	3.54	1.27	17	3.38	1.11	9	0.34
Investment in infrastructure	3.63	0.94	9	4.00	0.63	4	3.70	0.82	11	3.54	1.20	5	3.25	1.04	12	0.12
Supporting the local economy	3.63	1.00	10	3.67	0.82	13	3.57	0.99	17	3.85	1.21	6	3.50	0.93	1	0.88
Stakeholders' engagement	3.63	1.13	11	3.83	0.98	12	3.83	1.03	5	3.54	1.27	9	3.25	1.28	14	0.64
Knowledge sharing among workers and stakeholders	3.63	1.17	12	3.67	0.82	14	3.87	1.01	3	3.38	1.39	8	3.13	1.36	19	0.36
Capacity building	3.61	1.08	13	4.00	0.63	5	3.74	1.05	9	3.62	0.96	11	3.25	1.28	15	0.09
Reducing reliance on imported material s	3.57	1.04	14	3.83	0.11	7	3.18	1.04	20	3.69	1.11	16	3.38	1.11	10	0.89
Government support through policy framework	3.57	1.06	15	3.67	1.03	18	3.52	0.99	19	3.85	0.99	19	3.25	1.19	17	0.35
Financial incentives by the government (grants and subsidies)	3.57	1.10	16	3.67	0.82	15	3.61	0.94	14	3.54	1.33	3	3.38	1.51	11	0.98
Training and education for stakeholders	3.53	1.01	17	3.50	0.55	19	3.61	0.94	15	3.62	1.04	18	3.25	1.19	18	0.59
Research and development support	3.53	1.08	18	3.83	0.75	10	3.65	0.98	13	3.16	1.13	2	3.00	1.51	20	0.90
Continuous innovation adoption	3.51	1.10	19	3.67	0.82	16	3.57	0.99	18	3.54	1.39	12	3.25	1.28	16	0.94
Effective communication framework	3.47	1.08	20	3.67	0.82	17	3.61	1.03	16	3.31	1.32	20	3.25	1.17	13	0.86

MS= Mean Score, SD = Standard Deviation, *p* = significant difference, * = significant

5. Conclusions and Recommendations

Building construction has a crucial share in the sector-wide industrial activities which contribute to Nigeria's ranking among the seven countries of the world that account for one-third of the global climate crisis. The study established the off-site construction practices that are applicable to construction sustainability for carbon footprint reduction, environmental impact reduction, and resource efficiency for building infrastructure delivery in Nigeria. These are prefabrication of steel structures, manufacture of off-site energy systems, off-site fabrication of structural steel stairs and handrails, preassembly of fire protection systems, fabrication of custom woodwork and cabinetry, production of prefabricated wall panels with integrated insulation, production of prefabricated bathrooms or kitchens, off-site construction of pre-engineered metal buildings, production of modular buildings or building sections, and manufacture of precast concrete foundations or footings, among others.

The study established the importance of the OC practices by the discovered positive influences on sustainable building infrastructure in the country viz. performance, accelerated project timelines, waste reduction and recycling, contribution to sustainable construction practices, efficient logistics management, design and engineering optimization, labor cost reduction, and cost efficiency. The study established 20 strategies for the expansion of the sustainable practices of the OC in Nigeria. These include~~d~~ the implementation of BIM for collaboration and coordination, development of local off-site facilities, incorporation of digital tools and automation in off-site construction processes, awareness campaigns, investment in infrastructure, government support through policy framework, financial incentives by the government, training and education for stakeholders, and research and development support.

Drawing on the study's conclusions, key recommendations are suggested by the study to enhance the sustainable effects of OC in the delivery of building infrastructure in Nigeria. These are embracing technology integration, leveraging digital tools and automation, prioritizing stakeholders' engagement and collaboration, optimizing logistics and transportation, leveraging waste reduction and recycling, exploring technical advancement, investing in workforce training and infrastructure, and implementing government supports.

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ACCIDENT SEVERITY AND VULNERABILITY ASSESSMENT OF OSOGBO-GBONGAN ROAD, OSUN STATE, NIGERIA

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Abstract
Mitigation of Road Traffic Accidents (RTAs) occurrence on roads enables safe transportation, good well-being of road users and economic growth. The occurrence of accident along Osogbo-Gbongan is rapidly increasing, thereby indicating a substantial number of occurrences in the coming years. This study sought to investigate the severity and vulnerability of accident-prone regions along the Osogbo-Gbongan road. Four years of accident data from the FRSC, Osogbo Branch were examined in terms of casualty, accident cause and location, and affected age group. The geometric characteristics were collected on-site by physical measurement to estimate the road's vulnerability at blackspot locations. The accident blackspots were identified as Ogo-oluwa (02+000), Ataoja (04+000), Abeere (06+000), Owode (10+000), and Akoda (15+000). The overall number of accidents in 2018, 2019, 2020, and 2021 were 144, 128, 168, and 313, accordingly, with speeding as the leading cause. The study revealed that male gender (active population) was most affected and there was declination of all assessed geometrical features from standard thereby being dangerously vulnerable to accident occurrence. Hence, they are blackspots of high accident vulnerability. The study recommends rehabilitation of identified blackspots on the existing road and encourages adequate design, supervision and construction of road infrastructures.

Keywords: Assessment, Blackspot, Casualty, Traffic, Severity, Vulnerability.

1.0 Introduction

According to WHO (2009), road transportation is of great importance to both nations and every individual as it facilitates the movement of goods and people. Its benefits include increased access to jobs, education, economic markets, healthcare, recreation, and hence, having a direct or indirect positive impact on the health situation of the masses. However, rapid increase in road traffic activities offer negative effect on people's health, economy, society and environment at large thereby resulting to road traffic injuries, road crashes, air pollution, greenhouse gas emission, community severance, noise etc.

The incidence of road traffic accidents in developing countries is significant as a result of increased vehicle ownership and population growth, compromising road safety targets (Antonio *et al.*, 2019). A road traffic accident (RTA) is a collision between a moving vehicle and another vehicle or pedestrian on a roadway that frequently results in injuries, temporary or permanent disabilities, property loss, and death (Oluwayemi *et al.*, 2020). Road traffic accidents occur as a result of a malfunctioning driving system (Katerina *et al.*, 2020), which is of considerable worry to everyone's health as it results in injuries and deaths (Muthusamy *et al.*, 2015). Ozor & Ozoegu (2020) identified two types of road traffic accidents: random and unwanted occurrences and unforeseen events.

The worsening effect of road traffic crashes in developing countries especially in Nigeria is becoming significant and highly affecting the economy and society thereby mounting severe pressure on the people and environment at large. Osogbo is from among the urban cities in Nigeria which experience significant road traffic accidents along its major routes and lesser occurrences within township roads. The study on the characterization of Road Traffic Accidents (RTAs) in Osogbo revealed that the route leading Osogbo to Gbongan (SGB-GBN) experiences the highest RTA counts annually (Baloye and Palamuleni, 2015). This study sought to investigate the severity and vulnerability of accident-prone regions along the Osogbo-Gbongan road through accident characterization and estimation of geometric data in conformance to the standard.

2.0 Methodology

2.1 Study area

This research was carried on Osogbo-Gbongan road situated within Osun State, Nigeria linking Osogbo to Gbongan (Figure 1), Ikire, Ife, Ibadan and Lagos. This road is one of the federal roads connecting Osogbo to other urbanized locations which spans between two junctions namely: Old garage junction of latitude 7°46'55.23"N and longitude 4°32'57.64"E to Gbongan junction of latitude 7°28'2.52"N and longitude 4°19'53.26"E thereby having an approximate length of 44 km. (Fadipe *et al.,* 2024). Along the road, there exist major locations like Orisumbare, Freedom park, *Aregbe*, *Ogo-Oluwa*, Independent Electoral Commission (INEC) State Headquarter Office, Abeere, Nigerian Police Force (Zone II), *Owode, Akoda*, *Sekona*, *Gbongan* etc. and junctions like Old-garage, *Olaiya*, *Ataoja, Abeere*, *Owode*, *Akoda*, *Sekona*, *Oogi*, *Gbongan* etc. The modes of transportation adopted on this road are cabs or taxi, mini buses (*korope/alake*) and motorcycles (*okada*) such that cabs and minibuses usually ply the primary roads while motorcycles are often used on the secondary routes (Baloye and Palamuleni, 2015).

2.2 Road Traffic Accident (RTA) data

The data on road traffic accidents was gathered from the Federal Road Safety Commission (FRSC), Osogbo command, and it covers the years 2018 through 2021. The databases contained data on the types and categories of vehicles involved, the route and location of the occurrence, the number and category of individuals involved, the number of injured and fatalities, the time and date of the occurrence, the daily casualty count, and the cause of road traffic accidents.

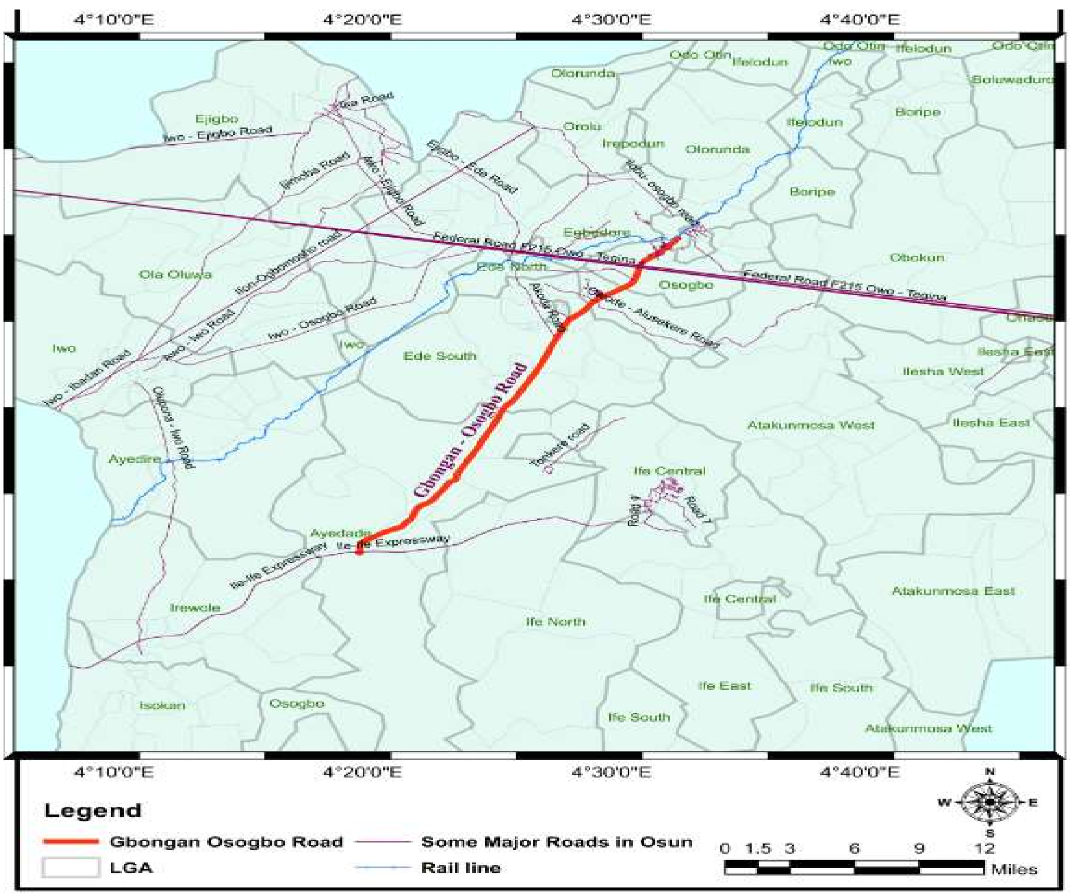

Figure 1: Osogbo-Gbongan Road (Fadipe *et al.* 2024)

The data was analyzed in percentage table and charts to present outputs from the analysis which include: characterization of accident based on casualty level (fatal, serious and minor), yearly and monthly rate of road traffic accident occurrence, time of the day, vehicles involved, age-group involve etc. The road traffic accidents within the study were characterized through assessment of occurrence over the period of years under consideration. Also, the route on which the accident occurred over the period of year under consideration were isolated from the database entries in order to determine the routes with significant occurrence and isolating the routes with the most occurrence for reconnaissance and road survey exercises such that location with accident counts of 10 and above were considered significant thereby naming the location as accident prone location.

2.3 Geometric Survey

Geometric survey is a survey which was undertaken to study the profile of the road features i.e., geometric parameters within the study area which include elevation/cambering of the road, pavement condition, condition of shoulder, width of pavement/shoulder and spot speed through onsite assessment and measurement using instruments. The above parameters were obtained on locations with significant accident occurrence. The causative factors known to contribute to accident on urban roads were identified based on existing literature (Aderinola *et al.,* 2017) within similar geographical area and engineering judgement through available information and explanatory analysis.

3.0 Results and Discussion

3.1 Road Traffic Accident data analysis

3.1.1 Casualty characterization

Figure 2 describes the casualty rate of accident along Osogbo-Gbongan road for the year 2018 to 2021(4 years) with emphasis on three accident types namely: minor, serious and fatal accidents. The rate of accident casualty for minor accident was 50.1 per cent, 44.2 per cent for serious accident and 5.70 per cent for fatal accident. The casualty rate is low (5.70 per cent), nonetheless, if by definition serious accident describes accidents leading to injuries then, the rate of injuries that may lead to permanent disability or death is high (44.2 per cent). Hence, casualty rate is on rise thereby amounting to 49.9 per cent. It explains that more people were involved in accident with great number suffering from accident and few were dead.

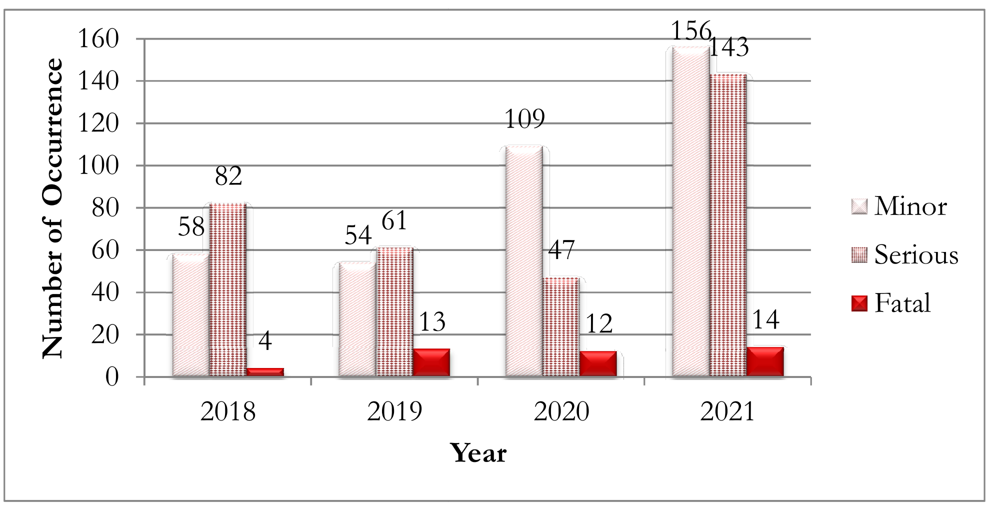

Figure 2: Yearly Casualty Rate
Source: Federal Road Safety Corp (FRSC), Osogbo Branch

In addition, the yearly increase or decrease in RTA occurrence within the study years was investigated and presented by Figure 3.2 revealing a remarkable decrease in accident occurrence of 11.1 per cent from 2018 to 2019, followed by significant increase of 31.3 per cent in 2020 and lastly and abrupt increase of 86.3 per cent in 2021.

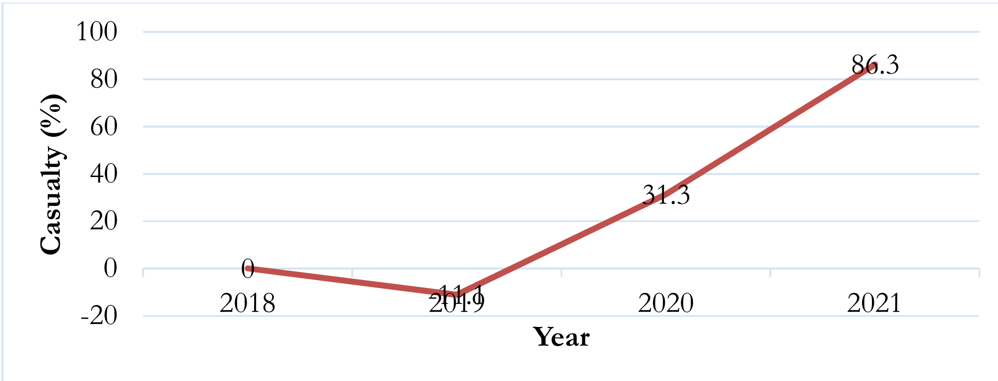

Figure 3: Yearly Casualty Trend
Source: Federal Road Safety Corp (FRSC), Osogbo Branch

3.1.2 Yearly distribution of RTAs

The yearly RTA counts as presented in Figure 3.3 revealed the trend of accident occurrence within the study period such that in 2018, 25 RTA counts (18.3 per cent) were recorded, when reduced to 14 RTA counts (10.2 per cent) in 2019 and again increased to 45 RTA counts (32.8 per cent) in year 2020 and, 53 RTA counts (38.7 per cent) in the year 2021. This implies that the rate of RTA counts was increasing annually; however, a 44 per cent reduction was observed between the years 2018 to 2019 over the four years and may be attributed to existence of improved road safety mechanisms which aligned with the findings of Baloye and Palamuleni (2015). However, the 32.8 per cent increase in the year 2020 can be attributed to the illegal vehicular activities observed by private and commercial drivers during the lockdown thereby indicating their negligence towards the country's law and regulations.

3.1.3 Monthly distribution of RTAs

Also, the monthly RTA analysis is presented in Figure 4 which revealed the trend of accident occurrence over the study period with most accidents occurring in July, September, November and December when all accidents were taken together. This explains the havoc experienced along the road in ember months, which may be attributed to increase in traffic and vehicular activities on Nigeria roads unlike other months, and they are characterized as festive periods (Ojo, 2020; Ogunbiyi, 2020).

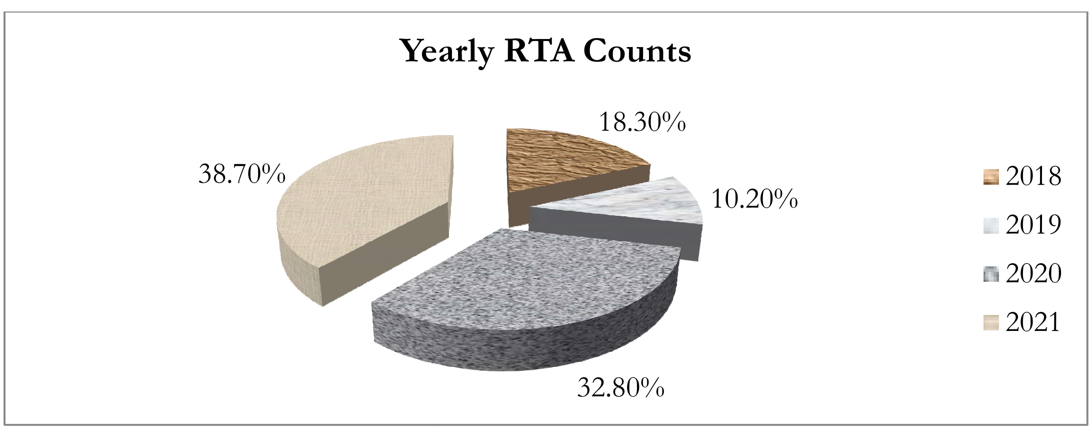

Figure 4: Yearly RTA Count
Source: Federal Road Safety Corp (FRSC), Osogbo Branch

3.1.3 Monthly distribution of RTAs

Also, the monthly RTA analysis is presented in Figure 5 which revealed the trend of accident occurrence over the study period with most accidents occurring in July, September, November and December when all accidents were taken together. This explains the havoc experienced along the road in ember months, which may be attributed to increase in traffic and vehicular activities on Nigeria roads unlike other months, and they are characterized as festive periods (Ojo, 2020; Ogunbiyi, 2020).

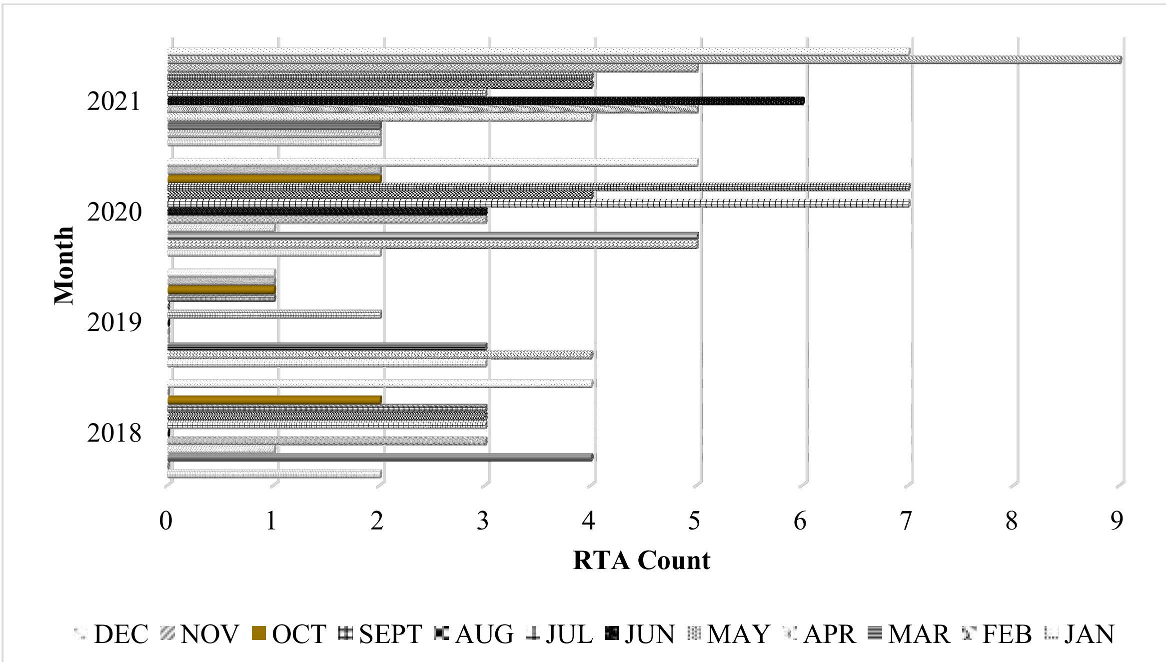

Figure 5: Monthly RTA Count
Source: Federal Road Safety Corp (FRSC), Osogbo Branch

3.1.4 Daily distribution of RTAs

More so, the time of occurrence of accident during the day were presented in Figure 6 in which 22 per cent of the accident occurred in the morning (5:00am-11:59am), 32 per cent in the afternoon (12:00pm-4:59pm), 28 per cent in the evening (5:00pm-8:59pm) and 14 per cent in the night (9:00pm-4:59). It shows that the least record of accident occurrence was at night while the most occurred in the afternoon thereby revealing the accident hours of the day.

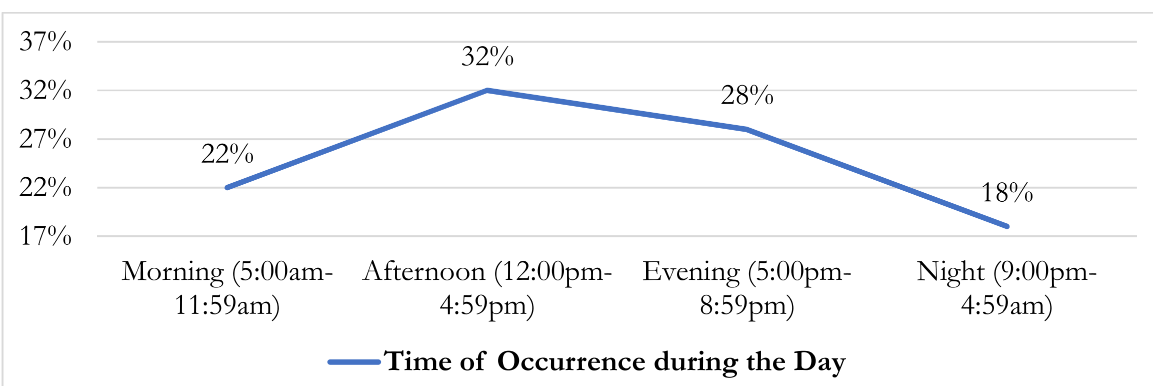

Figure 6: Time of Accident during the Day
Source: Federal Road Safety Corp (FRSC), Osogbo Branch

3.1.5 Categories of vehicles involved in RTAs

Considering the categories of vehicles involved in RTA along the study area, it was observed that various types of vehicles were involved as presented in Figure 3.6 which comprised of motorcycles commonly known as "*okada*", light cars such as cars; buses; heavy duty vehicles including trucks and trailers and suburban utility vehicles (SUV).It was deduced from the study that a total of 58 motorcycles (24.3 %), 88 cars (36.8 %), 49 buses (20.5 %), 24 trucks/trailers (10 %), 16 SUVs (6.7 %) and 4 (1.7 %) unidentified vehicle type (UVT) were recorded by the FRSC to have involved in accident over the study period whereby 49 per cent were private vehicles while the remaining 51 per cent were commercial vehicles.

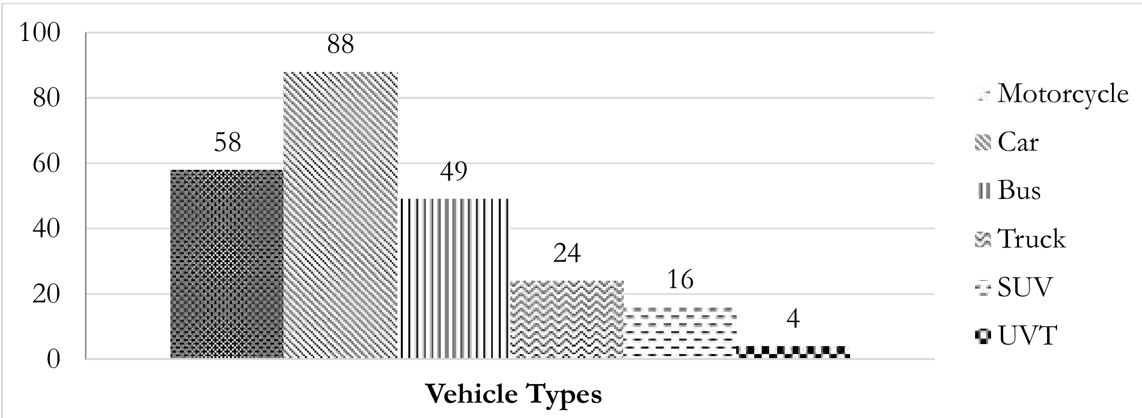

Figure 7: Vehicle involved in Accident
Source: Federal Road Safety Corp (FRSC), Osogbo Branch

3.1.6 Categories of victims involved in RTAs

Figure 8 presented the categories of road users affected with RTA which was broadly divided into two namely: adult and children. The result showed that a total of 763 victims were involved in RTA over the study years where 94 per cent (714) of them belong to the adult group (above 18 years) and the remaining 6 per cent (49) were children (less than 18 years). It was deduced that 73 per cent (557 victims) were male and the remaining 27 per cent (206) were females as shown in Figure 4.8. This agrees with the findings of Serge *et al*. (2019) which stated that accident affects breadwinners and people within the economically active age-group (18 years and above) which have significant effect on the countries' economy and health status.

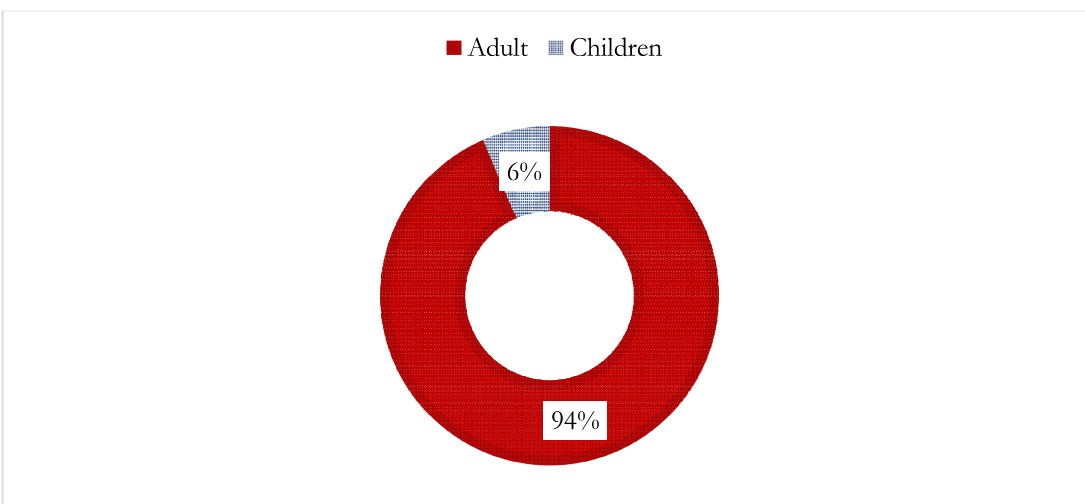

Figure 8: Categories of Accident Victims
Source: Federal Road Safety Corp (FRSC), Osogbo Branch

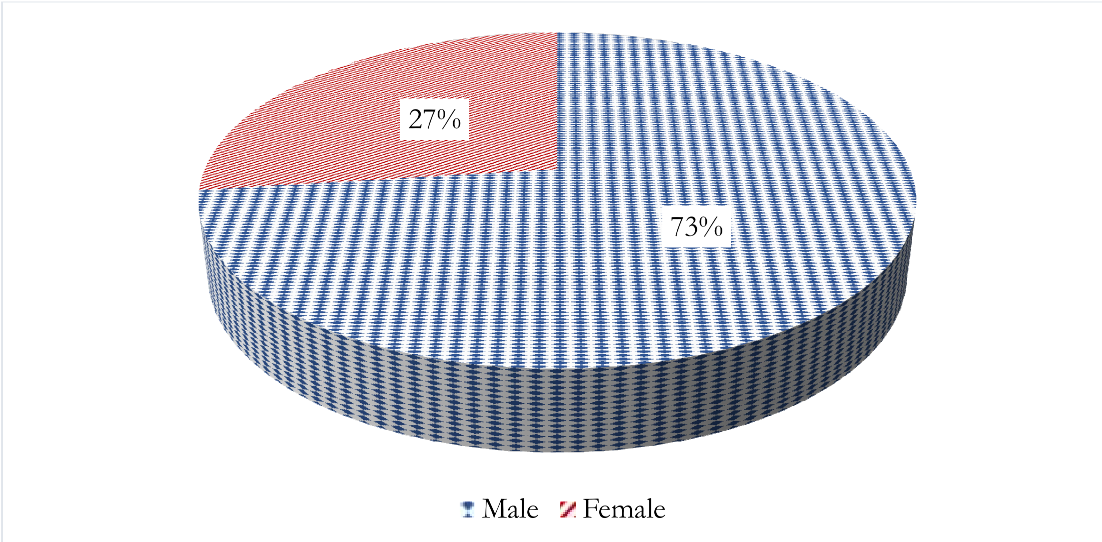

Figure 9: Gender of Accident Victims
Source: Federal Road Safety Corp (FRSC), Osogbo Branch

3.2 Road Geometric Survey

The vulnerability of the identified accident-prone locations was estimated by carrying out road geometry survey so as to obtain the geometrical features contributing to occurrence of accident along the study.

3.2.1 Spot speed

The spot speed as shown in Table 1 reveals that *Ogo-oluwa*, *Ataoja*, *Abeere*, *Owode* and *Akoda* had average speed of 56, 58, 68, 54 and 95 km/hr respectively. This shows that *Akoda* area observed the highest speed (95 km/hr) and *Owode* area had the lowest (54 km/hr). This is because *Akoda* area experiences free flow for vehicles as against *Owode* area which is usually affected by rural activities which include daily and weekly market activities. The estimated spot speeds were high and found to be above the expected 50 km/hr design speed thereby indicating susceptibility to accident due to speed violation. Qualitative remarks of the estimated spot speeds were given by Aderinola *et al.* (2017) whereby the *Akoda* area attributed with spot speed of 95 km/hr was fast; *Ogo-oluwa* area with 56 km/hr was moderate, *Ataoja* area with 57 km/hr was moderate and *Abeere* area with 68 km/hr was average, and segment 10+000 – 11+000 (*Owode* area) with 54 km/hr was moderate.

3.2.2 Condition of shoulder

The conditions of shoulder at the accident-prone locations were presented in Table 1 whereby defects found on the road shoulders include sand filling on paved road shoulders, partially and fully eroded road shoulder and absence of road shoulder, and the findings at the accident-prone locations. Defects on road ways along *Ogo-oluwa* area and *Abeere* were characterized as sandy while that of *Ataoja*, *Owode* and *Akoda* were characterized with potholes and cracks. Also, locations like *Ataoja* and *Akoda* village were faced with a problem arising from long parking of commercial vehicles and *Owode* Area with the market people occupying the road shoulder thereby causing uneasy flow of vehicles along their road sections. More so, this finding supports the results of Pokorny *et al.* (2020) that absence of shoulder or presence of narrow shoulders increases the possibilities of accident occurrence as they do not provide sufficient opportunity for evasive or recovery maneuvers.

3.2.3 Pavement condition

The pavement defects found at *Ogo-oluwa* and *Akoda* area were few isolated potholes and cracks. *Ataoja* area has no potholes but cracks which were widely distributed over the roadway section. The pavement condition at *Abeere* area was found to be potholes and wavy surface whose effect was evident as vehicle ply it. Pavement defects found at *Owode* area were large potholes surrounded by cracks. Having assessed the pavement conditions at the accident-prone locations, it was evident that major accident locations were badly affected with virtually all having pothole as defects thereby contributing to the possibilities of accident occurrence which is a threat to the safety and comfort of its users.

In addition, a section of the road which is few kilometers to *Owode* junction towards *Akoda* village thereby within chainage 11+000 (Dam Jay Oil and Gas area) had lost its structural form due to the presence of widespread pothole and peeled off road surface thereby resulting to travel delay and discomfort to road users. Austine (2011) had a similar finding during his economic valuation of poor road infrastructure in Lagos, a southwestern region in Nigeria where he highlighted pothole as the major pavement defect resulting to accident, delay in traffic flow and robbery, and vehicular damages.

Table 1: Spot speed, Pavement Condition & Condition of Shoulder

S/N	Section	Location	Spot speed	Pavement Condition	Condition of Shoulder
1	02+000	*Ogo-Oluwa*	56 (Moderate)	Crack and few potholes	Sandy (Bushy)
2	05+000	*Ataoja*	58 (Moderate)	Cracks	Eroded
3	07+000	*Abeere*	68 (Moderate)	Crack and Wavy surface	Absent
4	10+000	*Owode*	54 (Moderate)	Crack and large potholes	Absent
5	15+000	*Akoda*	95 (Fast)	Crack and few potholes	Absent

Source: Field Survey (2022)

3.2.4 Width of pavement

Table 2 shows the onsite evaluation of pavement width at the accident-prone locations whereby *Ogo-oluwa* has pavement width of 9.60 m, *Ataoja* has 7.40 m, *Abeere* has 9.38 m, *Owode* has 7.25 m and *Akoda* has 7.40 m. It was observed that *Ogo-oluwa* area has the largest width (9.6 m) which allows for more flow of traffic and side swipe for vehicles while *Owode* area has the least pavement width (7.25 m) though sufficient for free flow and also reducing flow of excessive traffic due to the presence of rural activities happening in the area. Therefore, all the existing pavement width are up to standard. However, existence of wider roads might increase the risk of over-speeding and frequent wrongful overtaking.

3.2.5 Elevation (Cambering)

The elevations at the accident-prone were shown in Table 2 such that *Ogo-oluwa* has 0.1, *Ataoja* has 0.2, *Abeere* has 0.3, *Owode* has 0.4 and *Akoda* has 0.2. In accordance with the measured elevations, the existing camber provided on the road were too low thereby impairing the functionality of the road and creating opportunity for accident occurrence. Also, an effect of low elevation was evident at *Abeere* area whereby moisture (water) is retained on the road rather than draining off the roadway.

3.2.6 Gradient of the road

Table 2 presents the road gradients were estimated on site at the accident-prone areas. The road gradient at *Ogo-oluwa* area was found to be 3.44 per cent, *Ataoja* area was 5.40 per cent, *Abeere* area was 9.60 per cent, *Owode* area was 11.00 per cent and *Akoda* was 5.90 per cent.This implies that *Ogo-oluwa* area which has the least gradient of 3.44 per cent is moderate when compared to the standard together with *Ataoja* and *Akoda* while the gradient of *Abeere* area and *Owode* area were characterized as being high for ease of travel. According to Hasibul *et al.,* (2019), roads with steep gradient have are more susceptible to higher accident rates in comparison to roads with mild gradient thereby indicating the vulnerability of *Ataoja*, *Abeere*, *Owode* and *Akoda* to accident.

Table 2: Width of Pavement, Elevation & Gradient of the Road

S/N	Section	Location	Width of Pavement	Elevation (Cambering)	Gradient of the Road
1	02+000	*Ogo-Oluwa*	9.6 m	0.1	3.4
2	05+000	*Ataoja*	7.4 m	0.2	5.4
3	07+000	*Abeere*	9.6 m	0.3	9.7
4	10+000	*Owode*	7.4 m	0.4	11.0
5	15+000	*Akoda*	7.4 m	0.2	5.9

Source: Field Survey (2022)

4.0 Conclusions

This research investigated the casualty rate at the study area which was high and also increasing annually at particular months like January and December having the most accident occurrence. More so, all the categories of vehicles including commercial and private vehicles were affected wherein victims of accident were adults. The identified accident-prone areas were: *Ogo-oluwa*, *Ataoja*, *Abeere*, *Owode* and *Akoda* area in relation to the significant number of accidents they had which were 14, 18, 31, 18 and 15 respectively.

The assessment of geometrical features of the accident-prone locations revealed the declination of all assessed features from standard thereby being dangerously vulnerable to accident occurrence. Hence, they are blackspots of high accident vulnerability. The severity of accident on the road leading Osogbo to Gbongan is extremely high and it is increasing thereby revealing the significant expected number of casualties in few years to come.

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Drivers and Challenges of Third Party Logistics Adoption in the Nigerian Construction Industry

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Abstract

Third-party logistics (3PL) companies' engagement in construction projects has shown to improve efficiency, save money, and assure timely delivery of materials and equipment in construction projects. However, despite the obvious benefits of employing 3PL in construction projects, the concepts are still underutilised in developing countries like Nigeria. This study examines the driving factors that influence the adoption of 3PL as well as the challenges hindering the adoption in the construction industry in Nigeria. The study adopted a quantitative research approach with the use questionnaire to collect information from construction professionals in Lagos, Nigeria. Descriptive and inferential statistics were employed to analyse the data. The findings show that improved efficiency, cost savings, risk management, and operational excellence are the important factors that influence the adoption of 3PL in the construction industry. The two important challenges faced by construction professionals in adopting 3PL are inadequate capacity and expertise and poor infrastructures. Moreover, the findings show a significant difference in the challenges in adopting 3PL in the Nigerian construction industry between construction professionals. The findings of the study could benefit the Nigerian construction firms to make better-informed decisions on the adoption of 3PL in solving material management problems by leveraging on the benefits it brings in achieving successful delivery of construction projects.

Keywords: Third party logistics, 3PL adoption, Supply chain management, Logistics management, Construction industry

1. Introduction

The construction industry globally is facing a number of issues that are impeding its effectiveness and productivity, such as managing stakeholder expectations, project delays, cost and schedule overruns, risk management, and procurement process management (Elhag *et al.*, 2020; Li & Liu, 2019; Muthukannan & Senthil, 2022). However, overtime the construction industry has found a number of ways to overcome its problems. These include using third-party logistics (3PL), supply chain management (SCM), and partnerships to increase productivity, save costs, and improve stakeholder engagement and communication. Third Party logistical (3PL) is a process where an outside organisation that handles all or a portion of a business's logistical needs (Marasco, 2008). As construction projects grow in size, adequate logistical procedures must be put in place to ensure efficiency and project success. These days, a lot of construction companies outsource their logistics to third-party logistics (3PL) companies so they can concentrate on important tasks and minimize costs (Ekeskär & Rudberg, 2020). On the other hand, supply chain management (SCM) involves the planning and administration of all logistics management, conversion, and sourcing and procurement operations (Council of Supply Chain Management Professionals [CSCMP], 2013). In order word, SCM involves the overall management of all processes involved in the movement of goods and services from their raw material state to their end users. SCM was developed and is now used as a strategic discipline as a result of market globalisation and the need for firms to maintain their competitiveness (Lambert, 2010). Supply chain management helps to organise and regulate the processes involved in the manufacturing and delivery of a commodity or service, from raw material procurement to final customer delivery. Chopra and Meindl (2019) found that SCM lowers costs, improves customer happiness, and strengthens organisational performance. As the supply chain of the construction firm becomes more intricate, costly to operate, and complex, it is imperative to assign all logistical tasks to a third-party logistics (3PL) supplier, who will handle them on the construction firm's behalf. With third-party logistics (3PL), businesses outsource distribution and logistics to a specialised company as part of their supply chain management strategy. This allows the outsourced firm to concentrate on its core competencies and skills while the 3PL manages logistical duties. In recent years, construction firms have recognized the potential benefits of integrating 3PL services into their operations in order to have improved efficiency, cost savings, and have access to specialized expertise in supply chain management and logistics. However, the adoption of third-party logistics in the Nigerian construction industry has been slow, with many firms still relying on traditional in-house logistics approaches (Windapo, 2021). This paper seeks to examine the primary drivers and challenges influencing the adoption of third-party logistics in the Nigerian construction industry. The study will fill the gap in understanding the factors influencing the integrating 3PL within Nigerian construction industry and shed light on how construction companies may utilise 3PL to their advantage in order to boost productivity, increase their competitiveness, and provide clients satisfaction. In addition, by identifying the potential challenges in the adoption of 3PL, construction stakeholders can work together to create a more efficient and resilient strategies to overcome these challenges to enhance the construction industry's overall performance.

2. Materials and Methods

The study adopted a quantitative research method with the use of structured questionnaire to obtain information from construction professionals in Lagos State Nigeria. The choice of the study area is as a result of having the large concentration of construction professionals (Odediran *et al*., 2013). A sample of 140 construction professionals was selected using the purposive sampling technique in order to give rich, detailed information pertinent to the topic under study. The questionnaire was divided three sections. Section A contains questions on the respondents' background; Section B focuses on the drivers for the adoption of 3PL in the construction industry while the third section examined the challenges of adopting 3PL in the construction industry, using a Likert scale range of 1-5; 5 (Strongly agree), 4 (Agree), 3 (Moderately agree), 2 (Disagree), and 1 (Strongly disagree). Frequency distribution and mean score were used to analyze the data obtained. However, to determine the degree of importance of drivers for the adoption of 3PL, results were interpreted using a mean scores range adapted from Alico and Guimba (2015). The categorization are as follow; 1-1.74 (Not Important), 1.75-2.49 (Slightly Important), 2.50-3.24 (Important), 3.24-4.00 (Very Important), while the degree of agreement on the challenges of adopting 3PL in the construction industry results were interpreted using a the mean scores range of 1-1.49 (Strongly Disagree), 1.50-2.49 (Disagree), 2.50-3.49 (Moderately Agree), 3.50-4.49 (Agree), and 4.50-5.00 (Strongly Agree). Furthermore, ANOVA was also used to examined statistical differences in the challenges faced in the adoption of 3PL by construction professionals in the results of the study.

3. Results and Discussion

3.1. Responses to Questionnaire Administered

Table 2 shows the respondents response rate to the study's questionnaire. The result on Table 2 shows 102 returned questionnaires, which were scrutinised for mistakes, omissions, completeness, and inconsistencies and judged to be satisfactorily finished.

Table 2. Response to questionnaire administered.

Questionnaires	Number
Administered	140
Returned	102
Response Rate	73%

3.2. Characteristics of Respondents

Table 3 shows the details of the participant of the research survey. The study findings revealed that majority of the respondents were Civil Engineers (37.3%), Builders (25.5%), Architects (19.6), Quantity surveyors (11.8), and other professionals (5.9). Others are professionals whose professions are not indicated in the questionnaire. Table 3 also revealed that 51% occupies other positions not indicated in the questionnaire, 13.7% of the respondents both occupied project manager, and site manager/engineer positions, while 11% and 9.8% occupied the position of chief executive/principal partner and site foreman, respectively. The respondents' years of professional experience revealed that 34.3% had between 6-10 years of experience, 21.6% had between 11-15 years of experience, 19.9% had over 20 years of experience, while 13.7% and

10.8% of the respondents had 16-20 years and 1-5 years of experience respectively. With almost 54.9% of respondents having more than ten years of work experience, it is reasonable to assume that the respondents were well-versed in the subject matter.

Table 3. Respondents' Details

Respondents' Professions	Frequency	Percentage
Architect	20	19.6
Builder	26	25.5
Civil Engineer	38	37.3
Quantity Surveyor	12	11.8
Others	6	5.9
Total	102	100%
Respondents Position		
Chief Executive/Principal Partner	12	11.8
Project Manager	14	13.7
Site Manager/Engineer	14	13.7
Site foreman	10	9.8
Other	52	51.0
Total	102	100%
Years of Experience		
1-5	11	10.8
6-10	35	34.3
11-15	22	21.6
16-20	14	13.7
Over 20	20	19.6
Total	102	100%

3.3. Drivers for the Adoption of Third Party Logistics in Nigerian Construction Industry

The study examines construction professional's perceptions on factors driving the adoption of 3PL in the construction industry; with outcome presented in Table 4. The 8 key factors that are likely to influence the adoption of 3PL were chosen from literature. The result revealed that the mean scores of 4 factors lies between the range of 2.50 – 3.24, indicating that these factors were identified to be an important drivers in the adoption 3PL in the construction industry, these factors are improved efficiency, cost savings and risk management with mean scores of 2.63, 2.61 and 2.55 respectively. However, the mean scores of the other factors lies between 1.75-2.49, indicating that these factor are slightly important factors that drives the adoption of 3PL in the Nigerian construction industry from the perception of the construction professionals.

Table 4. Drivers for the adoption of 3PL

Drivers	Mean Score	Rank	Remark
Improved efficiency	2.63	1	Important
Cost savings	2.61	2	Important
Risk management	2.55	3	Important
Operational excellence	2.53	4	Important
Increased flexibility	2.47	5	Slightly Important
Effective communication	2.29	6	Slightly Important
Improved customer satisfaction	2.19	7	Slightly Important
Technological capabilities	2.16	8	Slightly Important

These findings aligned with Ekeskär and Rudberg (2020) that the need to improve efficiency is an important factor in the adoption of 3PL in that construction firm, so that the firm can focus on their core activities of construction by outsourcing transportation, storage, and inventory management, while benefiting from 3PL's supply chain management experience. By outsourcing the logistical components of the construction process, construction firms may focus on achieving project objectives by accelerating project schedules, reducing delays, and improving the entire operational efficiency (Wang *et al.*, 2021). The studies of Dubois *et al.*, (2019) and Janné and Rudberg (2022) also corroborated the study findings that cost savings dives the adoption of 3PL. For construction organizations, using a 3PL system can result in significant cost reductions. Businesses may bargain for lower prices for warehousing, shipping, and other logistics services by taking advantage of the economies of scale offered by 3PL providers. Furthermore, 3PLs have access to cutting-edge technology and data analytics skills to optimize routes, cut down on empty miles, and save transportation costs. Construction firms may also save overhead expenses and manage resources more efficiently by outsourcing non-core services.

Another important factor for the adoption of 3PL in the construction sector from the study findings is risk management. The construction industry is naturally risky, with a variety of factors that might affect project duration and costs. 3PL suppliers play an important role in reducing risks (Mvubu & Naude, 2020). Outsourcing logistics operations allows construction firms to transfer the risks associated with transportation, warehousing, and inventory management to skilled specialists, thereby reducing the probability of delays, equipment damage, or supply shortages. Furthermore, Three-party logistics companies take a proactive approach to construction risk control. They identify and assess possible supply chain and logistics concerns. This will enable construction firms to adopt preventative actions and contingency plans, therefore lowering the impact of risks on project timeframes.

3.4. Challenges in the Adoption of 3PL in Nigerian Construction Industry

Despite the numerous benefits of 3PL, the construction industry has been slower to implement 3PL solutions than other industries. The study identified the challenges in the adoption of 3PL in the Nigerian construction industry. The results in Table 5 revealed that the mean scores of 2 factors lies between the range of 3.50 – 4.49, indicating that the construction professionals in Nigeria agreed that inadequate capacity and expertise and poor infrastructures are important challenges confronting the construction industry in adopting 3PL.

Table 5. Challenges in the Adoption of 3PL in Nigerian Construction Industry

Challenges	Mean score	Rank	Remark
Inadequate capacity & expertise	4.23	1	Agree
Poor infrastructure	4.02	2	Agree
Security concerns	3.27	3	Moderately Agree
Government regulations	3.24	4	Moderately Agree
Integration difficulties	3.08	5	Moderately Agree
Performance Risk	3.04	6	Moderately Agree
Provider selection	2.80	7	Moderately Agree
Loss of control	2.78	8	Moderately Agree
Additional cost	2.76	9	Moderately Agree
Communication & Collaboration issues	2.75	10	Moderately Agree

This result is congruent with that of Masudin et al (2020), which show that inadequate capacity and competence in 3PL operation is one of the key barriers to 3PL adoption in construction industry. The construction industry requires specialised knowledge and skills to handle logistics properly; yet, it has been discovered that there is a lack of trained personnel and competence in the logistic business. 3PL suppliers must have a thorough grasp of the construction business in order to deliver effective services. According to Ekeskär and Rudberg (2020), one of the complaints raised against a 3PL arrangement is the 3PL provider's lack of competency. Many construction industry stakeholders are hesitant to outsource their logistic components to 3PL providers because they may lack the competences and understanding required to manage logistics in a fragmented construction sector.

Poor infrastructures is another important challenges confronting the construction industry in Nigeria in adopting 3PL with a mean score of 4.02 and which lies between the range of 3.50 – 4.49 in the degree of agreement. This is similar to the findings of Harrison (2023), who found that infrastructural deficiencies impede the effective operation of logistics processes and supply sector in Nigerian. Inadequate infrastructure, such as roads, rail lines, and ports, increases transportation costs and causes delivery delays. The quality of infrastructure is crucial in logistics services and operations (Kuteyi & Winkler, 2022). Also, Chenikwi and Bebie (2023), also acknowledge that suitable infrastructure is required for logistics services to run well. When all of these infrastructure components are missing, several obstacles arise, discouraging construction firms from outsourcing their logistics functions. Overcoming these issues is critical for the effective implementation of 3PL in the construction sector, which will eventually lead to enhanced project delivery, efficiency, and cost reduction.

However, the other challenges with mean scores ranging from 2.50-2.49 in Table 5, were moderately agreed upon by the construction professionals as challenges facing the adoption 3PL in the Nigeria construction industry. This suggests that although the Nigerian construction industry faces a number of challenges in its adoption of third-party logistics, certain issues—like inadequate capacity and expertise and poor infrastructure are particularly pressing and call for immediate attention in order to enable wider acceptance and application of these logistics solutions.

Table 6. ANOVA for the Challenges in the Adoption of 3PL in Nigerian Construction Industry

Challenges	*F*	*p-value*
Poor infrastructure	5.438	0.001*
Inadequate capacity and expertise	2.000	0.101
Security concerns	0.844	0.500
Government regulations	3.386	0.012
Integration difficulties	0.742	0.566
Provider selection	6.178	0.000*
Loss of control	2.966	0.023
Performance Risk	4.926	0.001*
Additional cost	1.873	0.121
Communication and Collaboration issues	4.712	0.002*

*Significant at $p<0.05$ level.

Furthermore, the study examined statistical differences in the challenges faced in the adoption of 3PL (Table 6). As a result of their p value falling between 0 and 0.005, the results indicated a statistical difference in the respondents' challenges in adopting 3PL with regard to poor infrastructure, provider selection, performance risk, and communication and collaborations, depending on their professions.

The result implies that the challenges faced by construction firms in adoption of 3PL are not uniformly distributed across the Nigerian construction industry. Some construction firms might struggle primarily with infrastructure issues, while others find provider selection or performance risk more daunting. The differentiating factor may be as a result of the size, structure and geographical location of the construction firms (Ekeskär & Rudberg, 2020). When the firm is small, it may lack the resource to engage the services of a 3PL provider, while construction firms operating in different locations may face the challenge of coordinating logistics, making it difficult to standardize operations and leverage 3PL benefits.

4. Conclusions

The study examined the drivers and the challenges in the adoption of 3PL in the Nigerian construction industry. The findings show that increased efficiency, cost savings and risk management are the important drivers which influence 3PL adoption. However, inadequate capacity and expertise and poor infrastructure are important challenges that provide substantial obstacles in the adoption of 3PL in the construction industry. The Nigerian construction industry can significantly benefit from 3PL adoption through capacity building and strategic partnership with 3PL providers as well as infrastructural development by government. By overcoming these barriers, construction firms can enhance project delivery, reduce costs and improve overall competitiveness. Future study should look at particular case studies of successful 3PL implementation in Nigerian Construction projects and the development of a framework to evaluate the cost-effectiveness of 3PL for different types of construction projects in Nigeria.

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Compressive Strength of Concrete Incorporating NBRRI Pozzolana as Cement Replacement Material

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Abstract

Increase in construction activities resulting from the rise in population has led to rise in the demand for concrete globally. Concerns on the needs to mitigate the depletion of natural resources and environmental degradation, sustainable cement alternatives became a dire need. Thus, this study explored the use of NBRRI Pozzolana (NP) as replacement of cement in concrete. NP sourced from NBRRI plant, Ota, Nigeria was analysed using X-ray fluorescence spectrometry to determine its chemical compositions and its mineralogy and morphology were evaluated through X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM). Concrete mixes were developed by incorporating NP of 5 – 25% at a step of 5% replacement for cement. The control group was made up of concrete without NP. Slump test was performed on fresh concrete and compressive strength of hardened concrete specimens was measured at 7, 28 and 56 days of curing. The results showed the sum of SiO_2, Fe_2O_3 and Al_2O_3 of 90.39%, loss on ignition (LOI) of 0.97 and sulphur trioxide (SO_3) of 0.161 in NP. Also, XRD result showed that the major mineral occurred in amorphous phase is quartz while the minor phase are orthoclase, albite and muscovite and SEM result showed that NP contain several micro-pores with non-spherical, rough and uneven surface. The slump value ranged from 40 – 20 mm with 0 to 25% NP contents. The strength of concrete at 7, 28 and 56 days ranged 18.96 to 12.45 MPa, 25.38 to 17.79 MPa and 28.63 to 17.97 MPa. Using NP as a replacement for cement, the 10% replacement level demonstrated superior strength performance when compared to the design strength. It can be concluded that NP has the potential to be used as cement contents in concrete production.

Keywords: Concrete, Compressive strength, NBRRI pozzolana, Natural resources

Introduction

Concrete, a composite material fashioned by merging a binder (cement and lime) with aggregates, water and other admixtures in a designed quantity. With three tons as the annual global per capita used, concrete is currently the most utilized material, second only to water (Gagg, 2014). The quantity of concrete manufactured globally stands at roughly 4.20 billion m^3 per year, with more than 12.00 billion tons of material used each year (Tianming e*t al*., 2016).

The wide application of concrete in building sector is applaudable due to its strength, durability, flexibility and economy as well as its ability to be produced into virtually any shape and reproduce any surface texture (Olawale *et al*., 2021). However, concrete strength and quality are dependent on the cement type, cement quantity, water to cement ratio, aggregate type, aggregate size, aggregate content and particle size distribution of coarse aggregate and gradation of aggregate and mixing proportions (Larrard, 2014; Latifee, 2020).
Cement, the popular binder used in concrete production contributes largely to the setting time, workability and strength of concrete. However, the depletion of natural resources (limestone) used in the cement manufacturing is generating concerns worldwide (Mohamad *et al.* 2021). This is attributed to large material flows and huge amount of energy related to cement production have a significant impact on the environment (Tianming e*t al*., 2016; Kareem e*t al*., 2023). Thus, alternative material that can serve as substitute for cement due to its characteristics is needed to reduce the abatement of non-renewable natural resources (limestone) used in the production of cement.

The efficient usage of existing limited resources and the need for production of environmental friendly and affordable cement are global issues which have gained importance in the last few decades (Tianming e*t al*., 2016). This has instigated The Nigeria Building Research and Road Institute (NBRRI) to developed a pozzolanic material called NBRRI Pozzolana (NP). NP is manufactured from raw or calcined locally available clayey material or kaolin which is abundantly available in Nigeria. Pozzolans improved the characteristics of good concrete such as workability, resistance to sulphate attack, resistance to freezing and thawing, long term strength etc. (Olawale *et al.* 2019).

Few or minimal studies has been done on this developed material (NP) recently, this study is projected to reduces the usage of non-renewable natural resources used in the production of cement, reduces the negative impact to the environment, also to reduce amount of cement needed in concrete production as NP will be used as cement partial replacement which sum up to the reduction of cost of concrete.

1. Materials and Methods

The materials used in this study were NP, Cement, Coarse and fine aggregates and water. NP sourced from Ota, Ogun State, Nigeria served as partial replacement of cement in the modified concrete mixture. The Portland Limestone Cement (Dangote, 3X, 42.5N grade) sourced from a retail shop in Osogbo, Nigeria and conformed to BS 12 (1996) served as the main binding agent in all concrete mixtures. Sharp sand of 0.075 to 4.75 mm size range sourced from river boundary within Osogbo, Osun State, Nigeria was the fine aggregate used for all the concrete mixtures. Crushed granite of 5 to 19 was sourced from quarry at Obaagun, Osun State, Nigeria served as the coarse aggregate for all the concrete mixtures. Potable water suitable for drinking and sourced from Material Testing Laboratory, Osun State University, Osogbo was used throughout the mixing of concrete used in this study. Figure 1 shows the particle size distribution curve of sharp sand and granite.

Mix proportion and sample preparation

In this study, concrete mixes designed accordance with Building Research and Establishment method yielded a mix ratio of 1:2.12:2.75 (cement: sand: granite) for grade 20 concrete with water to cement ratio of 0.5. Cement was partially replaced with NP at 0, 5, 10, 15, 20 and 25% by weight of cement. Table 1 presented the ratio of varying constituents for concrete mixes. The mixing of the concrete paste was done after determining the physical properties of all constituent materials that was designed. The mixing of the materials was done in accordance with BS 1881-125 (1983). Batching by weight was adopted for each concrete mix. Shovel and trowel were used for the manual mixing. Lubricating oil was applied to rub the inner surface of the mould after cleaning the surface. Thereafter, it was filled with fresh concrete paste and compacted. The top layer of the mould was then leveled by removing excess concrete on the mould. The concrete was allowed to solidify by keeping it under room temperature of 25 °C and then it was demoulded and marked. The specimens were then cured in curing tank prior to testing.

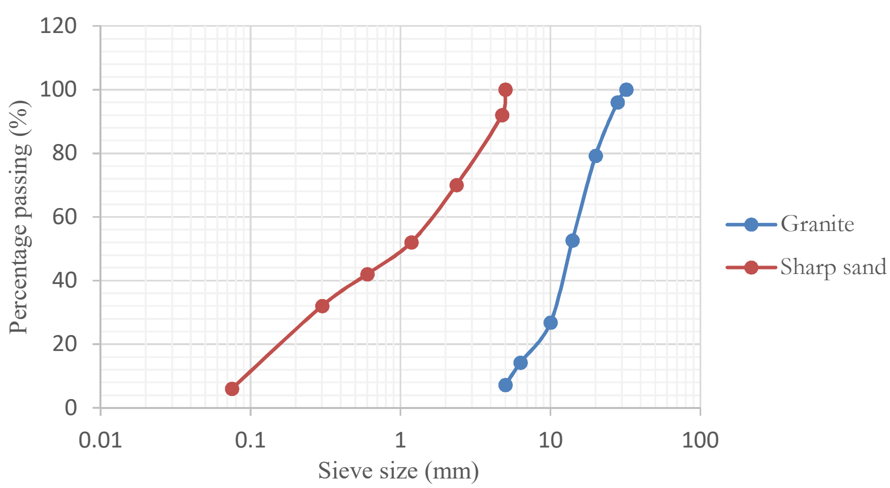

Figure 1: Particle size distribution curves of aggregates

Table 1: Constituents for concrete mixes

S/N	Specimen ID	Binder (kg/m^3)		Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
		Cement	NP			
1	NP-0	409.00	0.00	867.08	1124.75	205.00
2	NP-5	388.55	20.45	867.08	1124.75	205.00
3	NP-10	368.10	40.90	867.08	1124.75	205.00
4	NP-15	347.65	61.35	867.08	1124.75	205.00
5	NP-20	327.20	81.80	867.08	1124.75	205.00
6	NP-25	306.75	102.25	867.08	1124.75	205.00

Testing procedures

The chemical compositions of NP was determined through Xray Fluorescence (XRF) analysis in line with BS EN 196-2 (1995). The analysis was conducted at the National Steel and Raw Materials Exploration Agency, Malali, Kaduna State, Nigeria. Powdered.

The fresh concrete workability was evaluated through slump test according to BS EN 12350-2 (2009).

Concrete specimens of 100 mm x 100 mm x 100 mm cubes were subjected to compressive strength in accordance with BS 12390-3 (2009) after the curing ages of 7, 28 and 56 days, respectively. This test was performed on two specimens from each mix and compressive strength was taken as average from the two results.

Water absorption of concrete cubes of 100 mm x 100 mm x 100 mm were determined at 7, 28 and 56 days according to ASTM C642-13 (2013).

Results and Discussion

Chemical compositions of NP

The chemical composition of NP is presented in Table 2. The sum of the three primary compounds (SiO_2, Fe_2O_3 and Al_2O_3) in NP of 90.39% is more than 70%, the loss on ignition of 0.97 for NP is less than 6 and its sulphur trioxide (SO_3) is less than 4.0 as specified by ASTM C618-12 (2012) for natural pozzolans. This indicates that NP used in this study can be characterized as Type F class of pozzolans.

Table 2: Chemical composition of NP

Chemical Constituents	Compositions (%)
SiO_2	73.18
Al_2O_3	12.60
Fe_2O_3	4.61
CaO	1.59
SO_3	0.16

MgO	2.21
K_2O	0.24
TiO_2	1.51
LOI	0.97
$SiO_2 + Al_2O_3 + Fe_2O_3$	90.39

Workability of fresh concrete

The slump of concrete with various NP contents are presented in Table 3. The decrease in the fresh concrete slump observed with concrete with NP indicates the decline in the workability which was as a result of the rough, and uneven surface texture, non-spherical size particles with several pores of NP particles (Chin, 2021). In this case, more water is required for a given concrete consistency due to its adsorptive character of cellular NP particles and its high fineness which is the characteristics of pozzolanas (NP in this case). According to the slump results recorded in this study, the control concrete and concrete with different NP contents belong to S1 consistency class according to BS EN 206-1:2000. This finding reported in this study is in agreement with characteristic observed of other SCMs such as cashew leaf ash (Kareem *et al*., 2023).

Table 3: Slump of fresh concrete

NBBRI Pozzolana (%)	Slump value (mm)
0	40
5	30
10	25
15	30
20	30
25	20

Compressive Strength

The results of concrete compressive strength with different NP contents are shown in Figure 2. It can be deduced from the Figure 2 that the strength of concrete increases as curing days increases but declines with more the proportion of NP. At 7 days, the compressive strength of control sample was 18.96 MPa while it was 17.69, 17.17, 16.65, 15.68 and 12.45 MPa for concrete with 5, 10, 15, 20 and 25% NP, respectively. This is equivalent to 93.3, 91.87, 87.82, 82.70 and 65.66%, respectively, of the compressive strength of the control concrete. At 28 days, the compressive strength of control sample was 25.38 MPa while it was 22.87, 20.27, 19.29, 18.52 MPa and 17.69 MPa for concrete with 5, 10, 15, 20 and 25% NP, respectively. This is equivalent to 90.11, 79.87, 76.00, 72.97 and 69.70%, respectively, for the compressive strength of the control sample. At 56 days, the compressive strength of control sample is 28.63 MPa, while it is 24.32, 24.27, 20.93, 19.82 and 17.97 MPa for concrete with 5, 10, 15, 20 and 25% NP, respectively. This is equivalent to 84.95, 84.77, 73.11, 69.23 and 62.77%, respectively, for the compressive strength of the control sample. The reduction in compressive strength can be related to the presence of Potassium oxide and Magnesium oxide in pozzolan (NP in this case) which retarded the hydration reaction of concrete (Sunita and Rinku, 2021).These results agree with some previous researches where the presence of pozzolans caused the reduction in concrete compressive strength (Chin, 2021; Sunita and Rinku, 2021). As shown in Figure 4, concrete with up to 10% NP exhibited the compressive strength which is more than the design concrete strength of 20 N/mm² for grade 20 concrete while, the compressive strength of 15 N/mm² for grade 15 concrete was achieved at 28 days for concrete with up to 20% NP which indicates that 10% replacement is considered as the optimum replacement level in the M20 concrete as the compressive strength decreases afterward.

Water absorption

The water absorption results of concrete with various NP contents are presented in Table 4. The water absorption of the control concrete were 0.65, 0.43 and 0.17% at 7, 28 and 56 days, while it ranged from 0.76 to 1.00%, 0.59 to 0.77% and 0.32 to 0.64%, respectively with increase in NP content from 5 to 25%. The water absorption values obtained for all the concrete with or without NP are less than 10% specified by Neville (2011). The results indicate that concrete with 25% NP content had the highest water absorption at 7 days, concrete with 20% NP content had the highest water absorption at 28 days and concrete with 25% NP

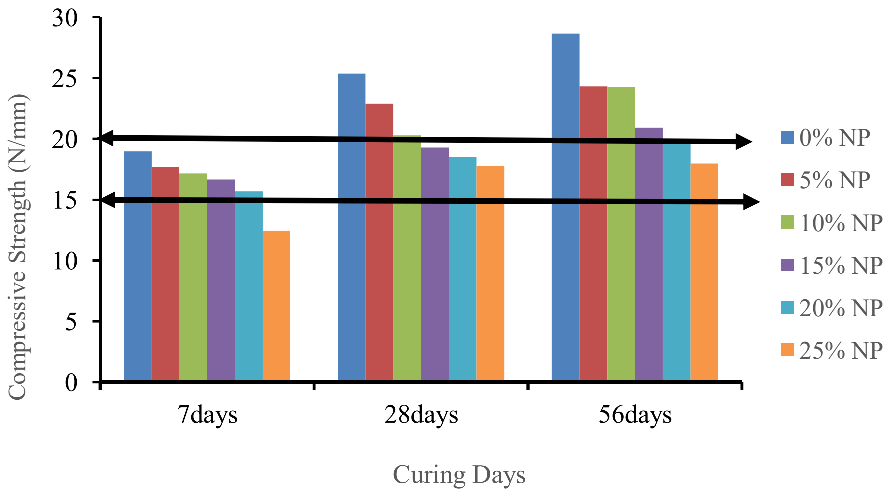

Figure 2: Compressive strength of concrete with varying NP content

content had the highest water absorption at 56 days. This result indicates that, concrete with higher NP content had highest water absorption which reduces the strength of the concrete and increases the level of permeability

Table 4: Water absorption of concrete with NP

NP (%)	Water Absorption (%)		
	7 days	28 days	56 days
0	0.65	0.43	0.17
5	0.76	0.59	0.32
10	0.87	0.74	0.37
15	0.76	0.57	0.47
20	0.69	1.03	0.41
25	1.00	0.77	0.61

Conclusions

The following conclusions were drawn from the various tests carried out during the course of the study

1. NP exhibited pozzolanic behavior with the presence of SiO_2, Fe_2O_3 and Al_2O_3 as its chemical constituent which addition of their weight is greater than 70% specified by ASTM C618-12 (2012).

2. The workability and compressive strength of concrete decreases with increase in NP contents but increases with increase in the number of curing days.
3. The addition of NP caused the decline in the concrete water absorption.
4. The optimum of 10% NP content is suitable as replacement for cement in normal concrete production.

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GROUNDWATER QUALITY ASSESSMENT OF SELECTED BOREHOLE WATER IN IREE, BORIPE LOCAL GOVERNMENT, OSUN STATE. NIGERIA.

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ABSTRACT

Water is a liquid that seems to be readily available, but access to clean and portable water can be a challenge in some places globally. Hence, due to the effect of consumption of borehole water in the vicinity it became necessary to perform quality assessment of water in Iree Community, Boripe Local Government in Osun state, Nigeria. Water samples were collected from five (5) boreholes, with varying depths. The water quality parameters were analyzed in accordance to standard methods. The ground water analysis reviewed includes pH, electrical conductivity, total dissolved solids (TDS), total suspended solids (TSS), turbidity, and hardness. The physical, chemical characteristics of borehole water collected from the different locations were analyzed and the results compared with WHO and NSDWO standard for potable water. The results of the physical analysis revealed that the quality of the water varies significantly among the different locations. Some boreholes have high levels of contaminants, while others have relatively clean water and also groundwater quality in the selected boreholes indicates some level of contamination. It is recommended that regular monitoring and testing of the groundwater be conducted to ensure that the quality remains safe for consumption, as this can help identify any potential contamination sources and allow for timely remediation actions.

Keywords: Water quality, Iree, Samples, Boreholes, Consumption.

1. Introduction

Water plays an indispensable role in sustenance of life and it is a key pillar of health determinant, since 80% of diseases in developing countries are due to lack of good quality water. Poor water quality continues to pose a major threat to human health. Diarrhoeal disease alone amounts to an estimated 4.1% of the total Disability-Adjusted Life Years (DALY) global burden of disease and is responsible for the deaths of 1.8million people every year (WHO, 2006). Consequently, water borne diseases such as cholera and typhoid often have their outbreak especially during dry season. High prevalence of diarrhea among children and infants can be due to the use of unsafe water and unhygienic practice. Thus, many infectious diseases are transmitted by water through fecal oral contamination. Disease due to drinking of contaminated water leads to the death of five million children annually and make 1/6 of the world population sick (Mustafa, Ibrahim, Haruna and Abubakakar, 2018).

Water which is treated by different Municipal bodies, meets all drinking water quality standards at treatment plant and at the point where the water enters the distribution system. Water quality deteriorates in distribution networks, during collection and storage, so it becomes obligatory to monitor water quality at each stage. Apart from all monitoring and surveillance, drinking water at tap may not be potable. By the time water reaches the consumer, its quality might be very different from what it was when it was when it left the plant. The management of distribution systems has become one of the most difficult challenges to providing safe drinking water as pipes are buried and not subject to the direct control of water utilities. Microbial contamination in distribution systems is a potential threat to public health.

The widespread reports on pollutants in groundwater have increased in recent years and have resulted to augmented public concern about the quality of groundwater. Groundwater bodies are prone to contamination from both anthropogenic and natural activities (Okuo, Okonji and Omoyerere, 2017). Some rural populations are heavily dependent on boreholes for their water supply, and are concerned about the quality of this water for direct consumption and other uses. Such concerns can be raised by what appears to be water pollution, or by disease symptoms perceived to be water related.

Aim:

The main aim of this research work is to assess the Groundwater Quality of selected Borehole water in Iree Boripe Local Government, Osun State, Nigeria.

Objectives:

The specific objectives of the research include:
(i) Determination of the heavy metal composition of water in Iree community.
(ii) Evaluation of the physiochemical constituents of water in Iree community, Osun State, Nigeria.

2. Literature Review

Water

Water (chemical formula H_2O) is an inorganic, transparent, tasteless, odorless, and nearly colorless chemical substance, which is the main constituent of Earth's hydrosphere and the fluids of all known living organisms (in which it acts as a solvent_. It is vital for all known forms of life, despite providing neither food, energy, nor organic micronutrients. Its chemical formula, H_2O, indicates that each of its molecules contains one oxygen and two hydrogen atoms, connected by covalent bonds. The hydrogen atoms are attached to the oxygen atom at an angle of 104.45^0 (Shove, 2018). "Water" is also the name of the liquid state of H_2O at standard temperature and pressure.

Properties of Water

Water (H_2O) is a polar inorganic compound. At room temperature, it is a tasteless and odorless liquid, nearly colorless with a hint of blue. This simplest hydrogen chalcogenide is by far the most studied chemical compound and is described as the "universal solvent" for its ability to dissolve many substances. This allows it to be the "solvent of life", indeed, water as found in nature almost always includes various dissolved substances, and special steps are required to obtain chemically pure water. Water is the only common substance to exist as a solid, liquid, and gas in normal terrestrial conditions, (Troell, Naylor, Metian, Beveridge, Tyedmers, Folke, Arrow, Barrett, Crepin, Ehrilich and Gren, 2014).

Uses of Water

(i) Agriculture

The most substantial human use of water is for agriculture, including irrigated agriculture, which accounts for as much as 80 to 90 percent of total human water consumption. In the United States, 42% of freshwater withdrawn for use is for irrigation, but the vast majority of water "consumed" (used and not returned to the environment) goes to agriculture (Matsuoka and Murton, 2018).

(ii) As a Scientific Standard

On 7 April 1795, the gram was defined in France to be equal to "the absolute weight of a volume of pure water equal to a cube of one-hundredth of a meter, and at the temperature of melting ice". For practical purposes though, a metallic reference standard was required, one thousand times more massive, the kilogram.

(iii) For Drinking

The human body contains from 55% to 78% water, depending on body size. To function properly, the body requires between one and seven liters (0.22 and 1.54 imp gal; 0.26 and 1.85 U.S. gal) of water per day to avoid dehydration; the precise amunt depends on the level of activity, temperature, humidity, and other factors.

(iv) Washing

Washing is a method of cleaning, usually with water and soap or detergent. Washing and then rinsing both body and clothing is an essential part of good hygiene and health.

(v) Transportation

Maritime transport (or ocean transport) and hydraulic effluvial transport, or more generally waterborne transport, 1S the transport of people (passengers) or goods (cargo) via waterways.

(vi) Chemical Use

Water is widely used in chemical reactions as a solvent or reactant and less commonly as a solute or catalyst. In inorganic reactions, water is a common solvent, dissolving many ionic compounds, as borehole as other polar compounds such as ammonia and compounds closely related to water.

(vii) Fire Considerations

Water has a high heat of vaporization and is relatively inert, which makes it a good fire extinguishing fluid. The evaporation of water carries heat away from the fire.

(viii) Recreation

Humans use water for many recreational purposes, as borehole as for exercising and for sports Some of these include swimming, waterskiing, boating, surfing and diving.

Microbial Aspects of Drinking Water

The greatest risk to public health from microbes in water is associated with consumption of drinking-water that is contaminated with human and animal excreta, although other sources and routes of exposure may also be significant. This chapter focuses on organisms for which there is evidence, from outbreak studies or from prospective studies in non-outbreak situations, of diseases being caused by ingestion of drinking-water, inhalation of water droplets or dermal contact with drinking-water and their prevention and control. For the purpose of the Guidelines, these routes are considered waterborne. Infectious diseases caused by pathogenic bacteria. viruses and parasites (e.g. protozoa and helminths) are the most common and widespread health risk associated with drinking-water.

3. Research Methodology

Sampling Location

Sampling stations used for the study are located in Iree community, Boripe Local Government Area, Osun State, Nigeria. This sampling station include; Mike Adelaja Crecent, Iga, Avana, Plastona and Iya kolo.

Sampling

Water samples was taken and store in a 1000ml sterilized bottle form; Mike Adelaja Crecent, Iga, Avana, Plastona and Iya kolo. These five (5) samples where labeled A-E respectively.

Samples was collected for physicochemical, microbiological, and trace metals analyses. Water samples for metals was preserved with concentrated nitric acid. Collected samples was kept in an ice chest and transported to the Hydrology Laboratory for examination.

4. Results And Discussion

Physiochemical analysis Result

Table 4.1: Result of the physiochemical analysis of the water sample

PARAMETERS	A MIKE ADELAJA CRESCENT	B IGAA 1	C AVANA	D YAKOYO	E PLASTONIA	WHO 2021 STANDARD	NSDWQ 2015
pH at Laboratory	6.9	5.83	5.81	6.79	6.48	6.5-8.5	6.5-8.5
Turbidity (FTU)	0.008	04.2	0.3.4	02.8	00.8	5	NS
Temperature in ^{O}C	31.3	31.0	31.1	30.5	30.0	$20^{0}C$ 68F	$<40^{0}C$
Total Alkalinity mg/l	220	208	80	568	72	200	
Total Hardness mg/l	190	316	340	180	166	120-180	150

Calcium Hardness mg/l	5.76	3.78	11.15	4.50	10.25	180	
Iron mg/l	0.0019	0.0039	-0.0006	-0.0001	0.0016	0.3	0.3
Copper mg/l	0.0092	0.0022	0.0030	0.0098	0.0190	2.0	
Conductivity	354	327	106	415	318	900	1000
Sulphate mg/l	4.94	3.70	2.50	2.90	3.30	400	100
Phosphate mg/l	176.0	178.6	172.8	164.8	169.6	6.5	
Total soluble solid	-0.01	0	-0.01	0	0	30	
Total Solids	-0.01	0	0	-0.01	0	NS	
Total dissolve solid	0	0	-0.01	0	1200		

Discussions

Temperature

The temperature of all water sample collected at the various locations varies from 30.0-31.3 which falls within the allowable WHO 2021 limit of <40^0C.

pH

The pH of all water samples collected at various location varies from 5.81-6.9 which falls within the WHO 2021 limit and the NSDWQ 2015 limit as presented in Table 4.1.

Total Hardness

Water hardness is the traditional of the capacity to react with soap; hard water requires considerable more soap to produce lather Hardness is one of the very important properties of ground water from utility point of view particularly for domestic purposes. From table 4.1 water hardness ranges from 166-340mg/1, sample collected at Mike Adelaja Crescent, Igaa 1, and Avana exceeded the maximum allowable limit of 120-180mg/1 recommended by WHO 2021 and 150mg/l as recommend by NSDWQ 2015 but sample collected at Plastonia and falls within the WHO and NSDWQ maximum allowable limit (150mg/l).

Calcium Hardness

The Calcium hardness for the water samples varies from 3.78-10.25mg/l for all analyzed samples which falls within the 180mg/l maximum permissible level for WHO 2021 standard as presented in Table 4.1.

Iron

The iron of water samples collected ranges from -0.0001-0.0039mg/l which falls within the WHO and NSDWQ maximum permissible level

Copper

Copper for the water samples collected ranges from 0.0022-0.190mg/ which fall within WHO 2021 and NSDWQ standard 2015

Chromium

Chromium for all the water samples analyzed ranges from 0.003-0.006 which falls within WHO 2021 and NSDWQ 2015 standard

Conductivity

Conductivity for all the samples analyzed ranges from 106.0-4 1 5mg/l which falls within WHO 2021 and NSDWQ 2015 standard as presented in Table 4.1.

Sulphate

Sulpbate for all the samples analyzed ranges from 2.50-4.94 which falls within WHO 2021 and NSDWQ 2015 standard, as presented in Table 4.1.

Phosphate

Phosphate for all water sample analyzed ranges from 164.8-178.6 which exceeded the WHO 2021 maximum permissible level

Total Alkalinity

Total alkalhnity for all the samples analyzed varies from 72.0-568mg/l samples collected from Mike Adelaja Crescent, Igaa I and Yakoyo exceeded allowable limit of 200mgl recommended by WHO 2021, but samples collected from Avana and Plastonia falls within the allowable limit of WHO 2021.

Total Soluble Solids

Total Soluble Solids for all the water samples analyzed ranges from 0-01.-Omg/l which falls within the allowable standard of WHO 2021

Total Solids

Total Solids for all the water samples analyzed ranges from 0-01.-0mg/l which falls within the allowable standard of WHO 2021

Total Dissolve Solid

Total Dissolve Solids for all the water samples analyzed ranges from 0-01.-0mg/1 which falls within the allowable standard of WHO 2021

5. Conclusion and Recommendation

Conclusions

(i) Based on the assessment of the groundwater quality of selected boreholes, it can be concluded that the quality of the water varies significantly among the different locations. Some boreholes have high levels of contaminants, while others have relatively clean water.

(ii) The groundwater quality in the selected boreholes indicates some level of contamination.

(iii) The contamination may be attributed to various sources such as nearby industrial activities, agricultural practices, or natural geological factors.

(iv) It is recommended hat regular monitoring and testing of the groundwater be conducted to ensure that the quality remains safe for consumption. This can help identify any potential contamination sources and allow for timely remediation actions.

Therefore the following recommendations were made:

(i) Groundwater quality should be monitored periodically to ensure its safety and identify any potential contamination sources. This monitoring should be conducted by trained professionals using reliable testing equipment.

(ii) It is imperative to educate the public about the importance of groundwater quality and the potential health risks associated with contaminated water. This can be done through community outreach programs, awareness campaigns, and dissemination of information about groundwater protection measures.

(iii) Based on the assessment results, it 1s crucial to take appropriate preventive measures to minimize potential contamination sources. This may include implementing regulations on land-use practices, enforcing proper waste disposal methods, and ensuring the maintenance and disinfection of boreholes.

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Review of Clustering Algorithms for Regional Drought Characterisation

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Abstract

Drought is characterised by a negative water imbalance originating from a deficiency of precipitation or a lack of available water resources for an extended period of time. However, due to climate change there is need to study drought patterns and characteristics. Currently, the main limitations of drought analysis is the lack of ability to classify spatial pattern according to its kind and concomitant regional characteristics. This ability is increasingly important because the effects of drought accumulate slowly over a considerable period of time, and move slowly to adjacent positions. As such the specific objective of this research is to review arrays of cluster algorithms supposedly needed for drought studies. *Myriads of scholars have considered clustering techniques as the most common approaches. Findings here unveiled the shortcomings and strength of composite clustering algorithms. It is clear here, that the choice of the cluster algorithm is relatively subjective, yet should be bore in mind, that is there is need to explore more than one cluster algorithms in fear of losing microscopic precipitation fact and for the ease of analysis of Spatio-temporal phenomena. In recognition of hydrological time series characteristics of trans-boundary interference and spatio-temporal variation, where zones or regions that share common boundary may inherit similar hydro-climatic characteristics that seem different from other part of the region. It is imperative, for hydro-climatic researchers to adopt clustering algorithm that reveals the degree of shared characteristics or membership properties, in this hierarchy that is; FCM, PCA, k-means and SOM, for effective water resource planning and management in the phase of climate change*

Keywords: Drought, Cluster, Water, Homogenous and Region

1.0 Introduction

The study of climate regionalisation is essentially the aggregation or delineation of regions with similar hydro-climatic characteristics and spatial continuity. In general, the regional behaviour of droughts has been studied by analysing the point behaviour (data analysis of point rainfall or streamflow) and then mapping the relevant parameters over a region or a country. The regional drought characterisation concept is solely based upon the basic idea of point-drought and drought-affected area; the former being related to a threshold (truncation level or critical level) below which a water shortage exists, whereas the later concept is related to another threshold (critical area) above which the integration of the various areas affected by point-droughts represent a significant portion of the whole region under study Chukwu (2024). Raziei *et al.* (2015) further developed a statistical drought distribution model on the regional level, which is operational in Portugal and applied to coherent regions in Europe. The coherent regions were delineated on the basis of Box-Cox parameters in the time series of drought variables with negligible levels of persistence. Currently, the main limitations of drought analysis is the lack of ability to classify spatial pattern according to its kind and concomitant regional characteristics. One important tool which is indispensable in regional analysis is the multiple regression algorithm which involves parameters of drought, geomorphology and climate for the development of regression equations (Wei *et al.* 2020). Kriging is one of several methods that use a limited set of sampled data points to estimate the value of a variable over a continuous spatial field.. It differs from simpler methods, such as Inverse Distance Weighted Interpolation, Linear Regression, or Gaussian decays in that it uses the spatial correlation between sampled points to interpolate the values in the spatial field: the interpolation is based on the spatial arrangement of the empirical observations, rather than on a presumed model of spatial distribution. Kriging also generates estimates of the uncertainty surrounding each interpolated value (Loukas, 2004). Among other emerging approaches for drought analysis are pattern recognition, for examples Machine Learning (ML) and Artificial Intelligence (AI), Deep Learning and Remote Sensing and neural networks, which are all subsets of machine learning, gainfully engaged in drought analysis especially, the unsupervised component namely; clustering algorithm (Otache 2008). It have proven to be the most viable framework in grouping of seemingly homogenous pools into clusters. Therefore, cluster analysis or clustering is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar (in some specific sense defined by the analyst) to each other than to those in other groups (clusters). It is a main task of exploratory data analysis, and a common technique for statistical data analysis, used in many fields (Jimoh *et al.*, 2023). In light of the foregoing, this research is tilted towards reviews of common clustering algorithms often use in drought analysis and in extension water resources characterisation.

2.0 Overview of Clustering Algorithm

2.1 Hierarchical Clustering

With the help of the HiClim R statistical package in R software as reported in Chukwu (2024), the longitude, latitude, elevation, Precipitation Concentration Degree (PCD), and Precipitation Concentration Period (PCP) of each grid point in the identified region can be used as the attributes in hierarchical clustering to identify the homogeneous climate regions. Among these, latitude, longitude, and elevation are useful for identifying geographically continuous regions and describing atmospheric variables that change over space (Ghosh *et al.,* 2016).The PCD and PCP can reflect the uneven distribution of rainfall within a year. In previous studies, Ghosh *et al.* (2016) demonstrated the reliability of the PCD and PCP for identifying homogeneous drought regions. To eliminate the influence of dimension, the grid characteristics, namely, latitude, longitude, elevation, PCD, and PCP were standardised before hierarchical clustering. However, Chukwu (2024), pointed out few weaknesses common to hierarchical cluster; it rarely provides the best decisions, does not work with a missing data, work poorly with mixed data types and its output dendrogram is commonly misinterpreted. Afterwards, the square of the Euclidean distance was used to calculate the distance between the points. Furthermore, the distance between the classes is often calculated using Ward's method. The appropriate number of clusters can be determined using the silhouette coefficient. The mathematical scheme below illustrate Hierarchical cluster

$$R_i = \sum_{j=1}^{12} r_{ij} \qquad \text{1a}$$

$$R_i = \sum_{j=1}^{12} (r_{ij}\, sin\theta_j) \qquad \text{1b}$$

$$PCD_i = \sqrt{R_{xi}^2 + \frac{R_{yi}^2}{R_i}} \qquad \text{1c}$$

$$PCP_i = arctan\left(\frac{R_{xi}}{R_{yi}}\right) \qquad \text{1d}$$

Where,

i refers to the year (example: i = 1961, 1962, : : : , 2017)

j stands for the month (j = 1, 2, : : : , 12) in a year.

r_{ij} represents monthly total precipitation in the j_{th} month of the i_{th} year

θ_j refers to the azimuth of the j_{th}month.

R_j expresses the total precipitation amounts of the I_{th} year.

R_{xi} and R_{yi} are the synthetic components in horizontal and vertical directions of the twelve month precipitation vector modules in the i_{th} year, respectively.

PCD_i and PCP_i represent the precipitation concentration degree and precipitation concentration period in the i_{th} year, respectively.

2.2 Empirical Orthogonal Function (EOF)

EOF decomposition was first established in 1902 as reported by Hongwu *et al.* (2020). It decomposes elements of a set of space time data into two functions, one dependent only on time and another dependent only on space, to analyse the spatial structure of element fields. Thus, EOF decomposition is commonly used to analyse spatial and temporal variations in meteorological elements. In contrast, Principal Component Analysis (PCA) is mainly used to find a few independent vectors in a dataset to reduce its dimensionality, thereby simplifying data handling and interpretation. However, the operational steps are basically the same, when the original variables are anomaly data or standardised anomaly data (Hongwu *et al.*, 2020). EOF decomposition and several variants thereof have been widely applied for analyzing spatial changes in hydrometeorological elements. Notably, EOF decomposition has been used to analyse drought occurrence in both time and space in Korea (Kim *et al.,* 2011). It has also been applied to establish contributions of annual evaporation, annual precipitation, and both warm-and cold-season precipitation, to the annual runoff of rivers in an arid zone to obtain quantitative estimates of the effects of climatic factors on reconstructions of annual runoff series in an ungauged area (Loboda, 2005). A Data Interpolating Empirical Orthogonal Function (DINEOF) has been used to analyse distributions of sea surface temperatures in a study demonstrating that DINEOF decomposition can be highly effective, even when very high proportions of data are missing (Sirjacobs *et al.*, 2011). In addition, Rotated Empirical Orthogonal Function (REOF) decomposition has been applied to analyse space time patterns of groundwater fluctuations in the Choshui

River alluvial fan, Taiwan, based on monthly observations of piezometric heads from 66 wells during the period 1997–2002 (Yu *et al.,* 2013). It has mild shortcoming of requiring adequate computation skill and mechanism. Therefore, it is a silent approach when it comes to regionalisation via geographic protocol and gives less insight to drought characteristics of the concern region (Loboda, 2005).

2.3 Principal Components Analysis (PCA)

Principal components analysis is a statistical procedure that transforms several (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components (PC) (Jimoh *et al.,*2023). The main objective of the PCA, specifically the principal factor analysis (PFA), are: (1) to reduce the number of variables (2) to detect structures in the relationship between variables (3) to reduce the system's information entropy, that is, the information not directly available about a system due to the uncertainty or randomness of data flow (Deng *et al*., 2014) and (4) to combine correlated variables into factors (Jimoh *et al.,* 2023). The determination of the number of components or factors to retain is often based on the Kaiser's rule, the factors whose eigenvalues are greater than 1 must be retained. The spatial patterns of the eigenvectors (factor loadings) represent the correlation between the original data and the corresponding factor time series. More localised patterns are obtained by applying the Varimax rotation technique to selected factor loadings (Karaman *et al*., 2017). The projection of the Standardised Precipitation Index (SPI) fields onto the orthonormal Eigen functions provides the factor score time series (Osborne *et al*., 2015). Factor scores are estimates of the actual values of individual cases (observations). For instance, the estimated factor score (regionalised SPI) on factor j for observation, or month, i, F_{ji} can be represented as follows:

$$F_{ji} = Z_{j1}W_{j1} + Z_{j2}W_{j2} + \cdots + Z_{jk}W_{jk} \qquad 2$$

Where:

W_j is the regression weight, multidimensional value referred to as factor score coefficient; and Z_i is the variable that is the SPI series or desire drought series at a single rain gauge. For any single common factor, an infinite number of sets of scores can be derived that would be consistent with the same factor loadings (Karaman *et al*., 2017). The factor scores are particularly useful to perform further regional analyses that have been identified in the factor analysis, such as fitting drought characteristics with copulas.When applied to the SPI or drought series values from a set of rain gauges, it allows their regrouping and consequently, the delimitation of climatic regions in relation to synoptic situations, that is regionalised. SPI series such as the three distinct areas with coherent climatic variability identified by Serinaldi *et al.* (2009) in Sicily from 1926 to 1996, the three homogeneous regions were adopted for drought characterisation in mainland Portugal. Santos *et al.* (2011) employed similar approach in two climatic sub-regions in the western Iran, all the analysis were based on the SPI field and effective delineate component series into homogenous subregion and finding out few remarkable shortcomings that data inputs produce result that are very much off the correct projection of the data. In the case of Raziei *et al.* (2015), the PCA was applied to the unsmoothed and smoothed SPI time series at the timescales of 3 and 6 months and the result was consistence with previous studies carried out by Chukwu (2024) in a related region, in that regard PCA consists of computing the covariance matrix of the SPI series with the corresponding eigenvalues (λ) and eigenvectors (v).

2.4 K-means Clustering Algorithm

K-means cluster analysis is an example of a hard partitioning algorithm (Chukwu, 2024).A set of *N* data $(x_1, x_2, \ldots x_N)$ in *d* dimensions is partitioned into *K* clusters, where each element in the data set is allocated entirely to a particular cluster. It is an iterative process whereby the data are initially partitioned, the mean position of each group calculated, and then the data partitioned again by allocating each datum to its nearest mean cluster position. The procedure terminates when no datum changes cluster or when the number of iterations reaches a pre-defined maximum. He *et al.* (2015) found that k-means clustering algorithm is able to search the synchronous variability of at-site SPI series and classify the homogeneous sub-regions over the study region as well as indicate that temporal evolutions are quite different over other candidate cluster algorithm explored as verified by Clustering Validation Indices (CVI) and sum squared error (SSE) in Guizhou province in southwest China. In a related study carried out by Pei *et al.* (2019) in Xinjiang province examines the variation of SPI-12 from the meteorological stations. It was reported that k-means cluster was enable to group the stations with similar temporal trends, thereby identifying three clusters; Cluster 1 is the driest, cluster 2 has a clear alleviating tendency of drought, and cluster 3 shows late occurrence of change point. Rajsekhar *et al.* (2011) used entropy approach for identification of homogeneous drought regions using standardised streamflow index (SSFI) for the Brazos basin in Texas over a time span of 1949–2000. Regions obtained using entropy theory were similar to the regions obtained with k-means clustering method. However, one problem that emerges when k-means method is used is a demand for a priori choose of the number of clusters in a region. To solve this problem, Gap Statistics is often recommended (Pham *et al.*, 2005). This Statistics uses the distortion of a cluster and it is determined as described by Carvalho *et al.* (2016).

2.5 Fuzzy C-means Clustering

The concept of fuzzy c-means (FCM) clustering is known as soft partition. It is a soft partitioned clustering algorithm, which means a data point belongs to every cluster with different degrees of belonging (membership), unlike hard partitioned clustering in which a data point belongs completely to one cluster only. The degree of belonging (membership) is inversely proportional to the distance between the cluster centre and the data point. The more the distance of the cluster centre from the data point, lesser the membership value of station for that cluster. Birpınar *et al* (2023) shows that soft partitioned clustering provides more information and is essential for obtaining homogeneous clusters. The homogeneity of the cluster is evaluated using L-moment-based homogeneity test (H-Test) as reported in Chukwu (2019). The fuzzy c-means (FCM) clustering algorithm optimises the objective function (3a). It consider a cluster c having M objects in which $Y_k$is the data vector for k_{th} object, k = 1,2,…, M. The fuzzy objective function is

$$J(U,C) = \sum_{K=1}^{M}\sum_{i=1}^{c} u_{ik}^{\alpha}\|Y_k - C_i\|^2 \qquad 3a$$

Where u_{ik}denotes the degree of belonging of k_{th} data point in the i_{th} cluster, $C_i$denotes the centre of the i_{th} cluster, $\|Y_k - C_i\|^2$ is the squared Euclidean distance between k_{th}data point and C_i and a is called fuzzifier or fuzziness index, which can have any value > 1.
Fuzzy c-means algorithm steps is given below:

Cluster centres are assumed randomly.

1. Using cluster centres, membership matrix is calculated using following equation.

$$u_{i\,<1}^{t} = \left[\sum_{j=1}^{c}\left[\frac{\|yk-c\ \|}{\|yk\quad cj\|}\right]^{\frac{1}{\alpha-1}}\right]^{-\,1} \qquad 3b$$

Where i = 1; 2, . . ., c and k = 1, 2; . . ., M.

2. Using updated membership values calculated in step 2 and equation 3b, new cluster centres are calculated using following equation

$$C_i = \frac{\sum_{k=1}^{M} u_{ik}^{2}\mathrm{yk}}{\sum_{k=1}^{M} u_{ik}^{2}} \qquad 3c$$

3. Membership matrix is updated using new cluster centres

$$u_{i\,<1}^{t+1} = \left[\sum_{j=1}^{c}\left[\frac{\|yk-c\ \|}{\|yk\quad cj\|}\right]^{\frac{1}{\alpha-1}}\right]^{-\,1} \qquad 3d$$

4. If $\left\|U^{(t+1)} - U^{(t)}\right\| < \varepsilon$, then the algorithm stops. Otherwise, go back to equation 3a

2.6 The Self-Organizing Map (SOM)

It is also known as Kohonen Map or Self-Organizing Feature Map, is an unsupervised neural network based on competitive learning (Otache, 2008). It projects high-dimensional input data onto a low dimensional (usually two-dimensional) space. Because it preserves the neighborhood relations of the input data, the SOM is a topology-preserving technique. The machine learning is accomplished by first choosing an output neuron that most closely matches the presented input pattern, then determining a neighborhood of excited neurons around the winner, and finally, updating all of the excited neurons. This process iterates and fine tunes, and it is called self-organising. The outcome weight vectors of the SOM nodes are reshaped back to have characteristic data patterns. This learning procedure leads to a topologically ordered mapping of the input data. Similar patterns are mapped onto neighboring regions on the map, while dissimilar patterns are located further apart. An illustration of the work flow of an SOM application is portrayed in figure 3. The data time series are rearranged in a 2D array such that the data at each time step are reshaped as a row vector. For each time step, the row vector is used to update the weight of the SOM via an unsupervised learning algorithm. This iterative process is called self-organising. The outcome weight vectors of the SOM nodes are reshaped back into characteristic data patterns. The SOM was introduced to meteorological and climatic sciences in late 1990s as a clustering and pattern recognition method (Karaman *et al*., 2017). It is found to be a useful tool in meteorological applications of different spatial and temporal scales: synoptic climatology, extreme weather and rainfall pattern analysis, cloud classification, as well as climate change analysis

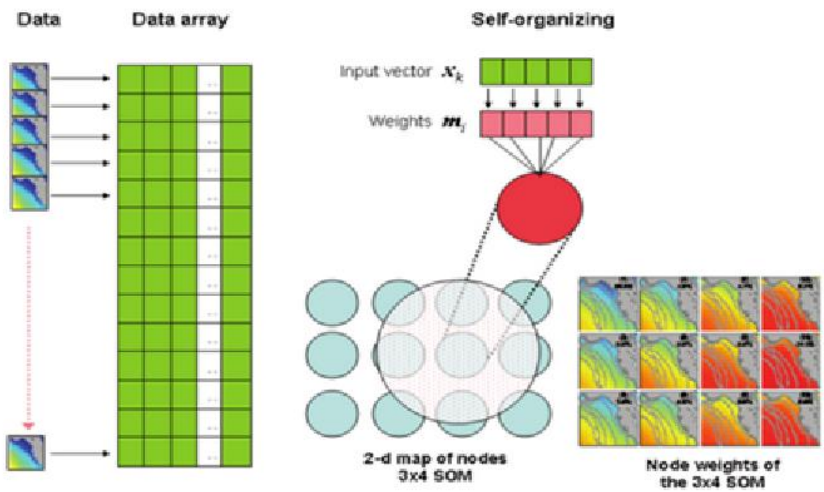

Figure 2: Illustration of SOM mechanisms (Liu *et al.* 2006b)

Tadross *et al.* (2005) extracted characteristic rainfall patterns over South Africa and Zimbabwe from rainfall data products, and studied the rain-fed maize for the region. Gutierrez *et al.* (2005) applied the SOM to analyse atmospheric patterns over Peru and local precipitation observations at two nearby stations for the purpose of downscaling multi-model seasonal forecasts. Liu (2007) used both EOF and SOM to extract ocean current patterns from the same data set (a long time series of velocity from a moored ADCP array), and found that the SOM patterns were more accurate and intuitive than the leading mode EOF patterns. Reusch *et al.* (2005b) also tested the SOM against the PCA method using synthetic datasets composed of positive and negative modes of four idealised North Atlantic sea level pressure fields, with and without noise components. Findings shows that the SOM was more robust than the PCA in extracting the predefined patterns of variability. While K-means is another popular artificial neural network widely used for clustering, after comparing the SOM and k-means methods, Bação *et al.* (2005) proposed the use of SOMs as possible substitutes for the k-means clustering algorithms. However, wide applications as a tool for feature extraction and clustering, the SOM remains a black box to most meteorologists and oceanographers. SOM new users may be perplexed by the choice of SOM parameters, because different parameter choices may result in different SOM patterns. This challenge may prevent some potential new users from pursuing further SOM applications.

2.7 Discriminant Analysis

The original dichotomous discriminant analysis was developed by Sir Ronald Fisher in 1936 (Green *et al*., 2008). It is different from an ANOVA or MANOVA, which is used to predict one (ANOVA) or multiple (MANOVA) continuous dependent variables by one or more independent categorical variables. Discriminant function analysis is useful in determining whether a set of variables is effective in predicting category membership (Green *et al*., 2008). Linear discriminant analysis (LDA), normal discriminant analysis (NDA), or discriminant function analysis is a generalisation of Fisher's linear discriminant, a method used in statistics and other fields, to find a linear combination of features that characterises or separates two or more classes of objects or events. The resulting combination may be used as a linear classifier, or, more commonly, for dimensionality reduction before later classification. Discriminant analysis is used when groups are known *a priori* (unlike in cluster analysis). Each case must have a score on one or more quantitative predictor measures, and a score on a group measure (Bökeoğlu *et al.,*2017). In simple terms, discriminant function analysis is the act of distributing things into groups, classes or categories of the same type.

Discriminant analysis works by creating one or more linear combinations of predictors, creating a new latent variable for each function. These functions are called discriminant functions. The number of functions possible is either $N_g - 1$ where $N_g =$ number of groups, or P (the number of predictors), whichever is smaller. The first function created maximises the differences between groups on that function. The second function maximises differences on that function, but also must not be correlated with the previous function. This continues with subsequent functions with the requirement that the new function should not be correlated with any of the previous functions. Given group j, with $\mathbb{R}_j$ sets of sample space, there is a discriminant rule such that if $x \in \mathbb{R}_j$, then $x \in j$. Discriminant analysis then, finds "good" regions of $\mathbb{R}_j$ to minimise classification error, therefore leading to a high "percent correct classified" in the classification table (Hardle *et al.*, 2007). Each function is given a discriminant score to determine how well it predicts group placement.

Compared with the other methods, Fisher discriminant analysis has advantages. First, it can take multiple factors into consideration **(**Xu *et al.* 2004**).** Therefore, it was applied to detect drought occurrences, it comprehensively takes the soil water and atmospheric moisture conditions into consideration. This is meaningful because atmospheric aridity or associated drought component has been reported to be more impactful for water and carbon fluxes under climate change (Xu *et al.* 2021). Second, the discriminant formula is created based on local observation; hence, it can be applied directly to the given research site without parameter localisation. Moreover, it is easy to apply because the established discriminant function is not complex and only employs the soil and atmospheric water conditions as the discriminating variables. This would help scientists better conduct field experiments. For example, if an *in situ* water condition control experiment is conducted, drought could be easily and rapidly determined by employing the easily measured soil water content (SWC) and vapor pressure deficit (VPD).

3.0 Conclusion

Findings here unveiled the shortcomings and strength of composite clustering algorithms. It is clear here, that the choice of the cluster algorithm is relative subjective, yet should be bore in mind, that is there is need to explore more than one cluster algorithms in fear of losing microscopic precipitation fact and for the ease of analysis of spatio-temporal phenomena. In recognition of hydrological time series characteristics of trans-boundary interference and spatio-temporal variation, where zones or region that share common boundary may inherit similar hydro-climatic characteristics that seem different from other part of the region. It is imperative, for hydro-climatic researchers to adopt clustering algorithm that reveals the degree of shared characteristics or membership properties, in this hierarchy that is; FCM, PCA, k-means and SOM, for effective water resource planning and management in the phase of climate change.

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Investigating the Hydraulic Barrier Properties of Compacted Lateritic Soil Treated with Sorghum Husk Ash

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Abstract

This study evaluates the hydraulic barrier parameters of lateritic soil admixed with Sorghum Husk Ash (SHA) using the West African standard (WAS) compaction energy. The index properties and subsequent classification of the soil sample were determined through natural moisture content, specific gravity, Atterberg limits, particle size distribution, X-Ray Diffraction (XRD), X-Ray Fluorescence (XRF), compaction, hydraulic conductivity (k), unconfined compressive strength (UCS) and volumetric shrinkage strain (VSS) tests. The sample was thereafter admixed with SHA up to 12% by weight of the lateritic soil at a step treatment of 3% SHA, and compacted at moulding water content (MWC): -2%, ±0%, +2%, +4% relative to optimum moisture content (OMC) to evaluate its effect on the barrier parameters (k, UCS, VSS) of the specimen. The sample was a reddish-brown soil classified as SW (Well-graded sand) and A-2-6(0) according to USCS and AASHTO classification systems, respectively. The liquid limit, plastic limit and plasticity index values were observed to be 30.0%, 17.5% and 12.5%, respectively, having a specific gravity of 1.86, maximum dry density (MDD) of 1.78 Mg/m³ and OMC of 12%. The barrier parameters were obtained as 1.49 ×10⁻⁷ cm/s, 51.0 kN/m², 9.54% for k, UCS, VSS respectively. The XRF result revealed that the SHA contains 65.4% oxides of $SiO_2+Al_2O_3+Fe_2O_3$*, making it a good pozzolanic material. The MDD and OMC of the treated specimen ranges between 1.71-1.81 Mg/m³ and 9.2-17.3%, respectively. The barrier parameters of the treated specimen when compacted with MWC relative to OMC ranges between* $1.03 \times 10^{-7} - 3.25 \times 10^{-7}$ *cm/s, 37.2 – 74.1 kN/m², 2.60 – 13.10% for k, UCS, VSS respectively. The least value of k* ($1.03 \times 10^{-7} > 1.00 \times 10^{-7}$ *cm/s) was obtained at 3% SHA content, the maximum value of UCS (55.6 < 200 kN/m²) obtained at 12% SHA, while the minimum value of VSS (2.60 < 4.00%) was recorded at 9% SHA. This study revealed that specimen compacted within the range of 11.76 – 12.00% MWC and treated with 9% SHA fulfilled the VSS condition, while other parameter conditions (k, UCS) were unfulfilled.*

Keywords: Barrier Parameters, Hydraulic Conductivity, Sorghum Husk Ash, Unconfined Compressive Strength, Volumetric Shrinkage,

Introduction

Lateritic soil as sustainable building materials are described as materials that meet the needs of the present generation without compromising the ability to adequately meet the needs of future generations (Persons, 2010). They are environmentally friendly materials. The high cost of construction projects led to a call for the incorporation of laterite in the past and recent projects. Compacted clay soil has the benefit of having a low hydraulic conductivity, making it a good liner material for municipal solid waste containment. Despite this benefit, compacted clay soils may have a high propensity for shrinkage and expansion, which could lead to instability issues when utilized as a medium to store Municipal Solid Waste (*MSW*) (Mitchell, 1993; Kleppe and Oslon, 1995). In order to build a hydraulic barrier system for the containment of *MSW*, it is required to investigate the compatibility of soils with low swelling potentials due to the high expansion potentials of clay soils.

One of the agricultural wastes and cementitious materials that can be utilized as an additive in the stabilization of laterite is Sorghum Husk Ash (*SHA*). According to the United States Department of Agriculture, 59.35 million metric tons of sorghum are produced globally. According to the data breakdown, the *USA* contributed 8,408,000 metric tons, Nigeria came in second with 6,550,000 metric tons, and Mexico came in third with 6,000,000 metric tons (Dalvi *et al.*, 2014). Sorghum, grown mostly in the northern part of Nigeria is manually produced after harvesting it, by threshing the stick or mechanically by combined harvester leaving a large amount of sorghum husk. Significant amounts of sorghum's husks are typically burned in the open before being dumped as dregs, which pollutes the environment and causes discomfort.

SHA has a good pozzolanic property when properly burnt (Tijani *et al.*, 2018), and can be utilized as an additive in stabilization of lateritic soil. However, in tropical and subtropical areas, laterites have been treated with various agricultural and industrial waste products, but limited research has been done to determine how *SHA* can affect the hydraulic barrier parameters of compacted lateritic soil used as a hydraulic barrier. Hence, this study investigates the potential of *SHA* in enhancing characteristics of compacted lateritic soil for use as a liner/cover material in a municipal solid waste (*MSW*) containment system.

Materials and Methods

Materials

The materials used for this study are lateritic soil, sorghum husk ash and water

Lateritic soil

The lateritic soil used for this study was obtained from the Osun State University water factory area in Osogbo, using the disturbed method of sampling at a depth of 0.5-1.0 m in order to avoid top soil/organic matter. The lateritic soil sample was transferred to soil Mechanics Laboratory in the Department of Civil Engineering, where it was air-dried and then sieved through sieve No 4 (4.75 mm opening) to obtain the final lateritic soils for the testing. A small portion of the soil was placed in a polythene bag to prevent moisture loss before natural moisture content test.

Sorghum husk ash

The sorghum husk obtained from Osogbo was subjected to open burning to obtain sorghum husk ash. The residue formed after complete burning was collected then subjected control calcination between 700 – 900 ^{o}C and sieved through *BS* Sieve No. 200 (75 μm aperture) to obtain fine ash, which was thereafter stored in an airtight container to prevent moisture and contamination from other materials.

Methods

Mineralogical and oxide composition: The mineralogical composition of the soil sample was studied with the aid of X-ray diffraction (*XRD*) techniques as stated by (Moecher, 2004), while the oxide composition of *SHA* was determined through X-ray fluorescence (*XRF*) analysis conducted at the National Geosciences Research Laboratory (*NGRL*), Kaduna.

Classification of soil sample: Natural Moisture Content (*NMC*), Liquid Limit (*LL*), Plastic Limit (*PL*), specific gravity (G_s) and particle size distribution tests were performed following the experimental guide in *BS* 1377-2 (1990) and Head (1992), to determine their index properties and then classify the soil samples using *AASHTO* and *USCS* (*AASHTO*, 1986; *ASTM*, 1992) systems of soil classification.

Compaction: Specimen preparation was attained through the guide in (Nigeria General Specification, 1997). The specimens were prepared by mixing *SHA* in a stepped concentration of 0, 3, 6, 9 and 12% by mass of natural soil and then compacted using West African Standard (*WAS*). Dry density was plotted against moisture content to obtain the maximum dry density and the optimum moisture content. By adhering to the West African Standard Compaction method, the study involved compacting lateritic soil at varying ratios of sorghum husk ash. This process led to the generation of dry density-moisture content curves, facilitating the identification of both optimum moisture content and maximum dry density. The integration of sorghum husk ash spanned from 3% to 12% of the total soil mass, incremented by 3% steps. Each proportion of treated lateritic soil, encompassing the control sample (0% *SHA*), was evaluated for its dry density and corresponding moisture content.

Hydraulic conductivity: Specimens were compacted in rigid-wall compaction mould and tested for falling head hydraulic conductivity test as outlined in Head (1992). After saturation, readings were taken consistently with change in hydraulic head after time, t (hours) intervals. Tests were terminated when the flow rates were within 10% of the average or when steady state condition was attained.

The hydraulic conductivity (*k*) was calculated using equation (1):

$$k = 2.3\frac{al}{At}\log_{10}\frac{h_1}{h_2} \tag{1}$$

Where:

$k = hydraulic\ conductivity$ $a = cross - sectional\ area\ of\ stand - pipe$

$l = length\ of\ sample$ $A = cross - sectional\ area\ of\ sample$

$h_1 = head\ at\ time, t_1$ $h_2 = head\ at\ time, t_2$

Unconfined compressive strength (*UCS*): Compacted specimens were prepared in line with the procedure outlined in clause 7.3 part 7 of *BS* 1377 (1990). Compacted specimens were protected (for 24 hours) from moisture lost and allowed to cure before testing. During testing, loads were applied to produce axial strain at a rate of 0.5–2.0 % per minute while recording the load and deformation from dial readings. The *UCS* was estimated from the expression in equation 2. This experiment was carried out on soil specimens prepared with -2%, ±0%, +2% and +4% water content relative to *OMC* using *WAS* energy level.

$$\sigma = \frac{P}{A'} \tag{2}$$

Where:

$\sigma(kN/m^2)$ = unconfined compressive stress

$P(N)$ = applied load

$A'(mm^2) = \frac{100A_o}{100-\varepsilon\%}$

$A_o(mm^2)$ = Initial cross-sectional area = $\frac{\pi D^2}{4}$

$D(mm)$ = Diameter of the compacted specimen

$\varepsilon(\%)$ = Percentage axial strain = $\frac{\Delta L}{L_o} \times 100\%$

$\Delta L(mm)$ = Change in length of the specimen

$L_o(mm)$ = Initial length of the compacted specimen.

Volumetric shrinkage strain: Specimens were prepared at moulding water contents -2%, ±0%, +2% and +4% of *OMC* using *WAS* compaction effort. Carefully extruded Specimen were allowed to desiccate at laboratory temperature $(25 \pm 2°C)$. The weight, diameter and length were monitored daily for 30 days until constant weight, diameter and length were observed consecutively.

The volumetric shrinkage strain (*VSS*) was calculated using equation (3):

$$VSS = \frac{Final\ Volume - Initial\ Volume}{Initial\ Volume} \times 100\% \tag{3}$$

Results and Discussion

Mineralogical and Oxide Composition of Soil and *SHA*

The *XRD* results in Figure 1 shows the presence of five different minerals; Kaolinite, Quartz, Orthoclase, Muscovite and Albite. The dominant material is Quartz (45%), while Kaolinite (9%), Orthoclase (12%), Muscovite (11%) and Albite (22%). These were also reported as the predominant mineral phases in lateritic soil in the work of Bodian *et al.* (2018).

Table 1 presents the result of chemical analysis performed on the *SHA*. The major chemical composition of *SHA* was silica (SiO_2) having the percentage composition of 61.36%. According to *BS EN* 197-1:2000, the reactive silicon dioxide content in a good pozzolan should not be less than 43.48% by mass. The result indicated that the sum of percentages of SiO_2, Al_2O_3 and Fe_2O_3 obtained for *SHA* was 65.37% and it is classified as Class *C* Pozzolan according to *ASTM C 618-15* (2015).

Index Properties of Natural Soil

The index properties of the natural soil, which includes the natural moisture content, the specific gravity, the Atterberg limit, the maximum dry density, and the optimum moisture content of the soil, are presented in Table 2. While the particle size distribution curve of the natural soil sample is shown in Figure 2. The natural soil samples is classified as *A-2-6 (0)*, according to *AASHTO* classification system (*AASHTO*, 1986), and as SW (Well graded sand) according to *USCS* (*ASTM*, 1992). The natural sample has natural moisture content of 18.0%, with specific gravity of 1.86. The Atterberg limits of the natural soil sample as presented in Table 2 are 30.0%, 17.5%, 12.5% for liquid limit, plastic limit and plasticity index, respectively.

Compaction Characteristics

Figure 3 shows the result of compaction of natural and *SHA* treated soil using the West Africa Standard compaction.

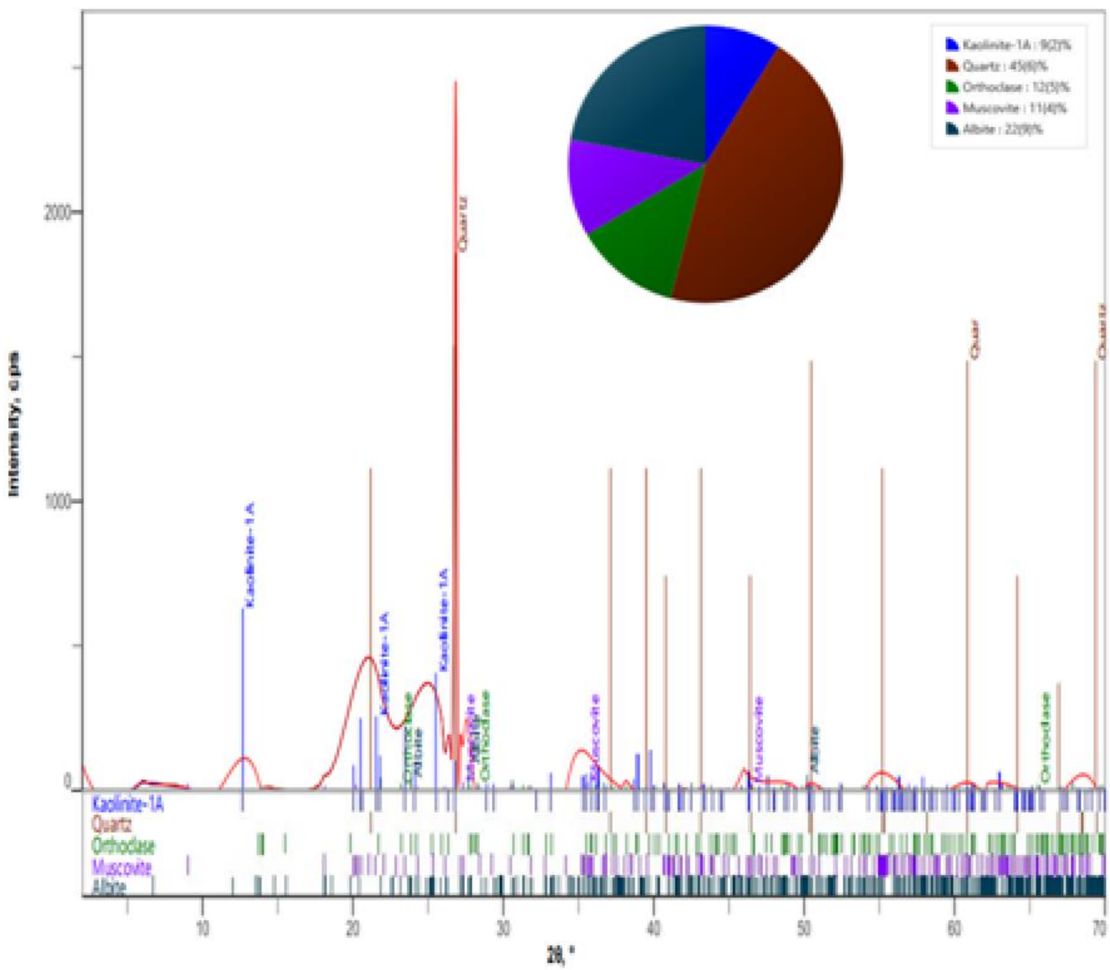

Figure 1: Mineralogy of the Natural Soil Sample

Table 1: Chemical Composition of Sorghum Husk Ash

Chemical components	% composition
SiO_2	61.359
Al_2O_3	1.858
Fe_2O_3	2.134
K_2O	10.062
MgO	5.019
CaO	5.031
P_2O_5	4.008
SO_3	0.780
TiO_2	0.37
LOI	7.400
$SiO_2 + Al_2O_3 + Fe_2O_3$	65.37

Table 2: Index Properties of Lateritic Soil

Properties	Quantity
Natural Moisture Content (%)	18.0%
Liquid Limit (%)	30%
Plastic Limit (%)	17.5%
Plasticity Index (%)	12.5%
Specific Gravity	1.86
Percentage passing sieve 200 (%)	3.6%
Maximum Dry Density, *WAS* (Mg/m^3)	1.78
Optimum Moisture Content, *WAS* (%)	12.0%
AASHTO Classification	*A-2-6 (0)*
USCS Classification	*SW* (Well graded sand)
Colour	Reddish Brown

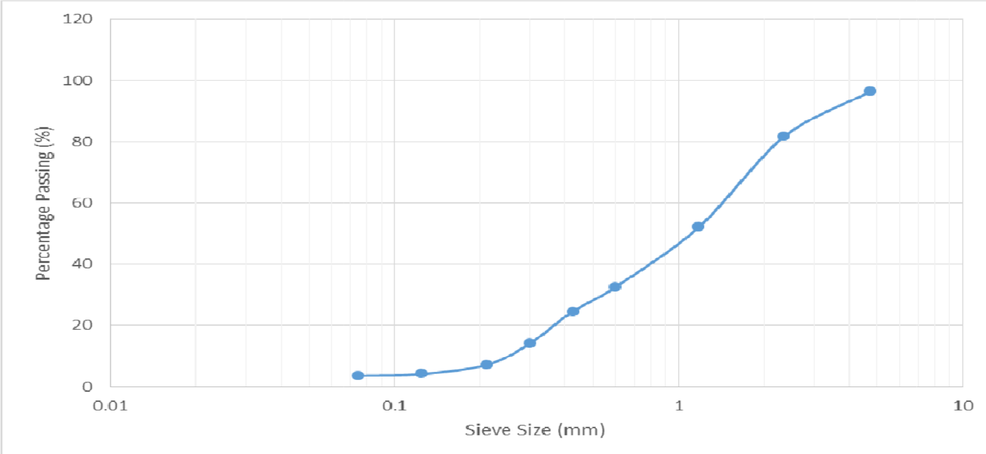

Figure 2: Particle Size Distribution Curve of the Natural Soil Sample

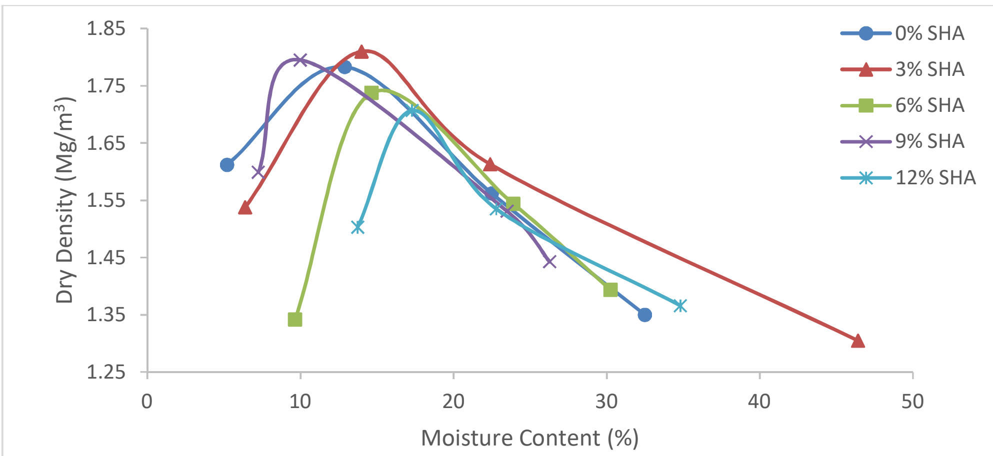

Figure 3: Dry Density Curve for Natural and Treated Specimen

Permeability

The variation of the hydraulic conductivity (*k*) with *SHA* content is shown in Figure 4. The soil sample with 0% *SHA* had a hydraulic conductivity of 1.49 x 10^{-7} cm/s. Increasing the *SHA* content of the sample from 0% to 3% decreased the hydraulic conductivity to 1.32 x 10^{-7} cm/s. However, subsequent increment in the *SHA* content up to 12% caused notable increase in the hydraulic conductivity, from 1.32 x 10^{-7} to 2.61 x 10^{-7} cm/s. Adeyemo *et al.* (2022) reported decrease in the value of *k* as cassava peel ash content is increased due to ash particles taking up voids within the compacted specimen and subsequently restricting fluid flow. However, the increase in *k* value observed in this study may be attributed to low compaction energy (*WAS*) employed for this investigation. The values of hydraulic conductivity obtained at every treatment level is greater than the maximum acceptable *k* value of 1 x 10^{-7} cm/s stated by Daniel and Wu (1993).

Strength

Figure 5 presents the unconfined compressive strength (*UCS*) curve obtained when plotted against *SHA* content. Initially, the inclusion of 3% *SHA* induced a noticeable decline in the *UCS* of the specimen from 68.0 kN/m² to 67.1 kN/m². This stark reduction translates to a substantial 1.32% decrease. A distinct trend emerges as the percentage of *SHA* rises. This subsequent surge in *SHA* content steadily enhances the *UCS* to its peak value (74.1 kN/m²) at 12% *SHA* content. This surge represents an 8.97% increase in strength when compared with the specimen devoid of *SHA*, but failed to meet the minimum acceptable *UCS* value of 200 kN/m². The initial strength reduction can be ascribed to the limited *SHA* content, which yields an insufficient impact. This improvement in the *UCS* of compacted specimen may be as a result of pozzolanic contribution of the *SHA* that increases the cohesion between the soil particles, this observation is in concurrence with the reports of Adeyemo *et al.* (2022); Moses *et al.* (2018) and (2016).

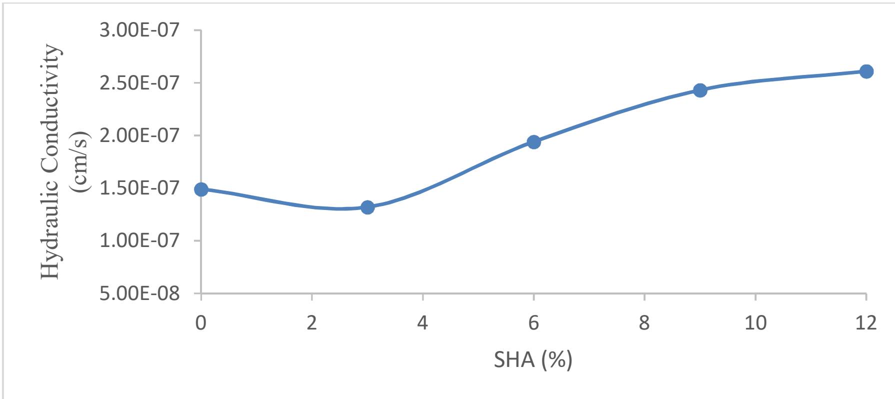

Figure 4: Plot of Hydraulic Conductivity against *SHA* Content

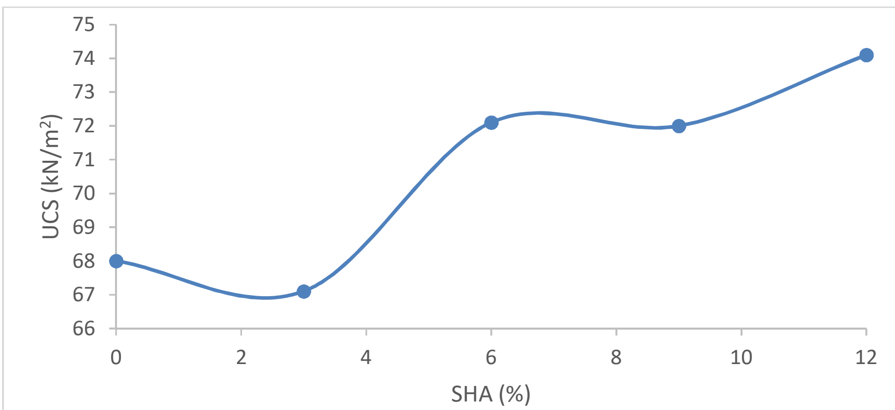

Figure 5: Plot of Unconfined Compressive Strength against *SHA* Content

Conversely, the subsequent strength augmentation can be attributed to the *SHA* ability to fill voids within the soil. Sani *et al.* (2019) also observed a similar trend in their investigation of *UCS* of admixed lateritic soil, and concluded that the admixture effectively diminished soil voids, resulting in the strength enhancement.

3.3 Volumetric shrinkage strain

Figure 6 shows the variation between the volumetric shrinkage strain and *SHA* content. The volumetric shrinkage strain of the natural soil is 9.54%. The *VSS* attained it minimum value (3.60%) at 9% *SHA* content. This decline from 9.54% (at 0% *SHA*) to 8.37%, 6.4%, 7.54%, 3.60% at 3%, 6%, 9%, 12% *SHA*, respectively. As reported in the works of Adeyemo *et al.* (2019b) and (2022), the decline may be attributed to binding potentials of the *SHA* and ash particles filling the available water pores thereby reducing the specimen's shrinkage potential. The least value of *VSS* (3.60%) obtained from this test is below the acceptable maximum value of 4% suggested in the works of Adeyemo *et al.* (2019b) and (2022).

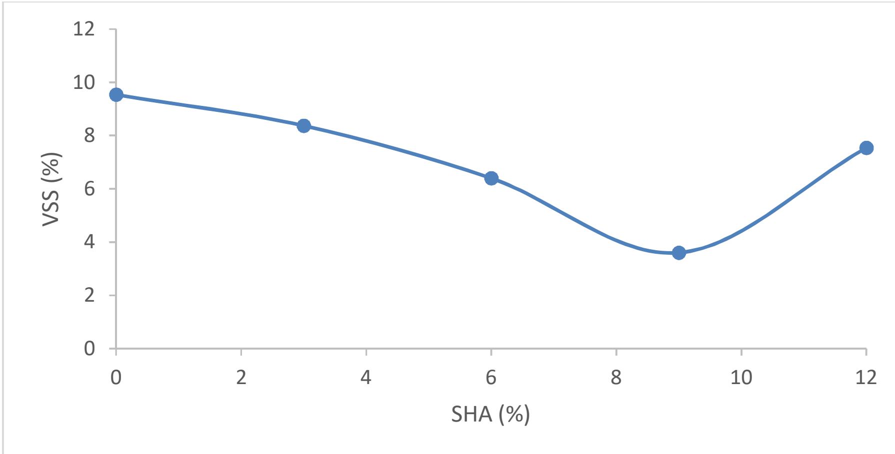

Figure 6: Plot of Volumetric Shrinkage Strain against *SHA* Content

3.3 Influence of varying moulding water content

The influence moulding water content (-2%, ±0, +2% and +4% relative to *OMC*) of the lateritic soil blended with varying proportions of *SHA* (from 0% to 12%) on *k*, *UCS*, and *VSS* are presented in Figures 7, 8 and 9.

From Figure 7 the hydraulic conductivity ranges between 1.03 x 10^{-7} – 3.25 x 10^{-7} cm/s when the moulding water content is varied through -2%, ±0%, +2% and +4% relative to *OMC*. Generally, the *k* values of tested specimens portray an increasing trend in all but 0% and 9% *SHA* treated specimen. From Figure 7, it can be deduced that none of the tested specimen produced less than the 1.0 x 10-7 cm/s suggested in the works of Adeyemo *et al.* (2019a), (2022) and Adeyemo and Bello (2024).

Careful study of Figure 8 revealed that the *UCS* of treated specimen ranges from 37.2 – 74.1 kN/m^2 as the moulding water content moves from the dry to wet side of *OMC*. Initial increase in *UCS* values was observed as the moulding water content is increased from 2% dry of *OMC* to *OMC*. Increasing the moulding water content beyond *OMC* (i.e., to 2% and 4% wet of *OMC*) generally results in strength decline across all *SHA* treatment level. The values of *UCS* obtained are generally well below minimum (200 kN/m^2) recommended for hydraulic barrier purpose.

Figure 9 presents the results of *VSS* of *SHA* treated lateritic soil under varying moulding water content conditions. The *VSS* values ranges from 2.60% - 13.10% as the specimen moulding water content moves from the dry to wet state. Specimens compacted with 2% dry of *OMC* (at 6% and 9% *SHA*) and *OMC* (at 9% *SHA*) produced *VSS* values that meet the acceptable condition of ≤4% *VSS* for hydraulic barrier in waste containment structures. Conversely, the *VSS* of specimens admixed with 0, 3 and 12% *SHA* content increases as the moulding water content is increased. As observed in Figure 9, *VSS* greater than 4% were produced as a result of the increasing water content. This observation is similar to those reported in the works of Adeyemo *et al.* (2019b), (2022) and Adeyemo and Bello (2024).

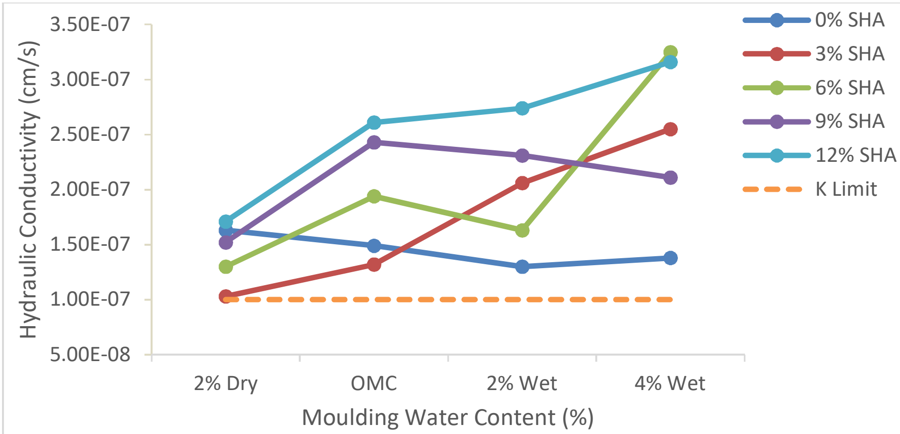

Figure 7: Plot of Hydraulic conductivity against Moulding Water Content Relative to *OMC*

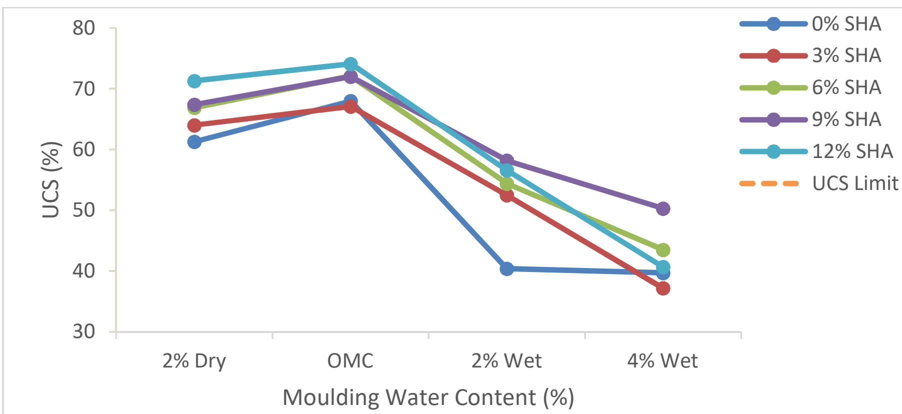

Figure 8: Plot of Unconfined Compressive Strength against Moulding Water Content Relative to *OMC*

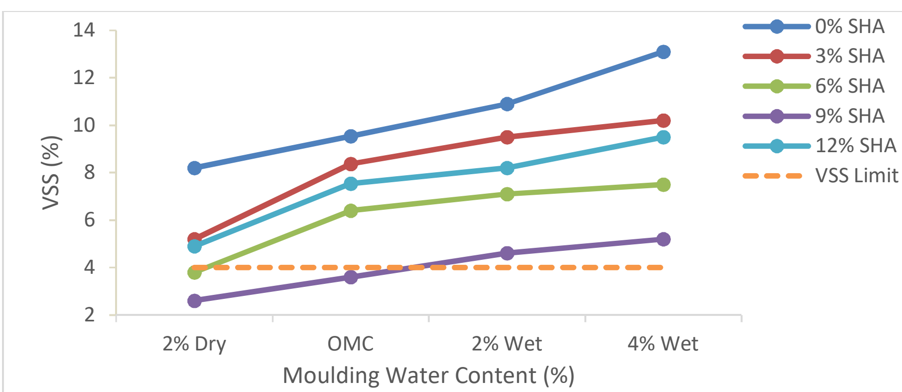

Figure 9: Plot of Volumetric Shrinkage Strain against Moulding Water Content Relative to *OMC*

4.0 Conclusion

From the outcome of this experimental investigation, it was established that:

- The lateritic soil used for this investigation is classified as *A-2-6(0)* according to the *AASHTO* classification system and *SC* (Well-graded sand) under Unified Soil Classification System (*USCS*).

- The *SHA* contains 65.4% oxides of $SiO_2+Al_2O_3+Fe_2O_3$, classified as Class *C* Pozzolan in accordance to *ASTM-C618*.

- Specimen compacted within the range of 11.76 – 12.00% *MWC* and treated with 9% *SHA* fulfilled the volumetric shrinkage strain condition, while other parameter conditions (hydraulic conductivity, unconfined compressive strength) were unfulfilled.

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Investigation on Stabilization Characteristics of Heavy Metals Contaminated Lateritic Soil for Hydraulic Barrier Applications

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Abstract

This study investigates the stabilization characteristics of heavy metals contaminated lateritic soil for hydraulic barrier applications by evaluating the effects of heavy metal contamination on the physical, chemical, and hydraulic properties of lateritic soil and identifying optimal stabilization strategies. Laboratory tests, such as: coefficient of hydraulic permeability (k), volumetric shrinkage strain (VSS) and shear strength (UCS) were conducted on untreated soil samples using British Standard Light method (BSL) and varying moisture contents (-2%, +2%, and +4% OMC). Classification according to AASHTO and USCS yielded A-2-6(0) and SC (Clayey Sand), respectively. At moulding moisture contents of -2%, +2%, and +4% for BSL, the hydraulic conductivity of the natural soil is 2.36×10^{-7}. This exceeds the hydraulic barrier material's maximum specification of $k \leq 1.0 \times 10^{-8}$ cm/s. Similarly, the hydraulic barrier criterion, which stipulates that shrinkage must not exceed 4%, is not satisfied by the volumetric shrinkage strain of the natural soil. This research establishes a baseline for evaluating the efficacy of amendments, with the usage of agricultural waste in solidifying and stabilizing contaminated lateritic soil for hydraulic barrier applications. In addition, it will contribute to the development of effective remediation techniques and sustainable reuse of contaminated lateritic soils in geotechnical applications, ensuring environmental safety and structural integrity.

Keywords: *Bamboo leaf ash, Geotechnical properties, Heavy metal contamination, Hydraulic barrier, Lateritic soil, Stabilization.*

Introduction

The abundance of lateritic soil and its unique properties in tropical and subtropical regions cannot be overemphasized. These soils, characterized by their high iron and aluminum oxide content, exhibit unique physicochemical properties that make them particularly suitable for containment systems (Dissanayake *et al.,* 2022). Lateritic soil can serve as an effective hydraulic barrier material in waste containment systems, provided it contains sufficient fines, enabling the compacted soil to achieve low hydraulic conductivity (Osinubi, 2012). The percentage of fines might be different between the tropical and temperate soils due to variation in climate, weathering and morphology (Indraratna and Nguyen, 2020). For waste containment applications, clay-rich soil barriers, such as lateritic soil are preferred materials for constructing liners and covers, leveraging their low hydraulic conductivity (Rowe, 2018).

According to the United States Environmental Protection Agency (EPA), hydraulic barriers are essential for preventing groundwater contamination and ensuring environmental sustainability (US EPA, 2020). Unfortunately, lateritic soil is increasingly exposed to heavy metal contamination due to industrial activities, mining operations, and improper waste disposal (Liu *et al.*, 2022). Soil contamination is often the result of inadequate waste management practices, including the direct release of industrial waste, polluted surface water infiltration, and storage tank ruptures (Oluremi and Ishola, 2024). Over recent decades, soil heavy metal contamination has intensified due to multiple human activities: industrial development, fossil fuel use, mining operations, metal processing, copper-based agricultural chemicals, and urban waste disposal. Cadmium (Cd), Lead (Pb), Mercury (Hg), Arsenic (As), Chromium (Cr), Nickel (Ni), Copper (Cu), Zinc (Zn) have been focused for their high toxicity and harmfulness, which has been on the control list of the United States Environmental Protection Agency (Peng *et al.,* 2022). These accumulated heavy metals pose a dual threat - they degrade essential ecosystem functions and, through the food chain, create serious risks to human health.

The contamination of lateritic soils with heavy metals presents a significant environmental challenge in geotechnical engineering applications. Opeyemi *et al.,* (2019) noted that untreated contaminated soils typically exhibit inadequate strength and stability, rendering them unsuitable for construction and posing environmental risks. Rai *et al.,* (2019), added that heavy metal contamination in soil extends beyond geotechnical effects, leading to diminished crop yields, disease outbreaks, threats to food security, and barriers to achieving sustainable development goals. Recent studies highlight the severity of heavy metal pollution in industrial and mining areas. Peng *et al.*, (2022) analysed 625 polluted sites in China, identifying Cd, Zn, Hg, Pb, and As as primary pollutants. Similarly, Fagbenro *et al.*, (2021) detected multiple heavy metal contaminants in soil and mine tailings in Nigeria's Osun State. Historical data from the Danube delta also reveal moderate contamination over the past 250 years (Mîndrescu *et al.*, 2022). These findings underscore the urgent need for effective remediation strategies.

Stabilization and solidification are treatment processes for reducing the toxicity and binding hazardous substances contained in wastes, such as sludge, from leaching into the environment. Soil stabilization involves modifying soil properties to improve strength and resistance to water-induced degradation through particle bonding, waterproofing, or a combination thereof. Among the investigation on stabilization characteristics of heavy metals contaminated lateritic soil for hydraulic barrier applications are optimum moisture content (OMC), unconfined compressive strength, hydraulic conductivity, atterberg limit and immobilization of heavy metals, depending on the intended application, such as alternative construction material or landfill cover. Previous studies have demonstrated the effectiveness of various stabilization/solidification agents, including fly ash, quicklime, Portland cement, and cement kiln dust, in immobilizing heavy metals within contaminated soils (Moon *et al.,* 2008). The use of these contaminated soils in hydraulic barrier applications requires careful consideration of their physical, chemical, and hydraulic properties to ensure both environmental safety and structural integrity. This study addresses the **limited research on natural heavy metal-contaminated lateritic soil** by evaluating **optimal stabilization strategies** under **British Standard Light (BSL) compactive effort.** It focuses on assessing **moisture content variations** to ensure the soil meets **hydraulic barrier standards ($k \leq 1.0 \times 10^{-8}$ cm/s, shrinkage $\leq$ 4%).**

This study aims to investigate the stabilization characteristics of heavy metal contaminated lateritic soil for hydraulic barrier applications. This study assesses the physical, chemical, and hydraulic properties of contaminated lateritic soil to identify the best stabilization methods using lab tests. It analyses soil treated with varying moisture contents, measuring hydraulic permeability, shrinkage, and compressive strength to determine its suitability as a hydraulic barrier and recommend remediation strategies for geotechnical use.

Table 1: Index Properties of the Natural Lateritic Soil

Parameter	Quantity
NMC %	13.7 %
G_s %	2.67
LL %	39
PL %	21
PI%	18
LS	11
% retained on BS No. 4 sieve	-
% Passing on BS No. 4	100
% passing on BS no. 200 sieve	20.4

AASHTO classification	A-2-6(0)
USCS classification	SC (Clayey *Sand)*
MDD (Mg/m^3	1.78 Mg/m^3
OMC (%)	16.4
UCS (BSL) kN/m^2	129.60
Color	Reddish Brown
Dominant Mineral	Halloysit

Table 2: Oxide composition of the natural soil sample

Oxide	Lateritic Soil (%)
Fe_2O_3	13.88
MgO	2.90
Al_2O_3	19.380
SiO_2	67.472
P_2O_5	0.2406
SO_3	0.0537
K_2O	0.3728
CaO	0.0558
TiO_2	0.9691
MnO	0.1821
CeO_2	0.43
SrO	0.05508
L.O.I	3.7

2.0 Material and Method

2.1 Material

2.1.1 Oora Mining Site

The soil sample for this investigation exercise was gotten from Oora mining site, at a **latitude: 7° 42' 33" N** and **longitude: 4° 36' 00" E**. The village was significantly impacted by the activities of both alluvial and artisanal mining. Oora is a village located in Osun State, in the Southwestern region of Nigeria. The village is known for the Oora River, which flows through it. Oora has minimal major construction projects and is characterized by its rural landscape. The Oora River shares a boundary with the Osun River at the village of Oora.

Figure 1: Oora mining site where lateritic soil sample was gotten for investigation

Samad (2022).

The soil samples was collected using disturbed sampling techniques at depths ranging from 0.5 to 1.5 m below ground surface at the dumpsite location. The samples were carefully sealed in moisture-proof bags to maintain the natural moisture content of the soil and prevent moisture loss or gain that could alter the soil's original properties. This preservation method aligns with standard practices for soil sampling and testing (ASTM D1557-12 (2021) and BS 1377-1:2016) for geotechnical investigations.

2.2 Methods

2.2.1 Heavy Metal Analysis on Lateritic Soil

The elemental analysis was conducted using an Agilent 720-ES Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) equipped with a megapixel CCD detector for simultaneous multi-element measurement. Sample introduction was automated using an Agilent SPS3 auto-sampler, and the instrument operation and data acquisition were controlled through Agilent Expert II software. Quality control and calibration procedures were implemented using two reference materials: Accustandard QCSTD-27 Quality Control Standard and deionized water obtained from an Elga B114 Wall Mounted Deionizer System. Working standards at various concentration levels were prepared through serial dilution of the multi-element stock standard. Calibration curves were established prior to sample analysis. Subsequently, samples were analyzed following the programmed sequence parameters established in the method worksheet.

2.2.2 Oxide Composition of the Natural Soil

The oxide composition of the soil was analyzed through X-Ray Fluorescence (XRF) Analysis. This methodology provides a comprehensive approach to determining the oxide composition of lateritic soil. The procedure combines multiple analytical techniques to ensure accurate results as indicated in Table 2.

Table 4: Concentration of Heavy Metals

Element	%
Cd	3.42
Pb	39.40
Cr	153.14
Ni	86.09
Cu	189.62
Zn	89.56
Fe	198253.25

2.3 Index Properties and Clay Mineralogy

Hydrometer and sieve analysis were carried out on the soil sample in accordance with the experimental guide provided in BS 1377-1:2016) and Head, 1992. The particle size distribution result was used to group the soil into AASHTO and USCS methods of soil classification. Figure 2 shows the particle-size distribution of the lateritic soil. The atterberg limit of the soil were determined (liquid limit (LL), plastic limit (PL), and plasticity index (PI) and specific gravity of the soil were established following the procedures outlined in BS 1377-1:2016). Additionally, to determine the clay mineralogy, the mineral constituents of the heavy metal contaminated soil sample was studied with the aid of Rigaku Miniflex X-ray diffraction (XRD) machine. To establish a consistent surface area, 2g of powdered sample was measured into the sample container and crushed using a glass slide. The sample holder is thereafter placed in the XRD multi-sample holder chamber. Similarly, the microstructural pattern of the compacted sample was studied using a scanning electron microscope (SEM) (Phenom ProX) produced by Phenomworld, Eindhoven, Netherlands. According to Elizadeh *et al.,* (2012), Scanning Electron Microscopy (SEM) is a prevalent technique for examining the microstructural characteristics of soil solids, providing insights into particle size, morphology, spatial arrangement, and aggregation within a soil matrix.

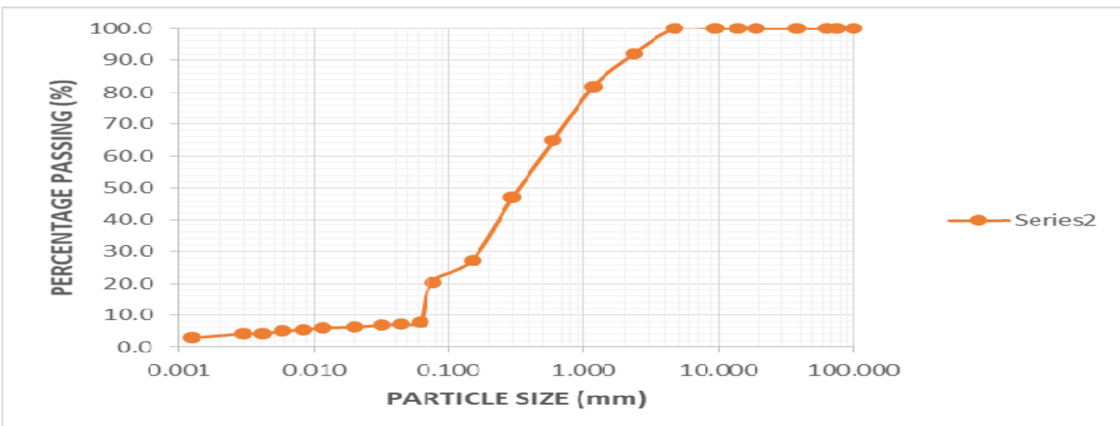


Figure 2: Particle Size Distribution Curve for Lateritic Soil

2.3.1 Compaction

The methodology for BSL compactive efforts involves compacting soil in layers with varying blow counts. According to Osinubi, 1998, BSL, requires compaction in three layers with 27 blows per layer. These procedures follow the standards established in BS 1377 and Head (1992). The hydraulic permeability, Unconfined Compressive Strength (UCS), and Volumetric Shrinkage Strain (VSS) experiments were carried out on specimens molded with moisture contents of - 2%, 0%, +2%, and +4% in relation to the optimum moisture content (OMC) that was determined from BSL compaction tests.

2.4 Hydraulic Barrier Tests

2.4.1 Hydraulic Permeability

In accordance with Head (1992), the soil sample was prepared using a rigid-wall steel mould and immersed in water for at least 48 hours to ensure full saturation. Following this, the falling head permeation test was conducted to determine the hydraulic conductivity (k) of the soil sample. This method involves measuring the rate at which water flows through the soil as the water level decreases, allowing for accurate assessment of the soil's permeability characteristics. Once the saturation period was complete, a standpipe filled with deionized water was connected to the specimen to establish the flow head and facilitate flow measurement. The changes in flow head were continuously recorded as the water level decreased over time (t in hours). Each permeation test was terminated when the k values approached 10% of the average or when the flow reached a steady state. Equilibrium was achieved when the standpipe readings showed no significant fluctuations during the testing, demonstrating that the hydraulic conductivities varied by no more than 10%.

The hydraulic conductivity *k* for the specimen was determined in accordance with the submission of Sagay *et.al* 2011, Adeyemo *et al.,* 2022 and BS, 1377-1:2016).

2.4.2 Volumetric Shrinkage Strain (VSS)

Test specimen was prepared at varying moisture contents of -2%, 0%, +2%, and +4% relative to the optimum moisture content (OMC), using BSL compaction energy. The specimens were extracted from the steel mould using a hydraulic jack and subsequently subjected to control air-drying at a laboratory temperature of 25±2°C. Dimensional changes in both diameter and length were monitored at weekly intervals over a 28-day period until dimensional stability was achieved.

The equation used for calculating the V_{ss} was in accordance with Fadipe *et al.,* (2011) and Adeyemo *et al.,* (2022).

$$Vss = \frac{\text{Final volume} - \text{Initial volume}}{Initial\ Volume} x\ 100\% \quad (1)$$

2.4.3 Unconfined Compressive Strength

In line with BS 1377, (1990) clause 7.3 part 7, the Unconfined Compressive Strength (UCS) testing methodology begins with soil sample preparation at varying moisture contents of -2%, 0%, +2%, and +4% relative to the Optimum Moisture Content (OMC), using BSL compaction energy. The sample was compacted to a height-to-diameter ratio of 2.0-2.5, sealed in moisture-proof containers, and allowed to cure before testing. Prior to testing, specimen was measured for initial dimensions and mass, then centrally positioned in the loading frame with proper axis alignment. The test proceeds at a controlled strain rate of 0.5-2% per minute until reaching a clear peak load, 15% axial strain or obvious shear failure. The unconfined compressive strength was calculated using the equation σ = P/A, where P represents the applied load and A denotes the current cross-sectional area.

The UCS was carried out in line with the equation submitted by Adebara, *et al.,* (2016), Adeyemo et al., (2022) and BS, 1377-1:2016).

$$\sigma = \frac{p}{A'} \quad (2)$$

Where

σ (kN/m ^{2}) =unconfined compressive stress

P(N) = applied load

$$A'(mm^2) = \frac{100Ao}{100-\varepsilon\%}^2 \quad (3)$$

3.0 Result and Discussion

3.1 Index Properties of Lateritic Soil

Table 1 shows the index properties, while Figure 2 revealed the particle size distribution of lateritic soil that was sourced from Oora gold mining site. According to AASHTO soil classification, the sample falls into group A-2-6(0). This type of soil group (A-2-6(0)) represents a granular material with clayey fines which has limited potential as a hydraulic barrier due to its properties. The soil contains only 20.4% fines (passing #200 sieve), which is significantly lower than the recommended minimum of 30-50% fines typically required for effective hydraulic barriers (Adeyemo *et al.*, 2022). While the plasticity index of 18% indicates some clay content, the relatively low percentage of fines would result in higher hydraulic conductivity than desired for barrier applications, typically requiring values less than 1 x 10^{-7} cm/s for containment purposes (Adeyemo et al., 2022). The soil possess a natural moisture content of 13.7 % and a specific gravity of 2.67. The range of the soil specific gravity suggest that the soil possess Montmorillonite minerals in accordance with Bello, (2013). The Atterberg limit are shown in Table 1. The LL, PL, PI and LS respectively (39, 21, 18, and 11).

From the submission of Bello *et al.,* (2014), the plasticity classification of soils can be determined by their Liquid Limit (LL) values. The analysis framework indicates that materials with LL below 35% demonstrate low plasticity characteristics. When LL ranges from 35% to 50%, the soil exhibits intermediate plasticity behaviour. Soils with LL values between 50% and 70% are categorized as highly plastic. Very high plasticity is associated with LL measurements of 70% to 90%, while values exceeding 90% indicate extremely high plasticity properties. Based on this classification system, the analysis shows that the soil specimen falls within intermediate plasticity category.

3.2 Heavy Metal Concentration in Soil Sample

The presence of heavy metals in soil can result in the gradual contamination of groundwater (Ilori *et al.,* 2019).

Table 5: WHO permissible limits for heavy metals in plant and soil.

Elements	Target Value of soil (mg/kg)	Permissible value of plant (mg/kg)
Cd	0.8	0.02
Zn	50	0.60
Cu	36	10
Cr	100	1.30
Pb	85	2
Ni	35	10

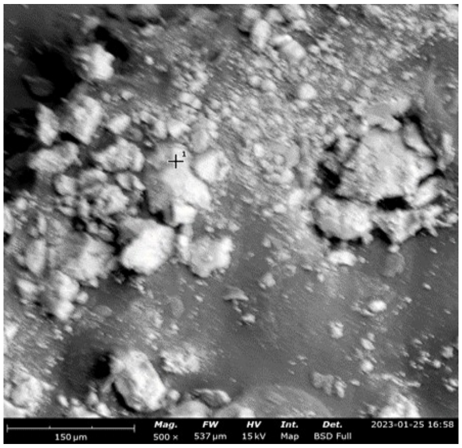
With reference to Table 5, the WHO permissible limit revealed that the soil sample is contaminated and if not treated can pose a threat to the environment if used geotechnical purposes.

3.3 Oxide Composition of the Natural soil Sample

The oxide composition of the specimen is shown in Table 2. The oxide composition was carried out with the use of X-Ray Fluorescence (XRF). Research by Sini *et al.* (2024) indicates that lateritic soil composition dominated by silica (SiO_2), aluminium oxide (Al_2O_3), and iron oxide (Fe_2O_3) characterizes a well-developed lateritic profile. According to Nascimento (2020), the high silica content coupled with moderate aluminum oxide suggests good strength properties and workable plasticity. Based on studies by Oyelami and Van Rooy (2016), the significant iron oxide content contributes to natural cementation and gives the soil its characteristic reddish-brown colour. The calculated silica/sesquioxide ratio ($SiO_2/(Al2O_3 + Fe2O_3)$) of 2.03 falls within the range that Ola (2021) describes as indicating moderate laterization. The presence of low basic oxides, as noted by Santha *et al*., (2022), indicates advanced weathering and leaching processes, while the Loss on Ignition value suggests moderate organic content and presence of hydroxides.

3.4 Micro Structure of Natural Soil

The SEM-EDX analysis of the lateritic soil reveals significant oxygen dominance with the highest concentration of 68.11% atomic and 58.18% weight concentration, which according to Syafalni *et al.* (2010) indicates substantial presence of oxides and hydroxides typical of weathered lateritic soils. The substantial presence of aluminum (10.21% atomic, 14.71% weight) and silicon (9.80% atomic, 14.70% weight) suggests the presence of clay minerals and quartz, contributing to the soil's plasticity and strength properties respectively. The notable presence of nitrogen (8.95% atomic, 6.70% weight) is unusual for typical lateritic soils and might indicate organic matter or surface contamination. The moderate iron content (1.64% atomic, 4.89% weight) confirms the laterization process and is responsible for the characteristic reddish coloration, while the minimal carbon content (1.28% atomic, 0.82% weight) could be attributed to organic matter or sample preparation.



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	68.11	58.18
13	Al	Aluminium	10.21	14.71
14	Si	Silicon	9.80	14.70
7	N	Nitrogen	8.95	6.70
26	Fe	Iron	1.64	4.89
6	C	Carbon	1.28	0.82

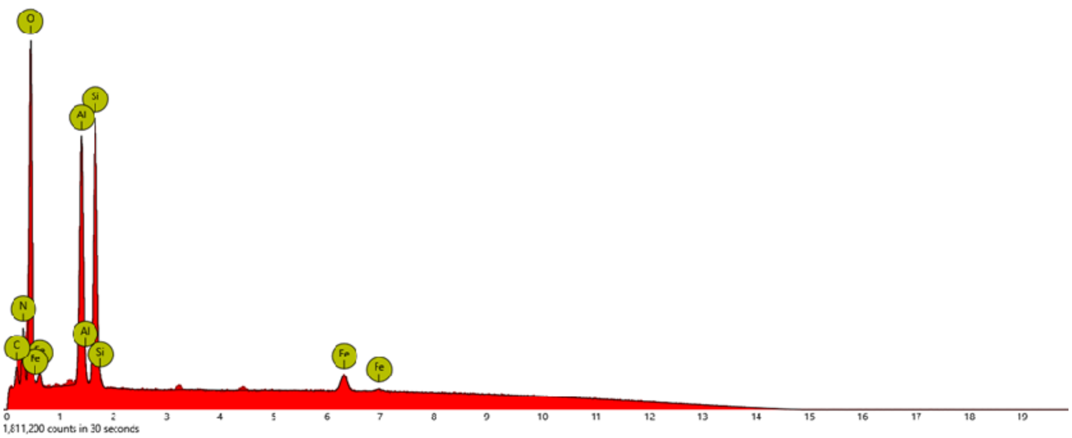


Figure 3: Scanning Electron Micrograph of the Natural Lateritic Soil Sample

3.5 Compaction

This compaction energy directly influences both the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the soil, as demonstrated through extensive laboratory testing procedures (Head, 2006). With BSL compaction effort, the achieved MDD of 1.78 g/cm³ and OMC of 16% indicates a fine-grained soil, likely with significant clay content (Craig, 2004). The relationship between these parameters is interconnected, as Das (2010) explains that the compaction energy has a direct relationship with MDD but an inverse relationship with OMC. At the optimum moisture content of 16%, soil particles achieve their best arrangement under BSL energy, resulting in the maximum dry density of 1.78 g/cm³ - a phenomenon thoroughly explained Fredlund, (2015). When moisture content deviates from this optimum value, either through insufficient lubrication between particles (below OMC) or excess water occupying void spaces (above OMC), the achievable dry density decreases (Craig, 2004; Das, 2010). If a higher compaction energy were applied, such as in WAS or BSH, it would typically result in a higher MDD value and a corresponding lower OMC value (Adeyemo, *et al.,* 2019, Head, 2006).

3.5 Hydraulic Barrier Parameters Lateritic Natural Soil

The experimental results for VSS, UCS, and *k* of the specimen are presented in Figures 4a, 4b, and 4c, respectively. These results were obtained at 2% on the dry side of the Optimum Moisture Content (OMC), at OMC, and at 2% and 4% on the side of OMC, utilizing BSL compaction method.

The results of the VSS of the lateritic sample as shown in Figure 4a demonstrates that VSS increases in lower to higher levels as the moulding moisture content increases. This factor show a positive correlation with VSS values. The trend of the result was in line with the findings of Adeyemo *et al.* (2019; 2022). The results on Figure 4a revealed that the VSS values compacted at BSL energy level does not exceed the regulatory limit of 4% for specimens compacted at the level. Also, with moisture contents ranging from 2% below to 4% above OMC failed to meet this requirement. This result shows that before the soil sample can be used as hydraulic barrier, there must be incorporation of suitable additives.

The UCS result is shown on figure 4b. It shows that BSL compaction energy level employed, does not meet the 200 kPa requirement discussed by Adeyemo *et al.,* 2022, Oriola, and Moses, 2011, and Daniel and Wu, 1993). The unconfined compressive strength (UCS) exhibited distinct patterns in relation to both compaction energy and moisture content variations. The relationship between UCS and molding moisture content demonstrated a more complex behavior. As moisture content increased from 2% below optimum moisture content (OMC) to 2% above OMC, UCS value showed a consistent upward trend. However, when moisture content reached 4% above OMC, UCS values decreased significantly from their peak values observed at 2% above OMC.

As discussed by Adeyemo *et al,* 2022 and Oriola and Moses, 2011, the observed strength development pattern can be attributed to two primary mechanisms. Initially, the increase in UCS correlates with the provision of adequate moisture for complete hydration processes, facilitating optimal strength development. However, the subsequent decline in UCS beyond 2% above OMC can be explained by several physicochemical factors: particle dispersion, reduced particle concentration, expansion of the diffused double layer, and diminished internal friction and cohesion. These factors collectively contribute to the deterioration of soil strength characteristics at higher moisture contents.

The *k* for the specimen at BSL was 2.36×10^{-7}. As shown in Figure 4c. The natural sample of the soil does not meet the hydraulic barrier specifications, as documented in previous researches by Adeyemo *et al.,* 2022, Oriola, and Moses, 2011, and Daniel and Wu, 1993). The hydraulic conductivity (k) demonstrated systematic variations in response to both compaction energy and moisture content modifications. As moisture content increased from 2% below optimum moisture content (OMC) to 2% above OMC, k values exhibited a consistent downward trend in the natural soil samples. However, at 4% above OMC, the hydraulic conductivity increased beyond the minimum value recorded at 2% above OMC. These findings align with previous research observations by Adeyemo *et al,* 2022 and Oriola and Moses, 2011.

The observed hydraulic behaviour can be attributed to two primary mechanisms. The initial decrease in hydraulic conductivity corresponds to enhanced soil particle deflocculation as molding water content increases, resulting in reduced interconnected void spaces. However, the subsequent increase in k value beyond 2% above OMC can be explained by particle displacement phenomena, which leads to the development of increased interconnected pore networks.

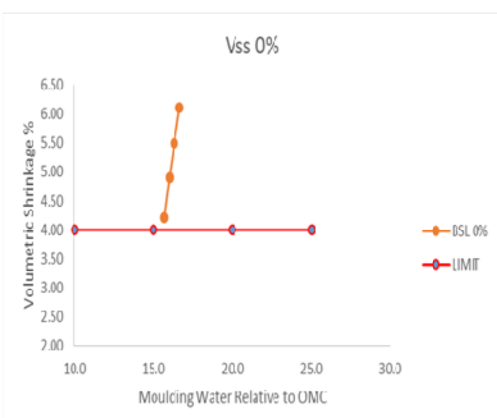


Figure 4a: Variation of moulding water for VSS

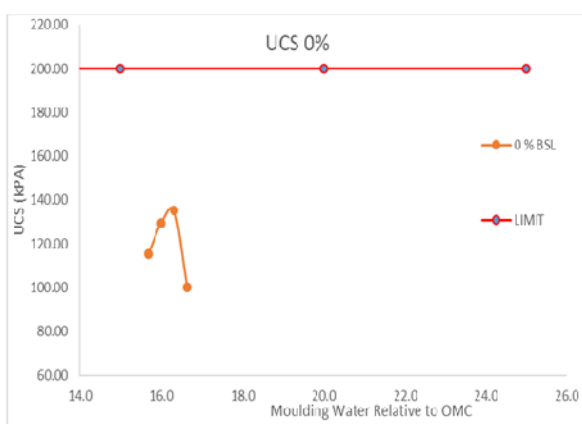


Figure 4b Variation of moulding water for UCS

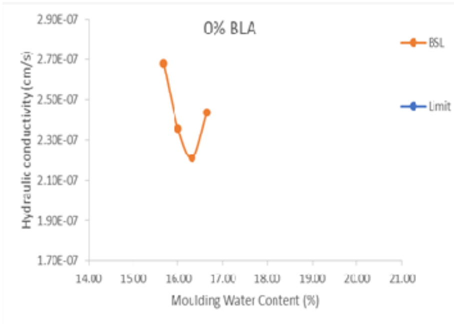


Figure 4c: Variation of Moulding Water for *k*

4.0 Conclusion

From the investigation carried out on the natural lateritic sample collected from Oora gold mining site, it was established that:

1. The soil sample belong to A-2-6(0) according to AASHTO classification and SC (Clayey Sand) according to USCS classification.
2. The concentrations of heavy metals detected in the soil exceeded the permissible thresholds established by WHO guidelines, indicating substantial environmental contamination. These elevated levels suggest potential environmental and health implications that warrant careful consideration.
3. The soil natural sample does satisfy Vss of < 4% regulatory limit set up for use as hydraulic barrier system and cannot satisfy the moulding moisture content that satisfy the hydraulic permeability of k $\leq 1.0 \times 10^{-7}$ cm/s
4. The natural soil failed to meet the minimum design criteria required for liner/cover applications in active waste disposal facilities. Further research is therefore recommended to investigate potential strength improvements through either the incorporation of suitable additives. Such modifications could potentially optimize the soil's performance to meet the requisite engineering specifications.

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Ecological Vulnerability Assessment of Trace Metals in Soils from Established Automobile Workshop in Ede, Osun State, Southwestern Nigeria: Geospatial and Exposure Risk Analyses

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ABSTRACT

Sustainable use of soil for agricultural purposes is crucial in ensuring food security and mitigation of starvation in the society hence, the need to identify the contamination status of soil. In this study, geospatial and exposure risk analyses were combined to assess the ecological vulnerability to toxic metals in soils from established automobile workshops in Ede, Osun State, Nigeria. Samples of soil from six automobile workshops were collected from topsoil (0-15 cm) and subsoil (15-30 cm) and analysed for Barium, Aluminium, Thorium, Vanadium, Uranium and Silver using Inductively Coupled Plasma Optical Emission Spectrometry (ICPOES). Results showed that the topsoil (0-15 cm) was grossly polluted with all studied metals except for Al that has more of its concentration in the sub soil (15-30 cm). Spatial mapping of metal concentrations indicated potential ecological hazard (PEH) for all studied metals in some workshops except for U whose concentration in all studied sites was within tolerable zone. Exposure risk assessment of the trace metals gives an estimated hazard index and all the sites were below the standard risk value assessed. This implies there is no current health risk hazards for humans emanating from the current analysed metals. However, continuous indiscriminate disposal of automobile waste will certainly increase the health risk hazard thus an effective pollution control should be implemented now at affected automobile workshops.

Keywords: Hazard index, Risk analysis, Trace metals, Heavy metals, Spatial mapping

1. Introduction

A rise in emigration rates to European countries has allegedly increased the rate of importations of used vehicles, commonly called "Tokunbo" car into the country (Amukali *et al.*, 2018) and Ede town in Osun State is not an exception. This influx has increased the demand for maintenance of these cars, which has led to a responding sharp rise in the number of automobile repair workshops within the community. In Ede town, more than hundred (100) automobile workshops were identified rendering vehicular services for all various ranges of automobiles. These activities which mostly involve a change of used engine oil and parts generate wastes which are indiscriminately discarded in the environment and thus may be a great source of soil contamination. Soil being a crucial resource to agricultural and global food security and functions in maintaining the adequate sustenance of the earth's ecosystems (Akinsanya *et al.*, 2020), its contamination is however a fundamental environmental problem in areas with unplanned sited automobile workshops (Ajeh *et al.*, 2022).

Reports has shown that automobiles introduce several toxic metals into the environment (Adelekan and Abegunde, 2011; Adedeji *et al.*, 2019) via the wear and tear of tires, engine parts, grease and oil leaks, metal seepages and panel beating (Achuba and Peretiemo-Clarke, 2009). These automobile-associated anthropogenic activities increase the exposure of the populace to these contaminants, from which used engine and other motor oils containing trace metals are indiscriminately discharged by artisans in automobile repairs and servicing (Anegbe *et al.*, 2019). The trace/toxic metals discharged ranges from lead (Pb), chromium (Cr), zinc (Zn), iron (Fe), copper (Cu) cadmium (Cd), down to the least reported one's aluminium (Al), silver (Ag), thorium (Th), vanadium (V), uranium (U) and barium (Ba). Some toxic metals have been reported to be used by living organisms at minute levels for biochemical activities. however, essential metals, when in excess is injurious to biota. For instance; excess zinc in the human body can also disrupt the immune system likewise excess copper intake have the tendency to provoke liver damage and initiate gastrointestinal complications (ATSDR, 2019).

This study is aimed at critically analyzing the least reported trace metals; aluminium (Al), silver (Ag), thorium (Th), vanadium (V), uranium (U) and barium (Ba) harnessed from automobile repair workshops that may also be of ecological threats and global concern. These elements have represented a controversial problem in soil from being a rare and unconcerned metal to becoming a major risk to the global environment (Gummow, 2011). Their toxicological effects in humans, animals and plants, their different sources of pollution and consequent significant environmental impact, have elevated the interest within the twenty-first century as reported in Reijonen et al. (2016) and Guagliardi, et al. (2016). Plants readily absorb these metals from soils, thereby redistributing them further in chains of food. Thus, in the environment, trace elements can ultimately be passed on to human beings. These processes may act as an environmental impedance to the local population's health. (Hanfi et al., 2021) Long term exposure to of these metals may elicit toxic effects on respiratory and digestive organs, kidneys, liver, skin and immune system of human beings (Jayawardana et al., 2015) as well as on the cardiovascular system. Moreover, the compounds of these trace metals exhibit carcinogenic properties (Korbecki et al., 2012). The workers and residents within the catchment area of the automobile repair workshops are at risk of exposure to contaminated soil through dermal(skin), ingestion(consumption), and inhalation.

2. **Materials and Methods**

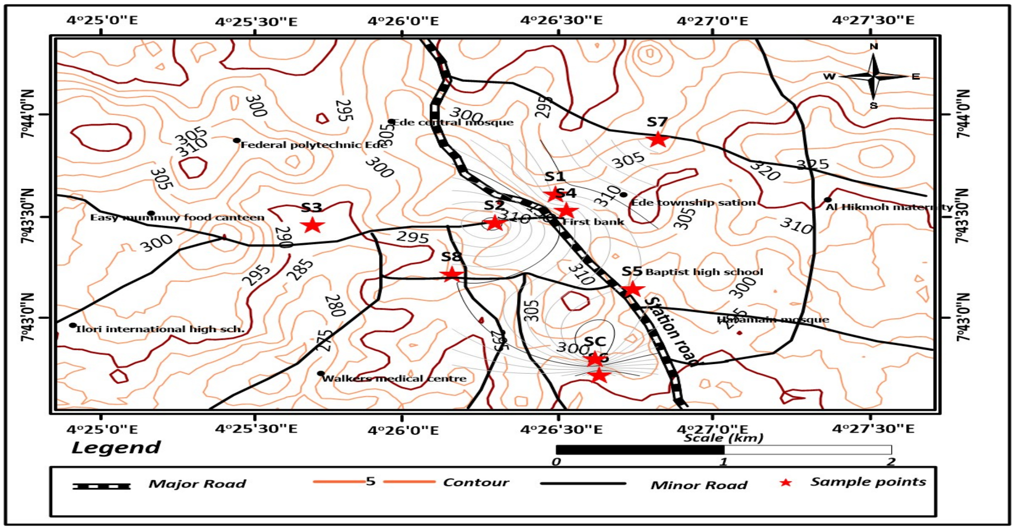

Figure 1: Topographical view of Study Areas

The data required for this study included the soil samples from selected auto mechanic workshops in Ede, Osun State. Soil samples were collected at a depth of 0 – 15cm (top soil) and 15 -30cm (sub soil) using soil auger from 5 different points at the automobile mechanic workshop in order to get a representative sample (composite sample) and transferred directly into clean, sterile containers. A control soil sample was obtained from a secondary virgin land (fallow soil) 5minutes walk away from one of the repair work shops. The location of the control sample was at the same geology (sedimentary formations) with the study area. Soil samples were air dried in the laboratory crushed in a porcelain mortar and sieved through a 2 mm (10 mesh size) stainless sieve.

One gram of the dried fine soil sample was weighed into an acid washed, round bottom flask containing 10 cm3 concentrated nitric acid (HNO3). The mixture was slowly evaporated over a period of one hour (1) on a hot plate. Each of the solid residues obtained was digested with a 3:1 concentrated HNO3 and HClO4 mixture for 10 minutes at room temperature before heating on a hot plate. The digested mixture was placed on a hot plate and heated occasionally to ensure a steady temperature of 150°C for over 5 hours until the fumes of HClO4 were completely evaporated (Jacob et al., 2009). The mixture was allowed to cool to room temperature and then filtered using Whitman No.1 filter paper into a 50 cm3 volumetric flask and made up to the standard mark with deionized water after rinsing the reacting vessels, to recover any residual metal. The filtrate was then stored in pre-cleaned polyethylene storage bottles ready for analysis.

Then samples for trace metal content was determined using inductively coupled plasma optical emission spectroscopy (ICPOES) described by Adesuyi et al. (2015a). The instrument's setting and operational conditions were done in accordance with the manufacturer's specifications. The instrument was calibrated with analytical grade metal standard stock solutions.

The result gotten from the laboratory was subjected to the use of SPSS for statistical evaluation for both descriptive and inferential statistics.

Arc. GIS software was used in plotting the spatial distribution of the analyzed element.

The health risk characterization was calculated and computed using the modified equations and references adopted from Ajeh et al., 2022; USEPA, 2013; Wang et al., 2012.

3. Results and Discussion

3.1 Concentration of Heavy Metals across selected Automobile Workshops

The concentration of Barium (Ba) was significantly ($P<0.05$) high at S6 (where heavy duty repairs engines are done) compared to the control site (SC) and other studied sites. There is no significant ($P>0.05$) difference in Ba concentration in SC (control with secondary fallow land) and S1 (where mini vehicles repairs are done). At 15-30cm deep, it is observed that the concentration of Ba is lesser in some sites generally (SC, S6, S7) excluding S1, S2, S4 and S8 that has a higher concentration of Ba than at 0 -15cm. (table 1).

The concentration of Vanadium (V) in studied sites was significantly ($P<0.05$) higher at S6(where heavy duty engine repairs are done) compared to the control site (SC) and other studied sites. There is no significant ($P>0.05$) difference in V concentration in SC (control with secondary fallow land), and S2 (where mini vehicles repairs are done). At 15-30cm deep, it is observed that the concentration of V is lesser in some sites generally (SC, S2, S6) excluding S1, S4, S7, S8 that has a greater concentration of V than at 0 -15cm (table1)

The concentration of Aluminium (Al) was significantly ($P<0.05$) high at S6 (where heavy duty engine repairs are done) compared to the control site (SC) and other studied sites. There is no significant ($P>0.05$) difference in Al concentration in S4 and S1(where mini vehicles repairs are done) also S2 (where mini vehicles repairs are done) and SC (control with secondary fallow land) have no significant difference. At 15-30cm deep, it is observed that the concentration of Al is lesser in most sites generally excluding S6 that has a greater concentration of Al than at 0 -15cm. (table 1)

The concentration of Thorium (Th) was significantly ($P<0.05$) high at S2, S4 (where mini vehicles repairs are done) and S8 (where heavy duty engine repairs are done) compared to the control site (SC) and other studied sites. There is no significant ($P>0.05$) difference in Th concentration in S8(where heavy duty engine repairs are done), S2 and S4 (where mini vehicles repairs are done). Also S7 (where heavy duty engine repairs are done) and SC (control with secondary fallow land) have no significant difference. At 15-30cm deep, it is observed that the concentration of Th is lesser in some sites generally excluding S4, S7, S8 that has a greater concentration of Th than at 0 -15cm. (table1)

The concentration of Uranium (U) was significantly ($P<0.05$) high at S6 (where heavy duty engine repairs are done) compared to the control site (SC) and other studied sites. There is no significant

($P>0.05$) difference in U concentration in S4 (where mini vehicles repairs are done) S6(where heavy duty engine repairs are done) also S1 (where mini vehicles repairs are done) and S4 (where mini vehicles repairs are done) have no significant difference. In addition, SC (control with secondary fallow land) S1, S2 (where mini vehicles repairs are done) S7 and S8 (where heavy duty engine repairs are done) have no significant difference in concentration of U. At 15-30cm deep, it is observed that the concentration of U is lesser and below detectable values in most sites generally excluding S4 that has a greater concentration of U than at 0 - 15cm (table1).

The concentration of Silver (Ag) in studied sites was significantly ($P<0.05$) highest at S6, S8 (where heavy duty engine repairs are done) compared to the control site (SC) and other studied sites. There is no significant ($P>0.05$) difference in Ag concentration in S6, S8 (where heavy duty

engine repairs are done), also S1, S2 (where mini vehicles repairs are done), SC (control with secondary fallow land) S4 (where mini vehicles repairs are done) have no significant difference in concentration of Ag. In addition, S7, S1 and S2 have no significant difference in concentration

of Pb at their areas. At 15-30cm deep, it is observed that there is no concentration of Ag at 0 - 15cm deep of SC, S4 and S8 area while S1, S2, S6 and S7 has a greater concentration of Ag than at 0 -15cm (table1).

3.2 Health Risk Assessment of Heavy Metals in Soil Across Study Area

The Hazard quotients (HQ) or hazard index (HI) > /= 1, and cancer risk (CR) from $10^{-6} – 10^{-4}$ were considered significant. non- carcinogenic and carcinogenic assessment result for analysed metals all fall below one thus are considered non significant to health risk at all studied depths and area. Cancer risk (CR) for studied metals in all depths was not detected (Tables 2-7). This is because the recommended cancer slope values as of the time of this study was not available to be used for CR calculation.

1. DISCUSSION

The United States Environmental Protection Agency (USEPA, 2005) recommends a soil barium

concentration of around 330 mg kg^{-1} in soils (USEPA 2005). The results from SC, S1, S2, S7 in this study fall within the recommended values. However, the Scientific Committee on Health and Environmental Risks recommends that the portion of the tolerable daily intake (TDI) for Ba exposure should not exceed 0.02 mg Ba per kg bodyweight per day. Cappuyns (2017) stated that with a Ba range of 69–709 mg/kg, less than 30% of the concentration were taken up by plants thus referred Ba as a low mobility element when compared to other heavy element. Nebo *et al.*, (2018) recorded minute concentration of Ba at the automobile workshop studied and it was attributed to the immobility of Ba from the surface to subsoil which agrees with this report. Chronic exposure to Ba results in hypertension, cardiovascular diseases, and other related health problems in humans and animals (WHO 2022). Furthermore, high Ba concentrations can reduce plant growth and development (Peana *et al.* 2021). Thus, Ba contamination can be an environmental and public health problem, mainly in waste deposits with high Ba concentrations.

The biogeochemical behaviour of Vanadium (V) is easily influenced by soil conditions including soil pH, organic matter, and microorganisms thus its easy percolation to the subsoil. Wu *et al.*, 2022; Chen *et al.,* 2020 reported a higher concentration of vanadium at the root parts of plants than at the aerial part that is above the earth surface. An average amount of vanadium in soils ranges from 10 to 220 mg/kg in an unpolluted soil and the results from this study all fall below the permissible range excluding S6 (where heavy duty engine repairs are done). In line with this study's report Oke and Mc'civer (2019) reported an increase in vanadium in automobile workshops in Ilorin when compared to its control and this could be due to the presence of automobile waste from steel alloys used in crankshaft, axles and gears. Beneficially, V elements can positively influence seed germination, flowering, plant growth and other plant physiology, even though they are not considered essential (Pilon-Smits *et al.*, 2009). It can also be useful in steel, battery, and pharmaceutical industries however at an increased rate beyond the threshold values it can be toxic and deleterious to plants and animals.

According WHO, (2011) the permissible limit of aluminium (Al) in soil is 36mg/kg and Al was dominantly found in each site across the studied depth which indicates high deposite of metal scraps waste. Al in the studied sites are higher than, that of Oke and M'civer, 2019 that recorded minute traces of Al in their study. Operations like smelting metals and wheels, use of sprays and additives that contain Al are major sources of Al in automobile workshop soils (Vitorello *et al.*, 2005; Onianwa *et al.*, 2001). Crops grown on soils with excessive aluminum concentrations can cause the plants to taken up the element and accumulate in edible parts which can result in the consumption of aluminum-contaminated food, which may have detrimental effects on human health (Poschenrieder *et al.*, 2008). Excessive exposure to aluminum can pose health risks to both humans and animals like neurological disorders such as Alzheimer's disease and Parkinson's disease (Klotz *et al.*, 2017).

WHO and FAO (2022) the highlighted permissible value of Thorium (Th) in soils as 11.7- 15ppm (11.7 - 15mg/kg) and hence all concentrations of Th in this study are all above the permissible concentration likewise. Th is positively used in nuclear reactors, medicine, aerospace (fuel for propulsion) and industrial applications (like catalysts). Reports from Ime *et.al.,* (2021) have shown values of Th well above the permissible target in study with *Manihot spp* that was cultivated in farms close to automobile workshop. Th being a radioactive element is usually lethal if not handled with care.

The values of Uranium (U) in sites they were detected are all well above the permissible threshold of 3ppm (3mg/kg) stated by FAO/ WHO, (2001) at the 0-15cm depth in this study while they are all below the threshold at 15 -30 cm depth except in S4. Oke and M'civer, 2019 recorded minute traces of U in their study that are all less than the permissible threshold of U. Literature has shown that exposure to U is lethal for plants, animals and man.

The maximum permissible concentration of silver (Ag) varies according to soil types ordinary chernozem is 4.4 mg/kg, in sierosands 0.9 mg/kg, and in brown forest soils (cambisols) 0.8 mg/kg (Shoults-Wilson *et al.,* 2011a) and the concentration across all sites where Ag were detected are above the threshold value stipulated by Kolesnikov *et al.* (2020) thus indicating the presence of toxic substances. The mechanism of silver toxicity in living organism is apparently involved in inhibition of enzymes and a decrease in the permeability of biological membranes (Sun *et al.* 2016), DNA damage, metabolic disturbance and cell necrosis.

Spatial Distribution and Health of Elements across Studied Workshops

The potential ecological hazard (PEH) of Ba, Al, V, U, Th and Ag are all minimal in most of study area. The few sites that are in within and above the PEH are commonly found in study areas (automobile workshops) where heavy duty engines are repaired. The increase in the element in the sampled soils may be attributed to the increased deposition of automobile wastes laddened with these elements on the study areas. The automobile workshops studied had values that were mostly within the potential ecological hazard (PEH) for heavy metals (like Ba, Al, V, Ag) and the level of the tolerable limit are constantly pushed and encroached into ecological hazard range with continuous deposition of automobile waste at the various studied workshops. The implication of the absence of heavy metal concentrations at the background level and the increase at a large area with PEH can be suggestive of progressive accumulation of HMs, which can inevitably lead to potential ecological and health risks to inhabitants in the future. However, the distribution of U, is well within the background values in all studied sites. Ogunkunle, *et al.* (2016) reported a spatial distribution of metals like Pb, Zn and Cd within the permissible threshold for environment far away from a high enriched steel production factory and a PEH of the same elements within the factory location. This still points to the fact that human activities that enrich soils with heavy contamination should be checked to avoid endangering of the inhabitants and the ecosystem at large.

In the current study, the health and cancer risk of all heavy metals studied in the sampled soils were relatively not detected across all the study sites despite the concentrations of metals in the soil being well above permissible threshold. This is due to the nonavailability of the indices required to compute the health risk characteristics. However, a notable levels of cancer risk might be obtained in the future when the indices in the metals are available.

Conclusion and Recommendation

The results of heavy metals analysed showed that most of the metals were higher than the permissible level for agricultural and uncontaminated soils and also when compared to the control and the continuous automobile workshop dumping activities might still increase the contaminants. The collected samples from different studied depths revealed the percolation (leaching down) of heavy metals into the soils as considerable higher concentration of metals were found in the sub soils (15 – 30cm) of some of the studied site thus suggesting positive leaching down of the analysed metals. These unplanned activities from the workshop have also been found to contribute immensely to the accumulation of some metals in different depths thus enlightenment of populace in the affected areas should be considered as an emergency by the government.

Table 1 Concentration of Heavy Metals across selected Automobile Workshops.

CONCENTRATION OF HEAVY METALS ACROSS SITES								
			Mini buses and cars			**Heavy duty engines**		
MINERALS (mg/kg)	**DEPTHS (cm)**	**SC**	**S1**	**S2**	**S4**	**S6**	**S7**	**S8**
Ba	0 - 15	328.23 ± 4.7^{d*}	318.12 ± 4.7^{e}	225.14 ± 4.7^{f}	476.60 ± 4.7^{c}	955.82 ± 4.7^{a*}	182.16 ± 4.7^{g*}	501.12 ± 4.7^{b}
	15 - 30	315.06 ± 4.7^{F}	325.88 ± 4.7^{E*}	640.45 ± 4.7^{A*}	573.32 ± 4.7^{B*}	530.93 ± 4.7^{C}	160.93 ± 4.7^{G}	524.17 ± 4.7^{D*}
V	0 - 15	83.30 ± 1.5$^{A\ f*}$	105.17 ± 1.5^{d}	86.34 ± 1.5^{e*}	124.39 ± 1.5^{c}	283.47 ± 1.5^{a*}	55.12 ± 1.5^{g}	134.68 ± 1.5^{b}
	15 - 30	72.40 ± 1.5^{E}	115.31 ± 1.5^{D*}	71.08 ± 1.5^{E}	145.97 ± 1.5^{C*}	148.81 ± 1.5^{B}	57.40 ± 1.5^{F*}	202.82 ± 1.5^{A*}
Al	0 - 15	13303.90 ± 252.4^{e}	20903.74 ± 252.4^{c}	10926.83 ± 252.4^{f}	18935.75 ± 252.4^{d}	65056.38 ± 252.4^{a*}	10671.53 ± 252.4^{f}	22903.29 ± 252.4^{b}
	15 - 30	16547.26 ± 252.4^{F*}	21440.00 ± 252.4^{D*}	18233.98 ± 252.4^{E*}	24049.32 ± 252.4^{C*}	33748.06 ± 252.4^{A}	13066.48 ± 252.4^{G*}	31185.52 ± 252.4^{B*}
Th	0 - 15	34.05 ± 6.3^{e*}	54.58 ± 6.3^{d*}	106.49 ± 6.3^{a*}	71.22 ± 6.3^{b}	66.7 ± 6.3^{c*}	ND	70.84 ± 6.3^{b}
	15 - 30	ND	34.04 ± 6.3^{E}	49.08 ± 6.3^{D}	103.00 ± 6.3^{A*}	53.14 ± 6.3^{C}	24.44 ± 6.3^{F*}	80.86 ± 6.3^{B*}
U	0 - 15	ND	42.023 ± 11.9^{b*}	ND	ND	110.455 ± 11.9^{a*}	ND	ND
	15 - 30	ND	0.00 ± 11.9^{B}	ND	87.535 ± 11.9^{A*}	ND	ND	ND
Ag	0 -15	3.96 ± 0.2^{c*}	ND	ND	4.116 ± 0.2^{b*}	ND	ND	4.917 ± 0.2^{A*}
	15-30	ND	3.780 ± 0.2^{B*}	3.702 ± 0.2^{C*}	ND	5.423± 0.2^{A*}	3.076 ± 0.2^{D*}	ND

Means with the different lowercase superscript letters are significantly different ($p < 0.05$) across site at 0-15cm depth; Means with different uppercase superscript letters are significantly different ($p < 0.05$) across site at 15-30cm depth; superscript ***** are significantly different ($p < 0.05$) between depths at each studied sites. ND connotes not detected

Table 2: Non-carcinogenic and carcinogenic risks of Barium (Ba) in soils Across Study area

LOCATION		CDInc			CDIca			HQ			CR			HI
SITES	**DEPTHS(cm)**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	
SC	0 -15	3.96E-06	1.11E-05	5.35E-05	1.54E-05	5.10E-05	9.50E-06	9.90E-05	na	na	na	na	na	9.90E-05
	15 -30	3.80E-06	1.06E-05	5.14E-05	1.48E-05	4.90E-05	9.12E-06	9.50E-05	na	na	na	na	na	9.50E-05
S1	0 -15	3.84E-06	1.07E-05	5.19E-05	1.50E-05	4.94E-05	9.21E-06	9.59E-05	na	na	na	na	na	9.59E-05
	15 -30	3.93E-06	1.10E-05	5.31E-05	1.53E-05	5.06E-05	9.43E-06	9.83E-05	na	na	na	na	na	9.83E-05
S2	0 -15	5.75E-06	1.61E-05	7.77E-05	2.24E-05	7.41E-05	1.38E-05	1.44E-04	na	na	na	na	na	1.44E-04
	15 -30	6.92E-06	1.94E-05	9.35E-05	2.70E-05	8.91E-05	1.66E-05	1.73E-04	na	na	na	na	na	1.73E-04
S4	0 -15	5.75E-06	1.61E-05	7.77E-05	2.24E-05	7.41E-05	1.38E-05	1.44E-04	na	na	na	na	na	1.44E-04
	15 -30	6.92E-06	1.94E-05	9.35E-05	2.70E-05	8.91E-05	1.66E-05	1.73E-04	na	na	na	na	na	1.73E-04
S6	0 -15	1.15E-05	3.23E-05	1.56E-04	4.50E-05	1.49E-04	2.77E-05	2.88E-04	na	na	na	na	na	2.88E-04
	15 -30	6.40E-06	1.79E-05	8.66E-05	2.50E-05	8.25E-05	1.54E-05	1.60E-04	na	na	na	na	na	1.60E-04
S7	0 -15	2.20E-06	6.15E-06	2.97E-05	8.57E-06	2.83E-05	5.27E-06	5.49E-05	na	na	na	na	na	5.49E-05
	15 -30	1.94E-06	5.43E-06	2.62E-05	7.57E-06	2.50E-05	4.66E-06	4.85E-05	na	na	na	na	na	4.85E-05
S8	0 -15	6.04E-06	1.69E-05	8.17E-05	2.36E-05	7.79E-05	1.45E-05	1.51E-04	na	na	na	na	na	1.51E-04
	15 -30	6.32E-06	1.77E-05	8.55E-05	2.47E-05	8.14E-05	1.52E-05	1.58E-04	na	na	na	na	na	1.58E-04

CDInc denotes Chronic daily intake/exposure dose non carcinogenic effect, *CDIca* denotes Chronic daily intake/exposure dose carcinogenic effect *HQ* denotes hazard quotient, *CR* denotes cancer risk, *ing* ingestion(oral), *inh* inhalation, *derm* dermal exposure routes *HI* denotes Hazard Index

Table 3: Non-carcinogenic and carcinogenic risks of Vanadium (V) in soils Across Study area

LOCATION		CDInc			CDIca			HQ			CR			HI
SITES	**DEPTHS (cm)**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	
SC	0 -15	1.00E-06	2.81E-06	1.36E-05	3.92E-06	1.29E-05	2.41E-06	9.97E-04	2.01E-01	9.70E-03	na	na	na	2.12E-

														01
	15 -30	8.73E-07	2.45E-06	1.18E-05	3.41E-06	1.13E-05	2.10E-06	8.66E-04	1.75E-01	8.43E-03	na	na	na	1.84E-01
S1	0 -15	1.27E-06	3.55E-06	1.71E-05	4.95E-06	1.63E-05	3.04E-06	1.26E-03	2.54E-01	1.22E-02	na	na	na	2.67E-01
	15 -30	1.39E-06	3.89E-06	1.88E-05	5.42E-06	1.79E-05	3.34E-06	1.38E-03	2.78E-01	1.34E-02	na	na	na	2.93E-01
S2	0 -15	1.04E-06	2.92E-06	1.41E-05	4.06E-06	1.34E-05	2.50E-06	1.03E-03	2.08E-01	1.01E-02	na	na	na	2.19E-01
	15 -30	8.57E-07	2.40E-06	1.16E-05	3.34E-06	1.10E-05	2.06E-06	8.51E-04	1.71E-01	8.28E-03	na	na	na	1.81E-01
S4	0 -15	1.50E-06	4.20E-06	2.03E-05	5.85E-06	1.93E-05	3.60E-06	1.49E-03	3.00E-01	1.45E-02		na	na	3.16E-01
	15 -30	1.76E-06	4.93E-06	2.38E-05	6.87E-06	2.27E-05	4.22E-06	1.75E-03	3.52E-01	1.70E-02	na	na	na	3.71E-01
S6	0 -15	3.42E-06	9.57E-06	4.62E-05	1.33E-05	4.40E-05	8.20E-06	3.39E-03	6.84E-01	3.30E-02	na	na	na	7.20E-01
	15 -30	1.79E-06	5.03E-06	2.43E-05	7.00E-06	2.31E-05	4.31E-06	1.78E-03	3.59E-01	1.73E-02	na	na	na	3.78E-01
S7	0 -15	6.65E-07	1.86E-06	8.99E-06	2.59E-06	8.56E-06	1.60E-06	6.60E-04	1.33E-01	6.42E-03	na	na	na	1.40E-01
	15 -30	6.92E-07	1.94E-06	9.36E-06	2.70E-06	8.92E-06	1.66E-06	6.87E-04	1.38E-01	6.68E-03	na	na	na	1.46E-01
S8	0 -15	1.62E-06	4.55E-06	2.20E-05	6.33E-06	2.09E-05	3.90E-06	1.61E-03	3.25E-01	1.57E-02	na	na	na	3.42E-01
	15 -30	2.45E-06	6.85E-06	3.31E-05	9.54E-06	3.15E-05	5.87E-06	2.43E-03	4.89E-01	2.36E-02	na	na	na	5.15E-01

CDInc: Chronic daily intake/exposure dose non carcinogenic effect, *CDIca*: Chronic daily intake/exposure dose carcinogenic effect *HQ*: hazard quotient, *CR*: cancer risk, *ing:* ingestion(oral), *inh:* inhalation, *derm:* dermal exposure routes *HI*: Hazard Index ,*na:* not available.

Table 4: Non-carcinogenic and carcinogenic risks of Aluminum (Al) in soils Across Study area

LOCATION		CDInc			CDIca			HQ			CR			HI
SITES	DEPTHS (cm)	ING	DER	INH	ING	DER	INH	ING	DER	INH	ING	DER	INH	
SC	0 -15	1.60E-04	4.49E-04	2.17E-03	6.26E-04	2.07E-03	3.85E-04	na	na	na	na	na	na	nd
	15 -30	2.00E-04	5.59E-04	2.70E-03	7.78E-04	2.57E-03	4.79E-04	na	na	na	na	na	na	nd
S1	0 -15	2.52E-04	7.06E-04	3.41E-03	9.83E-04	3.25E-03	6.05E-04	na	na	na	na	na	na	nd
	15 -30	2.59E-04	7.24E-04	3.50E-03	1.01E-03	3.33E-03	6.20E-04	na	na	na	na	na	na	nd
S2	0 -15	1.32E-04	3.69E-04	1.78E-03	5.14E-04	1.70E-03	3.16E-04	na	na	na	na	na	na	nd
	15 -30	2.20E-04	6.16E-04	2.97E-03	8.58E-04	2.83E-03	5.28E-04	na	na	na	na	na	na	nd
S4	0 -15	2.28E-04	6.40E-04	3.09E-03	8.91E-04	2.94E-03	5.48E-04	na	na	na	na	na	na	nd
	15 -30	2.90E-04	8.12E-04	3.92E-03	1.13E-03	3.74E-03	6.96E-04	na	na	na	na	na	na	nd
S6	0 -15	7.85E-04	2.20E-03	1.06E-02	3.06E-03	1.01E-02	1.88E-03	na	na	na	na	na	na	nd
	15 -30	4.07E-04	1.14E-03	5.50E-03	1.59E-03	5.24E-03	9.77E-04	na	na	na	na	na	na	nd
S7	0 -15	1.29E-04	3.60E-04	1.74E-03	5.02E-04	1.66E-03	3.09E-04	na	na	na	na	na	na	nd
	15 -30	1.58E-04	4.41E-04	2.13E-03	6.15E-04	2.03E-03	3.78E-04	na	na	na	na	na	na	nd
S8	0 -15	2.76E-04	7.74E-04	3.73E-03	1.08E-03	3.56E-03	6.63E-04	na	na	na	na	na	na	nd
	15 -30	3.76E-04	1.05E-03	5.09E-03	1.47E-03	4.85E-03	9.02E-04	na	na	na	na	na	na	nd

CDInc: Chronic daily intake/exposure dose non carcinogenic effect, *CDIca*: Chronic daily intake/exposure dose carcinogenic effect, *HQ*, hazard quotient, *CR*: cancer risk, *ing:* ingestion (oral), *inh:* inhalation, *derm:* dermal exposure routes, *HI*:Hazard Index, *na:* Not Available, *nd:* denotes Not Detected

Table 5: Non-carcinogenic and carcinogenic risks of Thorium (Th) in soils Across Study area

LOCATIONS		CDInc			CDIca			HQ			CR			HI
SITES	DEPTHS (cm)	ING	DER	INH	ING	DER	INH	ING	DER	INH	ING	DER	INH	
SC	0 -15	4.11E-07	1.15E-06	5.55E-06	1.60E-06	5.29E-06	9.85E-07	na	na	na	na	na	na	nd

	15 -30	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
S1	0 -15	6.58E-07	1.84E-06	8.90E-06	2.57E-06	8.48E-06	1.58E-06	na	na	na	na	na	na	nd
	15 -30	4.11E-07	1.15E-06	5.55E-06	1.60E-06	5.29E-06	9.85E-07	na	na	na	na	na	na	nd
S2	0 -15	1.28E-06	3.60E-06	1.74E-05	5.01E-06	1.65E-05	3.08E-06	na	na	na	na	na	na	nd
	15 -30	5.92E-07	1.66E-06	8.00E-06	2.31E-06	7.63E-06	1.42E-06	na	na	na	na	na	na	nd
S4	0 -15	8.59E-07	2.41E-06	1.16E-05	3.35E-06	1.11E-05	2.06E-06	na	na	na	na	na	na	nd
	15 -30	1.24E-06	3.48E-06	1.68E-05	4.84E-06	1.60E-05	2.98E-06	na	na	na	na	na	na	nd
S6	0 -15	8.05E-07	2.25E-06	1.09E-05	3.14E-06	1.04E-05	1.93E-06	na	na	na	na	na	na	nd
	15 -30	6.41E-07	1.79E-06	8.67E-06	2.50E-06	8.26E-06	1.54E-06	na	na	na	na	na	na	nd
S7	0 -15	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
	15 -30	2.95E-07	8.25E-07	3.99E-06	1.15E-06	3.80E-06	7.07E-07	na	na	na	na	na	na	nd
S8	0 -15	8.54E-07	2.39E-06	1.16E-05	3.33E-06	1.10E-05	2.05E-06	na	na	na	na	na	na	nd
	15 -30	9.75E-07	2.73E-06	1.32E-05	3.80E-06	1.26E-05	2.34E-06	na	na	na	na	na	na	nd

cdinc : chronic daily intake/exposure dose non carcinogenic effect, *cdica*: chronic daily intake/exposure dose carcinogenic effect, *hq*, hazard quotient, *cr*: cancer risk, *ing:* ingestion (oral), *inh:* inhalation, *derm:* dermal exposure routes, *hi*:hazard index, *na:* not available, *nd:* not detected

Table 6: Non-carcinogenic and carcinogenic risks of Uranium (U) in soils Across Study area

LOCATION		CDInc			CDIca			HQ			CR			HI
SITES	**DEPTHS (cm)**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	
SC	**0 -15**	nd	nd	Nd	nd	nd	nd	na	na	na	na	na	na	nd
	15 -30	nd	nd	Nd	nd	nd	nd	na	na	na	na	na	na	nd
S1	**0 -15**	5.07E-07	1.42E-06	6.85E-06	1.98E-06	6.53E-06	1.22E-06	na	na	na	na	na	na	nd
	15 -30	nd	nd	Nd	nd	nd	nd	na	na	na	na	na	na	nd
S2	**0 -15**	nd	nd	Nd	nd	nd	nd	na	na	na	na	na	na	nd
	15 -30	nd	nd	Nd	nd	nd	nd	na	na	na	na	na	na	nd
S4	**0 -15**	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd

	15 -30	1.06E-06	2.96E-06	1.43E-05	4.12E-06	1.36E-05	2.53E-06	na	na	na	na	na	na	nd
S6	**0 -15**	1.33E-06	3.73E-06	1.80E-05	5.20E-06	1.72E-05	3.20E-06	na	na	na	na	na	na	nd
	15 -30	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
S7	**0 -15**	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
	15 -30	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
S8	**0 -15**	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
	15 -30	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd

CDInc : Chronic daily intake/exposure dose non carcinogenic effect, *CDIca*: Chronic daily intake/exposure dose carcinogenic effect, *HQ*, hazard quotient, *CR*: cancer risk, *ing:* ingestion (oral), *inh:* inhalation, *derm:* dermal exposure routes, *HI*:Hazard Index, *na:* Not Available, *nd:* Not Detected

Table 7: Non-carcinogenic and carcinogenic risks of Silver (Ag) in soils Across Study area

LOCATION		**CDInc**			**CDIca**			**HQ**			**CR**			**HI**
SITES	**DEPTHS(cm)**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	**ING**	**DER**	**INH**	
SC	0 -15	4.77E-08	1.34E-07	6.45E-07	1.86E-07	6.15E-07	1.15E-07	na	na	na	na	na	na	nd
	15 -30	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
S1	0 -15	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
	15 -30	4.56E-08	1.28E-07	6.16E-07	1.78E-07	5.87E-07	1.09E-07	na	na	na	na	na	na	nd
S2	0 -15	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
	15 -30	4.47E-08	1.25E-07	6.04E-07	1.74E-07	5.75E-07	1.07E-07	na	na	na	na	na	na	nd
S4	0 -15	4.96E-08	1.39E-07	6.71E-07	1.94E-07	6.40E-07	1.19E-07	na	na	na	na	na	na	nd
	15 -30	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
S6	0 -15	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
	15 -30	6.54E-08	1.83E-07	8.84E-07	2.55E-07	8.43E-07	1.57E-07	na	na	na	na	na	na	nd
S7	0 -15	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd
	15 -30	3.71E-08	1.04E-07	5.02E-07	1.45E-07	4.78E-07	8.90E-08	na	na	na	na	na	na	nd

S8	0 -15	5.93E-08	1.66E-07	8.02E-07	2.31E-07	7.64E-07	1.42E-07	na	na	na	na	na	na	nd
	15 -30	nd	nd	nd	nd	nd	nd	na	na	na	na	na	na	nd

CDInc: Chronic daily intake/exposure dose non carcinogenic effect, *CDIca*: Chronic daily intake/exposure dose carcinogenic effect, *HQ*, hazard quotient, *CR*: cancer risk, *ing:* ingestion (oral), *inh:* inhalation, *derm:* dermal exposure routes, *HI*: Hazard Index, *na:* Not Available, *nd:* Not Detected

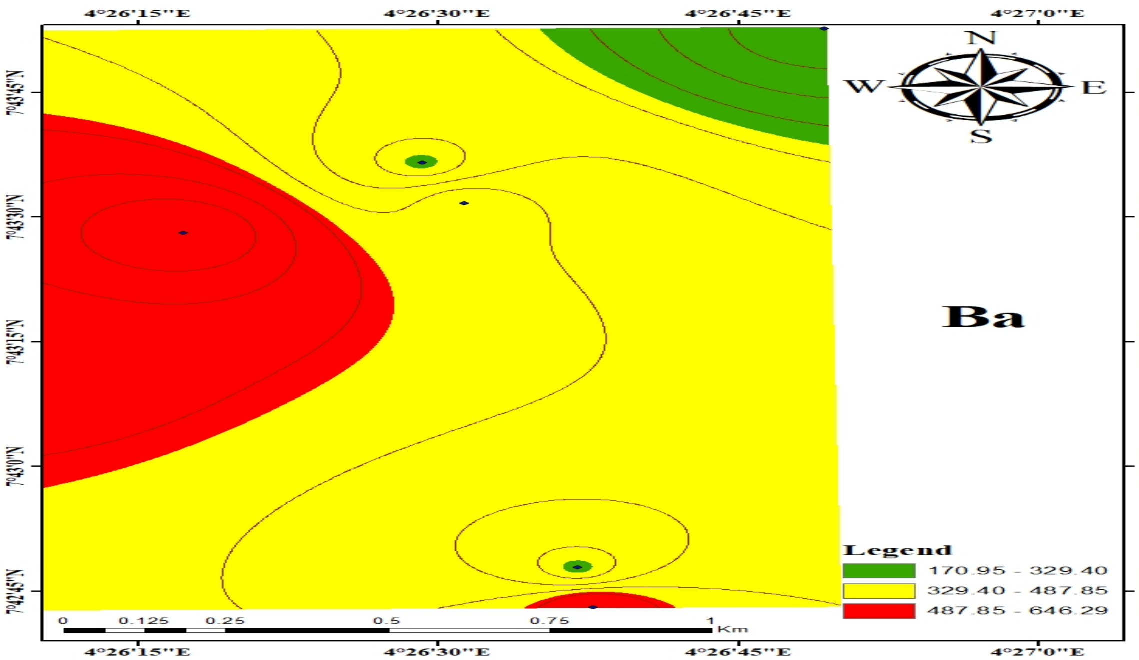

Figure 2: Spatial Distribution of Barium (Ba) Across Study Areas

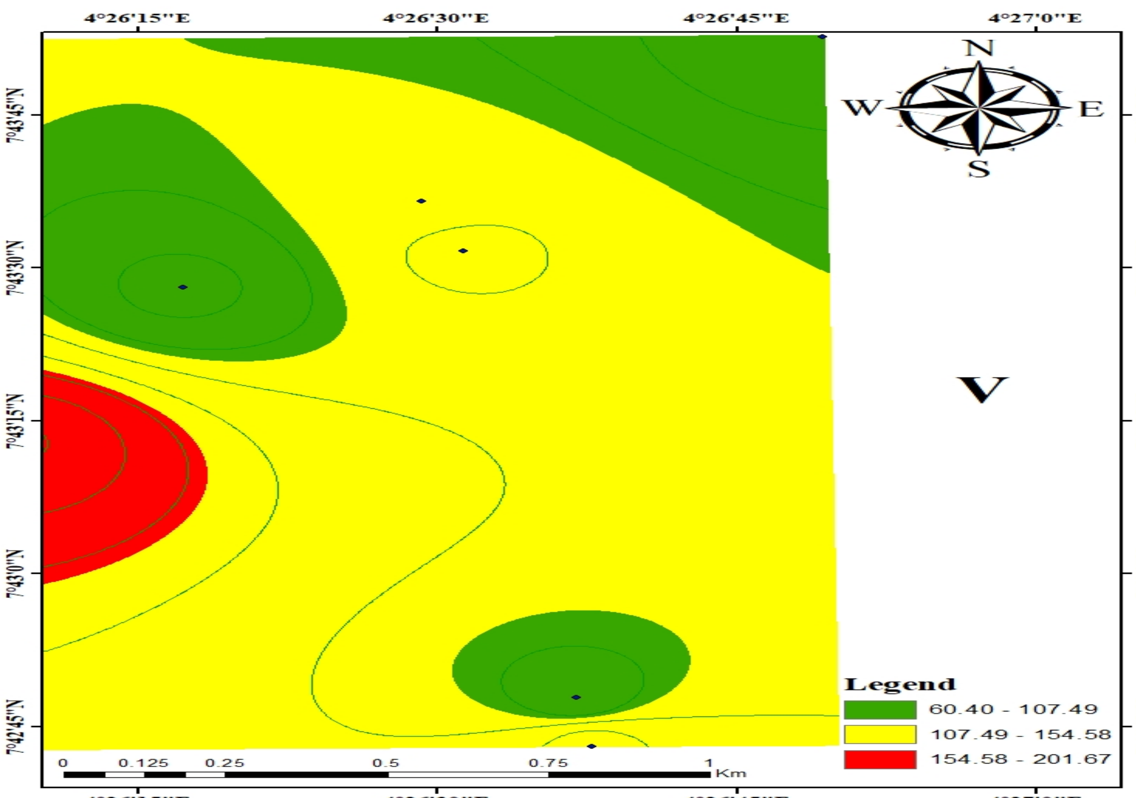

Figure 3: Spatial Distribution of Vanadium (V) Across Study Areas

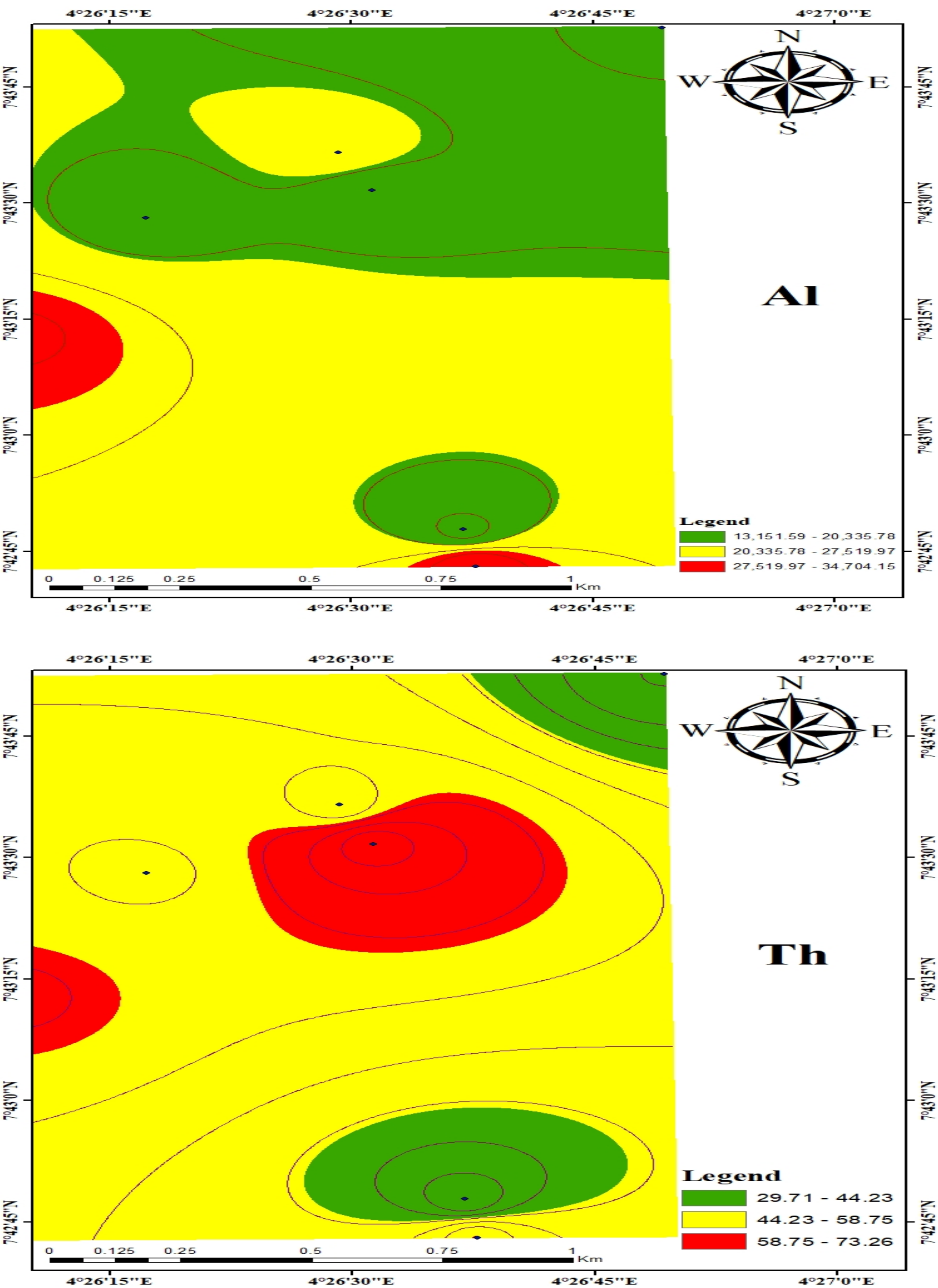

Figure 4: Spatial Distribution of a) Aluminum (Al) and b) Thorium (Th) Across Study Areas

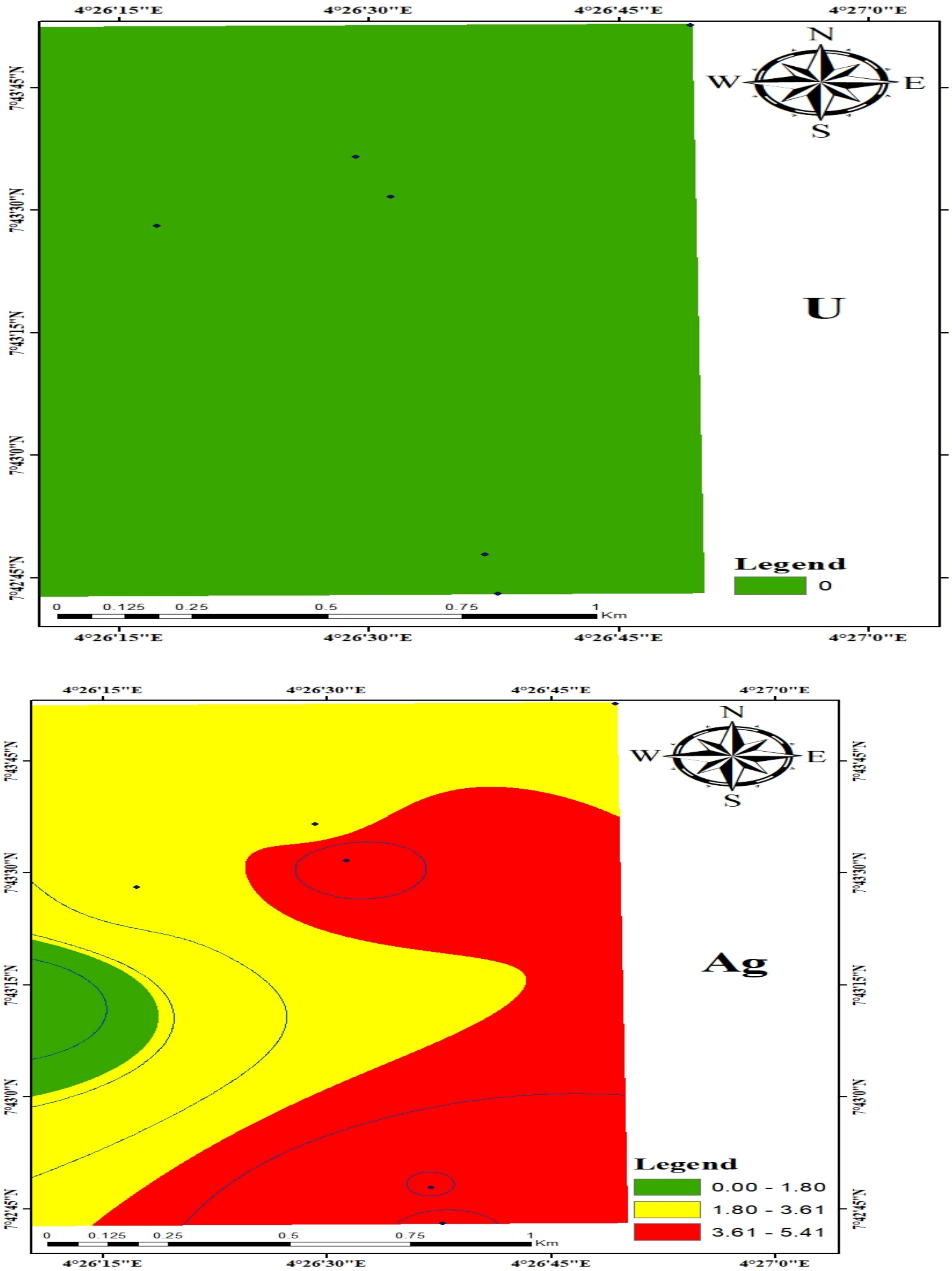

Figure 5: Spatial Distribution of Uranium (U) and Silver (Ag) Across Study Areas

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Effect of Handling Methods and Exposure Time on the Chemical Properties of Composted Cow Dung

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Abstract

Cow Dong *is the west product that come out from the animal after its excretory products a been eliminated. However, this west is a nutritive benefits to the soil. The study examines the influence of different handling methods and varying the length of exposure on the nutritive value of cow dung. The cow dung was subjected to three methods i.e (un-covered pile method, covered pile method and covered pit) and four exposure periods method for ninety days. The three differently handled cow dung was also exposed to the atmosphere for a period of (7, 30, 60, and 90 days).* The cow dung stored for each method were thoroughly turned thrice weekly to ensure a balanced composting process *The samples were subjected to laboratory analyses to determine the chemical properties related to ,organic carbon content, total nitrogen, phosphorus, potassium, sodium, magnesium and electrical conductivity. The results showed that nitrogen, phosphorus, calcium, magnesium, potassium which are plant's vital nutrients were significantly higher in cow dung treated with the covered and pit methods of handling. Losses of nutrients as an effect of the exposure time on the manure quality minimal at 7 and 30 days of exposures. Correlation analysis reveals a positive correlation of nitrogen with phosphorus. Nitrogen showed a highly significant correlation with calcium, sodium and magnesium at 0.01 and 0.05 levels of significance. The positive nitrogen and phosphorus interaction implies the complimentary role of both nutrients in plant nutrition. The results showed that the quality of cow dung can be improved by subjecting it to pit and covered methods of handling and nutrient losses can be significantly reduced by reducing the period of exposure to the atmosphere.* It would be erroneous to solely regard cow dung as just a vehicle for nutrient. Cow dung is also an important source of humus and has a beneficial long-term effect on the structure and carbon economy of the soil.

Keywords: Handling methods, Cow dung, Exposure Time, Compost.

1. Introduction

Cow dung is an important source of humus and has a beneficial long-term effect on the structure and carbon economy of the soil. Recently, researchers observed that addition of cow dung to biomass generated from palm oil industries improves the physical and chemical properties including nutritional composition of compost. palm oil biomass mixed with cow dung in the ratio of 1:3 significantly improved the compost quality with respect to various parameters such as ph, electrical conductivity and c:n ratio (Vanlauwe, 2020). thus, cow dung may not only act as a substitute for chemical fertilizers because it supplements organic matter, but also as a conditioner for soil (Okalebo, J.R. 2018). **Vakili, 2019** Tisdale, 2018).

Human population is increasing worldwide giving rise to intensive farming system and unsuitable cropland management that ultimately results in reduced soil fertility (**Adetuyi, F.C. (2020).**).Soil fertility depletion is the single most important constraint to food security (Ajayi, 2021). Low soil fertility is one of the greatest biophysical constraints to production of agro forestry crops across the world (Ajayi, 2021).In the past decades, intensive use of chemical fertilizers was advocated for crop production in the tropics in order to alleviate these nutrient deficiencies (Adebayo, 2020). Presently the use of chemical fertilizers as soil amendment has become cost intensive and beyond the reach of peasant farmers. Many disadvantages of widespread use of chemical fertilizers include increase in soil acidity, mineral imbalance and soil degradation Kuntashula, E. and Kwesiga, F.(2021). also reported that application of chemical fertilizer on highly weathered, low organic matter and nutrient poor soil without compensatory organic fertilizer under intensive farming system and shortened fallow periods could lead to nutrient imbalance and soil acidity with an attendant poor crop yield.

In view of these problems, the use of organic manure as a substitute for chemical fertilizers or in combination with chemical fertilizers at a reduced rate has become vital especially in this era of organic agriculture that reduces the negative effect of chemical fertilizers on environmental change. In recent years the focus on soil fertility research has been shifted towards the combined application of organic matter and fertilizers as a way to arrest the ongoing soil fertility decline in Sub-Saharan Africa (**Bray, 2021).**). The organic sources can reduce the dependency on costly fertilizers by providing nutrients that are either prevented from being lost (recycling) or are truly added to the system (biological N-fixation). When applied repeatedly, the organic manures lead to build-up of soil organic matter, thus providing a capital of nutrients that are slowly released (Badeda.2020) and at the same time increasing the soil's buffering capacity for water, cat-ions and acidity

Cow-dung is an organic manure and it is similarly called cow pats or cow manures. Cow dung is a by-product of the cattle industry and in any successful business, the by products must be used to their full potentialand cow dung is no exception. Data reeled out by Agricultural Sample Survey indicates that Nigeria is hugely endowed with an estimated 19.5 million cattle population, an impressive numerical information suggestive of huge production of cow dung. Cow dung provide high levels of organic materials enormously rich in plant desirable nutrients such as nitrogen, phosphorus and potassium as well as many other plant essential nutrients. (Badeda 2024) eported that cow dung contains the three major plant nutrients, nitrogen, phosphorus and potassium (NPK), as well as many essential micro nutrients such as Ca, Mg, S, Zn, B, Cu, Mn etc. that, in addition to supplying plant nutrients, manure generally improves soil tilth, soil aeration, and soil water holding capacity and promotes growth of beneficial soil organisms.According to (Adegunloye et al 2021), Carbon Nitrogen ratio in cow-dung manure is an indication that it could be a good source of protein for the microbes which involved in decomposition of organic matter.**While numerous benefits are attached to the use of cow dungs as organic manure, raw manure contains high levels of ammonia that may burn the plants with a repugnant odor,excess salts weed, seeds and pathogens that are potentially dangerous.For this reason, it is usually recommended that it be composted prior to its use as cow manure fertilizer, (**Walkley, 2020).

In composting, microorganisms decompose organic substrate aerobically into carbon dioxide, water, minerals and stabilized organic matter (Ducan 2020)) **thus, well composted cow manure has several benefits. Some of the benefits include elimination of harmful ammonia gas and pathogens (E. coli and Salmonella), as well as weed seeds.in addition, composted cow manure can add generous amounts of organic matter to the soil. By mixing this compost into the soil, the moisture-holding capacity of the soil is improved**(Cooke,G.W (2021)). Duncan, D.B., (2020). reported that, when compost is added into the soil, it improve nutrients and water-holding capacity of the soil. **This allows for more water retention, as the roots of plants can use the additional water and nutrients whenever needed. Furthermore, composted cow dungs improve aeration by breaking up compacted soils and also contains beneficial bacteria, which convert nutrients into easily accessible forms so they can be slowly released without burning tender plant roots.**

Cattle rearing in Nigeria ispredominantly done by nomads. They move seasonally from place to place in search for food and water for their cattle, their stay at specific locations as they transverse through states are transient. The dungs produced during this brief stay are scrapped off the earth daily, stockpiled on bare ground from where it is later transported to the fields where it is used by the local farmers as fertilizers. Most often, the cow dungs are freshly applied to crops or sometimes applied to crops after being left exposed for a long period of time. Cow dung **contains high levels of ammonia that may burn the plants** when applied to the plants freshly and if left exposed to the atmosphere, nutrients in the excreta are lost through volatilization (especially N), runoff and leaching (Baded 2019). As a result, small quantities of nutrients are potentially recyclable through manure within the farm system. Maximizing the value of livestock manure as a soil amendment resource is needed to improve its collection and conservation (Fares et al, 2020)). Making the most efficient use of cow manures depends critically on improving manure handling and storage. Most publications on cow dung manures and utilization analysis centered on its chemical, nutrient, biological and physical properties, but there was no information regarding the effective manure handling method and the length of time composted manures are to be exposed to safeguard its quality. In order to maintain the consistency of manure quality, it is necessary to discover the most efficient management strategies that can address nutrient losses during manure handling and storage. Therefore, this study was intended to identify the most effective method of handling of cow dungs and the periods of exposure that will maximize nutrient release and conservation.

2. Materials and Methods

2.1 Site Description and Dung Collection

The cow dung used for the study was freshly collected from the dairy cattle section of the National Animal Production Research Institute (NAPRI) Shika, Zaria. This is located at latitude 1°10'15"N, and longitude 7°0'32"E at an altitude of 667m above the sea level and found within the Northern Guinea Savannah ecological zone of Nigeria. Heaps of dungs were collected from the cattle pen very early in the morning. The freshly excreted dungs from these cattle were scooped from the floor of the cattle pen and then kept in a plastic container. The collection was done for 10 days to have sufficient quantity of cow dung for the research.

2.2 Experimental Procedure

During the 10 days of collection, the cow dung was emptied from the plastic container and mixed thoroughly then 3kg sample was taken. The 3kg sample taken was later divided into three equal portions (1kg each) and subjected to three different handling methods for three months. The three handling methods were un-covered pile(the dung was piled on the soil's surface and completely exposed to the atmosphere), covered pile method (the dung was piled on thesoil's surfaceand covered completely with a polythene material) and covered pit (the dung was piled in a pit of 2m wide and 2m deep, covered with a polythene material). The cow dung stored for each method were thoroughly turned thrice weekly to ensure a balanced composting process. Three months after thecow dung had been processed using the three different methods of handling as described, the resulting product known as composted cow dung was obtained. Eight core samples were taken from each of the three handling methods. Four from each of these eight composted samples were grinded and sieved. The sieved samples were collected in a polythene bag and appropriately labelled for easy identification before taken to the laboratory for chemical assessments. The last four were left exposed to the atmosphere for a period of 7,30, 60 and 90 days. At the end of each specified period, samples were collected,grinded, sieved and taken to the laboratory for chemical analysis.

2.3 Determination of Chemical Properties of the Composted Cow Dung

The chemical parameters (K, N, P, Ca, Na, K, Ca, Mg and OC) which are also known to be the important plant nutrientswere determined using standard existing procedures. The composted cow dungs organic carbon content was determined by Walkley- Black method (Allison 2020), total nitrogen content was by Kjedhal method (Bremer and Malvaney,1982), available phosphorus by Bray No.1 method (Bray and Kurth, 2021) and exchangeable bases (Na, K, Ca, Mg) by dry ashing method involving flame photometry and atomic absorption spectrophotometer (Chapman, 2020.

2.5 Statistical Analysis of Data

Data collected for this study showed a symmetrical distribution around their averages, therefore, parametric tests of mean comparison such as analysis of variance (ANOVA) was used to evaluate the statistical differences. The Statistical Analysis System (SAS, 2023)software was used to perform the one-way ANOVA.The means were separated using the least significant difference (LSD) at the probability level of 5% and the relationship between samples were assesses through simple correlation analysis.

3.0 Results and Discussion

3.1 Effect of Handling Methods and Exposure Time on Nitrogen Content of Cow Dung

3.1.1 Handling methods

Handling methods had a significant effect on the N content of cow dung. The mean values as presented in Table 1 below show that the pit and covered handling methods had the highest effect with the least effect from uncovered handling method. There was no significant difference in the content of Nitrogen for cow dung stored in a pit and the cow dung piled on the surface of the soilcovered with polythene but both methods were significantly different from the uncovered method of handling.Sauerlandt (1956) reported that when cattle dungis covered, important chemical changes occur in the heap.Carbohydrates are fermented resulting in the production of organic matter which is rich in nitrogen.Dungs exposed to the atmosphere have greater tendencies to volatilize. Losses from open dungs(uncovered) are gaseous. Nitrogen is lost in the form of ammonium –Nitorgen and nitrogen gases. Leaching is another way of in which nitrogen could be lost from cow dung. Leaching losses from unprotected heaps of cow dung(uncovered) could be significant.

Table-1: The mean effectof various handling methods on Nitrogen of the composted cow dung

Handling Methods	%(N)
Pit	0.24a
Uncovered	0.09b
Covered	0.24a

3.1.2 Exposure time

According to Table 2, the Nitrogen content of the cow dung was found to be influenced by the length of period it was exposed to the atmosphere before application to the field i.e with highest effect from 90 days followed by 60, 30 and 7 days. Cow dung exposed for 7 days was significantly different from from the one exposed for 30, 60 and 90days but the exposed cow-dung for 30, 60 and 90 days were statistically similar. This is an indication that both weather and length of exposure contribute to losses. According to (Muller 2019) who reported that nutrient losses are especially high in warm sunny weather.

Table-2: The mean effect of different periods of exposure on Nitrogen content of the composte dcow dung

Periods of exposure	%N
7 days	0.11b
30 days	0.16a
60 days	0.23a
90 days	0.25a

3.2 Effect of Handling Methods and Exposure Time on Phosphorus Content of Composted Cow Dung

3.2.1 Handling methods

According to Table 3, The pit and covered treatments had higher Phosphorus content than the uncovered treatments and were statistically similar but were significantly different from the uncovered treatment. (Muller–Samman and Kotschi 2019) reported that cow dungs treated in closed places are subjected to immense attack by various microorganisms and subsequent conversion of the dung for the purpose of producing humus. The risk of losses is minimal in cow dung stored in a covered place(Bray, 2021). Cow dung that is left uncovered from rain usually lead to increased losses of phosphorus dissolved in runoff water (Fares et al., 1974).

Table-3: The mean effectof various handling methods on Phosphorus of the composted

Cow-dung

Handling Methods	% P
Pit	0.575a
Uncovered	0.272b
Covered	0.56a

3.2.2 Exposure time

The statistical analysis in Table 4 revealed that cow dung exposed for only 7 days was significantly different from cow dung exposed for 30 days,while 30 and 60 days were not significantly different but were significantly different from 90 days. According to (Bray 2021) who reported that phosphorus losses increase with increase in the length of exposure.

Table-4: The mean effect of different periods of exposure on phosphorus content of the composted cow dung

Periods of exposure	%P
7 days	0.16c
30 days	0.41b
60 days	0.63b
90 days	0.67a

3.3Effect of handling and exposure time on potassium content of cow dung

3.3.1 Handling method

Handling methods had a significant effect on the Phosphorus content of cow dung. The mean values in Table 5 shows that the pit and covered handling methods had the highest and lowest effect, respectively. There was no significant difference in the content of Phosphorus for cow dung stored in a pit and the cow dung piled on the surface of the soil and covered with polythene but both methods were significantly different from the uncovered method of handling as corroborated by **Onwudike 2020 and** Walkley, 2020

Table-5: The mean effectof various handling methods on Potassium of the composted cow dung

Handling Methods	% K
Pit	0.575a
Uncovered	0.272b
Covered	0.56a

3.3.2 Exposure Time

The statistical analysis in Table 5 revealed that cow dung exposed for only 7 days was significantly different from cow dung exposed for 30 days,while 30 and 60 days were not significantly different but were significantly different from 90 days. According to (Bray 2021) who reported that phosphorus losses increase with increase in the length of exposure

Table-6: The mean effect of different periods of Exposure on Potassium content of the composted cow dung

Periods of exposure	%K
7 days	0.18a
30 days	0.24a
60 days	0.30a
90 days	0.30a

3.4 Effect of handling methods and exposure time on calcium content of cow dung

3.4.1Handling method

Table 7 shows calcium content of cow dung in the various treatments and were found to be significant. Calcium is essential for stem and root growth. The higher content of calcium in the cow dung was found in the cow dung that was treated in the pit and covered methods. The covered and the pit treatments were not different but were found to be significantly different from the uncovered treatment. The reason cannot be far from the fact that nutrients generated from the covered and the pit method were maximally conserved. Losses due to volatilization and leaching were nonexistent in both the pit and covered methods of treatments.

Table-7: The mean amount of Calcium in cow dung for different methods of handling.

Handling Methods	% Ca
Pit	0.132a
Uncovered	0.100b
Covered	0.147a

3.4.2Exposure Time

Table 8 shows a close observation on duration of exposure and revealed that the cow-dungs exposed for 7,30 and 60 days were statistically similar but were significantly different from cow dungs exposed for 90 days. Results of analysis also indicated that cow dung exposed for 90 days also had the calcium contents is not the same to that exposed for other periods as that expose for 60 days as the highest calcium content value

Table-8: The mean amount of Calcium in cow dung for different periods of exposure.

Periods of exposure	%Ca
7 days	0.11a
30 days	0.01a
60 days	0.18a
90 days	0.17b

3.5 Effect of handling methods and exposure time on magnesium content of cow dung.

3.5.1 Handling method

Results of statistical analysis in Table 9 reveal that pit and covered treatments were similar but were significantly different from the uncovered treatment. The covered had the highest magnesium content followed by the pit and uncovered gave the least. .Magnesium is essential for large leaf formation and it plays an important role in enhancing photosynthetic activities, according to (Okalebo, 2018).

Table-9: The mean amount of Magnesium in cow dung for different methods of handling.

Handling Methods	% Mg
Pit	0.170a
Uncovered	0.095b
Covered	0.19a

3.5.2 Exposure Time.

The results of statistical analysis in Table 10 reveal that magnesium content of cow dung was found to be statistically similar. The length of time of exposure did not have any significant influence as the dung was exposed, as affirmed by (**Onwudike 2020).** a close observation on duration of exposure and revealed that the cow-dungs exposed for 7,30 and 60 days were statistically similar but were significantly different from cow dungs exposed for 90 days. Results of analysis also indicated that cow dung exposed for 90 days also had the magnesium contents is not the same to that exposed for other periods as that expose for 60 days as the highest magnesium content value

Table-10: The mean amount of Magnesium in cow dung for different periods of exposure.

Periods of exposure	%Mg
7 days	0.18a
30 days	0.24a
60 days	0.30a
90 days	0.30a

3.6 Effect of handling methods and exposure time on Sodium content of cow dung.

3.6.1 Handling method

According to (**Anonymous, 2020)** results from Table 11 show that **the pit and the covered treatment had higher sodium content but were significantly different from the content of sodium in the uncovered method.** For almost all terrestrial plants, sodium is not essential for either growth and development, however, Na+ can be beneficial and 'nutritious' in other species. It has been observed many times that, during potassium deficiency, many (glycophytic) plants respond positively to sodium fertilization (**Isola, 2018).** Also, at low levels, sodium not only is harmless but can be very useful, particularly in low potassium conditions. This is because, in hydrated form, sodium and potassium are chemically and structurally very similar (Amtmann and Sanders, 2019). Thus, many of the roles that potassium plays in plant cells, including some of the metabolic ones, can therefore be fulfilled by sodium.

Table-11: The mean amount of Sodium in cow dung for different methods of handling.

Handling Methods	% Na
Pit	0.040a
Uncovered	0.15b
Covered	0.03a

3.6.2 Exposure Time

Data analysis in Table 12 show that cow dung exposed for a period of 30days had higher sodium content than dungs exposed for 60 and 90 days. Sodium losses were attributed to leaching effects. The magnitude of losses greatly exceed those recorded for nitrogen and phosphorus. Mengel and Kirkby (2020) reported that the losses of available sodium by leaching and runoff greatly exceeded those of nitrogen and phosphorus. A close observation on duration of exposure and revealed that the cow-dungs exposed for 7,30 and 60 days were statistically similar but were significantly different from cow dungs exposed for 90 days. Results of analysis also indicated that cow dung exposed for 90 days also had the Sodium contents is not the same to that exposed for other periods as that expose for 60 days as the highest calcium content value

Table-12: The mean amount of Sodium in cow dung for different periods of exposure.

Periods of exposure	%Na
7 days	0.01b
30 days	0.03ab
60 days	0.03ab
90 days	0.04a

3.7 Effect of handling method and exposure time on Organic Carbon content of cow dung

3.7.1Handling method

Statistical analysis in Table 13 reveals that though pit and uncovered gave the highest and lowest values, respectively; there was no significant difference in the three treatments although the losses with the uncovered method was high.Carbon is the foundation of life. The compounds that comprise living tissues are made of carbon atoms arranged in chains. They are major constituents of plant dry matter, as proved by (Mengel, 2020)

Table-13: The mean amount of OC in cow dung for different methods of handling.

Handling Methods	% OC
Pit	4.200a
Uncovered	3.600a
Covered	3.70a

3.7.2 Exposure Time

Table 14 shows that the 30 days had the highest OC value followed by 90 days and the was attributed to both 7 and 60 days however,there was no significant difference in the periods of time. Carbon produced during decomposition is lost to the atmosphere in the form of carbon dioxide andmethane. (Muller-Samman, 2019).

Table-14: The mean amount of OC in cow dung for different periods of exposure.

Periods of exposure	%OC
7 days	3.70a
30 days	4.20a
60 days	3.70a
90 days	3.80a

3.8 Effect of handling methods and exposure time the pH of cow dung

3.8.1 Handling Method

Table 15 shows that the highest and least mean effect of handling methods come from uncovered and pit however, the three methods of handling were found to be statistically similar indicating that dung treated in various ways had similar pH values.When cow dung is properly handled, lime need not to be added to the soil to achieve a desirable pH for plant growth. (Tisdale, 2018)

Table-15: The mean P^{H} values of cow dung for different methods of handling.

Handling Methods	% PH
Pit	8.300a
Uncovered	8.625a
Covered	8.60a

3.8.2 Exposure time.

Data obtained in Table 16 show that cow dung exposed for 30 days had the highest effect on pH followed by 7 days, 60 and 90 dayshowever, 7, 30 and 60 days were not different in their effect but only 90 days had different significant effect. The data obtained show a balanced pH range for all treatments suggestive of potentials of composted cow dung to provide the desired plant protection from toxic substances and rapid fluctuations in soil pH by means of absorptive capacity exerting a buffering action, (**Vakili, 2019)**

Table-16: The mean P^{H} values of cow dung for different periods of exposure.

Periods of exposure	% P^{H}
7 days	8.60a
30 days	8.76a
60 days	8.20a
90 days	8.17b

3.9 Effect of handling methods and exposure time on electrical conductivity values of cow dung.

3,9.1 Handling Methods

Electrical conductivity of a solution gives an indirect measurement of the salt content of any medium. The mean values in Table 16 show that the covered method of handling had highest effect followed by the uncovered and pit however, the covered and uncovered methods were not significantly different but the pit method showed significant different in its effect on electrical conductivity values of the composted cow dung as highlighted by (Tisdale, 2018) in his electrical conductivity of solutions measurement theory

Table-16: The mean EC values of cow dung for different methods of handling.

Handling Methods	% EC (dsm-1)
Pit	6.500b
Uncovered	7.17a
Covered	7.23a

3.9.2 Exposure Time

The mean values in Table 17 show that 7 days gave the highest effect followed by 30 days and 60 and 90 days gave the same least value however, the four levels of exposure time were not significant different in their effect on EC. The values were in the range of 4-8 dsm^{-1} indicating that they are slightly alkaline. Electrical conductivity values within this range in soil pose no problem to plant growth as backed by (Mokwuye, 2018)

Table-17: The mean EC values of cow dung for different periods of handling.

Periods of exposure	% EC (dsm^{-1})
7 days	7.06a
30 days	6.93a
60 days	6.90a
90 days	6.90a

4. Correlation Analysis

Nitrogen showed a highly significant correlation with calcium, sodium, magnesium and phosphorus at 0.01 level of significance. But showed a significant negative correlation (r=-0.58412) with pH at 0.05 level of significance. Nitrogen showed a non-significant correlation with organic carbon and electrical conductivity at 0.01 and 0.05 level of significance. Phosphorus showed a highly significant correlation (r=-0.18693 NS) with pH. Nitrogen and phosphorus interaction translate to many physiological observations on crop performance. Phosphorus has to be available for efficient nitrogen utilization. A good supply of nitrogen stimulates the growth and development as well as uptake of other elements. Cow dung protect crops from excess of toxic reactions by means of their absorption capacity exerting a buffering action. Calcium, sodium and magnesium negatively correlates with pH.Sodium and magnesium showed a negative non significantly correlation with electrical conductivity values indicating that microorganism activities on manures lead to a soluble nutrient generation and conservation and organic acids produced during decomposition are readily processed by soil microorganisms with the cow dung exerting its buffering capacity. Potassium had a non-significant correlation with calcium and magnesium. Potassium has a highly significant correlation (r=0.59456) with phosphorus. Maintaining a balance between potassium and other elements such as phosphorus, nitrogen, calcium and magnesium is an important goal in soil fertility as further confirmed by (Kwakye, 2020)

Table-18: Correlation analysis showing the effect of different handling methods and different periods of exposure on the chemical properties of cow dung

	Na(Cmol kg$^{-)}$	Ca(Cmolkg$^{-)}$	Mg(Cmol kg$^{-)}$	K(Cmolkg$^{-)}$	P(Cmgkg$^{-)}$	OC(g/kg)	p^h	EC(dsm^{-1})	N(g/kg)
Na	1.00000								
Ca	0.79312**	1.00000							
Mg	0.84255**	0.8917**	1.00000						
K	0.50325NS	0.47451NS	0.31514NS	1.00000					
P	0.88787**	0.92247**	0.85684**	0.59456**	1.00000				
OC	0.38626NS	-0.05900NS	0.07096NS	0.47261NS	0.11338 NS	1.00000			
p^h	0.52241NS	-0.57766*	-0.42834NS	-0.71505**	-0.68668*	-0.00833NS	1.00000		
EC	-0.3549NS	-0.123O2NS	-0.08455NS	-0.59769NS	-0.18693 NS	-0.039937 NS	0.476.9 NS	1.00000	
N	0.87572**	0.84099**	0.92162**	0.39408NS	0.91510**	0.04402NS	-0.58412*	-0.1877 NS	1.00000

* = Significant(P< 0.05)

* * =Highly significant (P<0.01)

NS = Non-significant (P>0.05)

Conclusion

This study sets out to identify the effect of Cow dung which is the most commonly used and readily available organic fertilizer. Nevertheless, great amount of organic matter and essential nutrients are still lost due to lack of care in the collection of the dungs, handling and storage. Results from this study showed that nitrogen, phosphorus, potassium, sodium, magnesium, calcium, which are plant essential nutrients showed a remarkable increase when they are handled using the covered and pit methods as impirically carried out and based on the findings, it is concluded that:

1. These essential plant nutrients were further conserved when only exposed for a period of 7 and 30 days. Nutrient losses accompanied with uncovered cow dungs are enormous.
2. The benefits of covering cow dungs reduce the effect of leaching and volatilization. Additional losses may occur when cow dungs are left for long period unprotected from rain and sun.
3. Results from this study, proffered advice on the best method of handling cow dung and the duration for which cow dung can be exposed to achieve maximum nutrient generation and conservation.
4. Finally, conserving nutrient is a very important aspect of cow dung management, the result of the experiment should not be interpreted to narrowly. It would be erroneous to solely regard cow dung as just a vehicle for nutrient.

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Application of Innovative Technology - Artificial Intelligence in Property Management Practice in Osun State, Nigeria: The Awareness, Challenges, and Strategies to Overcome

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Abstract

Real estate practice globally is gradually and steadily witnessing drastic significant transformational changes with the emergence and application of modern technologies, particularly Artificial Intelligence (AI). AI integration into real property management practices in Osun State by the real estate managers is still in its infancy stages. This paper therefore investigates the level of awareness, the specific challenges faced by property managers in Osun State in its adoption, and the likely strategies needed to overcome the perceived challenges. The study adopted a mixed-methods research approach, incorporating surveys and interviews with property managers and other stakeholders. Findings revealed low level awareness, significant challenges related to infrastructure and cost, and hence, suggest a framework that will foster AI adoption in the property management sector in Osun State.

Keywords: *Artificial Intelligence, Property Management, Awareness, Challenges, Osun State, Nigeria*

1. Introduction

The revolutionalization of the global industries including the property management sub-sector of the real estate industry by Artificial intelligence (AI) have become issues of topical discuss in recent times. Different sectors in nations across the globe are beginning to leverage on AI for enhanced customer services, improve operational efficacy and efficiency as well as, the assurance of automate decision-making Processes. Gabe and Nakagawa (2020) observed that, the application of AI in real property management spanned across areas as automated tenant screening, predictive maintenance, smart building management, virtual assistants and rental pricing algorithms. Nevertheless, the extent of AI permeation in the real property management practice in the developing nations as Nigeria and particularly, Osun State, a less urbanised state can be said to be relatively unexplored. Okonkwo and Adewunmi (2021) decry the proportions of the manually driven real property management practices in Nigeria; characterized by inefficiencies in tenant selection and management, maintenance scheduling and archaic rent collection procedures. However, previous literatures have attributed slow rate of AI's adoption and it's potentialities in the Nigeria real estate market to lack of skilled labour in the area and labour cost, infrastructural challenges, high costs among others.

The property management subsector of the real estate market in Osun State is yet to fully explore and utilize the enormous capabilities of AI, due to the low-level awareness among practitioners and other similar challenges. Earlier studies as Jones (2022), Mahmood et al. (2021), Abiodun and Shittu, (2021) highlighted the importance of AI applications in property management to include but not limited to the enhancement of operational efficiency, improve service delivery, streamlining of processes as market analysis and lease management, reduction in costs, tenant communications and by affording the property managers ample time to concentrate on some other important strategic functions. Mahmood et al (2021) however, submitted that, the successful application of AI in real property management requires adequate technological know-how and infrastructure, sustainable and affordable implementation costs among others.

This paper therefore explores the level of awareness of AI technologies among real estate practitioners, particularly, the professional property managers in Osun State, Nigeria, practicing under the umbrella of the Nigeria Institutions of Estate Surveyors and Valuers as well as the charlatans and identifies the major challenges impeding its adoption and application. Furthermore, the study, suggested strategies to overcome the observed challenges and facilitate the integration of AI into property management practices in the state. By examining the state of AI in property management in Osun State, this study contributes to the broader discourse on the digitalization of the Nigerian real estate industry, emphasizing the need for technology-driven solutions in property management, thereby provoking a new area of crucial discuss in this all-important profession.

2. **Literature Review**

AI applications, its awareness and perception in property management, challenges and strategies to overcome the barriers.

In recent times, issues of the adoption and application of Artificial Intelligence (AI) in real property management has increasingly gained attention with earlier scholars highlighting its potentials of digitizing and revolutionizing the real estate industry in Nigeria. The integration of Artificial Intelligence (AI) into the real estate sector, particularly, the real property management sub-sector is overwhelming.

Globally, property management practice in the contemporary time is becoming more AI-driven than what it used to be in the time past. Gabe and Nakagawa (2020) observed that apart from real property management operations as tenant management, predictive maintenance and market analytic; real property management AI -driven solutions could help in automated routine tasks as lease management, rent demand and collection, tenant communications as well as increasing efficiency and productivity through the reduction in human errors. Decision making in risk assessment and dynamic real estate pricing can be done with high level precision through AI. It's ability to process large real-time data within a short time is of great advantage to the property managers. Similarly, Jones (2022) asserted that the current global trends in the adoption of AI tools for real estate practice portend a brighter future for the industry. He noted an integral part of AI-powered systems in the optimization of building management, particularly in the smart buildings. Through AI, property managers can predict equipment failures and schedule preventive maintenance, significantly reducing downtime and maintenance costs. This is particularly important in regions with ageing infrastructure, where maintenance challenges are prevalent.

Though, despite the trending emergence of the adoption and application of AI technologies in property management practices across the world, particularly, in the developed nations, it awareness and application in the developing economic seems to be low. According to Okonkwo and Adewunmi (2021) who concluded that most property managers in Lagos, Nigeria are not familiar with the use of AI advance technology as most of them rely majorly on the application of the traditional property management strategies. Their study further underscores the need for increased training / education and awareness on the benefit of AI adoption and application within the purview of the Nigerian property management subsector. In line with the above assertion, the study of Adeoye and Akinola (2019) revealed that, though, it is a fact that some property managers in the Metropolitan areas of Nigeria have joined the world in the adoption and application of the basic digitalization transformation, the quest for the adoption and application of a more advanced AI technology is been hampered by a lack of awareness and perceived complexity. This is consistent with Mahmood et al. (2021), who argue that the limited awareness of AI's potential, particularly in less urbanized areas like Osun State, hampers its adoption. Their study also notes that without proper understanding, property managers are less likely to invest in AI technologies.

Previous studies as Adeoye and Akintola (2022), Mahmood et al. (2021) and Amadi and Nwosu (2020) has identified some major key hindrances to the adoption and applications of AI in real property management practice in the developing nations. Digital technological infrastructure with poor and unreliable internet connectivity is one of the foremost challenges identified as a hindrance to the widespread integration and application of AI in property management system. Its integration in some part of Osun State will be difficult as AI solutions require a strong, reliable and stable power and digital infrastructure, which many parts of the state cannot boost of.

Cost and the lack of technical expertise was also identified in previous literatures to be another limiting factor. The setting up and running of an AI is a capital-intensive venture as it requires huge initial and long-term capital outlay. Most of the practicing real estate firms and charlatans that dominate the real estate industry in the state are either of the small or at best medium-sized property management firms. Hence, the possibility of raising the required financial resources for the setting up and maintenance of the AI resources could be a burden to the firms. Ugochukwu and Ibe (2020) opined that without financial support and incentives from either the government or private sector or the combinations of both, most estate firms in Nigeria will find it difficult in adopting AI solutions in property management practice.

Also, Jones (2022) and Gabe and Nakagawa (2020) argue that, where the infrastructure exists, the dearth of professional expertise who is familiar with AI terrain and capable of integrating AI technologies in property management could hinder its adoption and application, hence poses a significant challenge, especially in the developing world. Closely related to this, is the issues of legal and regulatory framework which scholars as Bello and Adeola (2023), Babajide and Oluwafemi (2021) and Adeoye and Akinola (2019) have identified to be a barrier to the application and adoption of AI technologies in property management. Policies on AI usage and adoption in property management must not contradict any of the existing laws of the land. It must be aligned with all laws including data privacy and both landlords and tenant rights

However in order to overcome the aforementioned challenges, earlier scholars as Oladipo and Fagbemi (2024), Jimoh and Falola (2023), Mahmood et al (2021) have suggested several strategies in literatures among which are the improvement of technological infrastructure which is hope to promote and provide the required solid foundation for the adoption of AI in property management and the practice of contemporary real property management system even in a less urbanised states like Osun. Furthermore, scholars +as Ugochukwu and Ibe (2020), Olatunji and Alabi (2020) and Oshin (2019) argued that incentives and financial supports from both private and public bodies in term of tax holiday, lower interest rate, subsidies and palliatives could lower entry cost for the adoption and application of AI technologies in property management. All these could make AI technologies cheaper and more accessible to smaller firms that would otherwise be priced out of the market. The role of capacity building through education, training and retraining programs was emphasized by Okonkwo and Adewunmi (2021). The scholars further stated that industrial partnership and collaboration could go a long way in bridging the knowledge gap by providing the property managers with hand-on practical experiences in the general Information and communication Technology (ICT) software as well as in the use of relevant Artificial Intelligence packages.

Adeoye and Akinola (2019) asserted that having a clear regulatory and Policy frameworks that focuses on the specific role of AI in property management practice will enhances its widespread adoption and application. However, they warned that such policies should be clear and specific on cybersecurity, data privacy and ethical considerations that align with international best practices and legal standards.

3. Methodology

The study adopted a mixed – method research approach by collecting comprehensive quantitative and qualitative data on the awareness, Challenges and strategies for the adoption and application of Artificial Intelligence in real property management practice in Osun State, Nigeria. This research approach engenders a thorough understanding of the current AI tools applications in property management horizon, thus providing both contextual insights and numerical data. The data was collected from active property managers (professional and charlatans), while the other stakeholders explained the level of government commitment to the AI adoption in property management practice initiatives in the state.

For the quantitative component of the research, the study adopted a cross-sectional survey research design. This aspect of the research x-rays the level of AI awareness, adoption and application among the property managers. While semi-structured interviews were employed for the qualitative research component. The interviews allowed for a deeper exploration of the basic challenges and the required strategies for AI-driven property management practices in the study area.

To obtain population sample for the study, stratified random sampling method was adopted. This method ensures that participants are drawn from the most active property markets within the study area. These property markets cut across both the urban and semi-urban areas as Osogbo, Ile Ife, Ede, Ilesha, Iwo and Ikirun all within Osun State. The Cochran's sample size determination formula was used to pick the sample size from the sample frame. The adoption of this formula ensures statistical reliability. The formula is $\boldsymbol{n = \frac{Z^2 P(1-P)}{e^2}}$

n = Sample Size

z = z - score (depends on confidence level chosen by the researcher (1.96 for a 95%)

P = the estimated proportion of the population (0.5)

e = error margin or confidence interval (0.06)

However, the study selected 152 out of the 250 participants using the Cochran's formula out of which 110 of the respondents was used for the quantitative survey. This comprises of 50 professional valuers from both the field and academia and 60 charlatans who are active participants in property management market in the study area. While 30 participants of 15 professional valuers,15 charlatans and 12 were chosen for the qualitative interviews. This help in the gaining of a deeper insights into the specific challenges and strategies for AI adoption in the study area. The interview was however guided by an open-ended semi-structured questionnaire designed to explore information on the perceived benefits of AI in property management; the major barriers to the adoption of AI technologies in the study area; probable solutions that could address these barriers and possible suggestions for government intervention in capacity building, and financial supports and incentives. The interviews which lasted for 40 minutes were conducted either in person or via phone calls, depending on the choice or availability of the respondents. All the interviews conducted were recorded with the consent of the participants, transcribed and later triangulated for analysis. In all, a total of 150 participants were selected for this study.

Quantitative data was collected through the design and administration of structured questionnaire. Data collected were data on the awareness, adoption and application of AI technologies in the practice of real property management in the study area, the challenges and strategies to overcome it. To get the perceptions of the respondents on the key factors impeding the adoption and application of AI in property management in the study area, the study adopted Relative Importance Index (RII). The formula used for the calculation of RII is:

$$\textbf{R.I.I.} = \frac{\sum W}{A*N} = \frac{5n5 + 4n4 + 3n3 + 2n2 + 1n1}{5*N}$$

Where;

W = weight given to each of the respondents' perceptions ranges from 1 to 5;

n5 = strongly agreed; n4 = agreed; n3 = undecided; n2 = disagreed; n1 = strongly disagreed

A = Highest response integer (5) and

N = Total number of respondents

The questionnaire was divided into four sections: The first section deal with the demographic profile of the respondents; the second section explore issues on AI awareness, their familiarity with AI technologies and if such technology have been implemented in their firms. The third section elicit information from the respondents on the challenges or the barriers to AI adoption and application. Finally, the respondents were asked on issues relating to the strategies for overcoming the barriers or the challenges to AI Adoption and to suggest possible solutions and strategies that will enhance AI adoption. The process of questionnaire administration and collection which lasted for a month was done both in person and electronically. This, apart from enhancing ease of administration also ensures high response rate.

4. **Results and Discussions**

Table 1 shows the demographic profile of respondents selected and used for the study, the number of questionnaires administered, and the numbers correctly filled and retrieved. In all 110 questionnaire was administered on the selected respondents who cut across professional property managers and the charlatans. Those respondents considered professional property managers are those with the right education and certifications in estate management profession. That is, the Associate Members of the professional body that are registered to practice in the country. The charlatans are those that, though, maybe graduate in other field but are not certificated to practice any aspect of real estate management profession. As presented in Table 1, out of the 110-questionnaire administered on the respondents, 83 representing 75% of the total administered questionnaires was adequately and correctly filled and returned for analysis. This gives a good responses rate for the study.

Table 1: Respondents' Type and Questionnaire Administration

Locations	Respondents	Questionnaire Administered	No Retrieved	% Rate
Osogbo	Prof. Manager	10	8	80
	Charlatans	15	14	93
Ede	Prof. Manager	10	9	90
	Charlatans	10	9	90
Ile Ife	Prof. Manager	10	9	90
	Charlatans	15	12	80
Ilesha	Prof. Manager	10	7	70
	Charlatans	15	13	87
Iwo	Prof. Manager	10	7	70
	Charlatans	5	4	80
Total		110	83	75

Source: Field survey, 2024

In order to demonstrate the credence and reliability of the study, the professional standing of the respondents on whom the questionnaire was administered was assessed and presented in Table 2. From the Table, all the professional property managers used for the study (100%) are professionally qualified and are registered with the relevant professional body; hence, allow by law to practice estate management and valuation in the country. On the other hand, those considered charlatan and used for this study are the local agents who have no certification in estate management education but are well known and highly patronised by property owners in the locality. Those that were considered as such and used for the study have no formal knowledge of real property management but practice in the areas as local agents.

Table 2: Professional Qualification of the Respondents

Location	Respondents	Professional Qualification	Freq	% Rate
		ANIVS + RSV	10	100
	Prof. Manager	ANIVS		
Osogbo		ANIVS		
	Charlatans	No ANIVS	15	100
		ANIVS + RSV	10	100
	Prof. Manager	ANIVS		
		ANIVS		
Ede	Charlatans	No ANIVS	10	100
		ANIVS + RSV	10	100
	Prof. Manager	ANIVS		
Ile Ife		ANIVS		
	Charlatans	No ANIVS	15	100
		ANIVS + RSV	10	100
	Prof. Manager	ANIVS		
Ilesha		ANIVS		
	Charlatans	No ANIVS	15	100
		ANIVS + RSV	10	100
	Prof. Manager	ANIVS		
Iwo		ANIVS		
	Charlatans	No ANIVS	5	100

Source: Field survey, 2024

Tale 3 presents the respondents' years of experience in property management in the various locations selected for the study. The Table revealed that all the respondents have been in the business of property management for more than 5years; hence, have the required knowledge and experience to provide answers to the questions contained in the questionnaire. This shows that, these sets of respondents are in the best position to provide answers to questions on the non-adoption of AI in property management in the study. This further shows the reliability and credibility of the choice of respondents and the probable responses from them.

Table 3: Respondents' Years of Experience in Property Management in the Study Area

Location	Respondents	Years in Practice	Freq	% Rate
		≤ 5 years		
	Prof. Manager	> 5 years	8	100
Osogbo		≤ 5 years		
	Charlatans	> 5 years	14	100
		≤ 5 years		
	Prof. Manager	> 5 years	9	100
		≤ 5 years		
Ede	Charlatans	> 5 years	9	100
		≤ 5 years		
	Prof. Manager	> 5 years	9	100
Ile Ife		≤ 5 years		
	Charlatans	> 5 years	12	100
		≤ 5 years		
	Prof. Manager	> 5 years	7	100
Ilesha		≤ 5 years		
	Charlatans	> 5 years	13	100
		≤ 5 years		
	Prof. Manager	> 5 years	7	100
Iwo		≤ 5 years		
	Charlatans	> 5 years	4	100

Source: Field survey, 2024

The study found that the awareness level, acceptance of AI technology and its application in property management firms in the study area as presented in Table 4 is high among the professional property managers (100%) but with low usage of about 24%. While the non-professional (charlatan) have very low awareness level of 17% but 92% of them agreed to its usage. Only 16 property managers out of the 110 property managers that filled the questionnaires are using AI tools in their operations.

This suggests that despite global awareness in AI applications across industries, its penetration into the Osun state property management remains limited.

Table 4: Awareness and Acceptance of AI Technology by Property Managers in the Study Area

Respondent	Variable	Response	
		YES (%)	NO (%)
Professional Manager	Are you aware of AI application in property management?	50 (100)	0
Charlatan		10 (17)	50(83)
Professional Manager	Do you agree with this idea?	50 (100)	0
Charlatan		55 (92)	5(8)
Professional Manager	Are you applying this technology in your firm?	12 (24)	38(76)
Charlatan		4(7)	56(93)

Source: Field survey, 2024

Table 5 provided responses on the adoption and applications of AI in property management practice in the study area. From the Table it could be seen that, the area where AI is mostly and commonly applied both fully and partly is in virtual tenant communication and meetings (73%), followed by automated market analysis (27%). This shows that, there is a lot of work to done to move practitioners to the realities of life as the world itself has moved from analogue to digital era. Every industry in the world has moved including the real estate industry; hence, the practitioners must joint in the emerging trend.

Table 5: AI Technology Adoption and Application in Firms in the Study Area

In what area do your apply AI Tools for Property Management in your Firms	Full usage (%)	Partly in use (%)	Not in use (%)
Virtual Property Touring	10(10)	8(7)	92(84)
Predictive / Preventive Maintenance	8(7)	13(12)	89(81)
Automated Rent Demand and Rent Collection	12(11)	15(14)	83(75)
Automated Market Analytic	20(18.2)	10(9.1)	80(73)
Virtual Tenant communication and Meetings	30(27)	50(46)	30(27)

Source: Field survey, 2024

To rank the perceptions of the respondents on the various challenges to AI adoption and application in real property management exercises in the study area, Relative Important Index (RII) using 5-point scale was employed. The key barriers as identified in literature by successive scholars are inadequate technological infrastructure, high cost of implementation, lack of technical expertise, and regulatory framework gaps. As presented in Table 6, inadequate technological infrastructure was identified as a barrier to the adoption and application of AI technology in property management task in the study area with RII 0.982 ranking first among the other factors. The application of AI tools require strong, high-speed and reliable internet connectivity as cloud-based platforms and Internet of Thing systems for a reliable smart real property management practice. Achieving this in Osun state is more of an illusion. In addition to internet is the problem of power supply and cost. This failure reflects the total infrastructure failure of the nation, particularly where the digital divide between the urbanised cities as Abuja and Lagos and the less urbanised cities as Osogbo and Ede limits the acceptance and applicability of contemporary technologies. Investment in digital infrastructure to improve digital connectivity in the less urbanised areas is crucial for the adoption and applicability of AI technologies in the real property sub-sector.

The lack of technical expertise ranked 2nd with an RII of 0.964 was perceived by the respondents as a serious obstacle blocking the actualisation of the digitalisation of the real property management market in the study area. Most of the property managers, especially, the charlatans lacked the requisite technical skills for the implementation and management of AI systems. This observed gap confirms the urgent need for capacity building as workshops, certification programs, and on-the-job training as well as enlightenment campaign in the property management sub-sector of the real estate market. This is congruent with the assertion of Ankeli et al (2023) who calls for the urgent and immediate attention and the need to re-evaluate the current property management strategies in Osogbo due to technological illiteracy. The modern-day AI technology used in property management operations such as machine learning algorithms and automation tools, requires high level specialised knowledge

Another critical barrier factors based on the perceptions of the respondents is the high cost of implementing AI systems. This factor ranked 3rd with an RII of 0.873. This indicate that the implementation of AI is capital intensive; hence, may be difficult for smaller property management firms with slim purse to invest and integrate into.

The need for a clear-cut regulations and policies governing AI use in property management, particularly in relation to data privacy, Cybersecurity, and tenant rights was stressed and considered to be an important factor. This is consistent with Adeoye and Akinola (2019) who asserted that a clear-cut regulatory framework will enhances widespread adoption and application of AI in property management. The uncertain or a not too clear policies or guideline governing AI adoption in property management was seen as a major deterrent to AI adoption.

Table 6: Key Factors Impeding the Adoption and Application of AI in Property Management

variables	Strongly Agree (5)	Agree (4)	Undecided (3)	Strongly Disagree (2)	Disagree (1)	∑WV	RII	RANK
Lack of Technical Expertise	90(82)	20(18)	0	0	0	530	0.964	2nd
Regulatory Framework Gap	65(59)	20(18)	5(5)	10(9)	10(9)	450	0.818	4th
Inadequate Technological Infrastructure	100(91)	10(9)	0	0	0	540	0.982	1st
High Cost of Implementation	80(72)	10(9)	5(5)	10(9)	5(5)	480	0.873	3rd

Source: Field survey, 2024

The study identified strategies that could be adopted in order to overcome the numerous challenges confronting the adoption of AI in property management in the study area. The identified strategies are:

The use of modern Technological Infrastructure

An improve strong, uninterrupted and reliable power supply, internet connectivity and digital infrastructure is essential for AI adoption. An easy way out of the current infrastructure decay in Osun state as suggested by Ankeli et al., (2023) and supported 100% by the respondents as shown in Table 7 is the engagement of public-private partnerships in infrastructure provision and management. Hence, investing in digital infrastructure is a critical step toward enabling AI adoption and application in Osun state.

Provision of Financial Supports and Incentives

Table 7 revealed that, 91% of the respondents are of the view that, the private sector contributions or government financial support or the combination of both and other similar incentives, such as palliatives, subsidies, tax holidays or breaks, donations, low or reduced interest on loans are required to boost, encourage and increase AI adoption and applications. These inducements would help cut down the financial encumbrances on property management firms, especially, the small and medium-sized firms. The granting of subsidy and the reduction in interest rate on loans will make the investment and use of AI technologies cheaper and more affordable, as tax wavier or incentives could encourage real estate managers to invest more in the digitalisation of the real property industries.

Capacity Building, Training Programs and Enlightenment Campaign

The Table revealed that, 95% of the respondents recommended the inclusion or introduction of training programs targeted at AI and digitalisation transformation in real property development and management curriculum. The need for embarking on aggressive public enlightenment campaign to education the general public and particularly, the real estate practitioners and the charlatans engaged in property management task was also emphasised. Training and capacity-building initiatives could help in bridging AI in property management skills gap and help in equipping the property managers with competencies necessary to adopt, manage and apply AI tool in property management in the study area.

Development/formulation of Regulatory Frameworks

Furthermore, the study revealed that 81% of respondents emphasized the need for a clear-cut regulatory framework and policies to govern AI adoption, management and usage in property management task. The regulatory framework should focus on issues as cybersecurity, data privacy and tenant rights to AI adoption and application in Nigeria and Osun state to be precise. The establishment of a strong and comprehensive guideline/regulatory framework for ethical use of AI in property management that promote innovative thinking and protect both the interest of the property manager and the tenants is crucial. This will provide the property managers with more confidence in AI adoption and application and the engenders real property sector digitalisation transformational dream of the real estate professionals.

Table 7: Strategies to Overcome AI Adoption and Applications in the Study Area

Variables	Freq	% Rate
Investment and the use of modern Technological Infrastructure	110	100
Provision of Financial Supports and Incentives	100	91
Development/Formulation of Regulatory Frameworks	89	81
Capacity Building, Training Programs and Enlightenment Campaign	104	95

Source: Field survey, 2024

5. Conclusion and Recommendations

The study explores the adoption and application of Artificial Intelligence (AI) in real property development and management in Osun State, Nigeria, focusing on its level of awareness, adoption, and the strategies to overcome the barriers. Findings from the study apart from exposing the possible potentials of AI revolutionalization of the real estate market through cost reduction, enhanced efficiency and its predictive capabilities, the possibility of its full adoption and application remain an illusion. The identified barriers are more pronounce in less urbanised state as Osun with less developed digital infrastructure; hence, property managers often apt for the traditional methods of real property management. The study highlighted several strategies, that if effectively and efficiently implemented, the AI adoption and application in the property management subsector could significantly improve leading to increased productivity, enhance tenant satisfaction and robust decision making. The results underscore the need for collaborative work that will drive AI adoption and application between the private sector, government and educational institutions. It is the hope that improvement in infrastructure, provision of financial supports and incentives, encouragement of building capacity, training and enlightenment campaign and the establishment of a clear policy guideline and regulatory frameworks, Osun State can take meaningful steps toward integrating AI into property management practices.

It is on the findings of this study that the following recommendations are put forward:

a. That the Osun State government should embark on collaborative efforts with private sectors to invest in digital and other critical infrastructure development in the state. A strong, reliable internet connectivity with stable power supply source and access to digital tools are necessary areas for a successful and sustainable AI technologies in property management implementation.
b. Again, there is the urgent need for the state government to reinvent or introduce financial support and incentives, tax holiday or reduction, low interest rate on property loan to help smaller property firms to grow and key into AI solutions.
c. The need for a concerted effort at capacity building, training programs and enlightenment campaign targeted at building the technical capacity and skills of the property managers on AI and digital technologies. This can be achieved through collaborations between educational institutions, government and industrial associations.
d. Furthermore, the need for a clear-cut policy guideline and regulatory frameworks cannot be overemphasis as it underscores the development of laws that govern AI in property management adoption and applicability in the state. This will further help in cybersecurity, data privacy and ethical use of AI. The development of these frameworks will boost property managers confidence to invest in AI technologies, especially, when it became clear that its operations is in line with best practices and legal standards.
e. Awareness campaign will help in bridging the knowledge gap as well as encourage the exploration of AI technology by property managers.

The implementation of these recommendations will help the adoption and application of AI in property management in Osun state. It will engender a more efficient, innovative and data driven real property management practices that will benefit all stakeholders.

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Characteristics and Predictive Evaluation of Sesame Straw Ash Based Concrete

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Abstract
Concrete is widely utilized in buildings, and due to a rise in construction activity, there is a growing need for locally available materials for cement replacement in concrete production. This study evaluated the effects of sesame straw ash (SSA) as an alternative material for cement (Portland limestone cement) in concrete production, and a predictive model was developed. The effects of SSA on the characteristics and microstructure of SSA-cement paste were evaluated by varying the quantity of SSA as a partial replacement for cement and 3, 7, 28, 56 and 90 days were considered for curing. The influence of Sulphuric acid on SSA concrete is also observed. However, slump, compressive strength, and durability tests were carried out on the fresh and hardened concrete. The DataFit software was used to develop models using the experimental data obtained from the lab. The result of workability showed that addition of SSA content decreased the slump of fresh concrete, and stepped up the strength of concrete. The percentage of weight retained by concrete after exposure to H_2SO_4 solution decreases as the percentages of SSA content and immersion period (age) in H_2SO_4 solution increase. The scanning electron microscopy (SEM) analysis of SSA-concrete pointed out more voids were discovered as the portion of SSA stepped up. The result of hydrated SSA-cement pastes revealed the existence of the most important hydrates such as portlandite and C-S-H. The results of FTIR indicated that the shifting of the major bands of the C-S-H location to get specific information regarding the hydration of cement and the decalcification process that happens throughout the ageing of the hydrated cement paste. The regression models established have R^2 values as 89% and 91.1% for compressive strength and retained weight of concrete respectively, and this indicated that the models are enough for predicting the strength of concrete produced with SSA. It was concluded that the optimum percentage of SSA content to use should not be more than 10 %.

Keywords: Sesame straw ash (SSA), Cement, workability, compressive strength, SEM, FTIR;

Introduction

The usage of industrial and agricultural wastes in concrete as alternative materials for cement is a crucial matter to proffer a sustainable solution bedeviling the environmental, raw resources and saving energy. Many of the alternatives and supplementary cementing materials are rice husk ash (RHA), ground granulated blast furnace slag, silica fume, fly ash and ash from woods (Gunduz and Kalkan, 2019. According to a study conducted by Sulaiman *et al.,* (2020) addition of sesame straw ash (SSA) decreased the flow (workability) and compressive strength of mortar, but increased the soundness, setting times, and consistency of SSA-cement paste. However, the compressive strength of SSA-mortar increased as the curing period increased. According to a study carried out on the effect of adding Sesame stalks fiber (SSF) to the concrete mixture by Elmardi *et al.,* (2021) claimed that the strengths of SSF-concrete decreased as the percentage of sesame stalks fibre (SSF) increases, however, the addition of (SSF) increases the concrete resistance against crack growth. The durability of concrete is a vital characteristic that vehemently assesses the service life of structural concrete (Ogork *et al.,* (2015). A study by Yuksel *et al.,* (2007) highlighted that the durability of any concrete is its power to withstand any physical and chemical attacks that contribute to the disintegration of the service life of the concrete. A study carried out by Adamu *et al.,* (2021) disclosed that the water permeability and water absorption of pervious concrete blended with RHA and CCW have a negative influence on the durability of pervious concrete. However, the RSM models generated indicated a high degree of relationship between the responses and the variables. Adole *et al.,* (2011) described that concrete made with GHA and immersed in $MgSO_4$ and NaCl solutions performed excellently with strengths of 21.05 N/mm² and 22.55 N/mm² respectively. They concluded that GHA-concrete can function well in soils having $MgSO_4$ and NaCl. Ofuyatan *et al.,* (2018) worked on the assessment of strength characteristics of CPA-concrete, and their findings showed that the compressive strength and resistance to H_2SO_4 attack have improved remarkably at 10 % CPA. According to a study conducted by Ogork *et al.,* (2015), the regression model developed for GSA-RHA modified concrete weight retained after exposure in HCL with R^2 as 0.683 was enough for prediction of the sensitivity of pozzolanic activity of GSA admixed with 10 % RHA in an acidic environment. And they also stated that the resistance of GSA-concrete was found to be better than concrete blended with GSA-RHA against HCl. Umale and Joshi (2019) stated that as the immersion period increased, the influence on the strength and cut down in a mass of the specimens ballooned. They finally concluded that the effect of Hydrochloric (HCl) and Nitric acid on concrete is higher as equated to H_2SO_4 acid, and the complete submersion of the concrete specimens in 10 % HCl for 60 days led to a high decline in strength closed to 47 %, that is 45 % Nitric acid and 25 % H_2SO_4 acid. The study focuses on assessing the influence of Sesame straw ash (SSA) as an alternative material for cement in concrete and microstructure of cement paste. This study focuses on evaluating the effects of sesame straw ash (SSA) as an alternative material for cement (Portland limestone cement) in concrete production, and developing predictive models.

Materials and Methods

The Portland limestone cement (PLC) used was Dangote BlocMaster, grade: 42.5R, having a moisture content of 1.81 % and specific gravity of 3.16. The fine aggregate used was sourced from Zaria Local Government Area, Kaduna State, Nigeria, with a specific gravity as 2.68. The coarse aggregate used has a specific gravity of 2.68. Sesame straw ash (SSA) used was obtained by burning the sesame straw (SS) sourced from Jigawa State, Nigeria. It has, a specific gravity of 2.69, and an LOI of 0.3 %. The water used was potable, sourced from the Department of Civil Engineering laboratory of ABU, Zaria, Kaduna State, Nigeria. The workability test was performed on fresh concrete in line with BS 1881:102 (1983). The compressive strength test on SSA-concrete was conducted in conformity with BS 1881-116: (1983). Regression models were generated from data obtained from experimental tests using DATAFIT 9 software to predict the strengths of concrete made with various portions of SSA. In generating the models, the influence of SSA and curing duration were looked at. The software develops different model equations.

Results and Discussions

Slump of Fresh SSA-Concrete

Figure 1 shows the result of the slump test conducted on concrete made with a portion of SSA in 0, 5, 10, 15, 20, and 25 %. The results indicated that the slump of the fresh concrete mix stepped down as the portion of SSA went up. The decrement maybe because of the high surface area of SSA for constant water content (Sulaiman and Aliyu (2020**).** It may also be accredited to the density of the SSA which is less than that of cement and particle size fineness.

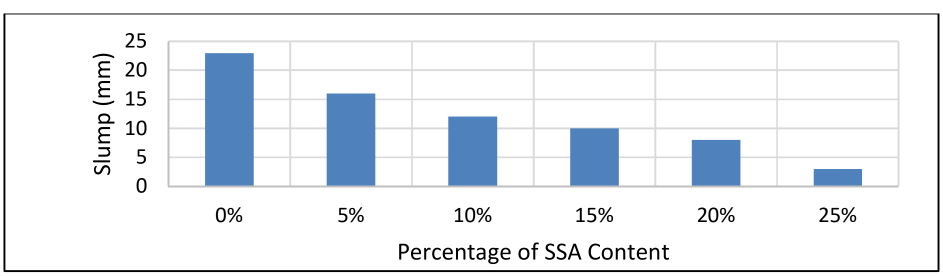

Figure 1: Relationship between Slump and percentage of SSA Content

Compressive Strength of SSA-Concrete

The results of the strength of SSA-concrete are demonstrated in Figure 2. It has been discovered that the strength of SSA-concrete diminishes as the portion of SSA raises, and steps up as the curing period escalates. However, it was noticed that at 28 days of curing, the strength of concrete made with 10 % SSA overstepped the target design strength of 20 N/mm². However, the cut down in the strength of concrete as the portion of SSA stepped up maybe as a result of the cut down in the quantity of cement for the hydration (Prasanphan *et al.,* 2010). It may also be due to the dilution consequences of cement (Ogork and Ayuba 2014; Sulaiman *et al.,* 2024).

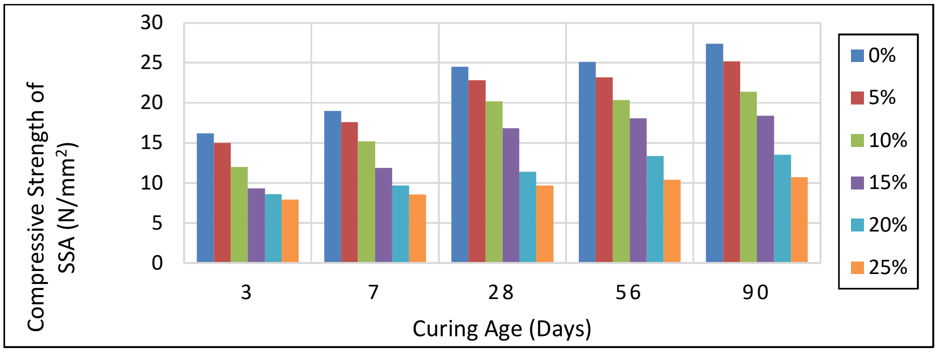

Figure 2: Relationship between Compressive Strength and Curing Age

Durability of SSA-Concrete

The influence of sulphuric acid on SSA-concrete is displayed in Figure 3. The percentage of weight retained after exposure to H_2SO_4 solution decreases as the portion of SSA and immersion period (age) in H_2SO_4 solution increase. It was found out that the Portland limestone cement concrete offered a better resistance to H_2SO_4 aggression than SSA-concrete. The less resistance of SSA-concrete to H_2SO_4 attack when equated with control may be attributed to higher porosity of SSA-concrete due to uncomplete production of C–S–H gel throughout hydration, this explanation is in agreement with (Ogork. *et al.*, 2015). The loss of weight of concrete specimens in 5 % concentration of H2SO4 solution was because of ettringite formation. H_2SO_4 attacks $Ca(OH)_2$ and form $CaSO_4$ that is stripped out of concrete (Kumar and Baraik 2016).

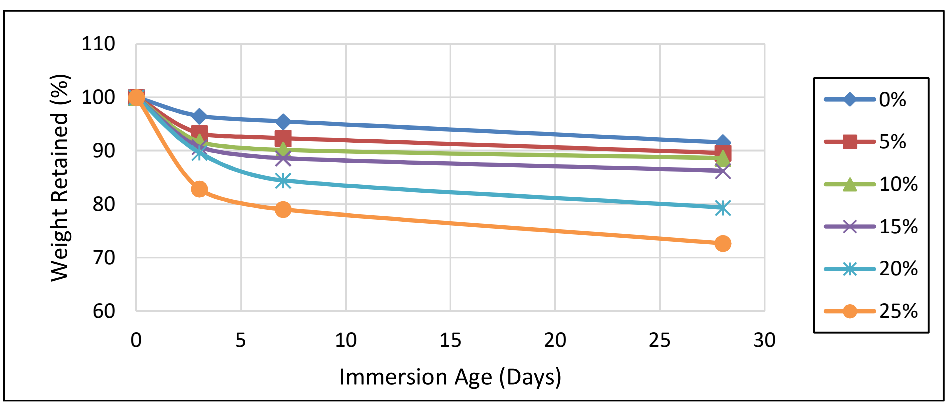

Figure 3: Relationship between Weight Retained and Immersion Period (Days)

SEM Analysis of SSA-Cement Paste

The SEM photographs of cement 0 and 5 % SSA-cement paste were shown in plate 1 and plate 2 respectively, in which the microstructure of hydrated SSA-cement paste was visualized. Plate 1 shows fewer voids in the cement paste and more compact fibrous C–S–H that were constituted in cement paste at 28 days of curing. These gel molecules filled up the hollows in the cement paste, allowing the paste to become a stockier matrix. While plate 2 indicates less C-S-H and many voids in addition to more places of anhydrous SSA molecules compared to the control paste sample. This was because of the low pozzolanic reaction of SSA which may lead to less strength of concrete and high porosity of the concrete. Moreover, plate 3 shows the SEM photograph of SSA-cement paste. It was found that C-S-H gel was immensely dispersed on the hydrated SSA-cement paste mixture which was the major reason for efficient strength.

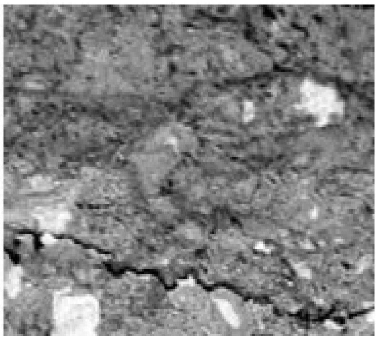
Plate 1: SEM of 0 % SSA

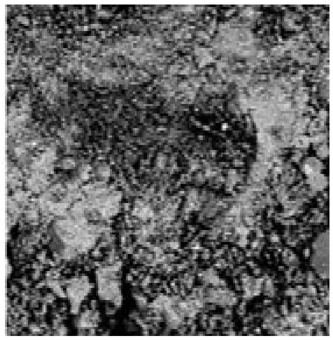
Plate 2: SEM of 5% SSA

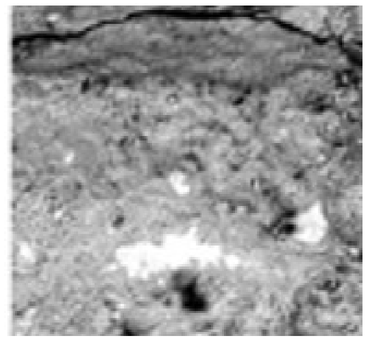
Plate 3: SEM of 10 % SSA

Fourier Transform Infrared Spectroscopy (FTIR) of SSA-Cement Paste

Figure 4 presents the FTIR spectra of 0 % SSA-cement paste sample at 28 days of curing. The vibration modes of OH groups are displayed by the spacious bands between 3369.5, 2113.4, 1982.9 cm^{-1} for 0 % SSA and the small band, which relate with the bending vibration modes OH bonds situated at 1796.0 cm^{-1}, this shows that the absorption bands at 3369.5, 2113.4, 1982.9, 1796.0 cm^{-1} correspond to OH bending and widening vibration of sorb water molecules on the surface of binder constituents, However, the band located at 1401.5 cm^{-1} for both specimens is associated with the asymmetric increase of Si – O and Al – O bonds (Mohammed *et al.,* 2019). Bands 1006.4 cm^{-1} and 1010.1 cm^{-1} for both samples revealed the presence of O – Si – O vibration attributed to asymmetrical stretching bands vibration. Moreover, the absorption peak at 711.9 cm^{-1} corresponds to the one-sided stretching of Si–O–Si and Si–O–Al. The same pattern was observed from Figure 5 for 10 % SSA content.

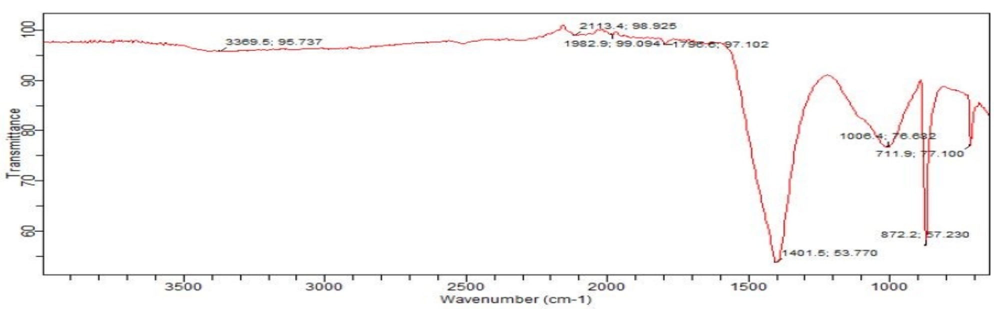

Figure 4: FTIR for SSA-Cement Paste at 0 % SSA Content

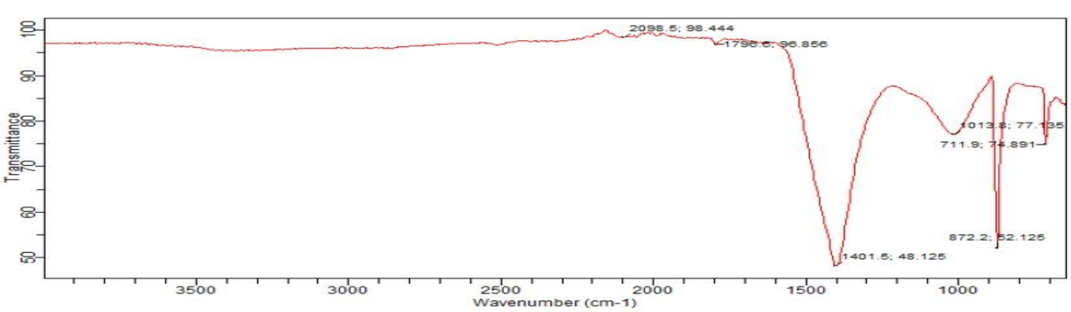

Figure 5: FTIR for SSA-Cement Paste at 10 % SSA Content

Regression Models of Compressive and Weight Retained Strength of SSA-Concrete

The regression equations driven from DataFit 9 software for the models are demonstrated in Equations 1 and 2 while the analysis of the statistical results is displayed in Tables 1 and Table 2.

$f_C = 19.96 – 0.549X_1 + 0.0822X_2$ (1)

$f_w = 3.027 – 0.0582X_1 + 0.00997X_2$ (2)

Where f_C and f_w are compressive strength and weight retained of SSA-concrete, X_1 is a portion of SSA at 0, 5, 10, 15, 20, and 25 % while X_2 is curing age at 3 d, 7, 28, 56, 90 days.

The null hypothesis states that the SSA content and curing age of samples do not influence the strength of concrete. At 0.05 level of significance, the P-value is equal to 0.000 for curing and SSA. Therefore the zero hypothesis (H_O) is declined in both cases since the P-value is extremely low and this indicated that tall variables are majorly significant ($P < 0.05$) highlighting that the difference in the strengths of concrete is because of SSA content and curing age. The validation of strengths of SSA-concrete models was carried out by looking into the coefficient of determination. The coefficients of determination, (R^2) are 89 % and 91.1 % for compressive strength and weight retained of concrete respectively, this proves the variation of concrete compressive and weight retained of concrete is extremely dependent on the variations of SSA and curing duration. This confirms that the models are adequate for prediction.

Table 1: Statistical Analysis of Compressive Strength and Weight Retained of SSA-Concrete Model

	Variables	Coeff	Standard Error	T-ratio	P - Value
	Constant (Y)	19.96	0.7633	26.1484	0.0000
Compressive strength	A	- 0.549	0.0425	-12.9501	0.0000
	B	0.0822	0.0111	7.3761	0.0000
$R^2 = 0.89$					
$AdjR^2 = 0.88$					
	Constant (Y)	3.027	0.0751	40.2903	0.0000
	A	-0.0582	-0.00419	-13.8959	0.0000
Weight Retained	B	0.00997	0.00110	9.08724	0.0000
$R^2 = 0.911$					
$AdjR^2 = 0.904$					

Table 2: ANOVA of Compressive Strength and Weight Retained of SSA-Concrete Model

Concrete Strength	Df	SS	MS	F	P - Value
Compressive Strength	2	876.473	438.237	110.798	0.0000
Weight Retained	2	10.5679	5.2839	137.8366	0.0000

Conclusions

Based on the results presented, the following conclusion was drawn:

(i) The addition of SSA dropped off the workability and compressive strength of concrete.

(ii) The SEM analysis of SSA-concrete pointed out more voids as the portion of SSA stepped up.

(iii) The result of hydrated SSA-cement pastes revealed the existence of the most important hydrates such as portlandite and C-S-H. .

(iv) The regression modes established for strengths of concrete are enough for predicting the compressive strength, weight retained of concrete produced with SSA.

(v) It was concluded that the optimum percentage of SSA content to use should not be more than 10 % SSA.

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Emerging Shift from Petrol Motor Spirit (PMS) to Liquefied Petroleum Gas (LPG) Powered Generators in Nigeria: A Review

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Abstract

In recent years, the urge to utilize cleaner sources of energy has gained traction on the global stage. Nigeria is endowed with abundant reserve of Natural gas which is the cleanest source of fossil fuel in the world having a proven reserve of about 206.53TCF thereby making it one of the countries with the largest proven reserve of natural gas. Liquefied Petroleum Gas (LPG) is popularly referred to as cooking gas and it consists primarily of propane and butane and its currently meeting a high percentage of cooking needs in Nigeria. This study examines the emerging shift from Petrol Motor Spirit (PMS) to Liquefied Petroleum Gas (LPG) powered generators for power generation in Nigeria, driven by a confluence of economic, environmental, and policy factors and identifies factors that can enhance the rate of development of the LPG industry in Nigeria. Traditionally, PMS powered generators have been ubiquitous due to their availability and lower initial costs, but the mid-2020s have witnessed a significant transition towards LPG generators. This shift is propelled by the escalating cost of PMS, driven by subsidy reforms and price volatility, alongside the economic benefits of LPG, including lower fuel costs and maintenance expenses. Environmental considerations play a crucial role, as LPG generators emit fewer pollutants, thereby contributing to improved air quality and public health.

Keywords: Liquefied Petroleum Gas, Petrol Motor Spirit, Generators, Nigeria, Economic factors, Environmental sustainability.

1.0 Introduction

Nigeria, as Africa's largest economy, has historically relied heavily on Premium Motor Spirit (PMS) to power small generators across residential and commercial sectors due to the country's irregular grid power supply (Nwaogu and Dike, 2023). In the absence of reliable public electricity, PMS-powered generators became a staple for many Nigerian households and businesses (Eboh *et al.,* 2022). However, recent government actions to remove subsidies on PMS have led to a sharp rise in fuel prices, exacerbated by global oil price fluctuations and inflationary pressures (Central Bank of Nigeria, 2023). These economic shifts have imposed financial challenges on Nigerians who depend on these generators.

Moreover, Nigeria's global environmental commitments have intensified discussions around transitioning from PMS to alternative fuels. As the world seeks cleaner energy options to combat climate change, Liquefied Petroleum Gas (LPG) has gained traction as a viable alternative to PMS in Nigeria. This transition is bolstered by Nigeria's vast natural gas reserves, estimated at over 206 trillion cubic feet, which not only promise an abundant supply of LPG but also position it as a more affordable and environmentally sustainable option for electricity generation compared to PMS (Aderemi and Ogunbanjo, 2023; IEA, 2023).

Nigeria has one of the largest oil reserves in Africa, estimated at approximately 36.9 billion barrels, which has historically positioned the country as a major player in the global energy market (NNPC, 2021). However, despite this wealth in fossil fuels, Nigeria's electricity grid has been characterized by frequent outages and inefficiencies, leading households and businesses to rely on off-grid solutions, predominantly PMS-powered generators (Nwaogu and Dike, 2023). Over the years, these generators have become essential for coping with Nigeria's unreliable grid, providing a supplemental energy source that supports daily operations across residential and commercial sectors (Eboh *et al*., 2022).

Historically, government subsidies made PMS relatively affordable, keeping generator costs manageable even for low-income households (Okoro *et al.,* 2020). However, recent subsidy reforms have significantly increased the cost of PMS, a move designed to relieve the government of the financial burden of fuel subsidies while aligning with global economic realities and reducing fiscal deficits (Central Bank of Nigeria, 2023). Alongside inflationary pressures, these reforms have caused PMS prices to soar, placing a heavier financial strain on households and businesses reliant on generators (IMF, 2023).

Additionally, the global shift towards cleaner energy sources due to climate change concerns has further complicated Nigeria's reliance on PMS. Many international organizations and domestic advocates are pressing for reduced carbon emissions and a transition to renewable energy sources, which would decrease dependence on fossil fuels (IEA, 2023). While the country has vast potential for renewable energy generation—particularly from solar and wind—this sector is still in its infancy, with PMS and diesel generators remaining the primary sources for off-grid power generation (Aderemi and Ogunbanjo, 2023).

2.0 LOG Utilisation

Nigeria holds an estimated 206.53 trillion cubic feet (TCF) of natural gas reserves, making it one of the most gas-rich countries in Africa (Nigerian National Petroleum Corporation, 2023). This substantial reserve positions Nigeria to enhance its energy security by transitioning from imported petroleum products to locally available and abundant natural gas. The utilization of these reserves could significantly reduce Nigeria's reliance on imported fuels, mitigate the economic impact of fluctuating global oil prices, and provide a cleaner, cost-effective alternative for power generation (NNPC, 2023). Such a shift would also align with the country's broader environmental commitments, as natural gas emits fewer greenhouse gases compared to traditional fossil fuels like PMS and diesel.

LPG is increasingly used in Nigerian households primarily for cooking, heating and, more recently, as a substitute fuel for powering generator sets. Its reputation as an affordable and efficient alternative to PMS is steadily growing, particularly as LPG burns cleaner and offers economic savings (Aderemi and Ogunbanjo, 2023). With rising PMS prices and environmental concerns, LPG's appeal as a household fuel is further enhanced. The Nigerian National Petroleum Corporation reports that domestic LPG consumption has surged in recent years, reflecting its expanding role in both energy efficiency and cost savings for Nigerian households (NNPC, 2023).Table 1 summarizes current statistics on LPG utilization in Nigerian households

Table 1 LPG utilization in Nigerian households

Category	Usage Statistics	Source
Average Monthly Consumption (Households)	72,000 metric tons	NNPC, 2023
Annual Growth Rate	25% (last 5 years)	NNPC, 2023
Average Cost Savings (Compared to PMS)	30-40%	Aderemi and Ogunbanjo, 2023
Percentage of Households Using LPG	40% of urban households, 20% of rural households	Nigerian Energy Commission, 2023

In terms of cost, while the initial conversion or purchase of an LPG generator may require a higher investment, operational expenses are generally lower due to the comparatively stable and lower cost of LPG. As LPG adoption gains momentum in Nigeria, recent reports suggest a 30% increase in LPG generator purchases, reflecting growing consumer awareness and interest in environmentally friendly alternatives (Nigerian Energy Commission, 2023). Table 2.2 summarizes key comparison metrics between PMS and LPG generators:

Table.2 Comparison metrics between PMS and LPG generators

Comparison Metric	PMS Generators	LPG Generators	Source
Fuel Efficiency	Moderate	High	Obi et al., 2023
Maintenance Frequency	High	Low	Aderemi and Ogunbanjo, 2023
Emissions	High CO2 and NOx emissions	Lower CO2 and NOx emissions	Nigerian Energy Commission, 2023
Operational Costs	Higher (due to fuel costs)	Lower (with stable LPG prices)	Nigerian Energy Commission, 2023

2.1 Economic Factors Driving the Shift

The shift from Petrol Motor Spirit (PMS) to Liquefied Petroleum Gas (LPG) powered generators in Nigeria has been significantly influenced by the escalating costs of PMS. The removal of fuel subsidies, which began in earnest in 2020 under the administration of President Muhammadu Buhari, marked a turning point. The government's decision to phase out subsidies on PMS aimed to address fiscal deficits and align fuel prices with global market rates. However, this policy change led to sharp increases in PMS prices, which have continued to rise due to global oil price volatility and domestic inflationary pressures (Central Bank of Nigeria, 2023).

The latest pronouncement by the Tinubu administration in 2023 further reinforced this shift in policy, effectively ending the subsidy on PMS. As a result, fuel prices skyrocketed, further exacerbating the operating costs of PMS-powered generators, which are commonly used by households and small businesses in Nigeria (Central Bank of Nigeria, 2023). The Central Bank of Nigeria (2023) reports that the price volatility of PMS, driven by both global market fluctuations and local economic challenges, has made it increasingly difficult for consumers to predict fuel costs, further straining their budgets. This ongoing volatility in PMS prices has been a key driver in the transition to LPG-powered generators, which offer more stable fuel costs and lower maintenance requirements. As a result, LPG adoption is steadily increasing, as it presents a more cost-effective alternative for powering generators compared to the rising costs of PMS (Nigerian Energy Commission, 2023).

LPG offers several economic advantages over PMS, leading to an emerging shift in Nigeria from PMS to LPG generators. Due to its lower fuel costs and higher energy density, LPG provides a more cost-effective solution for energy production (Aderemi and Ogunbanjo, 2023). LPG's clean-burning properties also mean that it causes less wear on engine parts, resulting in reduced maintenance frequency and associated costs, which further contributes to overall savings for consumers (Obi *et al.*, 2023). The lower operational costs, coupled with environmental incentives, are driving households and businesses to consider LPG as a viable alternative to PMS-powered generators. This trend highlights a growing awareness of LPG's cost and environmental benefits as Nigerians seek affordable, reliable power solutions (Nigerian Energy Commission, 2023). The emerging shift from Petrol Motor Spirit (PMS) to Liquefied Petroleum Gas (LPG) powered generators in Nigeria is particularly impactful for small businesses and households. As PMS prices continue to fluctuate due to subsidy reforms and inflation, many small enterprises and households have turned to LPG as a more stable and affordable alternative for power generation. Case studies have shown that the adoption of LPG has provided significant financial relief and operational efficiency for Nigerian businesses.

For instance, a case study in Lagos highlighted that small retail businesses using LPG generators reported a 30% reduction in operational costs compared to those using PMS generators. This shift was largely attributed to the lower cost of LPG and reduced maintenance needs, as LPG generators require less frequent servicing due to cleaner combustion and fewer carbon deposits (Obi *et al.*, 2023). Furthermore, a study in Abuja found that households that switched from PMS to LPG generators experienced a reduction in energy expenditure, which allowed them to reallocate savings to other household needs, thereby improving their overall quality of life (Aderemi and Ogunbanjo, 2023). The Nigerian Energy

Commission (2023) further notes that in rural areas, where access to a stable grid is limited, the transition to LPG-powered generators has been particularly beneficial. These households not only experience cost savings but also enjoy more reliable power, which enhances productivity and living standards.4. Environmental Impact

2.2 Environmental considerations

The transition from Petrol Motor Spirit (PMS) to Liquefied Petroleum Gas (LPG) powered generators in Nigeria is not only driven by economic factors but also by environmental considerations. Studies have shown that LPG-powered generators produce significantly fewer greenhouse gases (GHGs) and harmful pollutants compared to PMS generators, which is a major advantage in the context of global climate change efforts. LPG is a cleaner-burning fuel, emitting lower levels of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx), and sulfur dioxide (SO_2) when compared to PMS (Global Clean Energy Council, 2023).

Research indicates that LPG combustion results in 20-30% lower CO_2 emissions than PMS, and significantly reduced levels of CO, NOx, and SO_2, which are common pollutants that contribute to smog and acid rain. The Global Clean Energy Council (2023) emphasizes that these reductions in harmful emissions make LPG a more environmentally sustainable option for power generation. This shift is particularly important for Nigeria, where air pollution from fossil fuel-based generators has been a growing concern, especially in urban areas where generator use is widespread.

In addition to the environmental benefits, the lower emissions of LPG also contribute to better air quality, which is vital for public health in densely populated areas. As such, the growing adoption of LPG-powered generators aligns with Nigeria's commitment to reducing its carbon footprint and improving environmental sustainability (Global Clean Energy Council, 2023)

The shift from Petrol Motor Spirit (PMS) to Liquefied Petroleum Gas (LPG) powered generators in Nigeria carries significant public health benefits, particularly in improving air quality and reducing respiratory issues. Studies have shown that LPG-powered generators emit fewer harmful pollutants such as particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx), and sulfur dioxide (SO_2), all of which are major contributors to air pollution and associated health problems (Aderemi and Ogunbanjo, 2023). These pollutants have been linked to a range of respiratory diseases, including asthma, bronchitis, and other chronic obstructive pulmonary diseases (COPD), which are prevalent in urban areas where generators are frequently used.

In Nigeria's major cities, where power outages are common, the widespread use of PMS-powered generators exacerbates air pollution, contributing to poor indoor and outdoor air quality (Obi *et al.*, 2023). The reduction in emissions from LPG generators can significantly alleviate the burden on public health by improving air quality, especially in densely populated urban areas like Lagos and Abuja. By switching to LPG, households and businesses could experience fewer incidences of respiratory ailments and other pollution-related health issues, as LPG combustion produces far fewer fine particulate matter and toxic gases compared to PMS (Global Clean Energy Council, 2023).

The adoption of LPG generators, therefore, not only represents a shift towards more sustainable energy practices but also holds promise for improving public health by reducing the harmful effects of air pollution. This shift is particularly important in Nigeria, where air pollution is a growing concern, especially in urban centres with high generator usage (Aderemi and Ogunbanjo, 2023; Obi et al., 2023).

In Addition, The emerging shift from Petrol Motor Spirit (PMS) to Liquefied Petroleum Gas (LPG) powered generators in Nigeria is aligned with the country's broader environmental commitments under international agreements, such as the Paris Agreement. Nigeria, as a signatory to the Paris Agreement, has committed to reducing its greenhouse gas emissions and limiting global temperature rise to well below 2°C, with an aspiration to limit it to 1.5°C above pre-industrial levels (United Nations Climate Change, 2023). The transition to LPG, a cleaner fuel compared to PMS, plays a pivotal role in helping Nigeria meet its climate goals.

LPG, being a low-emission alternative, produces fewer carbon emissions and harmful pollutants like CO, NOx, and SO_2, making it a key component in Nigeria's strategy to reduce air pollution and combat climate change. By shifting from PMS to LPG-powered generators, Nigeria can significantly lower its carbon footprint, particularly in urban areas where generators are widely used. This transition is critical in achieving Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement, which include reducing emissions and promoting the use of cleaner energy sources (United Nations Climate Change, 2023). Furthermore, the adoption of LPG aligns with Nigeria's commitment to promoting sustainable energy practices and contributing to the global effort to mitigate the impacts of climate change. By encouraging the use of LPG-powered generators, Nigeria not only addresses its domestic energy needs but also strengthens its position in the global climate change dialogue (United Nations Climate Change, 2023).

2.3 Challenges in Nigeria's Energy Sector

The energy sector in Nigeria faces several significant challenges, many of which have persisted for years. These challenges hinder the country's ability to provide reliable and affordable energy to its population. (Sambo, 2009) opined that the key challenge is Inadequate Infrastructure, which is one of the primary challenges in Nigeria's energy sector is the inadequate and aging infrastructure, which limits the capacity to generate, transmit, and distribute electricity efficiently. This has led to frequent power outages and has forced many businesses and households to seek alternative energy sources.

(Akuru & Okoro, 2011) highlight that despite Nigeria's abundant energy resources; access to modern energy services is still restricted, especially in rural areas. This gap in energy availability between urban and rural regions exacerbates social and economic inequalities. The Nigerian energy sector has been plagued by inconsistent policies, regulatory challenges, and corruption. The lack of clear, long-term energy policies has hindered investment and the development of the sector (Adenikinju, 2008). Oparaku (2003) points out that the heavy dependence on fossil fuels in Nigeria has serious environmental consequences, such as air pollution and the release of greenhouse gases. Additionally, the environmental damage linked to oil exploration in the Niger Delta has raised questions about the sustainability of the country's energy practices.

The energy landscape in Nigeria is complex, characterized by a mix of traditional and modern energy sources, significant challenges in infrastructure, and a heavy reliance on fossil fuels. Addressing these challenges requires a comprehensive approach that includes investment in infrastructure, diversification of energy sources, and the development of clear, consistent policies to promote sustainable energy use.

2.4 Policy and Regulatory Landscape

The Nigerian government has recently implemented several policies to promote the use of Liquefied Petroleum Gas (LPG) as a cleaner and more affordable alternative to Petrol Motor Spirit (PMS) in power generation. The Nigerian Ministry of Petroleum Resources (2023) reports that these initiatives include tax incentives for LPG equipment manufacturers and subsidies to reduce the cost of LPG-powered generators, thereby making them more accessible to households and small businesses. These policies are aimed at encouraging the transition to LPG-powered generators and reducing Nigeria's reliance on PMS, while also addressing environmental concerns related to PMS combustion.

Despite these incentives, several barriers hinder the widespread adoption of LPG-powered generators. One significant challenge is the inadequate infrastructure for LPG distribution, especially in rural and semi-urban areas where access to LPG refueling stations is limited. Additionally, safety concerns related to LPG storage and handling remain prevalent, deterring some consumers from fully embracing LPG as an alternative fuel source (Aderemi and Ogunbanjo, 2023). Another major obstacle is the high initial conversion cost for existing PMS generator owners, which can be a financial burden, particularly for small businesses and low-income households (Obi *et al*., 2023).

To overcome these barriers and accelerate the adoption of LPG-powered generators, it is recommended that policymakers focus on strengthening the LPG distribution network, particularly in underserved areas, to ensure a reliable supply of LPG for consumers. Public awareness campaigns should also be launched to educate Nigerians about the benefits of LPG, including its cost-effectiveness and environmental advantages. Additionally, policies to reduce conversion costs, such as providing subsidies or low-interest loans for the retrofitting of PMS generators to run on LPG, could significantly ease the financial burden on consumers and encourage more widespread adoption (Nigerian Ministry of Petroleum Resources, 2023).

2.5 Prospects for LPG Adoption

The long-term prospects for Liquefied Petroleum Gas (LPG) adoption as an alternative to Petrol Motor Spirit (PMS) in generator power systems in Nigeria are promising. If LPG-powered generators become mainstream, significant cost savings are expected for both consumers and businesses. LPG offers a more stable fuel price compared to PMS, which is subject to fluctuations due to global oil price changes and domestic subsidy reforms (Nigerian Ministry of Petroleum Resources, 2023). Over time, the reduced operational costs, including lower maintenance expenses and fewer fuel-related interruptions, could make LPG-powered generators a more economical and reliable energy source, especially for small businesses and households reliant on backup power (Obi et al., 2023). Moreover, the transition to LPG would contribute to reduced pollution levels. LPG combustion produces fewer greenhouse gases and harmful pollutants like carbon monoxide (CO), nitrogen oxides (NOx), and sulfur dioxide (SO_2), improving air quality and public health, particularly in densely populated urban areas (Global Clean Energy Council, 2023).

Energy independence is another key benefit of widespread LPG adoption. With Nigeria's substantial natural gas reserves, estimated at over 206 trillion cubic feet (Nigerian National Petroleum Corporation, 2023), LPG has the potential to be a locally sourced and more sustainable energy alternative. By expanding the domestic LPG supply and distribution networks, Nigeria could reduce its dependence on imported fuels and mitigate the volatility of global fuel prices.

However, for these benefits to materialize, a significant increase in public awareness is crucial. Educating consumers about the environmental, economic, and safety advantages of LPG-powered generators will help build confidence and encourage adoption. Public awareness campaigns can also address safety concerns related to LPG use, particularly regarding storage and handling practices, to ensure that consumers fully understand the risks and mitigation measures (Aderemi and Ogunbanjo, 2023).

Future research should focus on comprehensive lifecycle assessments of LPG versus PMS-powered generators, including their long-term economic and environmental impacts. Real-world trials comparing the performance, efficiency, and emissions of LPG and PMS generators would provide valuable data to further support the adoption of LPG. Additionally, research into optimizing the LPG distribution infrastructure and retrofitting existing PMS generators for LPG use could provide solutions to some of the barriers hindering adoption (Nigerian Energy Commission, 2023).

3. Prevailing Factors

The shift from Petrol Motor Spirit (PMS) to Liquefied Petroleum Gas (LPG) powered generators in Nigeria is driven by economic, environmental, and policy factors.

3.1 Economic Factors

LPG offers significant cost savings compared to PMS, as it provides more stable pricing and lower operational costs, including reduced maintenance and fuel-related interruptions (Obi *et al*., 2023). With over 206 trillion cubic feet of natural gas reserves (Nigerian National Petroleum Corporation, 2023), Nigeria has the potential for energy independence, reducing reliance on imported fuels and mitigating global price volatility. Additionally, LPG combustion efficiency leads to long-term savings for businesses and households (Nigerian Ministry of Petroleum Resources, 2023).

3.2 Environmental Factors

LPG is a cleaner-burning fuel, producing fewer greenhouse gases (GHGs) and pollutants like carbon monoxide (CO), nitrogen oxides (NOx), and sulfur dioxide (SO2) compared to PMS (Global Clean Energy Council, 2023). This reduction in emissions would significantly improve air quality, especially in urban areas where generators are heavily used, and reduce the environmental impact of power generation. Furthermore, LPG adoption would mitigate health issues associated with poor air quality, such as respiratory problems (Aderemi and Ogunbanjo, 2023).

3.3 Policy Factors:

The Nigerian government has introduced policies, including tax incentives for LPG equipment manufacturers and subsidies for LPG-powered generators, to encourage adoption and reduce PMS reliance (Nigerian Ministry of Petroleum Resources, 2023). These initiatives align with Nigeria's commitment to global climate agreements, such as the Paris Agreement, which aims to reduce greenhouse gas emissions (United Nations Climate Change, 2023).
These economic, environmental, and policy drivers position LPG as a cost-effective, cleaner, and sustainable energy solution for Nigeria's generator market.

4.0 Critical factors for LPG Adoption

As Nigeria possesses one of Africa's largest natural gas reserves, estimated at over 206 trillion cubic feet (Nigerian National Petroleum Corporation, 2023), LPG offers an opportunity for energy independence and a reduced reliance on imported fuels. However, widespread adoption will require strategic government support, infrastructure expansion, and public education to overcome existing barriers, such as high initial conversion costs and limited distribution networks.
By focusing on cleaner and locally abundant energy sources like LPG, Nigeria can work towards addressing its power challenges in a way that aligns with global climate goals while delivering economic and health benefits to its citizens. As such, the adoption of LPG generators presents not only a path toward reliable electricity but also a meaningful step in Nigeria's broader energy transition.
To sustain and accelerate the shift from Petrol Motor Spirit (PMS) to Liquefied Petroleum Gas (LPG) powered generators in Nigeria, the following factors are critical.

4.1 Research Needs

Further research is essential to fully understand the long-term economic and environmental impacts of LPG adoption. Comprehensive lifecycle assessments, including real-world trials comparing the efficiency, emissions, and operational costs of PMS and LPG generators, will provide valuable data to guide policy decisions and inform consumers. Additionally, studies focused on optimizing LPG infrastructure and retrofitting existing PMS generators will help address technical challenges and reduce the barriers to widespread LPG adoption. Research into alternative clean energy solutions, such as biogas and solar hybrid systems, will also complement the ongoing transition by offering diverse, sustainable energy options for Nigeria.

4.2 Government Support

Government policies play a pivotal role in facilitating this energy transition. Beyond tax incentives and subsidies, there is a need for increased investment in LPG distribution networks to ensure widespread accessibility, particularly in rural and underserved areas. Strengthening safety regulations and providing consumer education on LPG use will further build public trust and encourage adoption. The government must also continue to align LPG adoption with broader environmental goals, ensuring that the transition to cleaner energy supports Nigeria's climate commitments under international agreements like the Paris Agreement.Additionally, supporting innovation in the LPG sector through funding for research and development of more efficient and affordable LPG-powered technologies is crucial for long-term sustainability. By prioritizing research and government backing, Nigeria can overcome the current barriers to LPG adoption and accelerate its transition to a cleaner, more sustainable energy future.

5.0 Conclusions

In conclusion, the transition from Petrol Motor Spirit (PMS) to Liquefied Petroleum Gas (LPG) powered generators in Nigeria presents a promising prospect for the country's energy landscape. This shift is driven by the numerous benefits of LPG, including reduced operating costs, lower emissions, and increased efficiency. As Nigeria continues to grapple with energy security challenges, embracing LPG technology can mitigate environmental degradation, enhance energy reliability, and stimulate economic growth. However, addressing infrastructure limitations, policy frameworks, and public awareness will be crucial to facilitating widespread adoption. With targeted investments and strategic planning, Nigeria can harness the potential of LPG-powered generators to ensure a cleaner, more sustainable, and energy-secure future.

To facilitate a seamless transition to LPG-powered generators in Nigeria, the following recommendations are proposed: Firstly, the government should establish a comprehensive policy framework and incentives to encourage LPG adoption, including tax waivers and subsidies for LPG infrastructure development. Secondly, investment in LPG storage facilities, distribution networks, and retail outlets should be prioritized to address supply chain gaps. Additionally, public awareness campaigns should be launched to educate consumers about the benefits and safe handling of LPG. Furthermore, manufacturers should be encouraged to produce LPG-compatible generators that meet Nigerian standards. Lastly, the government should collaborate with international organizations to develop training programs for technicians and engineers on LPG technology, ensuring a skilled workforce to support the transition.

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Application of Queuing Theory in Banking Systems in Nigeria: A Review

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Abstract

Efficient service delivery is crucial for customer satisfaction in Nigeria's competitive banking sector. Queuing theory, a mathematical tool for analyzing waiting lines, can optimize service processes and enhance customer experiences. This review explores its application in Nigerian banking, highlighting its potential to improve operational efficiency. While queuing models are widely used in global banking, their adoption in Nigeria remains limited due to infrastructural constraints, fluctuating customer demand, and cultural factors influencing service interactions. The review examines these challenges and explores emerging trends, including digital banking, mobile applications, and advanced analytics, as solutions for better queue management. By synthesizing existing literature, this paper underscores the transformative impact of queuing theory in Nigerian banks, positioning it as a key driver for improved service delivery and operational resilience.

Keywords: Queuing Theory, Banking Systems, Queue Management, Operational Efficiency, Service Optimization

1.0 Introduction

In the dynamic landscape of banking, delivering efficient, customer-centric services is essential for competitiveness, especially as consumer expectations for swift, seamless transactions continue to rise (Shashnawaz, 2024). As banks strive to enhance service efficiency, queue management has emerged as a critical factor influencing customer satisfaction and operational effectiveness (Usendok et al., 2023). Poorly managed queues can lead to excessive waiting times, customer frustration, and ultimately, loss of clientele to competitors (Mwinuka, 2023). Thus, optimizing queue systems has become a strategic priority for financial institutions, particularly in developing economies where banking infrastructure is often constrained.

Queuing theory, a branch of operations research and applied mathematics, serves as a powerful tool for analyzing and managing waiting lines in service environments (Afolalu et al., 2021). It provides mathematical models that help banks optimize customer flow, allocate resources efficiently, and minimize service bottlenecks (Forazandeh, 2022). In banking, where service delivery is highly time-sensitive, queuing models such as the M/M/1 and M/M/c systems have been widely employed to analyze and improve customer service operations (Yifter et al., 2023). Studies have shown that effective implementation of queuing models enhances customer satisfaction, reduces service delays, and improves overall bank performance (Radi et al., 2023).

The relevance of queuing theory is particularly pronounced in developing nations like Nigeria, where banking infrastructure faces persistent challenges, and customer volumes fluctuate unpredictably (Aminu, 2022). Many Nigerian banks struggle with overcrowded banking halls, inefficient queue management, and prolonged service times, leading to significant customer dissatisfaction (Ibukun-Falayi, 2021). These inefficiencies stem from several factors, including inadequate technological integration, limited service counters, and a high dependency on manual processing methods (Akinwunmi, 2021). Additionally, infrastructural deficiencies, such as unreliable power supply and poor internet connectivity, further complicate the implementation of automated queue management solutions (Aminu, 2022). Cultural factors also play a role, as customer behavior and expectations regarding service delivery influence queue dynamics in Nigerian banking halls (Tinuoye, 2021).

Despite these challenges, several studies suggest that structured queue management strategies, grounded in queuing theory, can significantly improve banking operations in Nigeria. For instance, the integration of electronic queuing systems, appointment-based banking, and digital self-service platforms has been identified as potential solutions to reduce congestion and enhance service efficiency (Thumma & Reinkensmeyer, 2022). Some banks have begun experimenting with hybrid queue management models that combine physical queue monitoring with digital ticketing systems, yielding positive results in reducing wait times. However, widespread adoption remains limited due to cost implications, resistance to change, and regulatory constraints (Aminu, 2022).

Emerging trends in digital banking, advanced analytics, and automation offer promising pathways for overcoming these challenges. Digital banking platforms and mobile applications are increasingly enabling customers to perform transactions remotely, reducing the need for in-branch visits and easing the demand on physical bank infrastructure. By adopting advanced analytics, Nigerian banks can use data-driven insights to predict peak times and adjust staffing levels accordingly, enhancing both customer experience and operational efficiency. Automation, including self-service kiosks and automated teller systems, presents further opportunities to streamline in-branch operations and reduce dependency on human tellers, although successful implementation will require efforts to address cultural resistance and encourage customer adoption of these self-service options.

This review paper seeks to examine the application of queuing theory within the Nigerian banking context, highlighting its role in addressing these operational challenges. It will explore various queuing models relevant to banking, assess current obstacles limiting their adoption in Nigeria, and identify emerging trends that could reshape queue management practices. By synthesizing insights from existing literature, this paper aims to offer a comprehensive understanding of how queuing theory can be leveraged to enhance customer experience and operational efficiency in Nigerian banks. The findings presented here provide a foundation for further exploration into strategic implementations of queuing theory that could transform Nigeria's banking sector, making it more resilient, technology-driven, and customer-friendly.

2.0 Methodology of Literature Selection

To ensure a comprehensive and well-structured review, this paper employed a systematic literature review (SLR) approach to analyze the application of queuing theory in the Nigerian banking sector. A systematic review method enables the identification, evaluation, and synthesis of existing research on a specific topic, ensuring that the study is grounded in credible academic discourse. This approach was chosen to provide a structured analysis of the theoretical foundations, practical implementations, challenges, and future directions of queuing theory in banking.

2.1 Literature search strategy

A structured search was conducted across multiple academic databases, including Google Scholar, IEEE Xplore, ScienceDirect, SpringerLink, and JSTOR, to identify relevant peer-reviewed journal articles, technical reports, and case studies. The review prioritized literature published between 2020 and 2024, ensuring that the discussion incorporates the most recent advancements and trends in queue management within banking. The search process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which facilitate a transparent and replicable methodology in systematic literature reviews.

The following keywords and Boolean search strings were used to retrieve relevant studies:

1. "Queuing theory in banking"
2. "Queue management in Nigeria"
3. "Customer waiting time and service optimization"
4. "Operational efficiency in banking"
5. "Banking service delivery and queuing models"

Additional searches were conducted using variations of these terms, including synonyms and related phrases, to ensure a broad yet focused scope of literature.

2.2 Inclusion criteria

To maintain relevance and academic rigor, the following criteria were applied:

1. Peer-reviewed journal articles, conference papers, and case studies published between 2020 and 2024.

2. Studies focusing on queuing theory applications in banking, particularly in Nigeria and other developing economies with similar banking challenges.

3. Research discussing the impact of queue management on customer satisfaction, operational efficiency, and banking performance.

4. Papers examining technological advancements, such as electronic queuing systems and AI-driven queue management solutions in banking.

3.0 General Applications of Queuing Theory in Banking

Queuing theory provides valuable frameworks for managing customer flow, optimizing service delivery, and reducing wait times in service industries, particularly in banking. Several queuing models are commonly used in banking systems, including:

3.1 Single-server models

Applied in situations where one teller or service representative handles customer transactions (Asanjarani, 2021). These models are typically used in smaller banks or branches with low foot traffic.

3.2 Multi-server models

More commonly used in larger branches or banks with high volumes of customers, where multiple tellers or service counters are available to handle demand (Azumah et al., 2021). These models help balance service capacity with customer arrival rates, minimizing customer wait time and enhancing operational efficiency.

3.3 Queue discipline strategies

These include "first-come-first-served" (FCFS), "priority queues," and "circular queues," which influence the order in which customers are served. Each strategy has its advantages depending on the type of service offered and the level of customer urgency.

3.3.1 First-Come-First-Served (FCFS): First Come First Served (FCFS) is a queue management system where customers are served in the exact order they arrive (Kumar & Upadhye, 2021). The first person to arrive gets served first, the second person second, and so on. This applies both to physical banking (waiting in line at a branch) and to transaction processing (the order in which payments or transfers are processed).

3.3.2 Priority queues: Priority queue is a queue management systems where transactions or customers are served based on their priority level rather than arrival order (Cui et al., 2023). This is different from FCFS because it allows more urgent or important items to "jump the line."

In Nigeria, banks have started incorporating queuing theory to improve efficiency, particularly during peak hours when customer volumes increase. However, these models have yet to be widely implemented across the sector due to several challenges, as discussed in the next section.

4.0 Challenges in Implementing Queuing Theory in Nigerian Banks

While queuing theory holds substantial promise, its adoption in Nigerian banks is hindered by several key challenges:

4.1 Infrastructural limitations

Many banks in Nigeria lack the necessary infrastructure to implement advanced queuing models. This includes inadequate physical facilities, outdated technology, and insufficient investment in digital systems

(Iwedi, 2024). For example, some branches still rely on manual queue management systems that cannot handle high volumes of customers efficiently.

4.2 *Fluctuating customer demand*

Nigerian banks experience highly variable customer demand, often influenced by external factors such as economic fluctuations, public holidays, and salary payment cycles. This inconsistency in customer flow makes it challenging to predict queue lengths and manage resources effectively using traditional queuing models (Aminu, 2022).

4.3 *Cultural factors*

Nigerian customers tend to exhibit different behaviors compared to those in other regions, such as longer wait times due to a lack of customer awareness or patience (Arinola et al., 2022). Additionally, some customers prefer face-to-face interactions, which further complicates efforts to implement efficient queuing systems, especially when self-service options or automation are introduced (Aminu, 2022).

5.0 Emerging Trends and Future Applications

Despite the challenges, emerging trends are creating opportunities for the effective application of queuing theory in Nigerian banks:

5.1 *Digital banking and mobile applications*

The rise of mobile banking and digital payment platforms offers new avenues for reducing physical queues in branches (Kaur et al., 2024). By shifting customer transactions to online platforms, banks can reduce in-branch traffic, enabling them to better manage queues during peak times. Digital banking tools can also provide real-time queue updates, allowing customers to choose optimal times for visiting branches.

5.2 *Advanced analytics and AI*

The integration of artificial intelligence (AI) and predictive analytics into queuing systems can significantly enhance the efficiency of queue management. AI-driven models can forecast peak periods based on historical data, enabling banks to allocate resources dynamically and reduce customer wait times (Hijry & Olawoyin, 2021). Moreover, AI-based chatbots can assist customers in managing their expectations and providing queue updates, improving their overall experience.

5.3 *Automation and self-service kiosks*

The introduction of self-service kiosks and automated teller machines (ATMs) for routine transactions such as deposits, withdrawals, and account inquiries has the potential to ease pressure on bank tellers (Olabimtan, 2022). These technologies can reduce the number of customers waiting in line, allowing staff to focus on more complex transactions.

5.4 *Queue management software*

A growing trend is the use of digital queue management systems, which provide real-time monitoring and analytics to streamline customer flow (Halim et al., 2021). These systems allow banks to implement sophisticated queuing models and adapt to changing customer demand more efficiently.

6.0 Conclusions

This review has highlighted the transformative potential of queuing theory in enhancing service efficiency in Nigerian banks. By leveraging mathematical models to predict customer flow, banks can optimize resource allocation, minimize wait times, and improve customer satisfaction. However, challenges such as infrastructural deficits, limited technological adoption, and cultural preferences for in-person banking hinder the effective implementation of queuing solutions.

To address these issues, future research should explore AI-driven queue management systems and strategies for increasing customer adoption of self-service technologies. A gradual transition to automated queue systems, alongside customer education and infrastructural investments, could improve acceptance and implementation. By embracing these advancements, Nigerian banks can create more resilient, efficient, and customer-friendly service environments that align with modern banking demands.

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APPRAISAL OF URBAN FARMING AMONG STAFF OF OSUN STATE POLYTECHNIC, IREE, OSUN STATE

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Abstract

The study appraises urban farming among staff of Osun State Polytechnic Iree (Ospoly), Osun State. The study assesses the prevalence of urban farming among Ospoly staff, examine the benefits of urban farming, evaluate the challenges faced by staff engaged in urban farming and identify strategies for promoting urban farming. There are 450 permanent staff members in Ospoly Iree (150 are teaching staff and 270 are non-teaching staff). 30% of the total numbers of staff were sampled for the study; this makes a total of 150 staff that was sampled. Thus, a structured questionnaire was administered on systematically sampled members of staff systematically sampled members of staff. Chi-Square was used to test the challenges of urban farming among Ospoly staff. Challenges of urban farming faced by Ospoly staff include limited space and land availability, harsh weather, exposure to pest, soil pollution, high labour cost and high startup cost. Chi square result showed that limited space and land availability, harsh weather, high startup costs are more significant. The study therefore recommends that there should be workshops and training on urban farming basics and regular updates on best practices and research.

Keywords: Urban, Farming, Staff, Ospoly

1. Introduction

Urban agriculture is any agricultural enterprise within or on the fringes of a town, city, or metropolis that grows or raises, processes, and distributes food and non-food products (Bryld, 2003). Various scholars have considered related practices, such as the production of agricultural products by urban residents within officially defined urban spaces (Zezza and Tasciotti, 2010). But others define urban agriculture as any farming activity occurring in built –up 'intra-urban' areas and 'peri-urban fringes of cities and towns (Thornton, 2008). Urban agriculture is the practice of farming in a city environment. It embraces the cultivation of crops, rearing of livestock, harvesting, processing, storage, marketing and distribution of agricultural products and by-products. It demands sound agronomic principles and practices including adoption of innovations for increased agricultural productivity Ogunbameru et al, (2004).

Urban agriculture refers to the farming of small plots of land available in urban environments or on the perimeter of the cities (Wilson, 2001). Urban agriculture could be practiced on rooftops, backyards, community garden and vacant public spaces (Aipira, 1996). Also, open balconies, veranda, undeveloped plots of land, unoccupied plots, urban outskirts, squatter plots, etc offer great opportunity for urban farming practice. Urban agriculture could serve as a source of supplement to the family food while providing a steady source of income to the family.

Presently, the global population is about half rural and half urban, but the world's cities are swelling (Wilson, 2001). However, in the next twelve years, ninety per cent of the projected 6.8 billion people in developing countries will live in the cities (Garrett, 2001). Garrett (2001) noted that in large, congested cities, urban poor might have a home garden or raise small animals as part of a coping strategy. As a result, urban farming is lifting hundreds of millions of people out of extreme poverty and improving nutrition and health standards around the world (Binns and Feredy, 2004). These varied definitions illustrate the peculiarity and diversity of urban agriculture and, therefore, the range of policies and actors it affects. Urban agriculture in Africa is as old as colonialism itself, when farming flourished in urban areas.

In Nigeria, the practice of urban agriculture plays a crucial role in enhancing urban food security and livelihood. This is because the cost of supplying and distributing food to urban areas that rely on rural production and imports, continue to increase. Also, the supply of food does not meet the demand of urban residents, especially the urban poor. An increase in food demand and a high rate of unemployment are common features in Nigerian cities. According to Olayioye (2011), traders, civil servants and artisans find it difficult to cope with the high cost of living. The poor income in the urban area has encouraged agricultural activities production within cities vicinity. Urban agriculture (UA) contributes to local economic development, poverty alleviation, the greening of the cities and the productive reuse of urban wastes (Oyedipe, 2009).

Urban agriculture's role has been ignored by most of the urban residents in improving their situation and it has been treated as having only very little contribution to the urban economy. As a result, people who engaged in urban agriculture have been unsupported and harassed, even in years of food shortages. Now, as the potential benefits of UA for food security and environmental management becomes better understood in policy circles, official attitudes in some countries are slowly but steadily changing (Arku et al., 2012). Urban agriculture engages more than 800 million people worldwide (UNDP, 1996) contributing about 50% to the food security safety of city dwellers (Appeaning – Addo, 2010).

The high cost of fuel in Nigeria presently has made commodities, foodstuff and other essential commodities to be very expensive. This has made living in Nigeria to be a herculean task and the civil servants are the worst hit because the amount being paid as their salary does not commensurate with one another. The salary being paid is arithmetic while the cost of living is on the geometric side. The civil servants need to supplement the salary being paid and there is need for farming which will supplement the income being received. Most of the workers are living in urban areas and their dwelling is made up of concrete floor and the need for urban farming is necessary and compulsory.

According to Egal, Valstar&Meerstock (2003), the contribution of urban agriculture to food security and poverty alleviation has recently become a subject of attention for policy makers. The high rate of poverty among urban households and the growing responsibilities to assure household survival has caused urban agriculture to become a crucial activity in developing cities (Anosike and Fasona, 2004). It is against this backdrop that this study examined urban agriculture as a measure of economic empowerment among staff of Osun State Polytechnic, Iree, Osun State.

2. Research Questions

i. What is the percentage of OSPOLY staff engaged in subsistence farming?
ii. What motivates polytechnic staff to engage in subsistence farming
iii. What are the benefits of subsistence farming to staff
iv. What are the challenges being faced by the staff in subsistence farming
v. How can subsistence farming be sustained and promoted among polytechnic staff

3. Objectives of the study

The objectives were to determine:

i. To assess the prevalence of urban farming among OSPOLY Staff
ii. To examine the benefits of urban farming
iii. To evaluate the challenges faced by staff engaged in urban farming
iv. To identify strategies for promoting urban farming

4. Materials and Methods

Osun state Polytechnic consist of 450 permanent staff (150 are academic/teaching staff 270 are non-academic staff. For the purpose of this study, 30% of the total numbers of staffs were sampled. This makes a total of 150 staffs that were sampled. Thus, a structured questionnaire was administered on the staff using systematic sampling. Analysis of Variance (ANOVA) was used to analyse the spatial variation in the challenges of urban agriculture among polytechnic staffs.

The Study Area:

The study was carried out in Iree, a town in Osun State. Geographically, Iree is located in southwest Nigeria and between longtitudes 7.55 North an latitudes 4.43 East. Iree is one of the major towns in Boripe Local Government Area of Osun State and it is located on the Osogbo-Ila –Orangun road, about 30 kilometers (19 miles) from Osogbo and 8 kilometers (5 miles) from Ikirun. It is surrounded by the following towns: Ikirun, Iba, Eripa, Ada, Aagba, Orooruwo, Obaagun, Iragbiji and Iresi. Iree is situated in a valley amidst seven prominent hills whih, in the past, served as a natural fortress in times of war-primarily during the Yoruba civil wars of the 19th century and most especially, from hostile neighbouring communities. The seven hills are: Eru Hill, Ilako Hill, Ipole Hill, Adanimole Hill, Aganna Hill, Apo Hill and Maye Hill. The 7-hill topography of the town makes it attractive to tourists. Iree is known as an educational town, Osun State Polytechnic, Iree was situated in the town making the community an educational one.

5. Result and discussions

5.1 Prevalence of urban farming among Polytechnic staff

4.1.1 Involvement in urban agriculture

Figure 1, shows that urban agriculture is prevalent among polytechnic staffs. Further analysis shows that 90% of the staffs are involved in subsistence farming

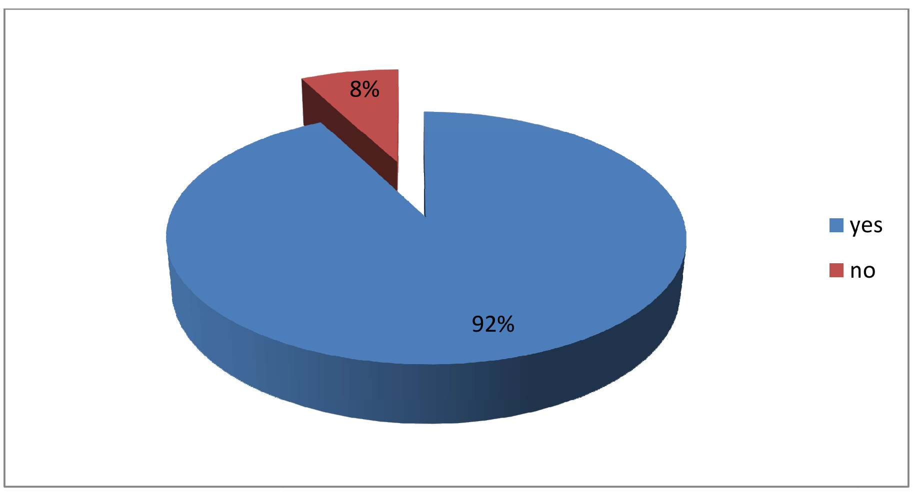

Fig 1: Involvement in urban agriculture

Source: Author field 2024

4.1.2 Type of urban agriculture involved in

Fig 2 shows that 72% of the polytechnic staffs are involved in subsistence farming because it is the easiest type of farming, while others involved in both subsistence and commercial farming.

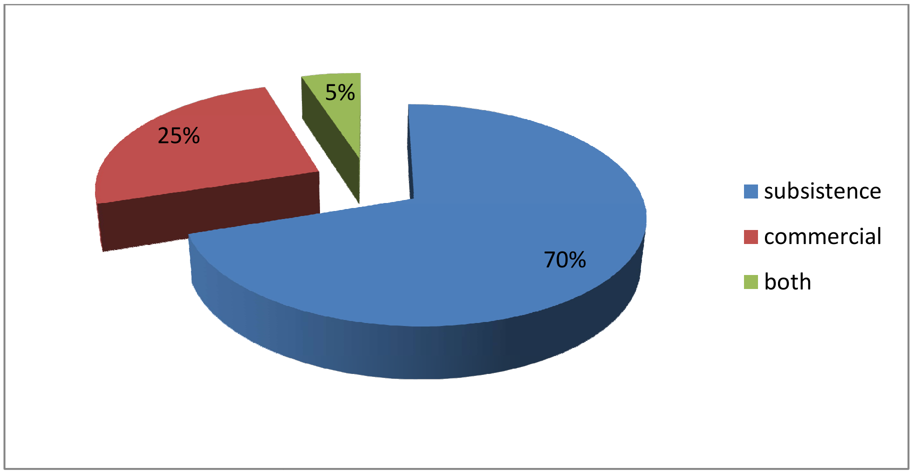

Fig 2: Type of urban farming

Source: Author field 2024

4.2 Benefits of urban farming

Table 1 shows that the benefits of urban farming among sampled staffs which are food access, reduced food cost, food security and increased education. While most staff indicated that urban agriculture helps them to get easy access to food (58%) and spend less on food (38%)

Table 1: benefits of urban farming

Benefits	Frequency	Percentage
Food access	**78**	**52**
Reduced food cost	**57**	**38**
Food security	**3**	**2**
Increased education	**12**	**8**
Total	**150**	**100**

Source: author field 2024

Table 2, presents the result of the chi square tests that explains the difference in the benefits of urban farming among sampled staff. It can be seen here that there is significant difference between the food access, increased education and food security while there is no significant difference between reduced food costs among staffs.

Table 2: chi square analysis of benefits of urban farming among sampled staff

Benefits	X^2 table	P value	Remark
Food access	39.606	.000	Significant
Reduced food cost	.880	.411	Not Significant
Food security	32.418	.000	Significant
education	9.637	.001	Significant

Source: author field 2024

4.3 Challenges of urban farming

Table 1 show that the challenges of urban farming among sampled staffs are limited space, harsh weather, high labour cost and high startup cost. Majority of the staff indicated that they are faced with the challenges of getting a startup capital (48%), while 30% of the staff indicated limited space and 10% indicated harsh weather.

Table 3: Challenges of urban farming

Challenges	**Frequency**	**Percentage**
Limited space/land availability	**72**	**48**
Harsh weather	**45**	**30**
High labour cost	**11**	**7**
High startup cost	**22**	**15**
Total	**150**	**100**

Source: author field 2024

Table 4, presents the result of the chi square tests that explains the difference in the challenges of urban farming among sampled staff. It can be seen here that there is significant difference in all the challenges among staff

Table 4: chi square table of the challenges of urban farming among sampled staff

Challenges	**X^2 table**	**P value**	**Remark**
Limited space/land availability	119.944	.000	Significant
Harsh weather	114.989	.000	Significant
High labour cost	55.100	.000	Significant
High startup cost	53.139	.000	Significant

Source: author field 2024

Table 5 presents the result of ANOVA establishing the spatial variation inchallenges of urban agriculture among polytechnic staffs. According to the table, it is observed that the harsh weather, high cost of labour and high startup cost varies significantly among the staffs while limited space does not vary among the staffs

Table 5: Variations in challenges of urban agriculture among polytechnic staffs

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Limited space	Between Groups	33.284	2	16.642	2.190	.114
	Within Groups	2393.836	315	7.599		
	Total	2427.119	317			
Harsh weather	Between Groups	24.034	2	12.017	17.836	.000
	Within Groups	235.145	349	.674		
	Total	259.179	351			
High cost of labour	Between Groups	25.888	2	12.944	2.313	.100
	Within Groups	2647.574	473	5.597		
	Total	2673.462	475			
High start up cost	Between Groups	184.663	2	92.331	200.094	.000
	Within Groups	129.203	280	.461		
	Total	313.866	282			

Source: author field 2024

5 Conclusion and Recommendations

The study examined urban farming among staff of Osun state Polytechnic (Ospoly) Iree, Osun State. The study concluded that the challenges of urban farming faced by Ospoly staff include limited space and land availability, harsh weather, exposure to pest, soil pollution, high labour cost and high startup cost. Chi square result showed that limited space and land availability, harsh weather, high startup costs are more significant. To make urban farming among Osun State Polytechnic Staff a viable opportunity for promoting food security, economic empowerment and community engagement, the following recommendations are needed:

(iv) Ospoly management should organize training and workshops on urban agriculture
(v) The management of the school can provide subsidize fertilizers and agro chemicals needed.
(vi) Also, Ospoly management can provide loan facilities to the staff for easy startup
(vii) The management should provide subsidized seeds, tools and equipment for staff.

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ASSESSEMENT OF ENTREPRENOURSHIP SKILLS OF PRISONERS OF MEDIUM SECURITY CUSTODIAL CENTER, KIRIKIRI TOWN, LAGOS STATE.

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Abstract

The study assesses the impact of Entrepreneurship skill of prisoners of medium security custodial center. Ten years data of the inmate trained and under training was collected from prison authority (2010 to 2022). structure questionnaire was used to collect data from the trainer of the inmate in different apprentice like tailoring, shoe maker, barbing, laundry and carpentry. Frequency table, simple percentages and graphs which include pie chart and histogram were used in the analysis. Time series analysis was also used to analyze the data collected. The study has shown that total number of four hundred and fifty-two was trained within the period of ten years. Analysis reveals thatt 2021 has the highest number and 2022 has the lowest number of trainees.(42 and 26 respectively). Tailoring had highest number of trainees (106) while barbing has lowest(79). In the ANOVA analysis of some of the vocational training the study discovered that p value is lower than 0.05, null hypothesis was rejected and concludes that the model is adequate in prediction and forecasting. This mean when time is zero the number of inmate in training increases yearly. The study recommends; every inmate must be involved in the entrepreneurship training, government should make provision for the occupation of the participant after their jail term, grant should be given to those who require for it, and there must be monitoring team to monitor all trained inmate at the end of their jail term.

Keywords: Entrepreneurship, skill, prisoner, medium, custodial, center

1. Introduction

Every year, thousands of formerly-incarcerated individuals re-enter their communities hoping to make a fresh start (Orakwe, 2021). According to Agomo (2019), data on recidivism indicates that, 67.8% of ex-convicts are likely to be rearrested within three years and 76.6% within five years. In terms of re-adjudication, approximately 49.8% of formerly-incarcerated individuals recidivate within three years and approximately 60% do so within five years. Re-incarceration rates among returning individual is 36.2% within three years, and 44.9% within five years. Any community with a large number of ex-convicts suffer reduced man power and resources, this hinders economic growth.

Due to this, the Federal Government of Nigeria introduced the Prison Entrepreneurship Development Programs in Nigerian prisons. These programs help to provide for the inmates good skills and attitudes to secure employment or be self employed. The prison entrepreneurship development programs include formal education, entrepreneurship education, vocational skills training, and prison agricultural program. The formal education scheme involves teaching and learning for inmates using the 6-3-3-4 system of education to expose them to basic skills of reading, writing, social and religious studies. Other subject offered include mathematics, social studies, English Language, biology, physics, chemistry, literature, economics, accounting and the likes. Some of the inmates are enrolled for external examinations like First School Leaving Certificate Examination, Junior Secondary examination and Senior Secondary School examinations. Entrepreneurship education involves teaching the inmates through the rudiments of entrepreneurship such as identifying needs, general business management, marketing, financial management, preparing business plans and proposal.

For the vocational skills training, the inmates are required to make a choice (Asokhia 2015). The chosen vocation cap must be within the limits of the inmates' jail sentence. At completion of the training and jail term, the inmates should be helped by the prison management to secure capital to set up. The prison agricultural program is a scheme that engages the inmates by making them work in the prison farms, thereby aiding them to learn valuable agricultural skills. These skills include all forms of practical farming skills, farm management, financial book keeping, and so on (Asokhia, 2015). Therefore, this study seeks to examine the effectiveness of prison entrepreneurship program in equipping prison inmates with entrepreneurship skills.

The entrepreneurship development programs introduced in the prisons is meant to aid successful re-entry into the society and engender productivity among newly released inmates by providing inmates with skills that will make them either employable or self-employed. In view of the above, this study was designed to appraise the impacts of prison entrepreneurship program in equipping prison inmates (in Lagos State) with entrepreneurship skills.

2. Aim and Objectives of the Study

The aim of this study is to examine the impact of entrepreneurship skills on prisoners in Lagos prison. The aim can be achieved by the objectives below:

i. To examine the level of vocational education given to prison inmates in Lagos prison
ii. To examine the vocational activities made available for prison inmates
iii. To examine the impact of the entrepreneurship education on prison inmates in the study area
iv. To examine the challenges faced by prison inmates during entrepreneurship education

3. Methodology

Types and Sources of Data

Primary data sources

The primary data to be obtained are

a. Reconnaissance survey: the study area was visited to know the condition of the correctional centre and inmates.
b. Personal interview and observations: during the visit to the study area, some of the trainer of the inmates was interviewed to know their notion about the entrepreneurship skills.
c. Questionnaire administration: questionnaires were administered to the trainer of the inmates to elicit information about the impact of the skills to their wellbeing.

Secondary source of data

This source was obtained through the review of existing bodies of knowledge on the subject matter. These include published textbooks, past projects and unpublished materials.

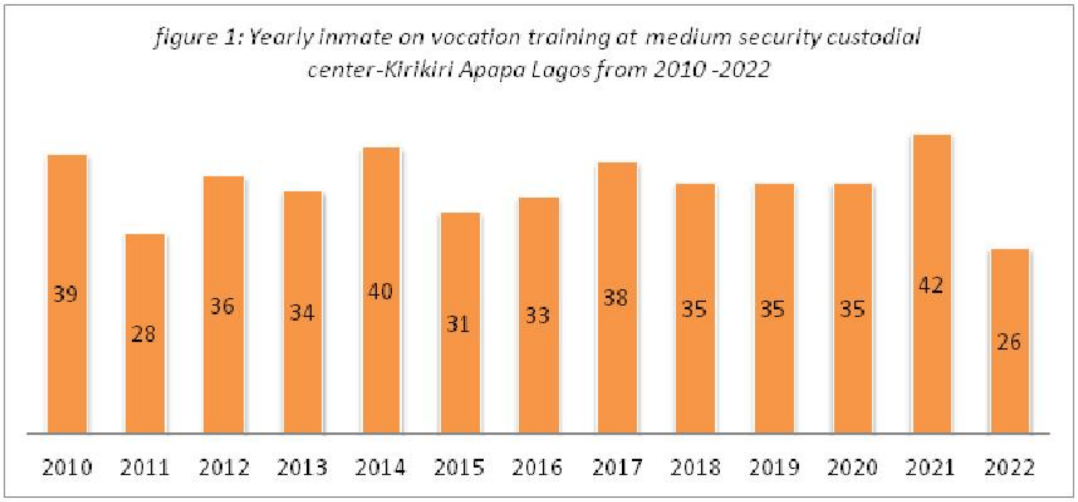
Sample Frame and Size

The population for this study comprised all trainers of inmate populations in prison facilities within Lagos State, as well as their employers involved in prison entrepreneurship programs. According to the Nigerian Prison Service, Lagos State records, the population totaled 1269.
A sample size of 10% (126 respondents) was selected from the population using a systematic technique. A total of 126 questionnaires were administered to the sampled respondents.

4. Data Presentation and Data Analysis

TIME SERIES ANALYSIS OF THE INMATE ON VOCATIONAL TRAINING AT MEDIUM SECURITY CUSTODIAL CENTER KIRIKIRI APAPA LAGOS FROM 2010 –2022

Figure 1 show that year 2021 has the highest number of inmate in the study year while 2022 has the lowest inmate in the year study



Sources: Medium Security Custodial Center KirikiriApapa Lagos

From figure 4.2, it show that year tailoring service(106) has the highest number of inmate follow by laundry service (95) in the study year while Barbing service(79) has the lowest inmate in the year study

Sources: Medium Security Custodial Center KirikiriApapa Lagos

TREND ANALYSIS OF INMATE ON TAILORING SERVICE

The model (Table 1) shows that a unit increase in time per year the number of inmate in tailoring service will increase by 0.071429, the intercept β_0= 7.653846 implies that the expected mean value of the number of inmate in tailoring service at medium security custodial center when time is zero is 8 for the year 2010 to 2022.

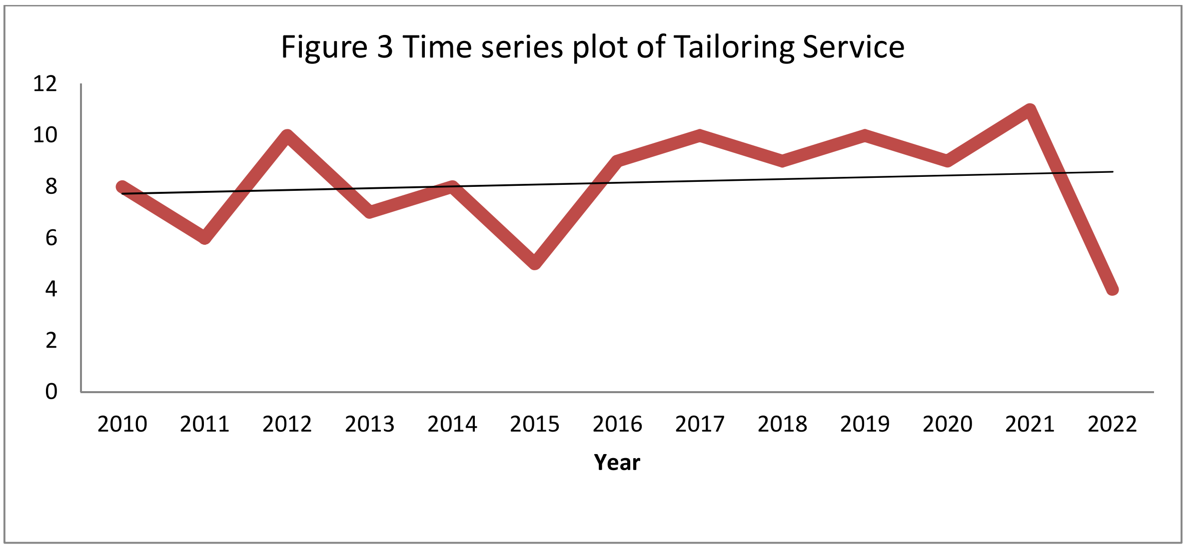
Table 1: Fitted Trend Equation

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	7.653846	1.288564	5.939826	9.73E-05	4.817736	10.48996
Year	0.071429	0.162344	0.439983	0.668469	-0.28589	0.428745

Source: Author fieldwork 2024

$$Yt = 7.653846 + 0.071429X_t$$

From Figure 3, it has been shown that there is a cyclical movement in the plot, which moved upward in 2021 which is the highest number of inmate in tailoring service at medium security custodial center in the year study and 2022 has lowest number of inmate in tailoring service at medium security custodial center.



Source: Author fieldwork 2024

TREND ANALYSIS OF INMATE ON SHOE MAKING SERVICE

The model (Table 2) shows that a unit increase in time per year the number of inmate in Shoe making service will increase by 0.10989, the intercept β_0= 5.538462 implies that the expected mean value of the number of inmate in Shoe making service at medium security custodial center when time is zero is 6 for the year 2010 to 2022.

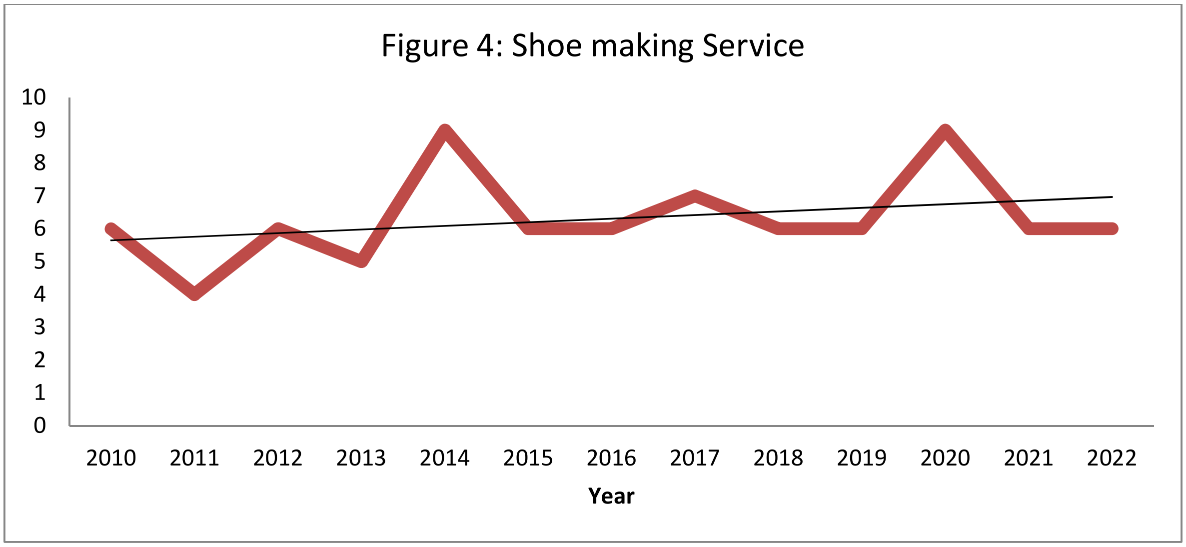
Table 2: Fitted Trend Equation

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	5.538462	0.804582	6.883648	2.64E-05	3.767588	7.309335
Year	0.10989	0.101368	1.084073	0.301522	-0.11322	0.332999

$$Yt = 5.538462 + 0.10989X_t$$

Source: Author fieldwork 2024

From the Figure 4, it has been shown that there is a cyclical movement in the plot, which moved upward in 2014 which is the highest number of inmate in shoe making service follow by year 2020 at medium security custodial center in the year study and year 2011 has lowest number of inmate in shoe making at medium security custodial center.



Source: Author fieldwork 2024

TREND ANALYSIS OF INMATE ON BARBING SALOON SERVICE

Table 3 shows that a unit increase in time per year the number of inmate in Barbing salon service will decrease by 0.18132, the intercept β_0= 7.346154 implies that the expected mean value of the number of inmate in Barbing salon service at medium security custodial center when time is zero is 7 for the year 2010 to 2022.

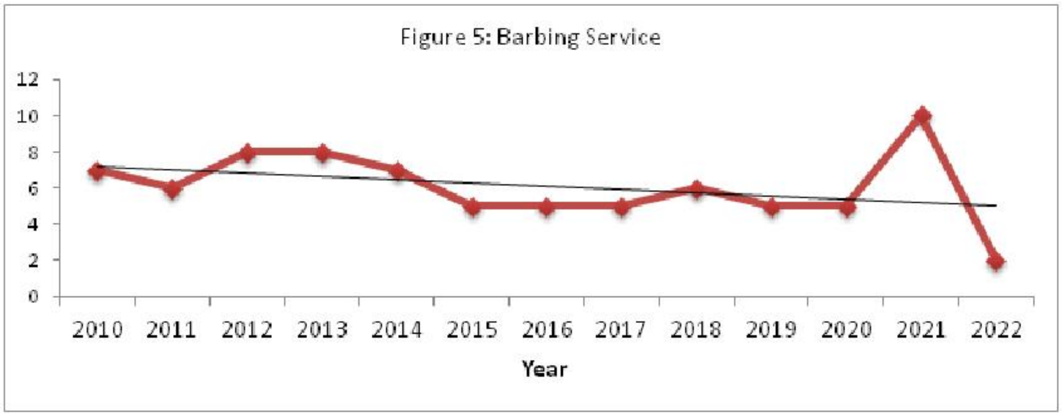
Table 3: Fitted Trend Equation

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	7.346154	1.135036	6.472174	4.6E-05	4.847955	9.844352
Year	-0.18132	0.143001	-1.26795	0.230995	-0.49606	0.133425

Yt = 7.346154-0.18132X_t

Source: Author fieldwork 2024

Also, From the plot in Figure 5, it has been shown that there is a cyclical movement in the plot, which moved upward in 2021 which is the highest number of inmate in Barbing salon at medium security custodial center in the year study and year 2022 has lowest number of inmate in Barbing salon at medium security custodial center.



Source: Author fieldwork 2024

TREND ANALYSIS OF INMATE ON LAUNDRY SERVICE

The model (Table 4) shows that a unit increase in time per year the number of inmate in Barbing salon service will decrease by the rate of 0.15385, the intercept β_0= 8.384615 implies that the expected mean value of the number of inmate in Laundry service at medium security custodial center when time is zero is 8 for the year 2010 to 2022.

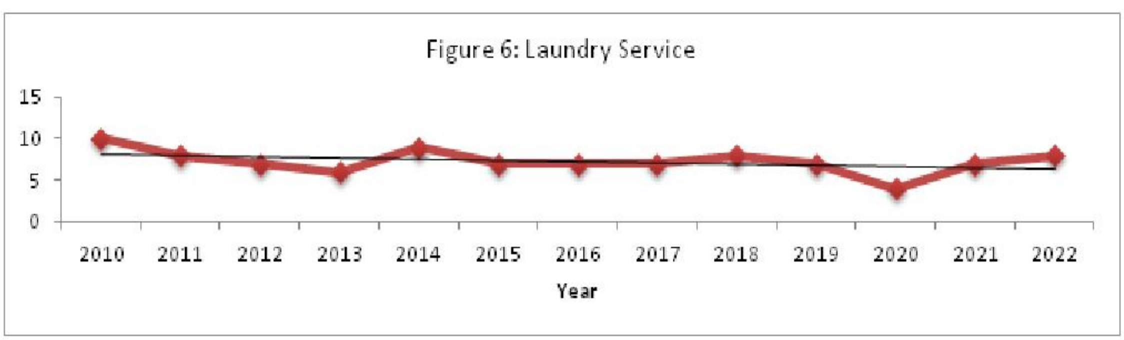
Table 4: Fitted Trend Equation

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	8.384615	0.80243	10.44902	4.76E-07	6.618478	10.15075
Year	-0.15385	0.101097	-1.52177	0.15628	-0.37636	0.068666

Y_t = 8.384615-0.15385X_t

Source: Author fieldwork 2024

Fig 6 show that there is a cyclical movement in the plot, which moved upward in 2010 which is the highest number of inmate in Laundry service at medium security custodial center in the year study while year 2020 has lowest number of inmate in Laundry service at medium security custodial center.



Source: Author fieldwork 2024

TREND ANALYSIS OF INMATE ON BARBING CARPENTARY SERVICE

The model shows that a unit increase in time per year the number of inmate in Carpentry service will decrease by the rate of 0.087912, the intercept β_0= 6.307692 implies that the expected mean value of the number of inmate in Carpentry service at medium security custodial center when time is zero is 6 for the year 2010 to 2022.

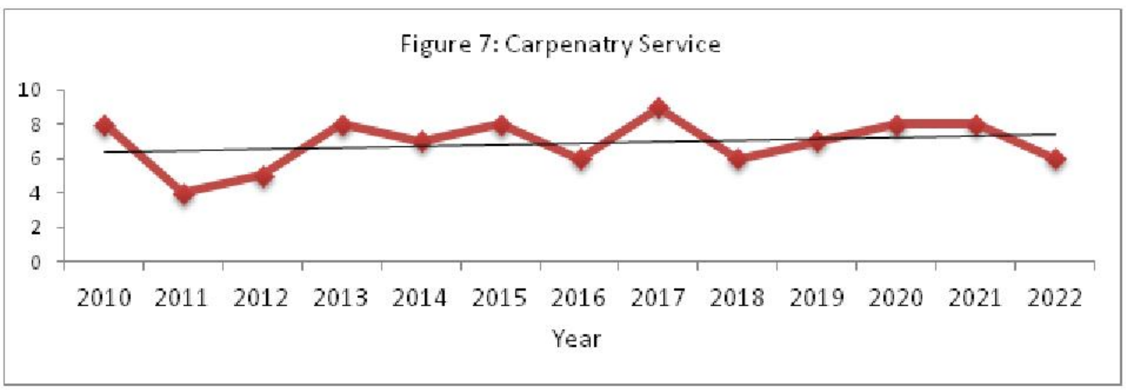
Table 5: Fitted Trend Equation

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	6.307692	0.860249	7.332399	1.48E-05	4.414296	8.201089
Year	0.087912	0.108381	0.811137	0.434487	-0.15063	0.326458

Y_t = 6.307692+0.087912X_t

Source: Author fieldwork 2024

Furthermore, fig 7 shows that there is a cyclical movement in the plot, which moved upward in 2017 which is the highest number of inmate in Carpentry service at medium security custodial center in the year study and year 2011 has lowest number of inmate in Carpentry service at medium security custodial center.



Source: Author fieldwork 2024

Table 5: FORCASTING ON THE INMATE IN VOCATIONAL TRAINING AT MEDIUM SECURITY CUSTODIAL CENTER KIRIKIRI APAPA LAGOS FROM 2023 –2027

Year	Tailoring Service	Shoe Making Service	Barbing Service	Laundry Service	Carpentry Service
2023	9	7	5	6	8
2024	9	7	5	6	8
2025	9	7	4	6	8
2026	9	7	4	6	8
2027	8	6	7	8	6

Source: Author fieldwork 2024

5. Conclusion

Entrepreneurship programs in prisons take numerous forms, from building trades, motor mechanics, fitting and turning, carpentry and upholstery, manufacturing of furniture and clothing to computer training. The premise of Entrepreneurship programs is that inmates who actively participate in these programs have a significantly lower likelihood of being reincarcerated and the acquisition of Entrepreneurship skills increases offenders' legitimate employment opportunities after release. Generally, the available research on Entrepreneurship education indicates that these programs are effective in reducing recidivism.

6. Recommendation

The study commends the government in the area of training inmate and discipline. These following recommendations were made.

1. Every inmate must be involved in the entrepreneurship training.

2. The government should make provision for the occupation of the participant after their jail term.

3. Grant should be given to those who require for it.

4. There must be monitoring team to monitor all trained inmate at the end of their jail term.

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Land Dispossession and Its Impact on Indigenous Communities in Kogi State, Nigeria.

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Abstract

Land dispossession is a pressing issue impacting indigenous communities in Kogi State, Nigeria. Despite the socio-cultural and economic significance of land to indigenous people of the state, they exist increasing cases of ancestral land depletion and total loss due to large-scale acquisitions driven by mining, agriculture, and infrastructure projects. The study, therefore, critically examines the impact of land dispossession on the vulnerable indigenous groups, with a focus on the socio-economic, environmental, and cultural consequences. The research explores how the activities of land grabbing, conducted without the free, prior, and informed consent of the local populations, disrupt traditional livelihoods, exacerbate poverty, and contribute to environmental degradation. Additionally, the study analyzes the inadequacies of Nigeria's legal frameworks, particularly the Land Use Act of 1978, which centralizes land ownership under state control, leaving indigenous communities with limited recourse to challenge expropriation. Data for the study were collected through focus group discussion, semi-structure interviews, document analysis and participant observation. Through qualitative research methods, including interviews with affected community members and policy analysis, the paper highlights the growing tensions between indigenous groups and the state, as well as the emergence of conflicts linked to land dispossession. The findings underscore the urgent need for policy reforms that protect indigenous land rights and promote sustainable development. This paper contributes to the broader discourse on land rights and indigenous sovereignty, providing insights for policymakers, development practitioners, and scholars engaged in issues of land governance in Nigeria and other African contexts.

Keywords: Land Dispossession, Impact, Indigenous Communities, Kogi State, Nigeria.

1. Introduction

Land dispossession and land grabbing are concepts that are alien to most communities in Nigeria. It has however become a critical and pressing issue affecting indigenous communities across states in Nigeria, particularly, Kogi State, where contemporary land grabbing have pervaded and marginalized the indigenous communities. Land, as an essential necessity of man and the basis of man existence and livelihood is often used as identity for indigenous peoples, thus, holds immense value thereby making its dispossession a deeply rooted psychological, cultural, socio-economic and political problem (Ankeli, 2022, Ojo, 2021, Ankeli et al., 2021 and Ankeli, 2019). Indigenous communities in Kogi State, Nigeria, particularly, the Igala communities are steadily and increasingly facing serious land grabbing challenges resulting from both public and private entities' massive land acquisitions processes either for mining, agriculture, and infrastructure development (Adeola & Yusuf, 2022). The land acquisitions exercises often done without obtaining formal consent from the aboriginal landowners, have profound implications for the affected communities.

Afolayan et al., (2023) observed that land dispossession disrupts traditional livelihoods, especially farming, which is the major occupation of the indigenous economy. In line with this assertions Ogundele and Adedayo (2020) asserted that the loss of arable land not only exacerbate food insecurity but also enhances the displacement of communities, cultural disintegration, and increased poverty rates. Ibrahim et al., (2021) further concluded that, environmental degradation resulting from mining and industrial activities has exacerbated the socio-economic vulnerabilities of indigenous groups, limiting their access to clean water and arable land.

Land dispossession in any part of the country can not be adequately discussed without recourse to the Land Use Act 1978. The Land Use Act 1978 in it section 1 transferred or vested the ownership right of every land in all the states in Nigeria to be held in trust by the governor of such a state. The Land Use Act instead of simplifying issues on land ownership, it rather compounds it. Hence, land dispossession issues in Kogi State, Nigeria (which Igala communities are part of) is also compounded by the inadequate legal frameworks and weak enforcement of land rights. Adeola (2020) therefore argued that Nigeria's Land Use Act of 1978 vests all land in the hands of the state governor thereby making the indigenous communities to be left with little recourse to challenge expropriation. This has led to tensions between the state and indigenous groups, with instances of protests and conflicts emerging in recent years (Ezeilo, 2023). This paper aims to critically examine the impacts of land dispossession on indigenous Igala communities in Kogi State, Nigeria, with particular focus on its socio-economic and cultural consequences. The paper analyzes the factors contributing to land dispossession, the role of state policies, and the responses of indigenous Igala communities to these challenges. It is the believe of the researchers that the study will contribute to the broader knowledge on land rights and indigenous sovereignty in Nigeria.

2. Literature Review

The Concept and Historical Context of Land, the environmental social and cultural impact

Land in Nigeria goes beyond its use for agricultural and economic production. It is a means to life and a measure of wealth. Amanor (2019) concluded that land in the Africa communities particularly, in Nigeria, is not only a means of economic production but a source of cultural identity, social status and spiritual connection. Hence, the dispossession, ejection or the forceful removal of a person or the entire community from their ancestral lands is often seen as an attack on such a person or the community at large. It often heightens tension that could result to crisis with profound implications for the aboriginal landowners. There are reports of land dispossession and land grabbing in Igala communities in the present day Kogi State, Nigeria. In recent times, the problem of land dispossession has escalated, with increasing encroachments on indigenous lands due to government-backed development projects, private sector investment, extractive industries among others.

Conceptually, issues of land dispossession are said to be deeply rooted in the colonial history of Nigeria, where colonial overlords appropriated land for mining, agriculture and other projects that were of interest to them. However, after the attainment of independence in 1960, the Nigerian state came up with series of policies targeted at the centralization of land ownership using various legal means or frameworks notably, the 1978 Land Use Act. The Act vested every land in any particular state in the hands of the state governor, thereby granting the state the power to allocate land for both public and private purposes. This policy, while intended to promote development, has often been criticized for its disregard for indigenous land rights and for facilitating land grabbing by political elites and private investors (Adewumi & Olajide, 2021). The persistence of these colonial legacies in Nigeria's land governance continues to exacerbate land dispossession, particularly in rural areas where indigenous communities rely heavily on land for agriculture and cultural practices.

The profound socio-economic impacts of land dispossession in the indigenous communities cannot be overemphasized. Afolayan et al. (2023) stated that there are evidential documents literatures that shows how the loss of ancestral lands leads to the disruption of traditional livelihoods, particularly in agriculture, which is the mainstay for most indigenous groups in Kogi State, Nigeria. It is though, a common knowledge that Nigeria is currently facing food crisis and the lack of access to land could aggravate community crisis in the community and the nation at large. To substantiate the, Adeola and Yusuf (2022) argued that the acquisition of large-scale land for mining and agriculture in Kogi State has displaced thousands of indigenous farmers, thereby pushing them into the urban centers where they struggle to find alternative means of livelihoods. There have been cases where tensions emanating from issues arising from land dispossession snowballed into full blown crisis resulting into complete breakdown of social and cultural structures within indigenous communities.

Land is not just an economic resource; it is also central to the social and spiritual life of indigenous peoples. Dispossession disrupts community cohesion, weakens traditional leadership, and erodes cultural practices that are closely tied to the land (Ogundele & Adedayo, 2020). For example, the Igala people of Kogi State have historically used land for communal rituals and ceremonies, which are now threatened by the encroachment of development projects on their sacred sites (Ojo, 2021). The Land Use Act further reduced the ownership right and absolute power of control over land by the indigenous communities over lands in their domain (Ankeli et al., 2023 and Adeola, 2020). According to Boone (2020) the interplay between state powers and the global capital shaped the dispossession of land in the post-colonial Africa, as investment and development were prioritized over the indigenous rights. This conceptualization thus, shade more lights on the systemic nature of land dispossession, where power imbalances between the state, corporations, and indigenous communities lead to widespread tension, displacement and marginalization.

In Kogi State, land dispossession has significant environmental impact on the indigenous communities. For instance, Ibrahim et al., (2021) pointed out that, mining activities in Kogi State has led to deforestation, water pollution and soil degradation thereby compounding the existing challenges of the communities particularly, those of the communities with high mining activities. Ezeilo (2023) further elucidated how environmental activities through land dispossession could heightened vulnerabilities to climate-related disasters, such as flooding and droughts, which disproportionately affect indigenous populations.

Although, the struggle for land rights in Kogi State specifically the Igala communities has been a complicated but continuous battle, that mirrors the tensions between development imperatives and indigenous sovereignty.

3. Methodological Approach

The study adopted a qualitative case study approach for the investigation of land dispossession issues and its impact on indigenous Igala communities in Kogi State, Nigeria. The ability of the approach to allow for a deep contextual understanding of phenomenon through an in-depth exploration of the complexity in the socio-economic, cultural, and environmental effects of land dispossession on specific indigenous groups within the state inform the rationale for its usage. Specific attention was focused on the intricate live experiences, power play economic, environmental and the socio-cultural dynamics that interplay in the Land dispossession procedure in communities. Data for the study were collected through focus group discussion, semi-structure interviews, document analysis and participant observation

The study conducted semi-structured interviews that captured perceptions, personal narratives and experiences with the indigenous community members/local leaders, policymakers, and representatives of non-governmental organizations (NGOs) in the communities. To share and compare experiences in collaborative environment, the study further conducted a focus group discussion with the local government land officers and the affected community members to gain collective insights into the social and cultural impacts of dispossession. More so, to understand the cultural significance of land to the people and its dispossession could impact or alter their life, the researchers spent two weeks in the affected communities to observe the people's daily life and social interactions. Furthermore, the available legal/acquisition documents were examined to ease the triangulation data.

In picking samples for the study, purposive sampling technique was adopted to select specific indigenes that were directly impacted by the land dispossession activities in the affected Igala communities in Kogi State. The selected Igala communities were picked from Idah, Igalamela, Ankpa and Anyangba communities due to the severity of land dispossession activities on their agricultural land.

The researcher conducted thematic data analysis that is iterative as the themes are continuously refined with the collection and analysis of new data. The key themes include loss of livelihoods, cultural disintegration, environmental degradation, and resistance strategies. The responses were recorded and later triangulated to harmonize the qualitative and quantitative data collected. However, the introduced quantitative research was to test the cognitive and psychometric proficiencies of the respondents. This was done using Relative Importance Index (RII) to rate the perceptions of the respondents on the presented variables. The identified variables from previous literatures on the respondents' perceptions were subjected to test. This was done on a 5 points Likert type scale to measure the affective and cognitive skills of the respondents. The formula used by Ankeli (2022) was adopted for this study:

$$\textbf{R.I.I.} = \frac{\sum W}{A*N} = \frac{5n5 + 4n4 + 3n3 + 2n2 + 1n1}{5*N}$$

W = the weight given to each respondents' statement ranges from 1 to 5. A = the highest response integer (5) where n5 = Strongly Agreed; n4 = Agreed; n3 = Uncertain n2 = Disagreed and n1= Strongly Disagreed, N = the total number of the respondents

4. Results and Discussions

The respondents selected for this study are those directly dispossessed of either their land, family/clan land or community land. In the Focused Group Discussions, the respondents were asked on how the activities of land dispossession affects their livelihoods. The generalities of the respondents in the selected communities responded that:

> *"Their farming land and ancestral land were taken away from them. They are facing serious cases of victimization and marginalization for lack of land to use for cultivation and other farming activities".*

The dispossessed respondents that have migrated to adjoining towns and cities but joined the Discussions have this to say:

> *"We are currently living in insecure condition. Our host communities have abused, dehumanized, exploited us with violence and constant threat of evicting us from their farmland".*

The consequences are that most of the able body men are now jobless as the communities are agrarian communities. The vulnerable (elderly men, women and children) are homeless, disrupted schooling for the children and reduced opportunities for these vulnerable individuals; thereby, becoming more of refugees in their homeland.

However, when asked on the compensation paid and its adequacy or otherwise. The few families that were compensated are of the opinion that the amount paid as compensation was not adequate. In their words

> *"The amount received as compensation was not enough to buy land in a new location and build a house; hence, as you can see, we are still here in this makeshift apartment".*

On the effects of land dispossession on the culture of the communities, the respondents in all the communities agreed that it has negatively affected their cultural practices.

> *"Culturally, some of the things we do previously can no longer be done due to the establishment of institutions (educational and industrial) resulting in the influx of people. This has seriously diluted/disintegrated our culture, thereby affecting or impacting on the richness of the culture."*

In order to comprehensively understand the environmental and socio-economic consequences of land dispossession on the selected Igala communities, factors identified in earlier literatures were tested and ranked. The tested and ranked factors are presented in Table 1 below.

Table 1: Land Dispossession's Environmental and Socio-economic Factors

Variable	5	4	3	2	1	∑W	R.I.I	Ranking
Environmental Damage and Food Insecurity	92	4	0	0	0	468	0.975	4th
Climate Vulnerability	65	20	5	6	0	432	0.900	9th
Housing problem	90	6	0	0	0	474	0.988	2nd
Impact on the Vulnerable	55	10	15	10	6	386	0.804	10th
Access to Education	30	15	10	30	11	311	0.648	6th
Internal Displacement	86	10	0	0	0	470	0.979	3rd
[5]Disruption to Social Networks	70	16	0	10	0	434	0.904	8th
Loss of Cultural Identity and Heritage	76	20	0	0	0	460	0.958	5th
Urbanization Effects	56	20	10	10	0	410	0.854	6th
Cross-Border Migration	80	10	0	6	0	452	0.942	7th
Widening Inequality and poverty levels	92	14	0	0	0	516	1.075	1st

Source: Field Survey, 2024. Significant level 0.5

Table 1 shows the outcome of the perceptions of the respondents drawn from the study communities. Out of the 10 variables presented as the impact of land dispossession in the communities, widening inequality and poverty levels ranked first with Relative Importance Index of 1.075. The selected communities are indigenous and agrarian communities; hence, relying more on land for their livelihoods. Land that should have ordinary been used for productive agricultural ventures were taken away. This to the respondents have exacerbated loss of job, idleness thereby engendered poverty. Housing/Shelter problems with RII of 0.988, according to the respondents ranked second most impactful factors. In the communities, land dispossession has brought about land tenure denial issues leading to shelter/housing problems, property right denial and possible further displacement. Aside inadequate housing conditions another resultant consequences of land dispossession is homelessness due to forced evictions and the breeding of slum or informal settlements in an urban area. People in this kind of poor living conditions are often faced with lack of access to clean water, pollution and other health risks.

Furthermore, it was obvious that, the dispossessed respondents were displaced and forced to migrate from their aboriginal land to other communities and at times across boarder. Hence, Internal Displacement with RII of 0.979 ranked third most impactful factors. This has created serious challenges, internally displaced persons (IDPs) who lack protection, over stretched infrastructure usage due to overcrowding thus engendering socio-economic tensions. The severity of the economic hardship and crisis tension caused by land dispossession has according to the respondents led to cross-border migration for safety and better opportunities.

Environmental Damage and Food Insecurity are other consequences of land dispossession in the communities studied; thus, ranked 4th with an RII of 0.975. Some of these communities have lost their habitat, while deforestation activities are in high gear due to mining, infrastructure development and commercial agriculture. The loss of animal and plant species due to ecosystem destruction, increased soil erosion and depletion of soil nutrients are negative consequences of land dispossession.

More so, the communities are deprived of their traditional Subsistence agriculture which is known to be a major source of food production for the locale. This has reduced food output thereby making the aboriginal to be market system dependent.

Adopting the set significant level of greater than 0.5 benchmark as used by Nuhu *et al.*, (2022), all the 10 variables tested according to the perceptions of the respondents have impactful effects on the indigenous communities studied.

5. Conclusion and Recommendations

As a complex activity with a wide-ranging impact, issues of land dispossession remain typical issues of global discourse. At regional and sub-regional levels, it has a profound impact on the cultural heritage and socio-economic lives of the aboriginal inhabitants of the various communities, particularly, the Igala communities in Kogi State, Nigeria. The basic traditional livelihoods of the people have been disrupted through loss of ancestral lands because of external pressures. The studied communities are agrarian communities that depend majorly on subsistence agricultural practices. Hence, the Impact of land dispossession in the communities goes beyond the disruptions of social cohesion and the eroding of cultural identifications but extended to economic marginalization and physical violence. It was observed that, the multifaceted activities goes deeper than the mere denial of access to ancestral land to food insecurity and heighten poverty rates with the consequences of social inequalities exacerbation, increase crime rate and conflicts. The paper therefore recommended the need for the reinforcement of the existing legal frameworks particularly, by according customary land tenure systems the appropriate recognitions, encouraging community active participation in land base decision-making processes, land registry digitalization, accountability and transparency in land transactions, inclusion and implementation of a more robust restitution and compensation mechanisms and the adoption of practices that encourages sustainable land use practices and livelihood diversification through awareness and advocacy.

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Automated Bottle Filling and Capping System Using Programmable Logic Controller and Supervisory Control and Data Acquisition for Enhanced Efficiency in Small-Scale Manufacturing

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Abstract

In many African nations, small-scale producers of liquid products, including detergents, soft and hard drinks, juices, dairy items, and bottled water, still rely heavily on manual filling and capping processes. These labor-intensive methods lead to slow production rates, significant product waste, and frequent spillage, all of which hinder efficiency and profitability. Traditional approaches involving manual labour or basic mechanical systems struggle to keep pace with growing production demands. These methods often lack precision, require substantial manpower, and limit scalability. By contrast, automated solutions offer higher accuracy, reduced waste, and decreased labour requirements. This study presents an automated bottling solution using Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) systems. Known for their reliability and rapid response times, In this setup, bottles are transported via conveyor belts for filling and capping before exiting the system and supporting a continuous production cycle. The results indicate that automation improves production efficiency by approximately 60% compared to manual methods, reducing production time, ensuring accuracy, and lowering operational losses. The integration of PLCs and SCADA creates a scalable, cost-effective solution suitable for small and large-scale producers alike. This research demonstrates how automation can enhance productivity, improve product quality, and lower costs.

Keywords: Automation, Programmable Logic Controller (PLC), SCADA, Filling and Capping, Process Control

1.0 Introduction

Bottling conveyor systems play a critical role in industries such as beverage production, dairy processing, and glass manufacturing. These systems vary in scale, from small supermarket sorting units to large industrial plants capable of handling thousands of bottles per hour. However, due to the high speed and complexity of operations, bottling lines are prone to breakdowns, with typical equipment availability rates ranging between 92% and 98% (Chakraborty *et al*., 2015). The use of industrial automation has become essential in addressing such challenges, improving productivity, and reducing operational costs. Automation replaces manual labour by employing control systems like sensors and programmable machines to handle repetitive tasks, while higher-level cognitive functions such as planning and decision-making remain under human supervision (Tiwary et al., 2017). By minimizing human involvement, automation ensures precision, reduces downtime, and improves production efficiency, making it vital in industries that depend on uninterrupted operations.

In bottling plants, Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) systems are widely employed to automate processes such as filling and capping. PLCs offer real-time control and are known for their simplicity, cost-effectiveness, and reliability. SCADA systems, on the other hand, monitor operations remotely, providing real-time process, visualization and enabling efficient troubleshooting (Suryawanshi *et al*., 2017).

In the proposed system, a conveyor transports bottles to the filling station, where it stops briefly to fill the bottles with a specified volume. Once filled, the bottles are moved to the capping section for sealing, before being directed to the exit. The process continues seamlessly as a new batch of bottles enters the line, ensuring a continuous production flow (Elahi *et al*., 2017). The benefits of automating the bottling process are substantial. It reduces production costs, improves worker safety by minimizing physical labour, boosts productivity, and enhances system reliability.

Objective of the Study

The main aim and objective is to automate Bottle Filling and Capping System Using Programmable Logic Controller and Supervisory Control and Data Acquisition for Enhanced Efficiency in Small-Scale Manufacturing

Statement of the Problem

Many small scale industries faces difficulties in bottling their products, thereby leading to wastage, reduce the staff morale and causes physical strain.

2.0 Materisls and Methodology

Bottle Detection Using Sensors

At the input side of the conveyor, bottles are securely positioned in designated holders attached to the conveyor system. Sensors are employed to detect the presence of bottles within these holders, triggering the appropriate filling and capping operations. A time delay is introduced to ensure the accurate detection and status setting of the bottles. If a specific bottle (e.g., bottle 1) is detected, the corresponding status bit in the PLC is set to 1; otherwise, it remains 0. The sensor outputs are transmitted to the PLC, which controls the filling and capping operations based on this input. When all the bottles on the input side are detected, the sensor signals, prompting the PLC to activate the corresponding pumps for the filling process. Conversely, if a bottle is missing, the associated pump remains inactive, preventing unnecessary operations. This ensures that the system efficiently handles only the bottles present on the conveyor, minimizing waste and operational errors.

Fig 2: Filling Operation

Bottle Filling Operation

Once the bottles are detected in the input side of the conveyor, the motor switches ON and it starts moving in the forward direction. The bottles then reach the desired position for filling and the conveyor stops. The corresponding pumps in process tank switch ON and filling operation takes place. If only bottle 1 is present then pump 1 switches ON and pump 2 and pump 3 remain switched OFF. There are three tanks present in the filling side namely: *process tank, concentrate tank (tank 1)* and *water tank (tank 2)*. Tank 1 and tank 2 have low level and high level sensors (LLS and HLS) respectively. Process tank has three level sensors (LLS, HLS and MLS). MLS is used to denote the middle level of the tank. When the liquid in the process tank reaches below low level (LLS) pumps in tank 1 and tank 2 switches on and the process tanks get filled. When the level of liquid reaches high level (HLS) the pumps in tank 1 and 2 switch off.

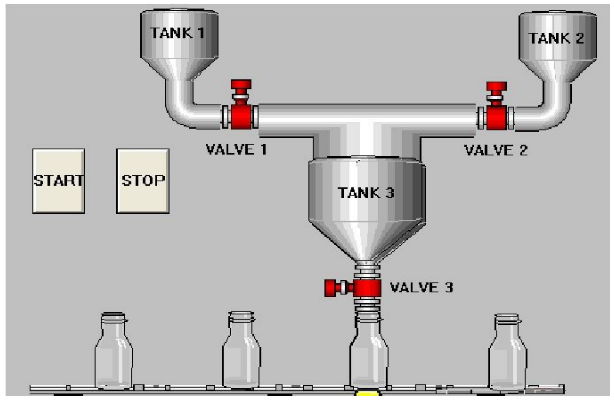


Fig 3. Process Description

USER-DEFINED VOLUME

The filling operation is accompanied with a user-defined volume selection menu. The desired volume is fed into the PLC and depending on the volume the filling of liquid takes place. The filling is done using timing operations. Thus the pump remains on for the pre-set value of the timer and switches off once time is out. Once the filling process is done the conveyor starts moving again.

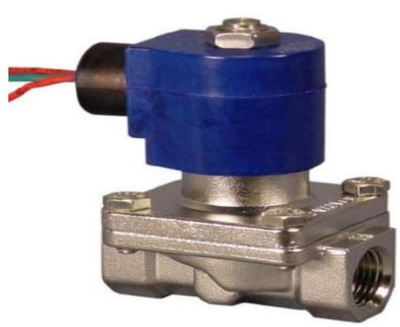
Hardware Components of Bottle Filling System

SOLENOID VALVE

A solenoid valve is an electromechanical controlled valve. The valve features a solenoid, which is an electric coil with a movable ferromagnetic core in its centre. This core is called the plunger. In rest position, the plunger closes off a small orifice. An electric current through the coil creates a magnetic field. The magnetic field exerts a force on the plunger. As a result, the plunger is pulled toward the centre of the coil so that the orifice opens. This is the basic principle that is used to open and close solenoid valves.

Solenoid valve is a control unit that when electrically energized or de-energized, either shuts off or allows fluid flow. The actuator takes the form of an electromagnet. When energized, a magnetic field builds up which pulls a plunger or pivoted armature against the action of a spring. When de-energized, the plunger or pivoted armature is returned to its original position by the spring action valve.

Fig 4: A solenoid valve



HOSE

A hose is a flexible hollow tube designed to carry fluids from one location to another. Hoses are also sometimes called pipes (the word pipe usually refers to a rigid tube, whereas a hose is usually a flexible one), or more generally tube Hose. The shape of a hose is usually cylindrical. Hose design is based on a combination of application and performance. Common factors are size, pressure rating, weight, length, straight hose or coil hose, and chemical compatibility.

Fig 5: Hose

PROXIMITY SENSOR

This sensor detects the presence of nearby objects without any physical contact. A proximity sensor often emits an electromagnetic field (infrared, for instance), and looks for changes in the field or return signal. The object being sensed is often referred to as the proximity sensor's target. Different proximity sensor targets demand different sensors. For example, capacitive proximity sensors or photoelectric sensors are suitable for a plastic target; an inductive proximity sensor always requires a metal target. Proximity sensors can have high reliability and long functional life because of the absence of mechanical parts and lack of physical contact between the sensor and the sensed object.

Fig 6: Proximity Sensor

PIPE

Plastic pipe is a tubular section, or hollow cylinder, made of plastic. It is usually, but not necessarily of circular cross-section, used mainly to convey substances that can flow—liquids and gases (fluids), slurries, powders and masses of small solids. It can also be used for structural applications; hollow pipes are far stiffer per unit weight than solid Pipes.

Fig 7: Plastic Pipes

FLOAT SWITCH SENSOR

A float switch is a type of level sensor, a device used to detect the level of liquid within a tank. The switch may be used to control a pump, as an indicator, an alarm, or to control other devices.

Some float switches contain a two-stage switch. As liquid rises to the trigger point of the first stage, the associated pump is activated. If the liquid continues to rise, (perhaps because the pump has failed or its discharge is blocked), the second stage will be triggered. This stage may switch off the source of the liquid being pumped; trigger an alarm, or both.

Where level must be sensed inside a pressurized vessel, often a magnet is used to couple the motion of the float to a switch located outside the pressurized volume.

Fig 8: Float switch sensor

DC SUBMERSIBLE WATERPUMP

A submersible pump (or sub pump, electric submersible pump (ESP) is a device which has a hermetically sealed motor close-coupled to the pump body. The whole assembly is submerged in the fluid to be pumped. The main advantage of this type of pump is that it prevents pump cavitations, a problem associated with a high elevation difference between pump and the fluid surface. Submersible pumps push fluid to the surface as opposed to jet pumps which create a vacuum and rely upon atmospheric pressure. Submersibles are more efficient than jet pumps.

Fig. 9 DC submersible water pump

SCADA DESIGNS

Programmable logic controller (PLC)

A programmable logic controller (PLC); or programmable controller is an industrial digital computer that has been ruggedized and adapted for the control of manufacturing processes, such as assembly lines, robotic devices, or any activity that requires high reliability control and ease of programming and process fault diagnosis. PLCs were first developed in the automobile manufacturing industry to provide flexible, ruggedized and easily programmable controllers to replace hard-wired relays, timers and sequencers. Since then, they have been widely adopted as high-reliability automation controllers suitable for harsh environments. A PLC is an example of a "hard" real-time system since output results must be produced in response to input conditions within a limited time, otherwise unintended operation will result.

Fig 10: PLC Unit

Overview

PLCs can range from small modular devices with tens of inputs and outputs (I/O), in a housing integral with the processor, to large rack-mounted modular devices with a count of thousands of I/O, and which are often networked to other PLC and SCADA systems.

Fig.11: A Networked PLC and SCADA System

They can be designed for multiple arrangements of digital and analog I/O, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed-up or non-volatile memory.

SCADA Design

SCADA (Supervisory Control and Data Acquisition) systems are essential for high-level process management. SCADA connects Programmable Logic Controllers (PLCs) and other devices to interface directly with the process equipment, providing a centralized command structure. Figure 12 illustrates the SCADA system layout, including control components and interaction points.

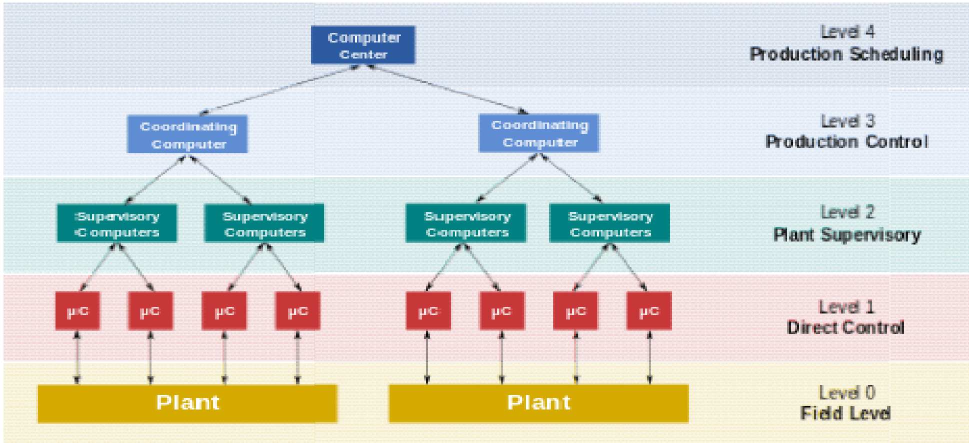


Fig.12: Functional levels of manufacturing control operation

The key attribute of the SCADA system is its ability to perform supervisory operations over a variety of other proprietary devices.

The accompanying diagram is a general model which shows functional manufacturing levels using computerized control.

Referring to the diagram,

- Level 0 contains field devices such as flow and temperature sensors, and final control elements, such as control valves.
- Level 1 contains the industrialized input/output (I/O) modules, and their associated distributed electronic processors.
- Level 2 contains supervisory computers, which collate information from processor nodes on the system, and provide the operator with control screens
- Level 3 is the production control level, which does not directly control the process, but is concerned with monitoring production and targets.
- Level 4 is the production scheduling level.

Level 1 contains programmable logic controllers (PLCs) or remote terminal units (RTUs).

Level 2 contains the SCADA software and computing platform. The SCADA software exists only at this supervisory level as control actions are performed automatically by RTUs or PLCs. SCADA control functions are usually restricted to basic overriding or supervisory-level intervention. For example, a PLC may control the flow of cooling water through part of an industrial process to a set point level, but the SCADA system software will allow operators to change the set points for the flow. The SCADA also enables alarm conditions, such as loss of flow or high temperature, to be displayed and recorded. The RTU or PLC directly controls a feedback control loop, but the SCADA software monitors the overall performance of the loop. Data acquisition begins at the RTU or PLC level and includes instrumentation readings and equipment status reports that are communicated to level 2 SCADA as required. Data is then compiled and formatted in such a way that a control room operator using the HMI (Human Machine Interface) can make supervisory decisions to adjust or override normal RTU (PLC) controls. Data may also be fed to a historian, often built on a commodity database management system, to allow trending and other analytical auditing.

However, SCADA systems may have security vulnerabilities, so the systems should be evaluated to identify risks and solutions implemented to mitigate those risks.

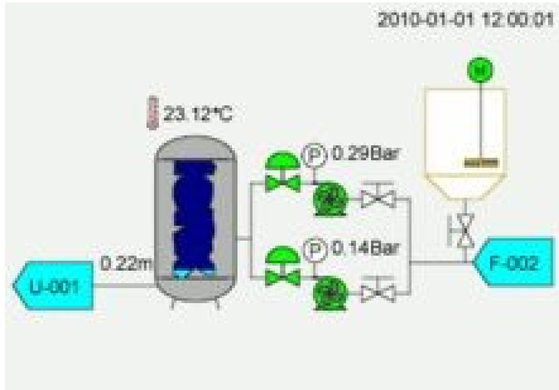


Fig 13: SCADA Components

- PLC/RTU programming

"Smart" RTUs, or standard PLCs, are capable of autonomously executing simple logic processes without involving the supervisory computer. They employ standardized control programming languages such as under, IEC 61131-3 (a suite of 5 programming languages including function block, ladder, structured text, sequence function charts, and instruction list) is frequently used to create programs which run on these RTUs and PLCs. Unlike a procedural language such as the C programming language or FORTRAN, IEC 61131-3 has minimal training requirements by resembling historic physical control arrays. This allows SCADA system engineers to perform both the design and implementation of a program to be executed on an RTU or PLC.

A programmable automation controller (PAC) is a compact controller that combines the features and capabilities of a PC-based control system with that of a typical PLC. PACs are deployed in SCADA systems to provide RTU and PLC functions. In many electrical substation SCADA applications, "distributed RTUs" use information processors or station computers to communicate with digital protective relays, PACs, and other devices for I/O, and communicate with the SCADA master in lieu of a traditional RTU.

Report and Discussion

Constructions and Designs, Mode of Operation

Implementation and Control

In constructing an automated system, two essential components are required: a robust control system and an implementation device. The control system processes mathematical logic to achieve the desired outcomes by implementing functions such as ON/OFF control, proportional regulation, and PID (Proportional-Integral-Derivative) control. This control system is executed through devices like microcontrollers or Programmable Logic Controllers (PLCs), which serve as the main interface for controlling automation tasks. Key components of an automated system include:

- **i.** Sensor
- **ii.** Signal conditioning
- **iii.** Control unit
- **iv.** Actuator
- **v.** Feedback

i. Sensor

These devices detect physical parameters (such as temperature, pressure, or motion) and convert them into signals interpretable by electronic systems. For example, a thermometer measures temperature and displays it, while a thermocouple converts temperature into a corresponding output voltage. Accurate calibration against standard values is critical to ensure reliable sensor performance. Sensors play a pivotal role in fields ranging from consumer electronics to aerospace, automotive, and industrial automation.

ii. Signal conditioning

Signal conditioning manipulates an analog signal to meet the specific requirements of subsequent processing stages. It is often necessary for converting, amplifying, and filtering signals for use in Analog-to-Digital Converters (ADCs). Signal conditioning is commonly executed by operational amplifiers (op-amps) that amplify signals to an appropriate level. Inputs for signal conditioning include DC and AC voltages, currents, frequencies, and electric charges, while outputs may include voltages, currents, frequencies, or relay activations.

iii. Control unit

The control unit acts as the central coordinator within a computer or motor vehicle. It fetches and interprets instruction codes, directing other units' operations through timing and control signals. This unit manages data flow between the Central Processing Unit (CPU) and other devices. In modern computers, the control unit resides within the CPU, while its function remains consistent with its original purpose of directing data flow through the processor.

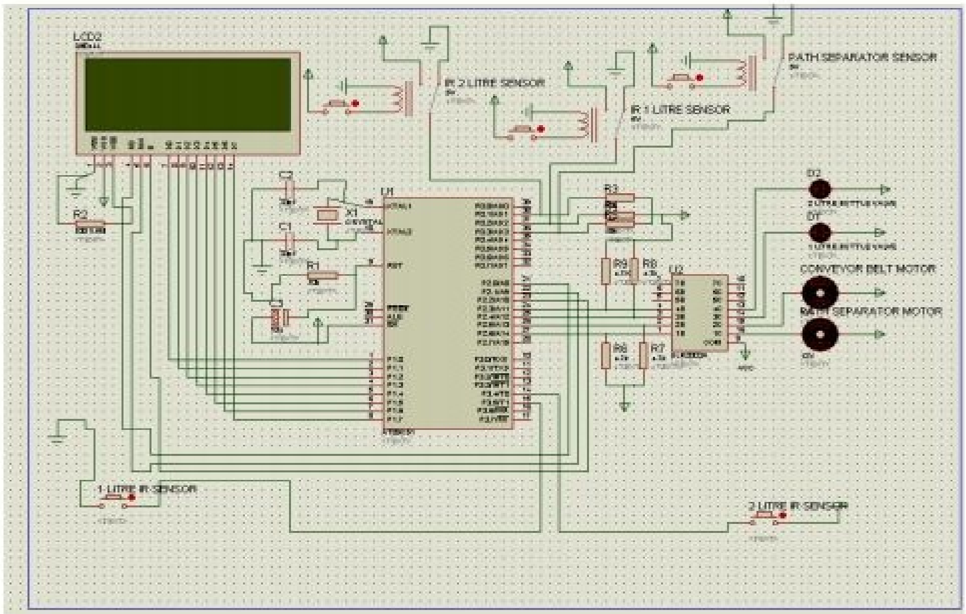
iv. Actuator

An actuator is a motor that moves or controls a system based on a given energy source, typically in the form of an electric current, hydraulic pressure, or pneumatic pressure. It translates this energy into motion, which drives the system's physical actions. Actuators are critical in applications where precise physical responses are required.

v. Feedback

Feedback is a process wherein information about the past or present influences current or future actions, forming a feedback loops. This cyclical flow of information is essential for controlling processes and ensuring consistent and reliable system performance

Simulated Circuit Diagram



The simulated circuit diagram in Figure 16 represents the control layout for the automated system. It includes sensors, relays, and the necessary circuit components integrated with a microcontroller to manage and monitor the various stages of operationFig 14: Circuit Diagram

Mode of Operation

The system operates by using Infrared (IR) sensors strategically positioned at specific heights to detect and sort bottles according to their dimensions. Here's how the operation unfolds:

i. Sorting Stage: When an IR sensor detects a bottle, it sends a signal to the controller. The controller activates a DC motor, which engages a push mechanism to sort the bottles.

ii. Filling Stage: After sorting, the bottle proceeds to the water reservoir area. Upon detection by another IR sensor, the sensor generates a logic signal (logic 1), which triggers two functions in the controller:

- First, the controller halts the conveyor belt by switching off the corresponding motor relay.
- Simultaneously, it activates the solenoid valve using a second relay, initiating the filling process.

Each phase of operation is finely controlled to ensure precise sorting and filling, with real-time adjustments managed through the system's embedded feedback loops.

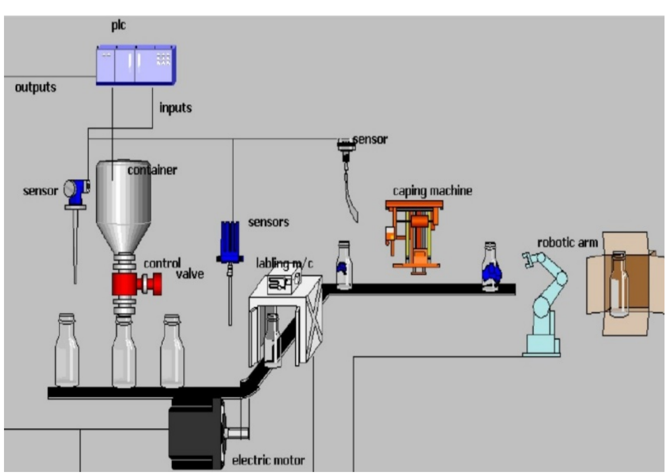


Fig 15: Prototype design of PLC-based automatic bottle filling station

Flowchart of Process

The flowchart in Figure 17 provides a visual summary of the system's step-by-step operational logic, from bottle detection and sorting to the filling process, illustrating how each sensor, actuator, and control signal contributes to the automation workflow.

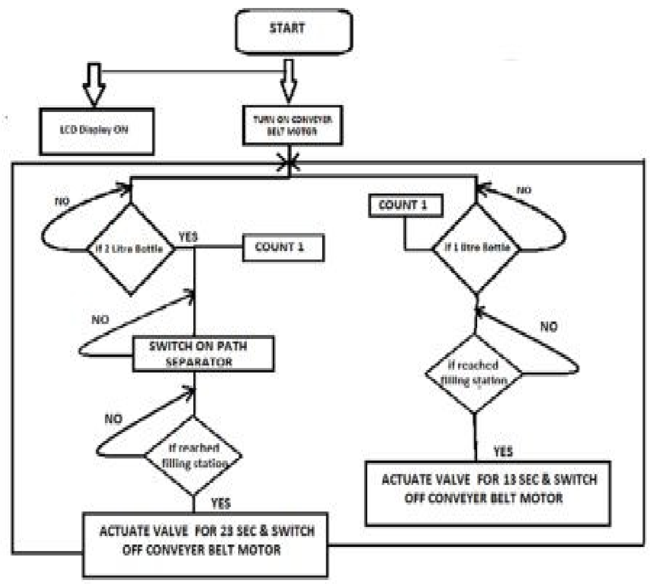


Fig 17: Flowchart of System Operation

The automation of bottling processes, particularly in sorting and filling operations, has demonstrated substantial improvements in efficiency, precision, and consistency. By reducing reliance on manual labour, the automated system decreases the likelihood of human error and significantly enhances production speed.

However, the initial costs of implementing such automated systems are relatively high, and operation requires skilled personnel.

This presents a trade-off between the efficiency gains and the resource requirements for setup and maintenance.

Conclusions

In this study, solenoid-operated valves were successfully used to control liquid flow during the bottle-filling process.

The system was designed to actuate these valves at specific time intervals, which ensured accurate and consistent filling levels for each bottle.

Additionally, height detection was employed to enable bottle sorting based on size, facilitating efficient handling and flow in the system.

Although the automated operations proved effective, the process of manually placing bottles on the conveyor belt pointed to an area where further improvement in material handling could be made.

The findings from this research underscore the trade-offs between manual and automated bottling operations. Manual systems are typically lower in cost and simpler to maintain, making them suitable for smaller-scale production. Conversely, automated systems, while requiring a higher investment, offer scalability, precision, and reliability, which are critical for high-volume production environments. The advantages of automation make it a valuable option for industries aiming to enhance production efficiency and achieve consistent output.

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Can Sump Pumps Provide a Sustainable Solution for Flood Resilience in Nigerian Flood-Prone Households?

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Abstract

Flooding remains a significant challenge for Nigerian communities, especially in flood-prone areas. This study reviews the question, "Can sump pumps provide a sustainable and effective household-level solution for flood resilience in flood-prone Nigerian communities?" Through a review of existing flood management technologies and an analysis of case studies from similar socio-economic contexts, this study explores the potential of sump pumps to improve flood resilience in low-income households. The findings suggest that while effective in managing internal floodwaters, sump pumps face limitations in affordability, accessibility, and reliability, especially in regions with inconsistent electricity supply. However, this technology could offer a viable solution by integrating solar-powered sump pumps and having supportive government policies. Practical recommendations are provided to guide the implementation of sump pumps alongside other mitigation strategies, such as green infrastructure, community-based approaches, and, most importantly, research. This paper concludes by highlighting the need for further research on implementing sump pumps in flood-prone areas of Nigeria to enhance urban flood resilience

Keywords: Flood Mitigation, Urban Flood Resilience, Low-Income Communities, Sump Pumps, Flood Prone Areas.

1. Introduction

Flooding has become a critical environmental challenge in Nigeria, intensified by rapid urbanization, deforestation, and climate change. Urban areas such as Lagos, Port Harcourt, and Ibadan experience frequent and devastating floods, which result in significant economic losses and social disruption. Moreover, these events affect low-income communities, where inadequate infrastructure and poor drainage systems increase the damage. Urban areas are gradually vulnerable due to poor drainage systems and blocked channels, often clogged by waste (Majumder et al., 2022). For many Nigerian households, particularly in flood-prone areas, these frequent flood events lead to property loss, health hazards, and displacement, severely impacting their ability to recover and rebuild. As the intensity and frequency of flooding continue to rise, effective household-level mitigation strategies have become essential to enhance the resilience of vulnerable communities (Louw *et al.,* 2019).

Low-income households in Nigeria face unique challenges when it comes to flood management. With limited access to robust infrastructure, these communities are often left to fend for themselves during flood events, relying on inadequate, reactive measures such as sandbags or makeshift barriers. (UNDP, 2023) The absence of affordable, sustainable flood mitigation technologies means that these households experience repeated cycles of damage and recovery, hindering their long-term development (Oladokun & Proverb, 2016). A key concern in existing flood mitigation strategies in Nigeria is the lack of attention to household-level solutions that are both cost-effective and sustainable, particularly for low-income residents in urban areas.

This paper contends that combined with other flood mitigation strategies such as green infrastructure and improved drainage systems, sump pumps can offer a viable, cost-effective solution to enhance flood resilience in Nigerian low-income households. Most sump pumps can handle between 1,800 and 2,200 gallons of water per hour, ensuring that basements remain dry even during heavy rainfalls. However, the successful adoption of this technology is subject to addressing the challenges related to affordability, accessibility, and reliability, particularly in areas with inconsistent electricity supply. Integrating solar-powered pumps and having supportive government policies will be critical in implementing sump pumps as a sustainable flood mitigation tool.

This study is conducted to answer the question, "Can sump pumps provide a sustainable and effective household-level solution for flood resilience in low-income, flood-prone Nigerian communities?" Specifically, it explores whether sump pumps can provide a practical solution to mitigate flooding in low-income communities where the main infrastructure is insufficient or inaccessible. By assessing the viability of sump pumps in the Nigerian context and comparing their performance with other household-level flood resilience measures, the study seeks to contribute to ongoing discussions on improving urban flood resilience through localized solutions.

2. Literature Review

2.1 Overview of Flood Mitigation Technologies

Flooding in urban and low-income settings has prompted the development of various flood mitigation technologies to minimize damage and enhance community resilience. Flood mitigation strategies generally fall into two categories: structural and non-structural. Structural measures include large-scale infrastructural projects such as levees, dams, and drainage systems designed to manage water flow and prevent inundation (Adelekan, 2016). However, these are often expensive and out of reach for low-income, flood-prone households. On the other hand, non-structural measures focus on minimizing flood damage through risk awareness, early warning systems, and community-based solutions (Parker & Priest, 2012).

Green Infrastructure as a tool for flood mitigation involves rain gardens that absorb and filter rainwater and permeable pavements that allow water to infiltrate, provide insulation, and absorb rainwater. These are regarded as natural and sustainable solutions to reduce flood damage. The recent advancements in mitigating flood levels are the use of innovative technologies. These technologies are increasingly being integrated as a part of flood mitigation strategy. The use of Smart Sensors and IoT devices encourages the real-time monitoring of water levels and weather conditions. Solutions to Flooding are also being considered in households, including homes elevated above expected flood levels, waterproofing walls, and installing backflow valves to prevent sewage from backing up into homes during floods. Given the limitations of large-scale infrastructure for flood mitigation in Nigeria, There is a need to explore household-level technologies as tools for flood mitigation, especially for at-risk communities

Sandbags are among the most widely used household solutions, and they are placed around homes to block water from entering. While cheap and easy to deploy, sandbags offer only temporary protection and are ineffective during severe flood events. Other emerging solutions include rainwater harvesting systems and green infrastructure like permeable pavements, which help absorb rainwater and reduce surface runoff (Chan *et al.,* 2018). In recent years, sump pumps have gained attention for their ability to manage floodwater at the household level, particularly in urban areas where centralized drainage is inadequate (DAE pumps, 2024).

2.2 Sump Pumps: History, Functionality, and Modern Enhancements

The development of sump pumps can be traced back to the early 20th century. The first practical electric submersible pumps were invented by Armais Sergeevich Arutunoff in 1916. His design was initially used for dewatering mines and ships and later adapted for oil drilling. By the 1940s, engineers began applying this technology to residential and industrial water pumping needs, marking the beginning of modern sump pumps. (Jeff, 2021)

A sump pump is designed to remove accumulated water from a sump basin, typically found in the basements of homes. Its primary function is to prevent flooding and keep the area dry. When the water level in the sump basin rises to a certain point, the pump activates and directs the water away from the home to a designated drainage area. There are two main types of sump pumps: submersible and pedestal.

Submersible pumps are installed inside the sump basin and are quieter, while pedestal pumps have the motor above the basin and are easier to maintain (Logan, 2024).

Modern sump pumps have seen significant advancements, particularly in efficiency and reliability. Innovations include:

(i) **Battery Backup Systems:** These ensure the pump continues operating during power outages, common during severe weather events (Logan, 2024).
(ii) **Smart Technologies**: Some sump pumps now have intelligent features that allow homeowners to monitor the pump's status via smartphone apps. These systems can send alerts if any issues exist, providing peace of mind (Logan, 2024)
(iii) **Improved Materials and Design**: Advances in materials science have led to more durable and efficient pumps. For example, corrosion-resistant materials and more efficient motor designs have extended the lifespan and performance of sump pumps (Jeff, 2021).

These enhancements make modern sump pumps more reliable and effective in protecting homes from flooding, which is increasingly important given the rising frequency of extreme weather events due to climate change (Logan, 2024). More recently, solar-powered sump pumps have emerged as a sustainable alternative, particularly in regions with inconsistent electricity supply.

2.3 Case Studies: Sump Pumps in Low-Income Regions

The use of sump pumps has been explored in various low-income and flood-prone regions, providing insights into their applicability in the Nigerian context. In Mumbai, India, a city that faces regular monsoon flooding, sump pumps have been introduced in select urban neighborhoods. Studies show that while sump pumps effectively reduce household flooding, their success is closely linked to the quality of local drainage systems and community awareness regarding pump operation and maintenance (Srinivas & Shaw, 2016). This finding underscores the importance of integrating sump pumps with broader infrastructural solutions.

In Bangladesh, where annual floods are a significant concern, community-driven initiatives have focused on promoting low-cost sump pumps as part of larger disaster resilience projects. These initiatives, led by local NGOs, involve training households on sump pump installation and maintenance. This approach has effectively increased the adoption of the technology and improved flood resilience at the household level (Reja & Shajahan, 2011). Such initiatives could serve as a model for implementing similar projects in Nigerian communities, where affordability and community engagement are key concerns.

In Kenya, solar-powered sump pumps have been piloted in rural areas that face seasonal flooding. These systems have been particularly successful in regions where access to electricity is limited, and the integration of solar technology has reduced operational costs over time. Renewable energy in this context highlights the potential for adapting sump pumps to Nigerian households, many of which experience frequent power outages during storms (Mwangi *et al.,* 2019). However, the upfront cost of solar-powered systems remains a challenge, particularly for low-income households, and government or NGO subsidies are required to ensure the extensive adoption of sump pumps.

In the Sherwood Forest neighbourhood of London, Ontario, a comprehensive flood risk reduction program was implemented, which included the use of sump pumps. Homeowners were educated about flood risks and incentivized to install sump pumps and other flood mitigation measures. The program significantly reduced basement flooding incidents, although some challenges were noted, such as the need for regular maintenance and occasional pump failures during extreme events (Sandink, 2011). This case highlights the importance of community engagement and education in successfully implementing sump pumps.

Detroit, a city with many low-income households, has faced significant flooding issues, particularly in its basements. The city promoted installing sump pumps and backflow preventers in its flood mitigation strategy. Using sump pumps helped reduce the frequency and severity of basement flooding. The town also provided financial assistance to low-income households to install these systems (Detroit Free Press, 2021). This case underscores the effectiveness of sump pumps in urban settings and the importance of financial support for low-income communities.

Post-Hurricane Katrina, New Orleans has implemented various flood mitigation measures, including the widespread use of sump pumps. The city provided grants and subsidies to homeowners to install sump pumps and other flood defenses. Sump pumps have played a critical role in reducing flood damage in homes, particularly in low-lying and low-income areas. The success of these measures has been supported by regular maintenance and community education programs (Garcia-Rosabel *et al.,* 2024). This case highlights the importance of financial incentives and maintenance programs in ensuring the effectiveness of sump pumps.

Jakarta, a city with many low-income households, frequently experiences severe flooding due to heavy rainfall and inadequate drainage systems. The local government and NGOs promoted installing sump pumps in residential areas as a flood mitigation strategy. The use of sump pumps significantly reduced the incidence of household flooding. Additionally, training sessions were conducted to educate residents on proper use and maintenance. This case underscores the importance of integrating sump pumps with broader infrastructural improvements and community education (Asdak, 2008).

Manila, a city prone to frequent flooding due to typhoons and heavy monsoon rains, has many low-income households. The government and NGOs promoted installing sump pumps as part of a comprehensive flood mitigation strategy. Using sump pumps helped reduce home water damage and improve community resilience. The program's success was attributed to strong community involvement and support from local authorities. This case highlights the role of community engagement and government support in successfully implementing sump pumps (Tabios III, 2023).

Accra, a city with many informal settlements, faces recurrent flooding. NGOs introduced sump pumps as a low-cost solution to manage floodwaters in these areas. Community-based organizations led initiatives to distribute sump pumps and provide training on their use and maintenance. Adding sump pumps reduced the frequency and severity of flooding in affected households. Community-led maintenance programs were crucial in ensuring the long-term functionality of the pumps. This case demonstrates the effectiveness of community-driven approaches in promoting the use of sump pumps for flood mitigation (Owusu & Obour, 2021).

3. Conceptual Framework

3.1 Key Concepts

Flood resilience refers to the ability of communities, households, or systems to anticipate, absorb, recover from, and adapt to flood events while maintaining functionality (Cutter *et al.,* 2008). This idea emphasizes short-term coping mechanisms during flood events and long-term strategies that enhance adaptive capacity. In urban areas of Nigeria, resilience has typically been compromised by rapid urbanization, poor planning, and limited flood mitigation infrastructure (Abdul-Rahman *et al.,* 2018).

Household-level flood mitigation focuses on interventions at the household scale that can reduce the impact of floods. This approach is critical for vulnerable communities where centralized flood management infrastructure is unavailable or ineffective (Abebe *et al.,* 2020). Such measures include structural interventions, like sump pumps, and non-structural interventions, such as community awareness and disaster preparedness (Martinez *et al.,* 2020).

At-risk communities are particularly vulnerable to flooding due to socioeconomic factors, poor infrastructure, and geographical positioning. These communities often lack the resources to implement large-scale flood defences, making household-level interventions even more critical (Sandink & Binns, 2021).

3.2 Role of Sump Pumps in Flood Mitigation

Sump pumps are mechanical devices designed to remove water from flooded areas within a household, typically from basements or low-lying structures. They operate by pumping out excess water into drainage systems, preventing water accumulation during flood events. While commonly used in developed countries, their role in flood-prone, low-income communities—like those in Nigeria—has not been extensively explored.

In the broader context of flood mitigation, sump pumps represent a localized, household-level solution. They provide immediate relief from water inundation but rely heavily on external factors such as reliable electricity or alternative energy sources like solar power.

Solar-powered pumps present a promising solution for flood-prone areas in developing countries, particularly where electricity access is unreliable (Wong, 2019; Giwa, 2021; Kayaga, 2021). Despite this potential, installation and maintenance costs remain a significant barrier to widespread adoption in low-income settings (Bhatt, 2019).

While sump pumps effectively deal with internal household flooding, they are not sufficient as a standalone solution. Their success depends on integration with broader community and urban flood resilience measures, such as improved drainage systems, rainwater harvesting, and green infrastructure (Wri & Ventures, 2014). Large-scale implementation of these systems can lead to significant reductions in flood risk, with discharge reductions ranging from 5% to 15% depending on urban characteristics (Cristiano *et al.,* 2021). Integrating GI with improved drainage can create a more resilient urban environment capable of handling extreme weather events (Copeland, 2015). Moreover, the effective use of sump pumps must consider the community's overall capacity for disaster preparedness and risk reduction in terms of its collective memory, risk-taking attitudes, and trust in mitigation measures (Viglione *et al.,* 2013).

Sump pumps, therefore, fit into a comprehensive flood resilience strategy where multiple mitigation approaches are combined to reduce risk and enhance recovery. By acting as a first line of defense for households, particularly in flood-prone urban areas, sump pumps can complement larger-scale flood management efforts like improved drainage systems or flood barriers (Jha *et al.,* 2012).

4. Discussion

Sump pumps have proven effective in managing localized household flooding by removing water from low-lying areas or basements and reducing water accumulation during severe weather events. In Nigeria's urban settings, where inadequate drainage systems worsen flooding risks, sump pumps can provide immediate relief by preventing floodwaters from entering homes. However, as highlighted in Mumbai, India, and Bangladesh studies, their effectiveness is closely linked to local infrastructure conditions and community engagement (Srinivas & Shaw, 2016; Reja & Shajahan, 2011). Without proper drainage systems, sump pumps risk becoming overwhelmed during extreme weather events, limiting their capacity to provide long-term flood protection. In Kenya, where solar-powered sump pumps were piloted in flood-prone rural areas, they proved highly effective in locations with frequent power outages (Mwangi *et al.,* 2019). Solar-powered sump pumps present a promising solution for Nigeria, where power reliability is a major concern, but the high initial cost remains a barrier. These case studies highlight the need for technological adaptation and infrastructure improvement for sump pumps to serve as a sustainable flood resilience tool in Nigeria.

One of the primary challenges of adopting sump pumps in low-income Nigerian households is affordability. While basic sump pumps can effectively mitigate flooding, their initial costs—with installation and maintenance expenses—may impede households with limited resources (Bhatt, 2019). For example, city-wide efforts to promote sump pump adoption in Detroit were successful only when financial assistance was provided to low-income households (Detroit Free Press, 2021). A similar approach, including subsidies or micro-financing options, could facilitate sump pump adoption in Nigeria.

Also, solar-powered sump pumps, though more sustainable and reliable in areas with unreliable electricity supply, are more expensive, limiting low-income households from accessing these technologies. Government intervention or NGO support to ensure even-handed access to these technologies. As evident in New Orleans after Hurricane Katrina, implementing financing schemes or subsidies would encourage broader adoption and reduce the financial burden on vulnerable communities (Garcia-Rosabel *et al.,* 2024). When comparing sump pumps to traditional flood mitigation measures such as sandbags, they offer a more permanent and effective solution for preventing internal flooding in homes. While sandbags are inexpensive and easy to deploy, they offer only temporary protection during flood events and are often ineffective in cases of severe flooding (Carnevale, 2024). In contrast, sump pumps provide continuous protection by actively removing water from inside homes, reducing the risk of long-term water damage and enabling quicker recovery post-flood. (Logan, 2024)

However, sump pumps should not be viewed as standalone solutions. As demonstrated in Jakarta and Manila, integrating sump pumps with broader flood resilience strategies—such as rainwater harvesting, green infrastructure, and improved community drainage systems—ensures more comprehensive flood protection (Asdak, 2008; Tabios III, 2023). In London, Ontario, for instance, sump pumps were part of a larger flood risk reduction program that also involved public education and infrastructural improvements, which greatly enhanced the overall effectiveness of flood mitigation efforts (Sandink, 2011). Thus, the most effective use of sump pumps in Nigerian households would involve integrating them into a multi-layered flood resilience strategy.

Sump pumps function most effectively when integrated with other flood resilience measures. In urban environments, this could involve combining sump pumps with green infrastructure (GI), such as permeable pavements and rain gardens, which reduce surface runoff and alleviate pressure on local drainage systems (Cristiano *et al.,* 2021). Research has shown that integrating sump pumps with GI solutions can reduce flood discharge by 5-15%, depending on urban characteristics (Copeland, 2015). By absorbing excess rainfall before it accumulates around households, GI solutions complement the action of sump pumps, enhancing their efficiency during extreme weather events.

Community-based flood management strategies further enhance the effectiveness of sump pumps by fostering local ownership and maintenance. In Bangladesh and Accra, community-driven initiatives have shown that engaging local residents in the installation and maintenance of flood mitigation technologies, such as sump pumps, leads to greater adoption rates and long-term functionality (Owusu & Obour, 2021; Reja & Shajahan, 2011). Nigerian communities could benefit from a similar approach, where community-based organizations facilitate training programs on using and maintaining sump pumps, ensuring sustainable, long-term operation.

5. Practical recommendations

5.1 Implementation Strategies

To effectively implement sump pumps in flood-prone Nigerian households, a multi-faceted approach is required. First, subsidizing sump pump costs is critical to ensure affordability for low-income communities. The government could provide financial support for purchasing and installing sump pumps, collaborating with non-governmental organizations (NGOs) and international development agencies, especially in highly vulnerable regions. A pilot test could be initiated in urban areas like Lagos, Ibadan, and other flood-prone areas. These pilot tests would help assess the feasibility and scalability of sump pumps being deployed in different socio-economic settings (Mwangi *et al.,* 2019). Additionally, partnerships with localized private companies specializing in solar-powered pumps could lower the cost of technology.

Training and capacity-building are equally important for successful implementation. Creating training programs for community members, particularly local artisans, is essential for properly installing and maintaining sump pumps. Local governments can engage in public-private partnerships to create workshops or training modules that teach households how to operate and maintain sump pumps efficiently. These capacity-building initiatives would help foster community ownership of the technology and reduce dependency on external help in the long term (Klinsky & Sagar, 2022).

5.2 Community Engagement

For sump pumps to be effectively adopted and maintained, community engagement must be at the core of implementation strategies. Involving local communities in the planning and deployment process increases awareness and ensures that the technology is well-suited to each household's specific needs and constraints. Participatory planning methods, where community members are involved in decision-making, can help tailor sump pump technology to the local context. This approach encourages a sense of ownership and responsibility among the residents, making the technology more sustainable in the long run (Srinivas & Shaw, 2016).

Community education campaigns are essential for raising awareness about the benefits and limitations of sump pumps and the importance of regular maintenance. Workshops, local radio programs, and community meetings can be used to disseminate information about flood preparedness and sump pump operation. Furthermore, educating households on complementary flood mitigation measures—such as ensuring proper drainage around homes and using rainwater harvesting systems—will enhance the community's overall resilience. (Prashar *et al.,* 2023).

5.3 Policy Support

The successful scaling of sump pumps in flood-prone Nigerian households requires strong policy support at both the local and national levels. The Nigerian government should prioritize household-level flood mitigation as part of its broader disaster risk reduction policies. This could be achieved by introducing specific policies that incentivize using sump pumps, such as tax breaks for households that invest in sustainable flood resilience technologies or grants for low-income families to install solar-powered pumps (Novotony *et al.,* 2010).

Another important aspect is integrating sump pumps into urban planning policies. City planners and local governments should consider household-level flood mitigation measures like sump pumps when designing new housing developments or upgrading existing infrastructure in flood-prone areas. By doing so, they can ensure that flood resilience is built into the design of both individual homes and broader community systems. Collaboration between the ministries responsible for urban development, environment, and disaster management will ensure a coordinated approach (Howes *et al.,* 2015).

5.4 The Role of Academia

Academic institutions are crucial in driving innovation and ensuring the long-term success of household-level flood mitigation technologies like sump pumps. Universities and research centers should prioritize research on sustainable and cost-effective innovations in flood resilience, including developing more efficient sump pumps that use alternative energy sources such as solar power.

Moreover, academic research can provide valuable data on the performance of sump pumps in diverse flood scenarios, identifying both the strengths and limitations of the technology. Research should focus on creating models that assess the long-term impacts of sump pumps in flood-prone areas, guiding policymakers on best practices for adoption. Additionally, universities can lead the way in educating future engineers, planners, and environmental managers about the importance of localized, sustainable flood mitigation strategies.

Conclusion

Flooding threatens low-income communities in Nigeria, where inadequate infrastructure exacerbates the effects of frequent flood events. As a household-level flood mitigation tool, Sump pumps, particularly solar-powered models, could be effective in managing localized flooding. However, their extensive adoption faces challenges due to cost, accessibility, and unreliable power supply. Also, there is a need for further research on implementing sump pumps in flood-prone areas of Nigeria to enhance urban flood resilience. Sump pumps can be valuable when integrated with broader flood strategies, such as green infrastructure and community-based approaches. Government policies, financial support, and community education are essential for successful implementation, alongside continued research from academia to refine the technology and tailor it to Nigeria's flooding events. Overall, sump pumps represent a promising component of a complex approach to improving flood resilience in vulnerable communities.

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ENERGY, EXERGY, SUSTAINABILITY AND CARBON IV OXIDE EMISSION ESTIMATION OF MANUFACTURING INDUSTRIES IN NIGERIA

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Abstract

This review paper explores the intricate relationship between energy, exergy, sustainability, andcarbon dioxide estimation in manufacturing industries in Nigeria. The study delves into the fundamental concepts of energy, exergy, and sustainability, emphasizing their significance in driving environmental stewardship and operational efficiency. It highlights the unique challenges and opportunities faced by Nigerian manufacturing industries in managing energy resources, improving sustainability practices, and estimating carbon dioxide emissions. The review examines the energy consumption patterns prevalent in Nigerian manufacturing industries, identifying key areas for energy efficiency improvement and showcasing case studies of successful energy management practices. The paper further explores carbon IV oxide estimation methods, carbon footprint reduction strategies, and the pivotal role of government policies and regulations in managing greenhouse gas emissions. It emphasizes how enhancing efficiency and reducing carbon footprint contributes to a more sustainable future for Nigerian manufacturing industries. Through the presentation of case studies and best practices, the paper showcases successful energy management initiatives, exemplary sustainability programs, and proven carbon reduction strategies adopted by Nigerian Manufacturing Companies. It also addresses the challenges faced in implementing sustainable practices, emerging trends and technologies for enhancing energy efficiency and sustainability, and provides policy recommendations aimed at promoting green practices in manufacturing.

Keywords: Energy, Exergy, Sustainability, Manufacturing Industry.

I. Introduction

Overview of Energy, Exergy, Sustainability, and Carbon Dioxide Estimation in Manufacturing Industries.

In the context of manufacturing industries in Nigeria, the interconnected dynamics of energy, exergy, sustainability, and carbon dioxide estimation significantly influence operational efficiency and environmental impact.

The overall exergy efficiency and energy efficiency can be improved by adopting industrial symbiosis (IS) measures. We found that adjusting the energy structure to use renewable energy and recycling solid waste can greatly reduce CO2 emissions. Many performance indicators of the entire industrial network were also examined in this work. It can be seen that integrated evaluation of energy and CO2 emissions with exergy is necessary to help to mitigate adverse environmental impacts and more effectively fulfill the goals for energy conservation and emissions reduction.

Exergy is defined as the maximum amount of work that can be produced by a system or a flow of matter or energy as it reaches mechanical, thermal, and chemical equilibrium with a reference environment There have been a number of studies conducted that analyzed the energy and exergy of domestic sectors . At present, exergy analysis has been applied on a large scale to the industry sectors and to energy conversion and utilization of specific industrial processes, (Junnian Wu, Ruiqi Wang , 2016)

Energy is vital for industrial processes, and understanding energy sources and utilization is crucial for efficiency. Exergy represents usable energy that can improve process design and performance. Sustainability is important for economic, environmental, and social balance in Nigerian manufacturing. Monitoring carbon dioxide emissions is critical for evaluating environmental impact and implementing mitigation strategies. According to International Energy Agency (2010), by the year 2030 the coal consumption rate will be more than 6000 million tonnes of carbon equivalents, and across the globe, 42% of electricity supply mainly comes from the coal power plants

Importance of Studying Manufacturing Industries in Nigeria

The study of manufacturing industries in Nigeria is crucial for economic development, energy efficiency, technological innovation, environmental impact, job creation, resource management, and global competitiveness. Understanding and analyzing these sectors can lead to policy formulation, improved operational practices, and enhanced growth opportunities for the country. (A. Ileri et al.1998)

Purpose and Scope of the Review Paper

This review paper examines energy, exergy, sustainability, and carbon dioxide estimation in Nigerian manufacturing industries, analyzing energy consumption patterns, exergy efficiency, sustainability practices, carbon dioxide emissions, policy implications, challenges, opportunities, and future directions for promoting a sustainable and energy-efficient manufacturing sector in Nigeria.

Energy in Manufacturing Industries

Definition of Energy and its Types

Energy can be defined as the capacity to do work or produce heat. It is a fundamental concept in physics and plays a crucial role in various aspects of our daily lives, including industrial processes, transportation, and electricity generation. In the context of manufacturing industries in Nigeria, energy is a key input that fuels production activities, drives machinery, and supports economic growth.

Energy Consumption Patterns in Nigerian Manufacturing Industries

Challenges and Opportunities for Energy Efficiency Improvement.

Energy consumption in Nigerian manufacturing industries plays a vital role in economic growth and development. Fossil fuels like oil, natural gas, and coal are primarily used for energy needs. Challenges with electricity supply lead to reliance on backup generators. Fuel consumption includes diesel, petrol, and gas usage. Energy efficiency measures, renewable energy integration, and government policies are essential for optimizing energy usage and sustainability."

The challenges faced by manufacturing industries include high energy costs, aging infrastructure, limited awareness, inadequate financing, and complex production processes. However, there are opportunities for improvement through technology innovation, energy management systems, employee engagement, renewable energy integration, government support, and partnerships and collaboration. These strategies can help optimize energy usage, reduce waste, and create a culture of energy efficiency within organizations.

Case Studies or Examples of Energy Management Practices

Energy management practices play a crucial role in improving efficiency, reducing costs, and enhancing sustainability in manufacturing industries. Here are some real-world case studies highlighting successful energy management initiatives implemented by manufacturing companies:

1.Toyota Motor Corporation

Overview : Toyota is renowned for its commitment to sustainability and energy efficiency in its manufacturing operations.

Energy Management Practice : Toyota implemented a comprehensive energy management system that includes energy audits, performance monitoring, and continuous improvement processes.

Results : The company achieved significant energy savings through measures such as energy-efficient lighting, optimized production processes, and employee engagement programs. Toyota's energy management practices have not only reduced operational costs but also lowered carbon emissions and enhanced operational resilience.

2. Unilever

Overview : Unilever is a multinational consumer goods company that has made a commitment to reducing its environmental footprint.

In Energy Management Practice , Unilever adopted a holistic approach to energy management, incorporating energy-saving technologies, renewable energy integration, and energy efficiency training for employees.

Results : By investing in energy management practices, Unilever has achieved notable reductions in energy consumption and greenhouse gas emissions across its global manufacturing facilities. The company's efforts have not only led to cost savings but also improved brand reputation and stakeholder engagement.

3. Siemens

Overview : Siemens is a leading industrial technology company all over world, prioritizes energy efficiency and sustainability in its operations.

Energy Management Practice : Siemens implemented an advanced energy monitoring and control system to optimize energy usage in its manufacturing facilities. This system allows real-time monitoring of energy consumption, identifies inefficiencies, and enables proactive energy management decisions.

Results : Through the implementation of energy management practices, Siemens has significantly reduced energy waste, increased operational efficiency, and achieved cost savings. The company's commitment to continuous improvement in energy management has positioned it as a leader in sustainable manufacturing practices.

4. General Electric (GE)

Overview : GE is a global conglomerate with diverse business operations internationally, including manufacturing.

Energy Management Practice : GE has embraced a culture of energy efficiency and innovation, leveraging advanced technologies such as data analytics, artificial intelligence, and predictive maintenance to optimize energy consumption in its manufacturing processes.

Results : By focusing on energy management best practices, GE has improved resource utilization, minimized downtime, and enhanced overall operational performance. The company's strategic approach to energy management has not only reduced costs but also paved the way for future growth and competitiveness in the market.

Knowledge of energy and electrical efficiency is essential to design, analyze, optimize and improve energy systems through appropriate energy policies and strategies. If such policies and strategies are implemented, many measures can be implemented to improve the efficiency of industrial boilers.(Kanoglu et al., 2007).

Exergy Analysis in Manufacturing Industries

Explanation of Exergy and its Relationship to Energy

Exergy evaluates energy quality by considering factors like temperature, pressure, and entropy. It measures the potential of energy to perform useful work and is used by engineers to assess efficiency and work output. Analyzing exergy flows helps optimize resource utilization, minimize waste, and improve system efficiency in manufacturing processes. It also provides insights into the environmental impact of energy conversions, enabling organizations to make sustainable decisions. In the realm of technological advancement, exergy analysis acts as a valuable tool for Exergy analysis is a modern thermodynamic method that complements energy analysis by incorporating both the first and second laws of thermodynamics. It aims to identify and quantify inefficiencies in thermal or chemical processes. By evaluating different thermodynamic factors, exergy analysis helps in understanding process effectiveness and identifying opportunities for improvement (Zafer Utlu, Arif Hepbasli, 2007).

Dincer et al. (2004) have also described in detail the links between energy and exergy, exergy and the environment, energy and sustainable development, and energy and exergy policy elsewhere. And exergy seems to be a key concept because it provides a link between the physical and technical world and the surrounding environment, and expresses the true efficiency of technical systems, making it a useful concept for finding improvements.

Exergy measures a system's potential to do work, representing the maximum work that can be extracted. Unlike energy, it can be consumed or destroyed due to irreversibilities. Exergy analysis requires fully specifying a reference medium's state, allowing for detailed evaluation of potential work and identifying areas for improvement in efficiency and sustainability.The exergy (E_x) contained in a system may be written as:

$$E_x = S(T - T_o) - V(p - p_0) + N_k (\mu_k - \mu_{ko})$$

where the intensive properties are temperature (T), pressure (p), and chemical potential of substance k (μ_k); and the extensive properties are entropy (S), volume (V), and number of moles of substance k (N_k). The subscript "0" denotes conditions of the reference environment. It is evident from this equation that the exergy of a system is zero when it is in equilibrium with the reference environment (i.e., when $T = T_o$, $p = p_0$, and $\mu_k = \mu_{ko}$ for all k).

Exergy analysis is a method that uses the principles of conservation of mass and conservation of energy, as well as the second law of thermodynamics for the analysis, design and improvement of energy and other systems. The exergy method is a useful tool to achieve the objective of the most efficient use of energy resources, because it helps to determine the true locations, types and sizes of waste and losses.(Marc. A. Rosen , Ibrahim Dincer,2001)

Application of Exergy Analysis in Assessing Energy Systems Efficiency

Exergy analysis is a valuable tool for evaluating energy systems in manufacturing industries, assessing performance, identifying inefficiencies, and optimizing operations. It helps quantify useful work derived from energy sources, pinpoint areas for improvement, and reduce waste. By revealing energy losses and opportunities for recovery, exergy analysis supports process optimization and resource conservation efforts. It also informs design and retrofitting of energy systems, aids in environmental impact assessments, and drives data-driven decision-making for enhanced efficiency and sustainability in manufacturing.

Exergy Analysis in Specific Nigerian Manufacturing Sectors

Exergy analysis in Nigerian manufacturing sectors like cement, food, textile, chemicals, and plastics offers opportunities to optimize energy efficiency, reduce waste, and promote sustainability. By evaluating energy flows and identifying inefficiencies, companies can enhance operational performance, lower costs, and align with environmental regulations. Exergy analysis supports energy-saving measures, process optimization, and resource efficiency to drive sustainable growth and competitiveness across industries in Nigeria.

Benefits and Limitations of Exergy Analysis

Benefits:

Exergy analysis provides a valuable framework for evaluating the efficiency and sustainability of energy systems in manufacturing industries. One of its key advantages is the comprehensive energy assessment it offers. By considering both the quantity and quality of energy flows, exergy analysis goes beyond traditional energy audits to provide a deeper understanding of thermodynamic efficiency within processes and equipment.

Exergy-based indicators have shown promise in addressing various deficiencies in environmental impact assessments. Exergy, as a valid measure, has been used in research studies to assess environmental impacts (Banerjee and Tierney, 2011; Chen et al., 2009; Hau and Bakshi, 2003; Hepbasli, 2008; Kirova Yordanova , 2010. It provides a comprehensive analysis considering material and energy flows, which makes it suitable for the evaluation of complex production chains (Apai et al., 2006; Bakshi, 2000 ; Zhang and Chen, 2010) .

Exergy analysis is a powerful tool for identifying energy losses and inefficiencies in manufacturing operations, allowing companies to prioritize improvements and enhance overall energy performance. It also uncovers optimization opportunities by pinpointing areas for process improvement and technological innovation, leading to increased efficiency and reduced environmental impact (Marc A Rosen, 2021). Additionally, exergy analysis promotes resource efficiency, waste minimization, material and energy recovery, and supports sustainable energy management practices by providing quantitative insights to decision-makers.

Limitations:
Exergy analysis has benefits but also limitations such as complexity and data requirements. Subjectivity in quantifying exergy destruction and challenges for SMEs in conducting assessments are also concerns. Additionally, focusing solely on thermodynamic efficiency may overlook other important sustainability metrics. The dynamic nature of manufacturing systems presents challenges in capturing all interactions. A holistic approach and continuous monitoring are necessary for long-term sustainability.

Sustainability Practices in Nigerian Manufacturing Industries

Definition of Sustainability and its Principles
Sustainability involves meeting present needs without compromising the ability of future generations to meet their own needs, encompassing environmental, social, and economic dimensions for long-term well-being. In Nigerian manufacturing industries, sustainability practices are essential for addressing challenges related to resource depletion, environmental degradation, social inequalities, and economic instability. Strategies include promoting eco-friendly businesses, supporting SMEs in adopting sustainable practices through capacity building, financial assistance, and collaboration among stakeholders (Tawanda Collins Muzamwese, 2016).

The content emphasizes the importance of responsible management, conservation of natural resources, reduction of waste and pollution, and protection of ecosystems in Nigerian manufacturing industries. It also discusses the need for sustainable practices, social equity, economic viability, inter-generational solidarity, transparency, accountability, collaboration, and resilience in order to achieve long-term sustainability and competitiveness.

Sustainable Manufacturing Initiatives in Nigeria
Nigeria is working to incorporate sustainability practices in its manufacturing sector through initiatives such as national policies, green manufacturing programs, renewable energy adoption, waste management initiatives, water conservation measures, sustainable supply chain practices, employee training, and certification standards to promote environmental, social, and economic prosperity.

Strategies for Improving Sustainability Performance

Nigerian manufacturing industries can improve sustainability by transitioning to renewable energy sources, implementing efficient resource management practices, focusing on green supply chain management, investing in sustainable technologies, training employees on sustainable practices, monitoring key sustainability metrics, and collaborating with stakeholders. Compliance with environmental regulations is also crucial.

Impacts of Sustainable Practices on Business Operations

Implementing sustainable practices in business operations can lead to cost savings and enhanced reputation. By adopting energy-efficient measures and reducing waste, companies can lower operational costs and attract stakeholders. This commitment to sustainability ensures regulatory compliance, protecting the environment and the company's reputation. Sustainable practices improve operational efficiency, boosting productivity and competitiveness. They also mitigate risks and enhance resilience for long-term success. Employee engagement and retention benefit from a focus on sustainability. Market differentiation is another advantage, appealing to environmentally conscious consumers and setting the company apart from competitors.

Overview of Greenhouse Gases and Carbon Dioxide Emissions

Greenhouse Gases (GHGs) :

Greenhouse gases, such as carbon dioxide, methane, nitrous oxide, fluorinated gases, and water vapor, trap heat in the Earth's atmosphere, leading to global warming. Carbon dioxide, mainly from human activities like burning fossil fuels and industrial processes, is a significant contributor to climate change. Manufacturing industries, responsible for significant CO_2 emissions, must take steps to reduce their carbon footprint through sustainable practices and cleaner technologies to mitigate their impact on the environment.Estimation of Carbon Dioxide Emissions in Manufacturing Industries :

In manufacturing industries, carbon dioxide emissions can be categorized into direct emissions from on-site combustion of fossil fuels, indirect emissions from off-site electricity generation, process emissions from chemical reactions, and lifecycle emissions encompassing the entire product life cycle. The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol aim to reduce CO2 emissions to combat global warming. China's rapid economic growth over the past two decades has led to a significant increase in CO2 emissions and other pollutants in urban areas (Xianting Li, Chuck WF Yu, 2012).

Importance of Reducing Carbon Dioxide Emissions :

Reducing carbon dioxide emissions is crucial for mitigating climate change and its adverse impacts on the environment and society. Limiting CO2 emissions helps slow down climate change, reduce its effects on ecosystems, weather patterns, and environmental balance. Additionally, reducing emissions is essential for regulatory compliance with laws and targets in many countries. Governments require industries to decrease their carbon footprint to demonstrate environmental responsibility and avoid penalties. Efforts to reduce emissions lead to improved resource efficiency and operational sustainability in manufacturing processes. This focus enhances resource management practices, resulting in cost savings, increased competitiveness, and long-term business viability. Optimizing resource use reduces emissions, streamlines operations, minimizes waste, and creates a sustainable production model benefiting both the environment and profitability.

Methods for Estimating Carbon Dioxide Emissions in Manufacturing

The methods for estimating carbon dioxide emissions in manufacturing industries include direct measurement, fuel consumption data, grid emission factors, process-based calculations, emission inventory tools, lifecycle assessment, and third-party verification. These methods help companies understand and manage their carbon footprint

Carbon Footprint Reduction Strategies in Nigerian Industries

Effective strategies for reducing the carbon footprint of Nigerian industries include focusing on energy efficiency improvements, waste management and recycling, sustainable supply chains, green building practices, employee engagement and training, and participating in carbon offsetting initiatives. By implementing measures like upgrading machinery, optimizing processes, and promoting recycling practices, industries can lower energy consumption and emissions. Sustainable sourcing, transportation practices, and green building features also contribute to decreasing carbon emissions from industrial activities. Engaging employees in sustainability efforts and supporting carbon offsetting initiatives further help industries achieve carbon neutrality and environmental responsibility (Boqiang Lin, Chuanwang Sun 2010).

Role of Government Policies and Regulations in Carbon Management

In the realm of carbon management within manufacturing industries, government policies and regulations significantly influence efforts to estimate and reduce carbon dioxide emissions. Governments set emission reduction targets, implement carbon pricing mechanisms like taxes or cap-and-trade systems, and encourage the adoption of renewable energy sources through incentives and subsidies. They also support research and development in carbon management technologies to drive innovation in reducing emissions. Furthermore, governments mandate monitoring and reporting requirements for industries to track emissions and foster collaboration among industry stakeholders, research institutions, and environmental organizations to drive concerted action towards carbon reduction goals. Additionally, governments enforce carbon management regulations and ensure compliance by imposing penalties for non-compliance, emphasizing the importance of environmental responsibility.

Energy, Exergy, Sustainability, and Carbon Dioxide: Interconnections

Linkages between Energy, Exergy, Sustainability, and Carbon Dioxide Estimation

The relationship between energy, exergy, sustainability, and carbon dioxide estimation is crucial for environmental management and resource utilization. Energy and exergy analyses highlight the importance of efficient resource use to improve sustainability performance. Integrating sustainable practices into these analyses can help industries enhance efficiency, reduce energy consumption, and lower carbon dioxide emissions. Carbon dioxide estimation allows organizations to quantify greenhouse gas emissions and develop strategies to mitigate them, supporting sustainability goals. Life cycle assessment (LCA) can provide a comprehensive view of environmental impacts associated with energy systems when integrated with energy and exergy analysis, aiding in decision-making for sustainable practices and environmental performance improvement.

Energy, exergy, sustainability, and carbon dioxide estimation are interconnected in environmental management.

Energy and exergy efficiency are important for reducing energy consumption and carbon dioxide emissions in industrial processes. Measuring and monitoring carbon dioxide emissions is crucial for meeting sustainability goals by reducing environmental impact. Integrating renewable energy sources into energy systems can help decrease reliance on fossil fuels and promote cleaner energy production methods. Exergy analysis can optimize resource use and minimize waste generation to enhance sustainability. Implementing carbon management strategies and incorporating life cycle assessment into decision-making processes are key for achieving sustainable development goals.

Integration of Sustainable Practices with Energy and Exergy Analysis

Incorporating sustainable practices into energy and exergy analysis is crucial for improving environmental management and resource utilization. By focusing on efficient resource use, industries can minimize waste and reduce their environmental impact. The adoption of renewable energy sources, such as solar and wind power, can help reduce reliance on fossil fuels and decrease carbon emissions. Carbon footprint reduction is a key aspect of sustainability initiatives, and energy and exergy analyses play a vital role in quantifying and reducing emissions. Integrating life cycle assessment with energy and exergy analysis provides a comprehensive view of environmental impacts and helps industries make informed decisions to promote sustainability and improve overall environmental performance.

How Improving Efficiency and Reducing Carbon Footprint Contribute to Sustainability Goals

ctices demonstrate how companies across different sectors have successfully implemented efficient practices to reduce carbon emissions, save costs, and improve their overall sustainability performance. These examples serve as inspiration for others looking to incorporate sustainability into their business strategies.

Case Studies and Best Practices

Successful Energy Management Initiatives in Nigerian Manufacturing Companies

Energy management is crucial for sustainable operations in manufacturing industries. By optimizing energy usage, companies can reduce costs, improve efficiency, and minimize environmental impact. Here are some successful energy management initiatives in Nigerian manufacturing companies:

1. Energy Audits: Conducting regular energy audits to identify areas where energy consumption can be reduced. This involves evaluating equipment efficiency, building insulation, lighting systems, and other energy-consuming processes.

2. Investing in Renewable Energy: Many Nigerian manufacturing companies are investing in renewable energy sources such as solar power to reduce reliance on grid electricity. By generating their own clean energy, companies can lower costs and reduce their carbon footprint.

3. Employee Training and Awareness: Providing training to employees on energy-saving practices and raising awareness about the importance of energy conservation. Engaging employees in energy management initiatives can lead to a more sustainable workplace culture.

4. Upgrading Equipment and Technology: Investing in energy-efficient equipment and technology can significantly reduce energy consumption in manufacturing processes. Upgrading to modern, energy-efficient machinery can lead to substantial cost savings over time.

5. Process Optimization: Implementing process optimization strategies to streamline operations and minimize energy waste. This includes improving production scheduling, reducing idle time, and optimizing workflow to maximize energy efficiency.

6. Monitoring and Data Analysis: Implementing real-time monitoring systems to track energy usage and identify opportunities for improvement. Analyzing energy data can help companies pinpoint areas of inefficiency and develop targeted solutions.

7. Collaboration with Government and Industry Partners: Collaborating with government agencies, industry associations, and other stakeholders to share best practices and access resources for energy management. By working together, companies can drive collective action towards sustainable energy practices.

Exemplary Sustainability Programs and their Impact

These case studies exemplify how exemplary sustainability programs can drive positive impact within organizations, communities, and the environment.

1. Dangote Group's Focus on Sustainability:

Dangote Group, a prominent Nigerian conglomerate, has placed a strong emphasis on sustainability through its strategic initiatives. With a commitment to reducing its environmental impact and enhancing societal well-being, the company has set ambitious targets in areas such as resource efficiency, community development, and responsible sourcing. By implementing sustainable practices across its operations, Dangote Group aims to create long-term value for both its business and the communities it serves. Through initiatives like promoting sustainable agriculture and investing in renewable energy projects, Dangote Group is making significant strides towards achieving its sustainability goals.

2. Cadbury Nigeria's Environmental and Social Responsibility Efforts:

Cadbury Nigeria, a subsidiary of the global confectionery company Cadbury plc, is recognized for its dedication to environmental and social responsibility. The company has implemented various initiatives aimed at reducing its environmental footprint and positively impacting society. Programs such as waste reduction, energy efficiency improvements, and community development projects have been central to Cadbury Nigeria's sustainability strategy. By engaging with stakeholders and promoting sustainable practices within its supply chain, the company not only benefits the environment but also enhances its brand reputation and fosters positive relationships with customers and communities. Cadbury Nigeria's commitment to sustainability serves as a model for other Nigerian companies looking to prioritize environmental and social concerns in their operations.

3. Sustainability Leadership: Lessons from Nigerian Companies like Dangote Group and Cadbury plc:

The sustainability efforts of Nigerian companies such as Dangote Group and Cadbury Nigeria exemplify the positive impact that can be achieved through a focus on environmental and social responsibility. By setting ambitious goals, implementing innovative strategies, and collaborating with stakeholders, these companies are driving change within their industries and contributing to a more sustainable future. Their commitment to sustainability not only benefits the environment and communities but also strengthens their competitive position in the market. As leaders in sustainable business practices, Dangote Group and

Cadbury Nigeria inspire others to follow suit and prioritize sustainability in their own operations, ultimately creating a ripple effect of positive change across the Nigerian business landscape.

Carbon Reduction Strategies that have proven effective

The Dangote Group and Cadbury Nigeria have demonstrated effective carbon reduction strategies through their transition to renewable energy sources and waste management/recycling initiatives, respectively. These initiatives not only align with sustainability goals but also showcase a commitment to mitigating climate change impacts while generating cost savings. Additionally, collaborative supply chain optimization among Nigerian companies and industry stakeholders has proved successful in reducing transportation emissions, optimizing packaging materials, and improving energy efficiency system-wide. These efforts highlight the power of collaborative action in driving impactful carbon reduction outcomes and fostering a more sustainable business ecosystem in Nigeria.

Challenges and Future Directions

Barriers to Implementing Sustainable Practices in Nigerian Industries

Barriers hindering sustainable practices in Nigerian industries include lack of awareness, limited funding, and regulatory complexities. Companies struggle to prioritize eco-friendly initiatives due to a lack of understanding about sustainability. Limited resources and funding prevent investments in sustainable technologies. Unclear regulations and inconsistent enforcement lead to a focus on short-term profits over long-term environmental goals, impeding progress towards sustainability.

Emerging trends and technologies driving energy efficiency and sustainability include:

1. Internet of Things (IoT) and Smart Energy Management Systems: IoT technology and smart energy management systems monitor, control, and optimize energy usage in real time, enhancing efficiency and sustainability.

2. Renewable Energy Integration and Microgrids: Adoption of renewable energy sources like solar and wind power reduces reliance on fossil fuels, cuts emissions, and enhances energy independence through microgrid deployment.

3. Energy Storage Technologies: Advancements in energy storage, such as lithium-ion batteries, support renewable energy integration, peak shaving, and grid stabilization.

4. Building Energy Management Systems (BEMS) and Green Building Technologies: BEMS and green building tech optimize HVAC and lighting for energy savings and improve building performance while reducing environmental impacts.

5. Circular Economy and Resource Efficiency: Transitioning to a circular economy model minimizes waste generation and promotes resource reuse, fostering energy efficiency and sustainability.

6. Artificial Intelligence (AI) and Machine Learning: AI algorithms optimize energy systems, predict demand, and automate management processes for continuous energy performance improvements.

Policy Recommendations for Promoting Green Practices in Manufacturing

Governments can play a crucial role in promoting sustainable practices in manufacturing industries. By establishing green procurement policies, providing financial incentives, and setting targets and regulations for sustainability, they can drive industry-wide adoption of eco-friendly technologies and processes. Additionally, supporting research and development initiatives, fostering public-private partnerships, and increasing access to green technologies can spur innovation and facilitate the transition to sustainable manufacturing practices. Improving data collection and reporting mechanisms while promoting circular economy principles further enhance environmental performance and promote long-term sustainability in the manufacturing sector.

Conclusion

Promoting green practices in manufacturing requires collaborative efforts between governments, industry stakeholders, and other key players. Government leadership is crucial in establishing regulatory frameworks and setting clear targets to drive industry-wide compliance. Manufacturing companies play a key role in investing in eco-friendly technologies and embracing circular economy principles. Access to green technologies and capacity-building programs are essential for enabling manufacturers to adopt sustainable practices. Improved data collection and reporting mechanisms are necessary for monitoring environmental performance and promoting continuous improvement. Promoting circular economy principles, such as resource efficiency and product lifecycle management, can drive sustainable production practices in manufacturing.

The review paper on energy, exergy, sustainability, and carbon dioxide estimation in Nigerian manufacturing industries makes several significant contributions to the field. It enhances understanding of energy and exergy analysis, provides insights into sustainable practices, addresses carbon dioxide estimation and management, offers policy recommendations for environmental improvement, and establishes a framework for future research directions. Overall, the paper consolidates existing knowledge, identifies gaps, and proposes recommendations to enhance environmental performance and sustainable practices in Nigerian manufacturing industries

Recommendations for Future Research and Action Steps:

In summary, the future research and action steps for Nigerian manufacturing industries should focus on conducting longitudinal studies, comparative analysis, technology adoption and innovation, stakeholder engagement, capacity building, policy development and implementation, collaboration and knowledge sharing, as well as monitoring and evaluation. These efforts aim to drive sustainable practices, improve energy efficiency, reduce carbon emissions, and enhance overall performance in the industry

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ASSESSMENT OF THE GEOTECHNICAL PROPERTIES OF LATERITIC SOIL AT VARIOUS DEPTH FOR USE AS PAVEMENT CONSTRUCTION MATERIALS

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Abstract

This study investigated the geotechnical properties of lateritic soils at various depths to assess their suitability as road pavement construction materials. The locations studied include Zone 11, Palm Crest, and Off Olanrewaju, all situated in the Owode Ede area of Osun State. Soil samples were collected from each location at depths ranges between 1-3 meters. The geotechnical tests performed on the samples include: natural moisture content (NMC), specific gravity, grain size analysis, Atterberg limits, compaction characteristics (Maximum dry density and Optimum moisture content), and the California Bearing Ratio (CBR). The results showed that the moisture content in Zone 11, Palm Crest, and Off Olanrewaju decreased with increasing depth. The liquid limit values for all locations exceeded the 35% threshold recommended by the Federal Ministry of Works and Housing. Maximum dry density values increased with corresponding decreased in optimum moisture content values for all the depth samples. Similarly, the CBR values recorded for these locations surpassed the 10% minimum required for subgrade materials. Based on these findings, the lateritic soil from the studied locations is suitable for use as subgrade material for light-traffic roads. However, to be used as a sub-base material, the soil would require improvement with admixtures such as cement or lime.

Keywords: Atterberg limits, California bearing ratio, Compaction, Depth, Locations

Introduction

The geotechnical characteristics of lateritic soil can vary significantly with depth, impacting its suitability for use in pavement construction. A thorough understanding of these changes is essential for effective pavement design and construction. Due to its widespread availability, lateritic soil is often chosen for such projects. In Nigeria and other tropical regions, lateritic soils are reddish and commonly used in construction for roads, houses, airfield pavements, and as foundation materials (Oluremi et al., 2017; Ishola et al., 2019). A lack of sufficient knowledge about soil behavior can lead to structural issues in road construction and other engineering applications, potentially causing significant damage (Oke and Amadi, 2008). In highway construction, the quality of the subgrade the layer that supports the sub-base or pavement is critical to withstand wheel loads. Subgrades that cannot support high loads, particularly clay subgrades prone to swelling when exposed to water, are unsuitable. Poor subgrade conditions, often stemming from inadequate material use, have been linked to road failures and accidents, especially when lateritic soil is improperly applied as a base or sub-base (Nwankwoala et al., 2014). The alarming rate of road accidents due to improper construction materials, particularly in the use of lateritic soil, highlights the need for comprehensive assessment of soil properties (Oke et al., 2009; Nwankwoala et al., 2014). Research on the geotechnical properties of lateritic soils has been conducted in various parts of Nigeria (Bello and Adegoke., 2010; Agbede and Osuolale, 2005 and 2007; Ishola et al., 2024), but limited information is available for the specific area of this study. This research aims to evaluate the geotechnical properties of lateritic soil at different depths to determine its suitability for pavement construction in the study area.

Materials and Methods

Materials

Lateritic soil and water are the essential materials used in this study The locations considered includes Zone 11, Palm crest hotel and off Olanrewaju all in owode ede. Five samples of soils were obtained at every 1m interval up to 5m from each depth. The total soil samples collected were fifteen (15) and was transported to the Civil Engineering Laboratory for analysis. The results of the samples were compared with FMWH (1997) standard.

Methods

The following tests were performed on each samples obtained : Moisture content, Specific gravity, Particle size distribution, Atterberg limit, Compaction test, California bearing ratio (CBR), Unconfined compression test. All the tests were carried out in accordance with procedures described in British standard 1377 (1990).

Natural moisture content

The moisture content of the soil was determined in accordance with BS 1377 (1990) Part 2; Test 1(A). A clean container was weighed and recorded. Then the sample was placed in the weighed container. The container with sample was then weighed to the nearest 0.01g and placed in an oven and dried at temperature 105-110^{0}C for 24 hours. The dried sample and container was weighed to the same accuracy. The moisture content was determined using the equation. The procedure was repeated three times from which the average natural moisture content was determined.

$$w = \frac{M_2 - M_3}{M_3 - M_1} \times 100 \qquad \text{eqn.1}$$

w = Moisture content in percentage

M_1 = Mass of container, (g)

M_2 = Mass of container + wet soil, (g)

M_3 = Mass of container + dried soil, (g)

Particle Size Distribution

The particle size analysis procedure was carried out in accordance with BS 1377 (1990): Part 2. The method of sieving adopted was the wet sieving. 200g of the soil sample was measured using the weighing balance and soaked for 24 hours. The sample was washed using BS sieve No. 200 (75μm aperture) in order to remove the silt content of the soil. The washed soil sample will be oven-dried (105^{0}C) for 24 hours and sieved through a batch of sieves from sieve No. 7 (2.4mm aperture) down to sieve No. 200 (75μm aperture). The mass retained on each sieve was weighed and recorded.

Specific gravity

Specific gravity of the soil was determined according to the BS 1377 (1990) Test (B) for fine grained soils. The mass of empty, dry density bottle was first measure recorded as (m_1). The bottle was then filled with the 200g of the soil sample which had already been air-dried. The bottle and the sample was measured and recorded as (m_2). The bottle was gradually filled with water and shaken to remove entrapped air in the mixture. The mass m_3 of the bottle, soil and water was taken and recorded. Finally, the bottle was emptied, washed and filled to the top with water and also weighed (m_4). All were weighed to the nearest 0.01g. The procedure was repeated for every soil collected at different depth. The soil's specific gravity G_s was calculated from the relationship:

$$G_S = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_1)}$$

eqn..2

G_s = specific gravity

m_1= weight of density bottle (g)

m_2 = weight of density bottle + dry soil (g)

m_3 = weight of bottle + soil + water (g)

m_4 = weight of bottle and water (g)

Atterberg test

Atterberg limits test otherwise known as plasticity test are consistency tests which include the determination of liquid limits, plastic limits and plasticity index of the natural and stabilized soil samples. They were conducted in accordance with Test 1(A) B S 1377 (1990) Part 2 for the natural soil and BS 1924 (1990) for the stabilized soils. In the liquid limit test, 200g of the sample material passing through sieve 425 μm was placed on a clean flat glass plate. Water was added gradually and mixed using palette knife or spatula to form homogeneous paste. A proportion of the paste was filled into the Casangrande apparatus and the top levelled off using a smooth chopping knife. Moisture contents was determined and plotted against corresponding number of blows on a semi-logarithmic paper and liquid limit determined at the moisture content corresponding to 25 blows. The procedure was repeated for soil collected at different depth.

For the Plastic limit test,a portion of the sieved dried natural soil using 425μm aperture was placed on a flat glass plate and mixed thoroughly enough to be shaped into a small ball. The ball was then rolled on the glass plate with palm of hand until it dried sufficiently. The sample was then divided into approximately four equal parts. Each part was rolled into a thread of about 3mm diameter till the thread startedcrumbling by shearing. The crumbled threads were immediately placed in a weighing pan for moisture content determination.
Plasticity Indices of the natural and modified soil samples were derived from the already determined values of liquid limits and plastic limits using equation 3.

PI = LL – PL
eqn. 3

Where
PI = Plasticity Index
LL= Liquid Limit
PL= Plastic Limit

Compaction test

Compaction tests on the soil samples were conducted in accordance with BS 1377 (1990) Part 3, using the British Standard Heavy (BSL) method. A 3 kg soil sample was thoroughly mixed with water until it reached 14-18% of the soil's weight. The wet soil was then placed into a 1000 cm^3 mold, with each of the three layers receiving 27 blows from a 2.5 kg rammer dropped from a height of 300 mm. After compaction, the extension collar was removed, and the top of the soil was carefully leveled using a straight edge. The combined weight of the mold and the compacted soil was then measured, with the previously recorded weight of the mold and base subtracted to obtain the weight of the soil sample.

Maximum dry density

After compaction, the collar was removed and the compacted sample leveled off at the top of the mould with a straight edge. The weight of mould used during the process was taken initially to the nearest 1g (M_1). The mould containing the leveled sample was then weighed to the nearest 1g (M_2). Afterwards, samples were taken from the compacted soil and the minimum of four sets of samples were taken for moisture content determination. The bulk density in Mg/m^3 was later calculated for each compacted layers using:

$$\rho = \frac{M_2 - M_1}{V} \quad \text{eqn.4}$$

Where
ρ= bulk density of the soil (Mg/m^3)
M_1=mass of mould (g)
M_2= mass of mould + compacted soil (g)
V= volume of mould (m^3)

The dry density of the soil was also calculated using

$$\rho_d = \frac{\rho}{1+W} \quad \text{eqn.5}$$

Where
ρ_d= dry density of the soil (Mg/m^3)
ρ=bulk density of the soil (Mg/m^3)
W= moisture content (%).

Optimum moisture content

The corresponding values of moisture content at maximum dry density (MDD) deduced from the graph of dry density against moisture content gives the optimum moisture content (OMC).

Determination of California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) test was carried out in accordance with BS 1377: Part 4 (1990). The soil sample used was first air-dried and pulverized sufficiently to run through BS sieve No. 4 (4.76mm). The specimen was compacted in a standard CBR mould having a nominal internal diameter of 152mm$\pm$0.5mm. The compaction was done in three layers; each being given 62 blows. At the end of the compaction, the top of the mould was properly trimmed with a straight edge to remove excess projected mould soil. The sample was sealed (tied up in polythene bag for 24 hours) to allow for homogeneity of the moisture in the soil sample and to prevent the loss of moisture. The mould, with base plate, containing the sample was placed (with the top face of the sample exposed) centrally on the lower platen of the testing machine with the appropriate annular surcharge discs placed on top of the sample. Plunger was allowed to penetrate the sample and the readings of the force gauge were recorded at intervals of penetration of 0.2 mm to a total penetration not exceeding 7.5mm. The penetration test was repeated for both top and bottom faces of the samples in order to obtain the soaked CBR values for the sample.

RESULTS AND DISCUSSION

Index Properties of Natural Soil

The moisture content of lateritic soil samples obtained at various depth from the three locations Palm crest, Zone11 and off Olanrewaju, all in Owode Ede were presented in Table: 1. In Zone 11, depth soil sample A has the highest moisture content when compared with the other two locations where lateritic soil from sample B has the second highest with sample C that have lowest moisture content value. However, the soil obtained at palm crest, the location C has the highest moisture content value which next to the highest in the location B, followed by location A. Lastly, in off olanrewaju, location, Sample A has the highest moisture content, followed by location sample C then location sample B. The changes in the moisture content recorded were attributed to different in pore pressure of the soils (Eze et al., 2015)

Table: 1. Moisture content of the sample location

Properties / Moisture content	Depth A (1m)	Depth B (2m)	Depth C (3m)
ZONE 11	14.1	13.8	13.5
Palm Crest	10.9	11.2	12.5
Off Olanrewaju	12.5	11.80	11.6

Specific Gravity

The specific gravity of soil samples collected from various locations is shown in Table 4.2. In Zone 11, the specific gravity at depth A is 2.54, followed by depth B at 2.50, and depth C with the lowest value of 2.43. In Palm Crest, the specific gravity at depth A is 2.50, followed by depth B at 2.42, and depth C at 2.38. At Off Olanrewaju, the specific gravity at depth A is 2.58, while depth B is 2.46, and depth C is 2.43. Higher specific gravity in soil indicates greater strength as reported in the study of Ishola et al., 2024.

Table: 2. Specific gravity of the depth samples

Properties / Moisture content	Depth A (1m)	Depth B (2m)	Depth C (3m)
ZONE 11	2.54	2.50	2.43
Palm Crest	2.50	2.42	2.38
Off Olanrewaju	2.58	2.46	2.43

Atterberg Limits

The Atterberg limits, including the liquid limit, plastic limit, and plasticity index for samples collected at three different depths, are presented in Table 4.3. In Zone 11, the liquid limit values for depth samples A, B, and C are 57.2%, 54.3%, and 48.7%, respectively, indicating that sample A has the highest liquid limit among the three. Similarly, for the Palm Crest location, depth samples A, B, and C have liquid limit values of 48.6%, 44.1%, and 41.7%, with sample A again showing the highest value. In the Off Olanrewaju area, the liquid limit values for depth samples A, B, and C are 45.8%, 41.5%, and 38.2%, respectively. These results indicate that the liquid limit values at all locations exceed the 35% threshold required for road construction according to Nigeria's general specifications. (1997)

The plasticity index (PI) of soil samples at various depths in Zone 11, Palm Crest, and Off Olanrewaju are reported in Table 4.3. In Zone 11, the PI values for depths A, B, and C are 23.8%, 24.2%, and 21.1%, respectively, with sample B having the highest PI, followed by samples A and C. At Palm Crest, the PI values for depths A, B, and C are 26.2%, 23.6%, and 19.4%, respectively. Here, sample A has the highest PI, followed by sample B, with sample C having the lowest. In Off Olanrewaju, sample depth A has a PI of 24.2%, sample depth B has a PI of 18.2%, and sample depth C has a PI of 15.7%. The PI values for all locations exceed the 12% threshold recommended for road construction materials by the Nigeria's general specifications. (1997)

Table: 3. Atterberg of the sample location

Properties / Atterberg Limit (%)	Depth A (1m)			Depth B (2m)			Depth C (3m)		
	LL	PL	PI	LL	PL	PI	LL	PL	PI
ZONE 11	57.2	33.4	23.8	54.3	30.1	24.2	48.7	27.6	21.1
Palm Crest	48.6	22.4	26.2	44.1	20.5	23.6	41.7	22.3	19.4
Off Olanrewaju	45.8	21.6	24.2	41.5	23.3	18.2	38.2	22.5	15.7

Compaction characteristic

The maximum dry density (MDD) of depth samples for Zone 11, Palm Crest, and Off Olanrewaju is reported in Table 4.4. In Zone 11, the MDD increases with depth samples, sample A having the highest value at 1.50 Mg/m³, followed by sample B at 1.51 Mg/m³, and sample C at 1.52 Mg/m³. For Palm Crest, the MDD values for the depth samples A, B, and C are 1.44 Mg/m³, 1.45 Mg/m³, and 1.46 Mg/m³, respectively. Meanwhile, Off Olanrewaju shows MDD values of 1.36 Mg/m³, 1.37 Mg/m³, and 1.38 Mg/m³ for samples A, B, and C, respectively. The variation in MDD values recorded was attributed to the differences in their specific gravity (Ishola et al., 2024).

The optimum moisture of content for all the locations-soil samples with variation in depths were presented in Table 4.(b). OMC values raised with an increase in depth for all the three locations A, B and C considered ranging (1.50 – 1.52%); (1.44 – 1.46%) and (1.36- 1.38%) respectively.

Table: 4. (a) Maximum Dry Density of the location sample

Properties/ Maximum Dry Density (Mg/m³)	Depth A (1m)	Depth B (2m)	Depth C (3m)
ZONE 11	1.50	1.51	1.52
Palm Crest	1.44	1.45	1.46
Off Olanrewaju	1.36	1.37	1.38

Table: 4 (b) Optimum Moisture Content of the location sample

Properties/Optimum Moisture content (%)	Depth A (1m)	Depth B (2m)	Depth C (3m)
ZONE 11	16.5	15.3	14.4
Palm Crest	18.3	16.4	15.6
Off Olanrewaju	15.4	14.6	13.8

California Bearing Ratio

The California Bearing Ratio (CBR) results for depth samples taken from three different locations are summarized in Table 4.5. In Zone 11, the CBR values are 13.6%, 13.4%, and 13.1% for samples A, B, and C, respectively. At the Palm Crest site, the values are 14.5%, 13.9%, and 13.2% for the same corresponding depths. For the Off Olanrewaju area, the CBR values are 15.8%, 15.5%, and 15.3% for samples A, B, and C. The CBR value decreased for all the locations with changes in depth and exceeded the 10% minimum required for subgrade material according to Nigeria's general specifications (1997)

Table: 5. The moisture content of the sample location

Properties / California Bearing Ratio	Depth A (1m)	Depth B (2m)	Depth C (3m)
ZONE 11	13.6	13.4	13.1
Palm Crest	14.5	13.9	13.2
Off Olanrewaju	15.8	15.5	15.3

CONCLUSION

i. The moisture content of the Zone 11, palm crest and Off Olanrewaju locations decreases with an increase in depth
ii. Liquid limit values recorded for the locations zone11, palm crest and Off Olanrewaju exceeded the 35% recommended by the Federal Ministry of Works and Housing.
iii. The CBR values recorded for the locations zone11, palm crest and Off Olanrewaju exceeded the 10% recommended for subgrade by the Federal Ministry of Works and Housing.
iv. Based on the results obtained from the locations considered, the lateritic soil could be used as a subgrade material for light traffic road. Improvement is needed on the materials by using admixtures such as cement or lime to be used as a sub-base material.

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Application of Data-driven Technologies in Agricultural Development-A Comprehensive Review

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Abstract

As farming activities become more mechanised, people now look for easier ways of getting things far beyond conventional or conservation agriculture, thereby increasing the activities of agricultural technology around its development. Today, agriculture has transformed from primitive traditional agriculture into a data-driven agricultural technology (AgTech) enterprise that most 20th-century farmers could imagine. Data-driven AgTech is used across the agricultural production value chains to improve efficiency, profitability, and sustainability. This paper reviews the application of different Technologies in agrarian transformation and the trajectory for future development. The paper predicted a promising future of data-driven agricultural technology development with continued innovations as the way out of identified challenges to reposition agriculture toward modern hi-technologies for sustainable growth. Integrated technologies also emerged to increase the effectiveness of smart agricultural machinery and obtain a competitive advantage. These advancements will definitely reshape the future of agriculture and ensure food security for the now future generations.

Keywords: Data-driven AgTech, smart agriculture, digital technologies, autonomous, biotechnology.

1.0 Introduction

As the human population grows, so does the quantity of land dedicated to feeding it; therefore, we will need to produce more food than we already do (Thomasson *et al.*, 2016, Aaron *et al.*, 2020). However, the production rate does not keep up with the expanding population, which is expected to reach 9.8 billion by 2050 (Omitti, 2019, Ntagu *et al.*, 2022) and 7 to 11 billion between now and about 2100, according to a United Nations assessment (Thomasson *et al.*, 2016). Therefore, there is an urgent need to enhance food production. In addition, meeting the demand for increased agricultural productivity is likely to become more difficult due to global climate change, subsistence practices, and a heavy reliance on chemical use, low adoption of conventional machinery among others, which are destabilising agents of the natural processes that allow for food sustainability, thereby creating a gap in meeting global food production.

Furthermore, a large quantity of high-quality agricultural land is being converted for urban and road usage, aggravating the demand for increased food production (Thomasson *et al.*, 2016). These issues considered collectively require an increase in food output per unit area during the next six decades (Thomasson *et al.,* 2016). Solving these difficulties demands an integrated approach to agricultural growth that is linked to the technological revolution. Since the Industrial Revolution, agricultural methods have evolved continuously, culminating in the agriculture (green) revolution in the mid-twentieth century. This transformation began with the reduction of travel distance in nomadic hunter-gatherer practices to machine-aided traditional and conservation agricultural practices, as well as the use of high-tech precision and automated equipment with less human intervention and a sustainable increase in yield (Xinshen *et al.*, 2016).

Several notable advances in the development of new agricultural systems, techniques, and technology have become critical components of self-sufficiency in food and fibre production. Several notable advancements have occurred in the agricultural technological revolution, including digital computers, improvements in data gathering, storage, and processing technologies, and innovations in sensor technology and robots. At each step, farming technology advances resulted in massive gains in crop yields per area of arable land. This massive increase in food production has supported a global population that has quadrupled in size over the last century. However, modern agriculture contributes to the sustainability challenge. The farmers rely on many of these techniques and modifications to boost output (Zhang *et. al.*, 2023).

Attempts to solve these food scarcity concerns relied on two essential tools: crop enhancement and agricultural production optimisation (Thomason *et al.*, 2016). Crop improvement is performed through improvement in the yield quality of agricultural products utilising techniques such as breeding and genetics, and high-throughput phenotyping (HTP), which rely on remote sensing and robotics. Crop output can be optimised using precision agriculture (PA), which largely relies on sensing and robots (Thomasson *et al.*, 2016). These technology tools have ushered in a new era of transforming agriculture into a data-driven, highly efficient industry in which automation (robotics), artificial intelligence (AI), and the Internet of Things (IoT) work together to modernise agriculture (Manish *et al.*, 2023). These technologies enable farmers to optimise resource use, reduce waste, and enhance overall sustainability as discussed in this paper.

2.0 Precision (Smart) Agriculture (PA)

Precision (smart) agriculture is a farm management system that uses high-tech devices to collect information and convert it into knowledge that can support and inform farming decisions on the ground (Kutigi *et al.*, 2018, Mushtaq, 2023). Precision agriculture relies heavily on electronics, Information Technologies (ITs), and communications to measure and determine site, plant, and animal-specific information relevant to sustainable production. A technological revolution in agricultural production has been sparked by precision agriculture, which is the foundation of future agricultural development. New farming techniques and equipment have been developed because of the pursuit of precision agriculture and related agricultural technology.

In addition to addressing pressing ecological, technological, environmental, and economic issues, this agricultural management system helps to advance sustainable agriculture. Crop status, weather forecasts, environmental changes, and the ability to manage fields divided into zones are all data generated by precision agriculture. This allows for the diversification of management decisions for individual field parts, as well as the optimisation of movement techniques, fuel management, and fertiliser amounts. The goals of precision agriculture are to maximise agricultural output while minimising expenses and environmental hazards (Abdulwaheed, 2019). Depending on the sensing technologies used, PA offers data-analysis techniques for multivariate optimisation of mapped data, automation technologies to measure precise production inputs at ideal times and locations, and spatiotemporal field data for precise positioning and mapping.

Precision agriculture approaches involve observing, measuring, and responding to varied data collected in the field. Other precision methods include mechatronic-sowing mechanisms for accurate and variable rate seed metering during planting, as well as the use of sensors to detect the presence of weeds, diseases, or insects, allowing pesticides to be administered only where necessary. Successful precision agriculture necessitates an awareness of site-specific information, the ability to make decisions based on site-specific information, and the use of physical instruments (such as aircraft, drones, and satellite imagery) to inform management decisions. These physical technologies are available for gathering remotely sensed images and analysing them using computer models to produce connections between site-specific variables that are then employed in decision-making. Soil conditions, soil fertility and nutrient content are typical site-specific information, as is crop yield information, which includes satellite images of crop health across the field (Abdulwaheed, 2019). Precision agriculture also monitors the appropriate amount of inputs (water, fertiliser, pesticide, fuel, and labour) needed to create high agricultural yields. Satellite imagery with high spectral resolution is currently available to get accurate data.

2.1 Precision Agriculture Technologies

Several precision technologies for agricultural applications have been developed over the years, necessitating the integration of three basic elements: information, technology, and management. Information is possibly the most significant resource available to modern farmers. Timely and reliable information is critical throughout the production process, from planning to post-harvest (Abdulwaheed, 2019). Crop traits, soil attributes, fertility requirements, weed and insect populations, plant growth response, harvest data, and post-harvest processing data are among the resources available to farmers. The precision farmer must seek out and apply the knowledge provided at each stage of the process.

Information gathering systems include positioning elements (e.g. machine vision, Global Positioning Systems), and know where equipment is located.

The second fundamental component is technology, which is fast expanding into real-time control mechanisms for monitoring and manipulating input reactions such as plant nutrients, herbicides, seeds, water, and other crop production inputs. Physical tools (e.g., aircraft, drones, and satellites) are examples of technology deployment, as are specialised sensors (e.g., real-time kinematics (RTK), laser-based equipment, and inertial devices), actuator devices (e.g., hydraulic cylinders, linear, and rotational electrical motors), and management, which combines the information obtained and the available technology into a comprehensive database system. Database elements such as electronic equipment (e.g., personal computers, embedded computers, industrial computers, etc.) supply information required to build input responses to site-specific conditions. Without the proper management and interpretation of this information, precision crop production will suffer a setback (Abdulwaheed, 2019). Precision agriculture technologies are classified into the following broad categories (Emmi *et al.*, 2014).

2.1.1 Information Collection Systems

Information gathering systems in agriculture, also known as intelligent agriculture, arose from the necessity to develop intelligent agricultural systems for energy and water conservation, as well as pollution-free, high-yielding, and high-quality agricultural produce. Agricultural information collection systems originated from the understanding of managing information from farm methods, equipment, and chemical control, which was enabled by agricultural modernisation principles (including digitalisation) in all aspects of agriculture.

Agriculture technology improves information flow by incorporating huge databases, which allows for faster and more precise analysis, ultimately leading to better decision-making and strategic planning. With advancements in agricultural technology, a wealth of information regarding soil pH, relative humidity, nutrient levels, soil moisture, past weather data, and other field variables can be collected and stored. Other important data that could be gathered include root and surface soil moisture values, vegetation density, crop types, field height, weather conditions such as past precipitation and temperature readings, agricultural activities (irrigation, sowing, harvesting), and many more (Thomasson, 2015). By analysing this data, future results can be predicted, risks appraised, practical cooperative management developed, and best practice judgments taken.

Management information system (MIS)

Management of farming operations is rapidly developing toward the integration of agricultural technology with data documentation to increase farm productivity sustainably. The latest developments are built around Information and Communication Technologies (Kutigi *et al.*, 2018), and the perception of integrating the surroundings in terms of environmental impact to improve the quality of the work environment and the social aspects of farming, ranching, and relevant professions. This helps overcome the difficulties in reading and recording the complexity of the agricultural environment and the beginning of the emergence of automated agricultural operations (Fountas *et al.*, 2015).

The advancement of ICT technology and the establishment of the ISOBUS protocol have considerably accelerated the development of agricultural automation (Fountas *et al.* 2015). The incorporation of precision agriculture technologies into everyday farm activities has given farmers the ability to deal with within-field variability as well as efficiently process and manage a massive amount of available information. However, there is a need to organise, specify, and evaluate the huge volume of information to provide knowledge and decision assistance. The ISOBUS protocol plays an important role in the development of precision agriculture by allowing for more efficient information exchange and storage between a wide range of sensors, processors, monitors, controllers, and software packages within agricultural equipment such as shaft monitors, pressure transducers, and servomotors (Fountas *et al.*, 2015, Abdulwaheed, 2019).

Furthermore, technological developments in onboard monitoring systems, as well as recent advances in tractor technology, allow for the development and implementation of status data connectors, which provide essential information for optimizing field operations and productivity. Technology development for agricultural data management has gained prominence with the advent of technologies such as the Differential Global Positioning System (DGPS) (Fountas *et al.*, 2015), on-the-go sensors (Kuang, *et al.*, 2012), and autonomous vehicles. These advancements necessitate explicit management information systems to control interactive information flow and provide useful real-time guidance for farm operations execution.

The incompatibility of data formats and interface variations make it difficult to integrate data collected by these new technologies into a cohesive farm management system (Fountas *et al.*, 2015). Therefore, the ISOBUS protocol is advised as a standard within the agricultural business to guarantee constant data interchange between the farm computers and the computing devices placed on farm machinery (Fountas *et al.*, 2015). Furthermore, the agricultural equipment sector is shifting to controller area networks for the automation of agricultural vehicle guidance systems and agricultural equipment communication systems with on-board data gathering systems.

Typical data monitoring and collection systems

Typical data monitoring and collection systems include guardian systems, satellite navigation systems, smart sensor network systems, etc.

Agricultural guardian systems: Using satellite imagery, agricultural guardian systems enable farmers to monitor plant health and crop productivity. They offer current data on disease, structural abnormalities, moisture stress, and nutrient levels. The Internet of Things (IoT) platform, image processing tools, machine vision, dead reckoning, remote sensing, GPS, sensor fusion, and steering controller are examples of guardian systems. Geographic Information Systems (GIS), miniature computer parts, posture detection, cloud computing, big data analytics, artificial intelligence, mobile computing, advanced information processing, telecommunications, and automatic control are additional guardian systems (Shamshiri and Ismail, 2013).

Internet of Things (IoT) and image-processing technologies: The Internet of Things (IoT) is a technology that bridges the barriers between the physical and virtual worlds by applying data collection and cognitive processing techniques. With sensors and data collecting capabilities that give farmers real-time information about crop health, weather patterns, and soil conditions, the Internet of Things (IoT) has had a big impact on agriculture. Farmers are able to make data-driven decisions thanks to the Internet of Things' transmission of data to mobile devices or centralised systems (Manish *et al.*, 2023). The Internet of Things (IoT), big data analytics, and digital technology integration have many uses in data management, decision-making, and the revolution of farm gear. Data-driven decision-making will be the norm, with machinery collecting and analysing vast amounts of data to optimise planting, harvesting, and resource management (Manish *et al.*, 2023).

Internet of Things (IoT)-based precision agriculture addresses the issue of autonomous manual data collection by controlling vital information such as soil conditions and air temperature. Internet of Things (IoT) technology had been used to gather information about several agricultural characteristics (things), such as soil moisture, temperature, and humidity via sensors and cameras sent to image processing devices for analysis. In addition, IoT-based computer and mathematical algorithms have been used in image processing approaches to classify images, extract features, and identify patterns. IoT integration extends beyond individual machines to provide connected agricultural ecosystems in which different equipment and devices exchange data. In another development, Mushtaq, (2018) reported the use of the combination of IoT technology and image recognition devices (installed CCTV cameras) in the identification of crop disease, crop growth, and rodents in the field. These technologies now allow us to assess agricultural production on a bigger scale and acquire real-time data on soil conditions, weather patterns, crop health, and equipment performance.

Remote sensing system: The growing capabilities of remote sensing techniques are constantly pushing the boundaries of agronomy and plant science, resulting in the creation of efficient management practices in addition, the selection of superior plant varieties to meet present and future food demand. Farmers can remotely monitor their fields and equipment through IoT-connected cameras and sensors, enabling them to respond quickly to any issues (Manish *et al.*, 2023). Remote sensing system through groundbased radiometric measurements had been used to detect rain (Bosisio and Cadeddu, 2015)

Satellite navigation technology: The use of satellites has transformed agricultural field monitoring by boosting the volume and frequency with which data are acquired. These satellites are outfitted with tools and technology that use visible and infrared light to gather data and images that can be turned into maps that let farmers keep an eye on crop conditions, crop evapotranspiration, crop water needs, and soil nitrogen levels. Satellite navigation technology has advanced rapidly in recent years, allowing for high-precision location services for agricultural labour (He Chenglong, 2014, Yueyang Li *et al* 2020). Satellite positioning and navigation systems have been used for tracking crop monitoring, agricultural machinery positioning, and intelligent operations, and crop growth all season long, even in large, inaccessible regions (Kapoor *et al.*, 2016, Yueyang Li *et al* 2020). The application of satellite technology in precision agriculture mainly reflects in the positioning of agricultural machinery and automatic navigation to reduce agricultural waste resources and improve the rate of utilisation of energy and the quality of agricultural machinery operation (Han, 2017, Chen, 2018).

Presently, it is possible to fully follow machine movement across large areas and estimate the ideal harvesting time by incorporating technologies like automation, robotics, global positioning systems (GPS), and navigation systems into their equipment manufacturing process. Most agricultural equipment manufacturers are currently incorporating competitive cutting-edge technology to boost the efficiency of smart agricultural machinery.

Satellite sensors are capable of detecting, measuring, and recording electromagnetic radiation reflected or emitted by the Earth and its surroundings for later analysis and data extraction. Satellite photos and aerial photographs from agricultural fields can provide extra information via that rely on space-derived data satellite-based platforms and can be refreshed whenever a satellite passes over a field to obtain cloud-free image. This information has enormous promises for helping farmers make water and nutrient-saving decisions.

Mobile technology: The use of Apps with features and market shares connected to agriculture are currently growing. Using smartphones, tablets, and other mobile devices, crop monitoring mobile apps can be used to keep eye on the vegetation in a field. From the convenience of a mobile device, these Apps assists in planning and managing scouting activities, managing weather conditions on the field, and receiving information on current farming events. The ability of mobile applications to operate without an internet connection is just one of the many advantages of this technology in agriculture.

The global positioning system (GPS): The global positioning system (GPS) is a ground-based technology that uses orbiting satellite photographs to collect precise location-specific data in real time near the Earth's surface (Shamshiri and Wan Ismail, 2013). The GPS-equipped receivers detect their location inside an agricultural field and adapt operations to maximise production or efficiency at that spot. For example, a GPS receiver locates a predetermined field location to collect soil samples, analyse and convert them in the laboratory to fertility map in a geographic information system (GIS).

When used in conjunction with farm management software, GPS technology speeds up record-keeping and allows communication between vehicles. Additionally, site-specific management (SSM), a system method to reorganise agricultural systems towards a low-input, high-efficiency, sustainable practice, has been made possible by the GPS, enabling significant advancements in agriculture (Toriyama, 2020). Crop scouting, yield mapping, field boundary mapping, intensive soil sampling, soil property mapping, soil-fertility variability sampling, weed and pest control, vehicle guidance, navigation control, and so forth are some specific areas of GPS applications in agriculture (Abdulwaheed, 2019). Based on indicators like moisture or chlorophyll levels, farmers may track crop conditions in real-time with the use of GPS tracking technology found in planters, smart irrigation systems, and harvesters. A typical example of GPS is the variable-rate technology (VRT) fertiliser applicators used in dispensing required measures of fertiliser across the field.

Geographic Information System (GIS): In precision agriculture, geographic information systems allow farmers to access documents like soil survey maps and plant traits that are often grown in a certain area. For precision agriculture, geographic information systems (GIS) gather, store, process, and display spatial data. The utilisation of these satellites and drones to collect data on particular crops, soil, climate, and topography is one of the most significant applications of this technology in agriculture. To generate digital maps for item features and position data, the GIS uses remote sensing to partition farms into distinct sections, areas, or zones based on soil type, nutrient availability, soil moisture content, pH rate, and pest infestation. Analysing various farm management alternatives by comparing and modifying data layers is another useful GIS capability.

Variable rate technology (VRT): Tractors that utilise variable rate technology in their navigation systems can improve resource allocation by fine-tuning input application rates (Toriyama, 2020). Variable rate technology (VRT) maps can be created using agricultural machinery management data, satellite images, or a combination of the two. The combination of ground and satellite data provides the maximum level of precision in controlling the tractor's inputs. VRA maps, for example, can be used with crop monitoring's space-derived data. Using proper maps for each input type allows growers to make the best use of agricultural inputs including seeds, fertilisers, and insecticides. Variable-rate technology (VRT) enables farmers to apply precise amounts of fertiliser, pesticides, seeds, and other materials to different portions of a field based on their requirements. In addition, farmers can test the soil for nutrients, such as nitrogen, and feed only those areas that lack certain nutrients.

2.1.2 Connected Farming Systems

The transition from smart (precision) farming to connected farming technologies is a good example of how quickly production technology is used in progressive agricultural growth at the turn of the twenty-first century. Unmanned aerial vehicles, autonomous machines, sensor-equipped robots, augmented reality, the Internet of Things (IoT), drones, and satellites are examples of connected agricultural technologies.

Aerial technologies (unmanned aerial vehicles): The introduction of aerial technology for crop management is based on the use of unmanned aerial vehicles (UAVs) to monitor crop conditions, yields, and other field conditions without human scouting. This is part of a significant shift in agricultural production over the years as it expands into commercial scale. The need for quick, constant, dependable, high-resolution image data above manned aircraft for agricultural remote sensing may be satisfied by unmanned aerial vehicles (UAVs) (Thomasson *et al.*, 2016). In a wide range of geographical and environmental investigations, including as mining, forestry, ecology, agriculture, coastal assessments, and river surveys, their use as platforms to gather high-resolution multi-spectral imaging is growing quickly (Han *et al.*, 2020).

Plant breeders and agronomists are interested in its use in determining precise and timely crop development status, including canopy greenness, leaf area, water stress estimation, and numerous geographic parameters (Han *et al.*, 2020). Hyperspectral cameras installed on drones and agricultural aircraft are used by UAV technology to monitor and collect data that is necessary for crop and soil management. Reduced fuel consumption and better outcomes when doing intricate multispectral, thermal, and hyperspectral soil investigations are two advantages of using UAVs in precision agriculture. To optimise crop productivity and prevent crop losses, UAVs can also be used for data analysis and field image resolution in both space and time (Zhang and Kovacs, 2012, Han *et al.*, 2020, Salamí *et al.*, 2020). The visual images gathered through

The visual pictures captured by the UAV's cameras during flight and ground control points (GCPs) are geographically recorded and stitched (mosaicked) together by the data management team to change the pixel placements based on positional data, to create a single huge image of each route pack. To position the acquired data, inertial sensors connected with the aircraft's camera systems, as well as GCPs, are employed to give metadata. Typical examples of airborne technologies are agricultural drones, UAVs for fertiliser applications, self-driving automobiles etc.

Today, the use of UAVs in agricultural productivity and precision fertiliser applications employing airborne flying vehicles like aircraft, helicopters, and scanners has grown in popularity. Fertiliser solutions can be applied by airplane in places where ground application is impractical, especially in hilly regions, forestlands, grasslands, or sugarcane fields. The laborious process of agricultural fertilisation has been made easier by the use of UAVs. Farmers may now target fertilisation much more precisely and with significant environmental benefits by integrating drone-recorded imagery with soil scanning.

*Agricultural drones (*AgDrones*):* AgDrones are small, remotely controlled unmanned aerial vehicles (UAVs) that weigh between 250g and 25kg classified into rotor-type and wing-type. They are embedded with memory cards, propellers, batteries, chargers, and a mission-planning tablet that has incredibly helpful one-click software that allows users to retrieve data and send it to a cloud for processing. High-resolution photos of crops and field features are captured by these UAVs, which are then visually or computationally analysed to reveal variations in light reflection that may indicate plant health or soil composition and be utilised to preserve future treatments. The capacity of agricultural drones to monitor crop progress, check for storm damage, apply pesticides and fertiliser, and make sure crops and livestock are healthy has revolutionised farming in recent years. Some advantages of AgDrones UAVs include low cost per flight and great image detail; nevertheless, the legal framework for their usage in agriculture is still under development (Thomasson, 2015).

Autonomous agricultural machines: Another notable advancement is the development of autonomous machinery, which allows self-driving tractors and robotic machinery to perform tasks with minimal human intervention, reducing the need for manual labour and addressing labour shortages in agriculture. Robots are electro-mechanical self-driving and flying machines that follow a program or circuitry to accomplish specific or a variety of functions in mechanised applications (Mili *et al.*, 2021; Ayanniran *et al.*, 2024a). Usually, autonomous machines, or robots, are designed to take the place of humans in labour-intensive jobs like harvesting crops by hand. The management of repetitive tasks related to precision spraying, irrigation, planting and transplanting, and site preparation has changed with the introduction of self-operated or semi-autonomous robotic devices. To reduce the farmer's workload and maximise process times and expenses, additional areas of use include fruit and vegetable spotting and harvesting, watering, grafting and cutting, trimming, monitoring, and colour classification, among other tasks (Ayanniran *et al.*, 2024a).

Autonomous tractors and drones outfitted with modern sensors can complete tasks with little human interaction. This not only improves efficiency, but also frees up farmers' time for more important tasks. They are outfitted with the necessary instruments (variable application rate sprayers, mechanical intra-row weed control, seed planters, etc.) and are automated for use in self-driving trucks equipped with accurate information collection systems capable of performing precision jobs. Figure 1 depicts a typical autonomous system comprising sensor and actuator systems commonly used in agricultural applications (Emmi *et al.*, 2014). Fully autonomous or robotic field devices are utilised in small-scale agricultural applications such as wine grapes, nursery plants, and some fruits and vegetables. The use of flying robots in agricultural operations, such as UAVs with machine vision and hand-like grippers, enables field-crop inspection for insects, pests, and so on, which is currently done by humans (Thomasson, 2015). With improvements in the Internet of Things (IoT) and the creation of smarter farming equipment, scientists are not only focusing on expanding automation, but also on developing robot navigation systems (Kumar and Ashok, 2021; Ayanniran *et al.*, 2024b).

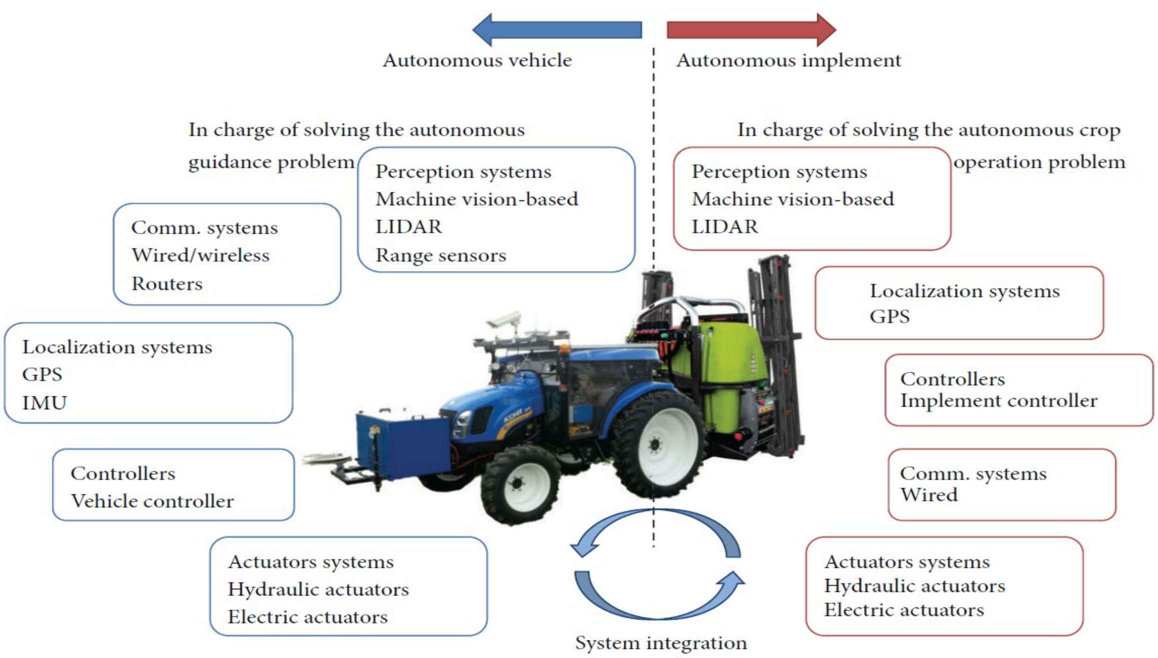

Fig. 1: Autonomous systems used in agricultural applications (Emmi *et al.*, 2014).

Wireless sensor network (WSN)

According to Sahota *et al.* (2011), wireless sensor networks are small, integrated environmental monitoring systems made up of tiny sensors that are used in precision agriculture to collect and send field data by detecting and tracking plant, soil, and weather variables. Within a greenhouse or an area, these systems gather climate parameters like temperature, humidity, and moisture, plant parameters like plant moisture, pest infestations, weed locations, and the size of stalks, fruits, and leaves, as well as soil conditions like temperature and fertility. They then send the data to the closest server via GPRS (Roham *et al.*, 2015). The system provides regular voice and SMS warning services and displays the greenhouse status using a web application, like Google Maps. Wireless sensor networks provide more accurate and efficient remote monitoring and control of related physical surroundings. Machine vision and other sensor technologies are employed in surveillance, climate control, and environmental data collection (Emmi *et al.*, 2014).

The wireless sensor network powered by solar or storage batteries operates when connected to a controller device to collect climatic and environmental data and deliver them into a database (hosted in a webserver at regular intervals), for analysis by Web or Smartphone applications. The WSN has been effectively applied to a variety of farm operations, including ranch automation, which includes auto-watering systems and secure temperature-controlled walls for domesticated animals and homestead valuables (Roham *et al.*, 2015). Other successful applications include lighting frameworks, in-house temperature control and security for ranch houses (Rekha *et al.*, 2012), auto-sprinkler and drip-irrigation frameworks (Hade and Sengupta, 2014), wireless control and irrigation monitoring solutions, remote wireless automation and monitoring of large farms, WSN for precision horticulture, and so on. The use of sensors in harvesting machinery has substantially increased their ability to detect grain moisture, sort harvested fruits on-site, perform selective harvesting, and much more, in addition to identifying ripe from unripe crops. Ultrasonic and other sensors are utilised to determine individual plant conditions at close range (Thomasson, 2015).

Several research findings have proved the usefulness of wireless sensor network technology in precision agriculture; nevertheless, the majority are limited to short-distance applications (Han *et al.*, 2019). Recent research has shown that multifunctional GCP systems and wireless networks interfacing with UAVs can increase GCP setup speed and allow GCP data collecting in real time during UAV flights. According to Han *et al.* (2019), wireless sensor network technology showed great promise for automating real-time communication to increase efficiency and for georeferencing, radiometric, and plant height calibrations to lower remote-sensing mistakes.

Machine learning used with artificial intelligence (AI): When incorporated into agricultural equipment, artificial intelligence and machine learning improve decision-making. Artificial intelligence (AI) algorithms are designed to evaluate data from many sources and offer insights into agricultural conditions, yield forecasting, and pest control. AI-powered equipment aids farmers in allocating resources and planting dates as efficiently as possible. Large volumes of data processed by machine learning algorithms can be utilised to locate patterns and abnormalities in crops, forecast crop disease outbreaks, suggest the best times to plant, and even evaluate the health of livestock using sensor data (Sarkar, 2020). Artificial intelligence-enabled robotic systems can accurately perform human jobs, reducing labour costs and human error (Sarkar, 2020). These devices can operate continuously, increasing productivity and efficiency while maintaining a steady level of crop quality. AI is always evolving, offering new intelligent solutions for agricultural production management. AI-enabled sprayers, for instance, can identify particular weeds and eradicate them without harming the crops being farmed.

Recent developments in connected agricultural systems: Presently, attempts are being made toward developing additional precision technologies, such as high-throughput plant phenotyping (HTPP), which utilise genetics, sensors, and robotics to enable flying robots to operate autonomously to determine important phenotypic characteristics, including height, leaf number, size, form, angle, colour, wilting, and stem thickness, are measured by the technology using several sensors. It provides immediate data or feedback that may be utilised to modify or manage normal functioning (Abdulwaheed, 2019). In related applications, sensors can detect many fruiting locations on thousands of plants on a regular basis. This allows breeders and geneticists to determine which kinds to include or exclude in additional testing, greatly accelerating research to better crops (Thomasson, 2015).

2.1.3 Automated Farming Systems

Automation is the use of machines to carry out tasks that were previously completed by humans or that they would not be able to do otherwise. Around 1946, the automobile industry coined the term "automation" to refer to the growing usage of automated machinery and controls in mechanised production lines. In general, automation is incorporating machines into any self-governing system. Automated systems are becoming more complicated and sophisticated because of automation technology's growing reliance on computers and computer-related technologies. Numerous other developing technologies, including robotics, have earned fame and prestige of their own due to the maturity of this technology.

Automation has changed agricultural operations, allowing farmers to operate more effectively and systematically. Irrigation systems, temperature-controlled systems for livestock and farm goods, fertiliser and chemical applications, and other farm operations have all been automated. Advances in the ongoing development of new agricultural systems and technologies, such as automated agricultural machinery and equipment, have become critical components of this progress.
In advanced economies, the agricultural industry is now heavily reliant on modern technologies such as robotics, automation, and computer-based systems that are replacing the complex tasks performed by humans; however, in developing economies, the sophistication of agricultural methodologies remains focused on the increasing complexity of agricultural system conservation (Aaron *et al.*, 2020).

Although agricultural production has a long history of development, high-tech advancements in agriculture are becoming more prevalent at an accelerating rate. The agricultural system is guided by an autonomous vehicle, such as a modified commercial tractor, specialised platform, or small vehicle, to carry out a cropping operation (such as harvesting, hoeing, and weeding), which is carried out by autonomous tools. There have been several attempts to create a completely autonomous agricultural system that combines self-driving cars with self-driving tools, resulting in unmanned and self-propelled hoeing and intra-row weed control devices that are connected to a tractor's three-point hitch. By scaling up the operational cars, collaborations between numerous autonomous vehicles sharing general tasks simultaneously could increase work rates and enable time-dependent jobs to fulfil deadlines (, Han *et al.,* 2019, Oliveira *et al.*, 2021, La Hera *et al.*, 2024). Such collaboration requires real-time wireless communication among vehicles on a peer-to-peer basis (Emmi *et al.*, 2014, Han *et al.,* 2019).

Robotics innovation in agriculture

Robotics is a subset of automation in which automated machines have anthropomorphic, or humanlike, characteristics, such as powered mechanical arms programmed to move through a sequence of motions to perform useful tasks, such as loading and unloading parts at a production machine or performing a series of spot-welds on the sheet-metal parts of an automobile body during assembly. In farming, robotics refers to the employment of autonomous robots and robotic systems to accomplish a variety of agricultural activities. These robots are intended to work effectively, correctly, and ceaselessly, increasing output while minimizing the need for manual labour. Robotic technology appears to be a promising option for precision agricultural demands because it can do boring operations while maintaining accuracy. As the examples above show, industrial robots are commonly utilised to replace human labour in factory activities. Autonomous devices that work remotely via telemetry are a well-known and effective agricultural robotic technology.
There have been advancements in the development of specialised autonomous robot fleets with the goal of operating agricultural vehicles under unified control. Small aircraft equipped with robotic grippers to move leaves, cameras and machine vision to trap insects, and a variety of other functions that require little human intervention have appeared. Furthermore, there are growing research concepts in robot fleets that provide numerous benefits in the application of appealing complicated and expensive smart machines to replace large and costly repetitive.

Robots are designed to perform efficiently and accurately, and they play an important role in data analysis and decision support. These robots are used for various duties such as fruit picking, weed removal, and even dairy farming. However, robotic agricultural applications have a variety of technological limitations, including an increase in the number of devices (sensors, actuators, and computers/controllers). As the number of fleet units increases, the mean time between failures decreases, which has a substantial impact on fleet reliability and the application of automated systems to real-world agricultural activities.

3.0 Emerging Agricultural Technologies

There is ample proof that the current global resources and technology are insufficient to meet the food needs of the world's expanding population, which is now estimated to be between 8.5 and 9 billion people. A United Nations report (Thomasson *et al.*, 2016) predicted that it will reach 9.5 billion by 2050 (Omitti, 2019; Ntagu *et al.*, 2022) and between 7 and 11 billion around 2100. The difficulty lies in boosting output without having negative environmental effects on food processing and production. The following cutting-edge agricultural technologies typically give answers to these problems.

3.1 Vertical Farming Technology

Instead of using traditional horizontal farming methods, which involve planting crops on dirt in open fields with natural sunshine and irrigation, vertical farming allows crops to be produced in vertical structures within regulated environments (Torres, 2024). With the use of artificial LED lights to replace sunlight, vertical farming is carried out in stacked layers inside climate-controlled structures using artificial growing media like air, water, and controlled structures (Torres, 2024). In comparison to conventional farmed surfaces, this could increase the farmed surface's productivity by a factor of four to six. The concept of vertical farming was established considering the constant population growth on the planet, rising soil deterioration due to erosion, and the worrying population concentration near urban cities.

A wide range of crops can be cultivated in vertical farming making it feasible to increase biodiversity; however, lettuce and other leafy greens are the most popular crops successfully grown in vertical farming, while investigations are ongoing for small fruits (e.g., strawberries), fruiting vegetables (e.g., tomato, pepper), and some larger fruit tree crops (e.g., apple, citrus, and peach). Cereal and row crops (e.g., corn, rice, wheat and soybeans) are still better suited for traditional farming.

Vertical farming benefits the producer, the environment, and consumers. Some of the key benefits of vertical farming are increased land usage for food production, safe and secure plant growing with reduced failure risk, access to fresh, organic, and diversified plants, and the possibility to protect the environment by conserving resources. Other benefits include the capacity to produce any sort of crop without regard to geographical or seasonal variations. However, some significant drawbacks of vertical farming include a lack of sufficient (and free) sunshine, the additional cost of installing artificial light sources, and expensive and energy-intensive humidity control via heating, ventilation, and air conditioning (HVAC) systems (Torres, 2024). Other restrictions include a lack of technological know-how in maximizing crop output under regulated environments.

Since the early 2000s, vertical farming has gained international attention as a cutting-edge agricultural technological option (Ling & Altland, 2021). Despite being a new technology and not being widely used yet, it has enormous growth potential as automation, crop production, and environmental control technologies that increase productivity and lower energy costs. There is crossover between the research being done on vertical farming and greenhouses. Scientists, nevertheless, are creating new, specialised vertical farming methods to meet the demands of their nation. The industry has the potential to significantly overtake roughly 50% of leafy green market supplies during the next ten years, despite the fact that future growth is difficult to forecast (Ling & Altland, 2021).

Common examples of vertical farming techniques include hydroponics, aquaponics, aeroponics, Controlled Environment Agriculture (CEA), and other soilless agricultural systems. Hydroponics is the process of growing plants (without soil) in water that contains nutrient-rich solutions. Aquaponics mixes aquaculture (fish farming) and hydroponics in a closed-loop system. Aeroponics makes use of roots suspended in the air, with the nutrient solution sprayed on them as a fine mist. Controlled Environment Agriculture (CEA) manipulates environmental elements to generate the best conditions for plant growth. Hydroponics and aeroponics techniques use 70% less water than traditional agriculture, conserving more water.

3.2 Biotechnology applications in agriculture

Biotechnology is the application of engineering and technological processes to life sciences, including agriculture, the environment, industry, and medicine. Thus, biotechnology employs biological systems, living creatures, or derivatives to create or change products or processes for specific applications. Biotechnology's application in agriculture, food production, and the environment has advanced to the point where it is now a viable tool for improving almost every conceivable economic aspect of animal and crop agriculture, forestry, aquaculture and fishery, as well as environmental protection. Agricultural biotechnology is the application of scientific procedures and techniques, such as tissue culture, molecular markers, molecular diagnostics, and genetic engineering, to transform economic plants, animals, and microbes for human and environmental benefit.

Biotechnology advancements have made a wide range of contributions to crop improvement, including the development of disease-resistant transgenic crops, genetic modification of transgenic crop varieties that are resistant to insects and diseases, and the development of new crop and animal product species (Kerr, 2019, Ntagu *et al.*, 2022). Aside from the creation of new physical products, biotechnological technologies provide valuable instruments for the conservation and management of existing biological variety, preventing species and genetic loss, and mitigating environmental degradation dangers. Biotechnology has aided in the development and adaptation of rapidly evolving technologies for next-generation sequencing by producing high-density molecular indicators that unravel the crop's genetic variation and identify genomic regions that regulate both quantitative and qualitative breeding traits to speed up this time-consuming crossbreeding

It is no longer helpful to use terms like "conventional" and "modern" to describe the breeding or management of plants and animals in the twenty-first century because biotechnologies are so widespread in the improvement programs of agricultural, aquaculture, and silviculture commodities globally. However, in terms of legislative debate and the perspective of many policy makers and users, distinctions like transgenic and non-transgenic biotechnologies remain genuine and are considered major issues (Mabaya *et al.*, 2015).

Biotechnology applications in plant agriculture

The development of methods like breeding and production; bioprotection and pest control; and the conservation and management of Plant Genetic Resources (PGR) are rapidly developing areas of biotechnology used in agriculture and forestry (Pautasso, 2012). Significant effects of biotechnologies on forestry and crop agriculture output are related to tissue culture-based technologies, such as somatic embryogenesis and micropropagation, which allows for the quick clonal replication of virus-free seedlings (Mabaya *et al.*, 2015, Ogbu and Namayanja, 2021).

Breeding and bioprotection: This entails selecting certain genetic variants of a few chosen plant species via procedures such as hybridisation, induced mutagenesis, controlled introgression of characteristics from multiple populations of the same or other species, and transgenesis. Using sophisticated biotechnology methods to create high-yielding, disease-resistant cultivars with greater palatability in order to rekindle farmers' enthusiasm in crop reproduction. A biotechnology approach has had a significant impact on the breeding of disease-resistant agricultural cultivars (such as maize streak virus and cassava mosaic) (Mabaya *et al.*, 2015; Ogbu and Namayanja, 2021).

Bioprotection entails deploying biological crop protection technologies to combat biotic hazards like pests and diseases. Biotechnology provides critical tools for diagnosing plant illnesses caused by both bacteria and viruses. These methods are especially useful when identifying the causative agent is challenging and knowing the nature of the pathogen is required to create and implement effective management strategies (Pautasso, 2012). In developing countries, diagnostic procedures are commonly employed for quarantine systems as well as seed and propagation material manufacturing.

Biotechnology application in animal husbandry: The use of biotechnology in animal husbandry began with the domestication of animal species in the early years of human civilisation, driven by a desire to obtain traits dictated by social, nutritional, and environmental needs, with no clear understanding of the molecular processes involved (Ahuja and Ramawat, 2014; Ogbu and Namayanja, 2021). Both conventional and biotechnologies have made significant contributions to increasing animal output, which can assist to alleviate poverty and hunger, minimise disease concerns, and promote environmental sustainability. There are already a large range of modern biotechnologies accessible that have already been employed in the major animal science disciplines of animal reproduction, breeding, and genetics; animal nutrition and production; and animal health. Numerous image sensor types, including RGB, multispectral, and thermal sensors, are mounted on UAVs to map phenotypes at the plot or plant scale resolution in order to expedite breeding and genetics research (Han *et al.*, 2020).

Biotechnology application in aquaculture and fisheries: Aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans, and aquatic plants. By farming, this implies modifications and intervention in the production cycle such as regular stocking, sorting, feeding and protection from predators to enhance production (Ahuja and Ramawat, 2014, Ogbu and Namayanja, 2021). Aquaculture covers a wide range of species and methods. It ranges from the production of fish in naturally occurring ponds in rural areas to the intensive culture of ornamental fish in plastic tanks in the middle of a city. Its systems can range from an intensive indoor system monitored with high-tech equipment through to the simple release of fry and fingerlings to the sea, but the aim remains the same to improve production. The four major areas where biotechnology have been used in aquaculture industry include genetic improvement and control of reproduction; biosecurity and disease control; environmental management and bioremediation; and biodiversity conservation and fishery management.

Biotechnology application in biodiversity conservation: Conservation of the earth's plant genetic resources is critical for both traditional and modern plant breeding efforts. Plant biodiversity also generates raw ingredients for the pharmaceutical, nutraceutical, culinary, and crop protection industries. For decades, huge quantities of sampled landraces and wild relatives of cultivated crops, totalling approximately six million samples of plant genetic resources, have been deposited in gene banks owned by national, regional, international, and private gene bank collections around the world. Conservation biotechnology regulates biodiversity in natural and altered ecosystems (including agroecosystems) to ensure renewal, conservation, and productivity, giving benefits and possibilities for current and future generations. Conservation biotechnology includes a wide range of technologies for use in plant (and animal) genetic resources and biodiversity management for food and agriculture, such as Artificial Insemination (AI), in vitro conservation, cryopreservation, DNA banking, micro-propagation, and molecular marker technology (Ogbu and Namayanja, 2021).

3.3 Benefits and challenges of data-driven technologies in agriculture

Benefits of data-driven technologies

1. Increased productivity and sustainability through improved efficiency and reduced labour costs.
2. Improved crop yield and quality through enhanced precision and accuracy in farming operations.
3. Reduce drudgery, decreased physical labour and improved working conditions.
4. Reduced chemical use and improved soil health, thereby promoting environmental sustainability.

Challenges of data-driven technologies

Significant challenges threatening sustainable development of data-driven technology include

1. High initial costs of investment in digital equipment like drone, aircraft, sensors, robots and machinery.
2. Poor governance due to economic instability leading to limited credit access by farmers.
3. Weak infrastructure constraints such as poor roads, storage, and maintenance facilities affects the adoption of agricultural machinery.
4. Government policy and regulatory frameworks on agricultural technology adoption are inadequate, and some of the policies remained unclear towards adoption.
5. Persistence of traditional farming practices over technology adoption

4.0 Conclusion and recommendations

Technological innovations have greatly transformed agriculture into data-driven, highly efficient industry, enabling farmers to optimise resource use, reduce waste, and enhance overall sustainability. In conclusion, a comprehensive analysis of the numerous data-driven agricultural technology advances showed that

1. The future of advancements in the future of data-driven technologies is bright.
2. The challenges of data-driven technology adoption are enormous among the small-scale farmers
3. Government should focus more on developing local infrastructures like access roads etc. that supports agricultural production

4. The persistence of traditional farming practices over technology adoption remained very high

Recommendations

1. Government support for data-driven technology through subsidies and import duties removal on agricultural inputs should be leveraged on
2. Government should do more in creating more accessibility to credit facilities by the farmers at lower interest rates
3. Provide credits and infrastructural supports for low income farmers to grow from the conventional mechanisation practice to data-driven agricultural practices
4. Government policy towards technology adoption should be strengthen via stronger legislations towards technology adoption.
5. Create more awareness through advocacy, workshops and training on the latest transition from the conventional agriculture to the digital agriculture as it is gaining credence globally today.

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Effect of Calcined Cow Bone on Geotechnical Properties of Lateritic Soil using British Standard Light.

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Abstract

Constant pavement damage on Nigerian roads and environmental contamination from solid waste generated at slaughterhouses like cow bones, have been creating serious issues. This study therefore, examined the use of calcined bone ash as soil stabilization treatment and its effect on the geotechnical properties of lateritic soil. The lateritic soil sample was collected from road construction burrow pit and cow bone was collected from Santo abattoir market both located at Offa, Kwara State. The cow bone was calcined at temperature of 500 °C and was pulverized to obtained fine particles termed Cow Bone Ash (CBA). The CBA was used in stabilizing the lateritic soil at ratios of 0, 2, 4, 6, 8 and 10%. Laboratory tests such as Natural Moisture Content, Oxide (XRF), Sieve Analysis test, Specific Gravity test (SG), Atterberg limit test, Compaction (BSL), California Bearing Ratio (CBR) and Unconfined Compressive Strength were carried out on the control and stabilized samples according to BS 1990. The Natural moisture content was 13.5%, and the chemical composition test shows a promising aggregate filler. The specific gravity of the soil and the ash were also determined to be 2.71 and 2.19 respectively. The sieve analysis result shows that the percentage passing 0.075 mm equal to 37.50%. Liquid Limit ranges from 27 to 39%, Plastic Limit ranges from 16.7 to 23.6%, and Plasticity Index also ranges from 10.3 to 15.4%. The Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) ranges between 1.72 to 1.87 g/cm³ and 13.7 to 23.1% respectively. The California Bearing Ration (CBR) for both soaked and unsoaked sample ranges between 5-13% and 33-79%, respectively. The study concludes that the use of CBA to a maximum of 8% as an additive in stabilization of lateritic soil is effective and therefore recommends its use in light and medium trafficked roads.

Keywords: Cow Bone; Lateritic Soil; Stabilization; Admixture; British Standard Light.

Introduction

Lateritic soil can be defined as weathered tropical or sub-tropical leftover soil, generally covered with sesquioxide rich solidifications (Helgren and Butzer, 1977). The soil comprises of high plastic clay; soil plasticity may cause cracks and damage on structural foundations, pavement, roadway or any other construction projects (Oyelami and Van Rooy, 2016). Lateritic soil stabilization enhances increase in its strength and durability by decreasing its porosity. This leads to durable roads and structures built with stabilized lateritic soil consequently sparing the expense of maintenance (Das, 2003). This also prevents future problems like swelling, cracks and damping that might lead to failure of the structure built with untreated lateritic soil. It is in this way significant to comprehend the actions of lateritic soil and subsequently sort out the strategy for soil stabilization (Dauda *et al*., 2019).

The American Society for Testing and Materials (ASTM) states the following reasons for soil stabilization: enhance its load-bearing capacity, improving soil permeability and enhancing the resistance of soil to weathering process and traffic utilization etc. (Obianyo *et. al*., 2020). Soil stabilization is the process of changing some of the soil properties by chemical or mechanical process. Stabilization reduced the shear strength of a soil and controls the shrink-swell properties of a soil, thereby improving the load bearing capacity of sub-grade to support pavements and foundations (Makusa, 2012).

Significant increase in the price of cement and conventional structural materials has brought about the requirement for utilization of domestic materials for construction application purposes

In view of its accessibility, cost viability and capacity to secure the environment. Lateritic soils are one of such locally accessible material which is a good option in contrast to regular conventional structural materials aside from a couple of issues (Taiwo and Adeboye, 2013).

Cow bone is a type of waste, which its production runs to millions of tones in Nigeria, from which bone ash is obtained (Ayininuola and Sogunro, 2014). The current removal system of burning in open sites and haphazard discard on any site turns out poorly for the wellbeing of individuals and it likewise establishes ecological danger. Utilization of Bone Ash (BA) disposal for road construction, for example, rigid pavement construction, is huge and thus serves different advantages to the surroundings. This application will advance waste administration at little expense, landfill reduction, decrease contamination by these wastes and increment financial base of butchers when such wastes are sold, consequently stimulating more production. Additionally, cow bone ash production requires less energy request as compared with Portland cement production and recovers the required unfamiliar trade spent on importation of cement and its parts. Previous work done of bone ash and lime focused on the morphology and compressive strength of stabilized lateritic soil (Ayininuola and Sogunro, 2014).

2 Materials and Methods

2.1 Materials and Sample Preparation

Lateritic soil is readily available and at abundance in Nigeria also used in many geotechnical engineering constructions. The lateritic soil was obtained from a depth of 1.5m below the ground surface. The samples considered for this research work was obtained from a borrow pit in Nigeria. The materials collected were dried at room temperature and ground to fine particles (<75mm). The samples are shown in Fig. 2.1.

Fig. 2.1 (a): Raw Lateritic Soil

Fig. 2.1 (b): Calcined Cow Bone

2.2 Preliminary Laboratory Tests

To effectively classify and understand the behavior of the lateritic soil samples used in this research, geotechnical tests on the both the natural and the stabilized samples were carried out in accordance with the procedural steps BS 1377 part 2-4 (1990) and BS on 1924 (1990). For the stabilized lateritic soil samples, the CBA was introduced in incremental order of 2, 4, 6, 8 and 10% by dry unit weight of the soil samples. Soil classification tests which included natural moisture, specific gravity, particle size analysis and Atterberg limits tests were performed on the soil samples.

2.2.1 Natural Moisture Content Test

The natural moisture content of each of the soil samples was determined by crumbled 20 g of the soil and placed it loosely in a clean can. The weight of the can was measured to the nearest 0.1 g and recorded as M_1. The can and its content was weighed and recorded as M_2, and then placed in the oven to dry at 105^oC to 110^oC for 1 day. After the drying, the can with its content was removed from the oven and allow cooling down. The can with its content was weighed and recorded as M_3. The moisture content of the soil sample was determined and expressed as percentage of the dry soil sample. The moisture content (w) is derived using equations 2.1 and 2.2 below:

$$w = \frac{Weig \quad of\ water}{Weight\ of\ drysoil} x\ 100\% \quad (2.1)$$

$$w = \frac{M_2 - M_3}{M_3 - M_1} x\ 100\% \quad (2.2)$$

2.2.2 Sieve Analysis

Particle size analysis test was carried out by shaking the soil sample through a set of sieves having progressively smaller openings. First, 300 g of the soil was weighed and washed through BS sieve No. 200 (75 μm aperture). The content remained on the sieve was thoroughly oven dried before passing it through the set of sieves. The following sieves numbers was stacked in descending order. These sieves used were: 4, 10, 16, 20, 40, 60, 100 and 200 as well as a receiving pan and their respective weights were taken and recorded. The washed oven dried soil sample were placed on the first sieve on top (BS sieve No. 4) and electrically vibrated for 10 minutes. Each sieve together with its content was then weighed and recorded. The test was carried out in accordance with the procedure outlined in BS 1377-2 1990.

2.2.3 Specific gravity test

In determining the specific gravity of the soil samples, 100g of dried soil samples that passed through 425μm opening were used for this test. A density bottle of 1 litre capacity with a rubber cork was cleaned, dried, weighed and recorded as W_1. The cork was removed, and 100g of the sample was poured into the bottle, the cork was replaced, weighed and recorded as W_2. Distilled water was poured into the bottle until it was half-filled with the water and topped by the cork. The bottle was shaken vigorously to remove all air-bubbles in the soil mass, and finally the bottle was filled to the brim with the water, the density bottle with the rubber cork was then wiped dry, weighed and recorded as W_3. The density bottle content was emptied and rinsed with distilled water, it was then filled with distilled water only and rubber cork replaced, wiped dry, weighed and recorded as W_4 and the specific gravity was computed using equation 2.5. The procedure was repeated for each of the three soil samples

$$Specificgravityofsoil = \frac{Density\ of\ water\ at\ 27°C}{Weight\ of\ water\ of\ equal\ volume} \quad (2.3)$$

$$= \frac{(W_2 - W_1)}{(W_4 - W_1)\ -\ (W_3 - W_2)} \quad (2.4)$$

$$= \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)} \tag{2.5}$$

2.2.4 Atterberg Limits Test

Atterberg limits measure the nature of fine grained fraction of a soil which passes through sieve size 425µm.The liquid limit (LL), the plastic limit (PL) and the plasticity index for the natural soil samples of all the four samples were determined in accordance with BS 1377-2 1990.
For the liquid limit test, 150 g of the soil samples passing 425µm were mixed thoroughly with distilled water using spatula until the mix formed a uniform paste. A small sample of the mixed soil was placed in the LL device. Using a cutting groove to cut through the centre of the placed soil sample in the cup, the LL device was run and the number of blows (N) required to close this groove through a distance of 13mm was counted and recorded. About 10 g of the paste was then taken from the two sides of the paste in the cup into the can and oven dried for 24 hours to determine the moisture content. The test was repeated four times and the logarithmic graph of number of blows against moisture content for the three soil samples were plotted, and the liquid limits (LL) were determined at moisture content at 25 blows.
A representative sample of about 50g was taken from the remainder of soil sample used in the liquid limit determination. This was thoroughly mixed with distilled water on a glass plate until it became sufficiently plastic enough to be moulded into ball. The ball of soil was then rolled between the palms until slight hair-line cracks appeared at the surface. The ball sample was splited into two samples. These two samples were further divided into four equal parts and each part being rolled into a 3mm diameter thread. Two cans of rolled soil samples were used to determine the moisture content of the cracked soil sample. and the plasticity index was computed using equation 2.6.

$$PI = LL - PL \tag{2.6}$$

2.2.5 Compaction Test

Compaction test is used in determining the optimal moisture content at which a soil will achieve its maximum dry density. That is to study the moisture-density relationship of compacted lateritic soil.

To carry out this test, air-dried lateritic soil sample of known weight passing through No. 4 sieve was compacted at known moisture content in a cylindrical mould of standard dimensions using a compactive effort of specific weight and frequency. Specimens are prepared so that the estimated moisture content is recorded. The moisture content is varied for at least two percent each and the moisture content increment not exceeding four percent. The process is repeated for various moisture contents and the dry densities are determined for each. The graphical relationship of the dry density to moisture content is then plotted to create a compaction curve. The maximum dry density (MDD) is the peak point of the curve and its corresponding moisture content which is also known as the optimal moisture content (OMC). The bulk density and dry density were computed using equation 2.7 and 2.8 respectively.

$$\mathrm{p} = \frac{\mathrm{m2-m1}}{1000} \tag{2.7}$$

$$\mathrm{p\delta} = \frac{100\mathrm{p}}{(100 \quad)} \tag{2.8}$$

2.2.6 California Bearing Ratio Test

The CBR mould was assembled with its base plate and weighed. The collar fitted and a filter paper placed at the bottom. 6 kg of the soil sample was thoroughly mixed with the OMC as determined from the compaction test. The mix was divided into five parts and the soil was compacted inside the mould in five layers with each layer receiving 27 blows of 4.5 kg rammer.. The collar was then removed and the edge of the mould trimmed off to flush with the top of the mould. The mould containing the sample was placed in the CBR machine with the top facing the plunger. The plunger was made to penetrate the specimen at a uniform rate of 1mm/min and readings were taken at intervals of 0.50mm penetration. The base plate was removed from the mould and the bottom face of the specimen was placed under the plunger and the reading taken as was done for the top surface. For soaked CBR, the compacted soil was soaked in water for 48 hours before subjecting it to CBR test as described above. The above procedure was repeated for the samples stabilized with CBA. The CBR was computed using equation 2.9.

$$CBR = \frac{\text{Measured Load}}{\text{Standard Load}} \text{ X } 100 \qquad 2.9)$$

2.2.7 Unconfined Compressive Strength Test

The UCS test were performed on the soil sample according to BS 1377 (1990) Part 7 using British Standard Light (BSL) energy level. The natural sample and stabilized sample were compacted in 1000 cm3 mould at their respective OMC. The sample were extruded from the mould and trimmed into the cylindrical specimen of 38.1 mm diameter and 76.2 mm length. The cylindrical specimens from the mould were cured for 7 days. At the elapsed day of curing the specimen was then placed centrally on the lower plate on the compression testing machine, and the compressive force is applied to the specimen with a strain control 0.01%mm. record was taken simultaneously of the axial deformation and the axial force at regular interval until failure of the sample occurs. The UCS of the sample was determined at the point of the stress-strain curve at which failure occurred. The UCS was calculated from the following equation:

$$Compressive\ Strength = \frac{Failure\ Load}{Surface\ area\ of\ Specimen} \qquad (2.10)$$

Table 2.1: Chemical Requirements for Pozzolanic Materials

Required Properties	Value
Silicon dioxide (SiO_2) + Iron oxide (FeO_2) + Aluminium oxide (Al_2O_3), min %	70.0
Sulphur trioxide (SO_3), max %	4.0
Moisture content, max %	3.0
Loss on ignition, max %	10.0

Source: (IS: 3812 part 1, 2003).

3.0 Results and Discussions

The lateritic soil sample used in this study is reddish brown in color and was gotten from a borrow pit at the depth of 1.5m. Thereafter, it was transported to Civil Engineering Soil Laboratory Federal Polytechnic Offa for Geotechnical Properties evaluation tests. The Cow Bone was collected from a meat processing industry (abattoir), sun dried and later calcinated at a temperature of 500 ^{0}C to become a useful ash. The results obtained are further discussed under different headings below.

3.1 Natural Moisture Content Test results

Preliminary test conducted to determine the natural properties of the soil revealed that the soil has a high moisture content of 13.62% due to the period of collection (rainy season) and the soil is reddish brown in colour (from wet to dry states). Natural moisture content of soils is a time variant parameter which depend to a large extent on the seasonal levels of surface and subsurface water (Jegede, 1988). Underwood (1967) proposed that soils with natural moisture content of 5%-15% are suitable engineering materials, natural moisture content of 16%-19% are marginal suitable engineering materials; and soils with natural moisture content values ranging from 20%-35% are unsuitable engineering materials.

The result is analysed in table below.

Sample ID	A	B	C
Weight of Empty Can (g) A	19.5	72	66.5
Weight of Wet Sample (g) B	20.5	69.5	62.5
Weight of Oven-Dried Sample (g) C	21	70.5	65
Moisture Content (%) = (B-C/C-A)*100	11.70	16.67	12.50
Average		**13.62**	

3.2 Chemical Composition of Cow bone ash.

ASTM C-618 (2005) specifies that the sum of SiO_2, Al_2O_3 and Fe_2O_3 for a supplementary cementing material should not be less than 70%. of the active oxides, silica is normally considered as the most important and should not fall below 40% of the total ASTM C618 (2005). The result of SiO_2, Al_2O_3 and Fe_2O_3 of cow bone ash tested was 15.16% which is low to that of 70% specified by ASTM C-618 (2005). It is the value of Calcium oxide and Phosphorous oxide that present in the cow bone ash that make it a supplementary cementious material.

Constituents (oxides)	**Percentages (%)**
SiO_2	15.00
Al_2O_3	0.00
Fe_2O_3	0.16
MnO	0.01
CaO	41.35
P_2O_5	13.15
K_2O	0.11
TiO_2	0.02
$S0_3$	0.45
Na_2O	0.01
MgO	0.00
Cl	0.04
Lol	9.30
PbO	0.00071
ZnO	0.10
Cr_2O_3	0.00001
SrO	1.07
NiO	0.00

3.3 Sieve Analysis Test.

Fig 3.1 shows that the percentage passing sieve 0.075 mm equal to 37.50%. Showing that the sample contain 1.6% Gravel, 16.1% Coarse Sand, 30.2% Medium Sand, 14.7% Fine Sand making a total of 61.0% Sand, 13.9% Silt, 23.6% Clay making a total percentage of Fines to be 37.5%. the soil is a Silty clay and was identified as A-6 Soil on the AASHTO classification system with group index of 1.59. Grain size distribution is one of the most important elements in the design of structures composed of soils (Naresh and Nowatzki, 2006).

It was also observed that the soils with higher fines possess higher moisture contents while soils with lower fines have less moisture contents. The lower the moisture contents the more suitable the soil is for engineering works because the lower the plasticity and compressibility, the better workability, less swelling and shrinkage potentials (USCS, 2000). Meanwhile, Federal ministry of works and housing (FMWH, 1997) specified that soil samples with < 35% fines permissible use for a good foundation material and ≥ 35% of fines are not good for subgrade/fill and base.

The table of the Sieve analysis is analysed in table and figure below.

Particle Description		**Particle Diameter (mm)**	**Mass Retained**	**Retained (%)**	**Percent Passing (%}**
	Cobbles	**100.000**			**100.0**
		75.000			**100.0**
GRAVEL	**Coarse**	**63.000**			**100.0**
		37.500			**100.0**
		19.000			**100.0**
		14.000			**100.0**
		9.500			**100.0**
	Fine	**4.750**			**100.0**
		2.360	**15.50**	**1.55**	**98.5**
SAND	**Coarse**	**1.180**	**18.50**	**1.85**	**96.6**
		0.600	**142.00**	**14.20**	**82.4**
	Medium	**0.300**	**145.00**	**14.50**	**67.9**
		0.150	**157.00**	**15.70**	**52.2**
	Fine	**0.075**	**147.00**	**14.70**	**37.5**
FINES	**Clay or Silt**	**<0.075**	**375.00**	**37.50**	

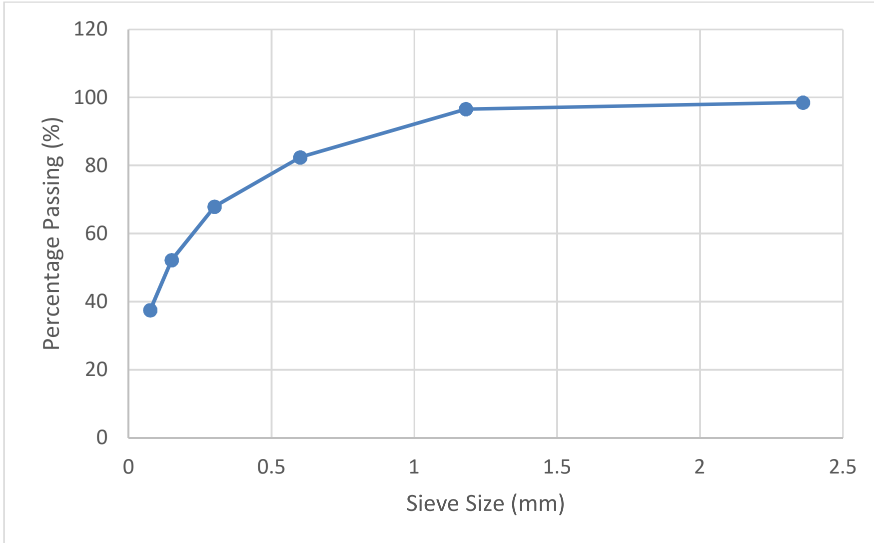

Fig. 3.1: Sieve Analysis Graph.

3.4: Specific Gravity of Materials

The average specific gravity of sample is 2.71. The value gotten ranged within the reported value in Das (2010) for clay minerals, as montmorillonite. Also, the result of the calcined cow bone ash had the value of 2.1 which is in accordance to ASTMC-218 for pulverized fuel ash that ranges between (1.9 – 2.4). The summary of specific gravity of lateritic soil and Cow Bone Ash is shown in tables below.

SAMPLE ID	**A**	**B**	**C**
Weight of Empty Pyconmeter M_1 (g)	18.5	18.5	18.5
Weight of Pyconmeter + Soil M_2 (g)	67.0	64.0	60.0
Weight of Pyconmeter + Soil + Water M_3 (g)	129.5	127.5	125.5
Weight of Pyconmeter + Water M_4 (g)	99.0	99.0	99.0
GS = $(M_2 – M_1) / (M_4 – M_1) – (M_3 – M_2)$	2.69	2.68	2.77
Average Specific Gravity of Lateritic Soil		**2.71**	

SAMPLE ID	**A**
Weight of Empty Pyconmeter M_1 (g)	5.5
Weight of Pyconmeter + Soil M_2 (g)	12.5
Weight of Pyconmeter + Soil + Water M_3 (g)	54.8
Weight of Pyconmeter + Water M_4 (g)	51.0
GS = $(M_2 – M_1) / (M_4 – M_1) – (M_3 – M_2)$	2.19
Specific Gravity of CBA at 500^{0}C	**2.19**

3.5: Atterberg Limit Test

Fig 3.2 demonstrated how the Plastic Limit (PL) drops from 23.6 percent at 0% to 16.7 percent at 10% CBA, while the Liquid Limit (LL) drops from 39.0 percent at 0% to 27.0 percent at 10%

CBA. The Plasticity Index (PI)_ value therefore falls from 15.4 percent at 0% to 9.6 percent at 4% CBA. As the Liquid Limit (LL) and Plasticity Index (PI) values are increasing together with the CBA content, swelling potential and compressibility characteristics are also decreasing. It was also observed that addition of CBA to the soil sample enhanced the performance of the lateritic soil. The stabilization of soil particularly with CBA which has a lower affinity for water may therefore account for the decrease in the Liquid Limit (LL) and Plastic Limit (PL).

Percentage of Cow Bone Ash (%)	Liquid Limit LL (%)	Plastic Limit PL (?%)	Plasticity Index PI (%)
0	39.0	23.6	15.4
2	35.0	23.2	11.8
4	31.0	21.4	9.6
6	30.5	20.5	10.0
8	29.0	19.3	9.7
10	27.0	16.7	10.3

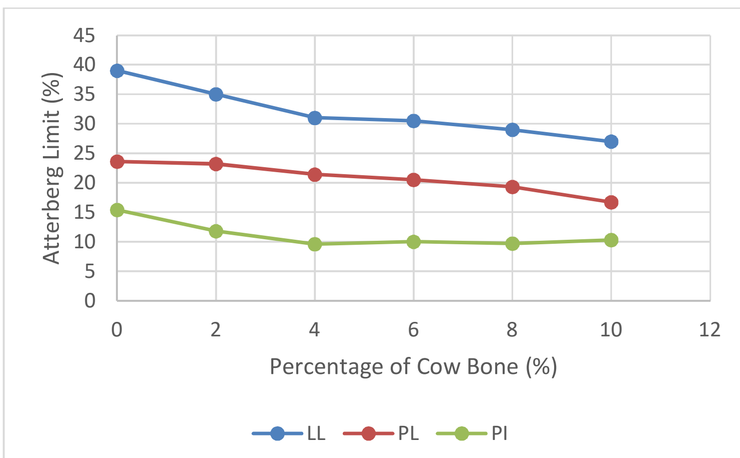

Fig. 3.2 Variation of Atterberg limit corresponding to Cow Bone ash content

3.6 Compaction Test results

Fig. 3.3 shows that MDD was decreasing with increase of CBA content while the OMC values increased with increase of CBA content. The modification of CBA for the soil sample in this regard which has a lower specific gravity value of 2.00 than that of the soil sample 2.71 can be attributed to the decrease in MDD values. It could also be as a result of the covering of the stabilized soil with CBA which leads to larger particles with greater voids between them and lesser density. The increased in OMC is due to the addition of CBA which decrease as the amount of free silt and clay fractions increases. Water is therefore required for these processes to occur since the OMC increases from 13.70 percent at 0% to 23.1 percent at 10% by dry weight of the soil. Conclusively, the result tends that more water is required to compress the soil-CBA combination.

Percentage of Cow Bone (%)	Maximum Dry Density MDD (g/cm^3)	Optimum Moisture Content OMC (%)
0	1.87	13.7
2.	1.84	14.6
4	1.80	15.4
6	1.78	16.7
8	1.74	18.9
10	1.72	23.1

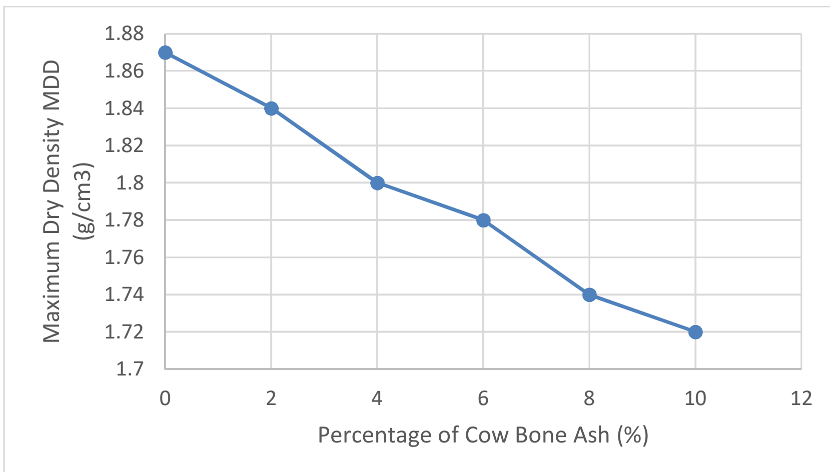

Fig. 3.3(a): Variation of maximum dry density against Cow Bone Ash (%)

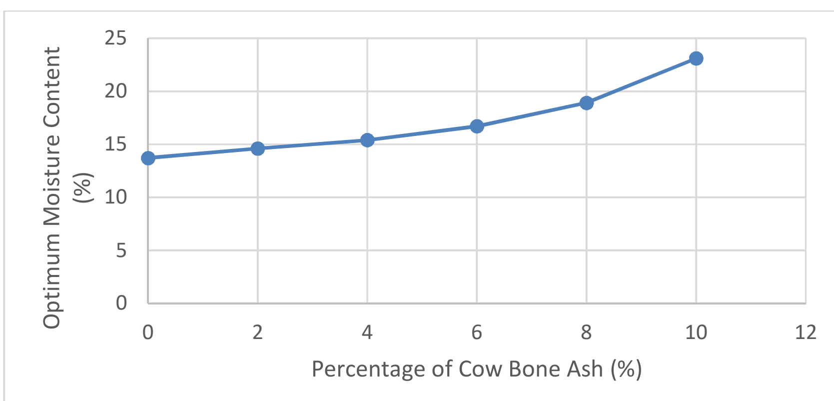

Fig. 3.3(b): Variation of Optimum Moisture content against Cow Bone Ash (%)

3.7 California bearing ratio test

According to fig 3.4, the CBR values increases from 5 percent at 0% to 13 percent at 10% CBA and 33 percent at 0% to 79 percent at 10% CBA for both soaked and unsoaked condition as soil weight increases respectively. The progressive appearance of these values is as a result of cementitious compounds in the soil due the interaction between CBA and the particular calcium hydroxide in the soil. These finding demonstrated that CBA stabilization significantly improved the soil sample strength

Percentage of Cow Bone Ash (%)	Soaked CBR (%)	Unsoaked CBR (%)
0	5	33
2	6	42
4	8	47
6	10	56
8	13	79
10	13	77

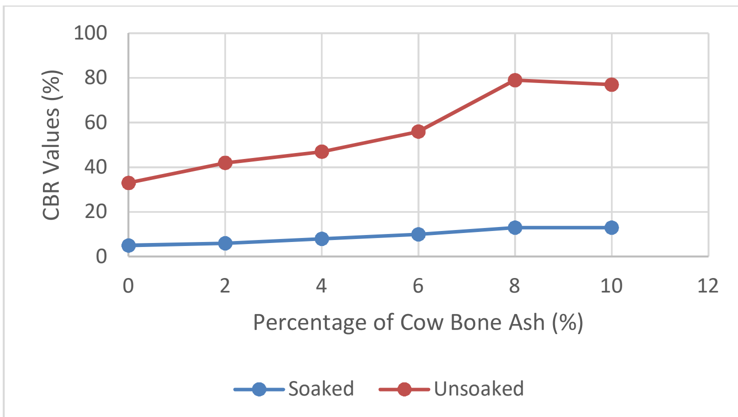

Fig. 3.4 Summary of CBR value against Cow Bone Ash Content

3.8 Unconfined Compressive Strength Test

Fig 3.5 demonstrates that the UCS value for the untreated soil sample is 214.9 kN/m² which increases to 289.5 kN/m² at 6% CBA content. The highest value was attained at 6% CBA when the soil produces cementitious compound in the CBA as a result of the presence of calcium hydroxide. The value of the UCS begins to drop from 8% CBA downward which demonstrates that not more than 6% CBA is needed to enhance the strength properties of lateritic soil while using the addictive.

Percentage of Cow Bone Ash (%)	UCS Values (kN/ m²)
0	**214.9**
2	**255.6**
4	**272.5**
6	**289.5**
8	**269.1**
10	**256.7**

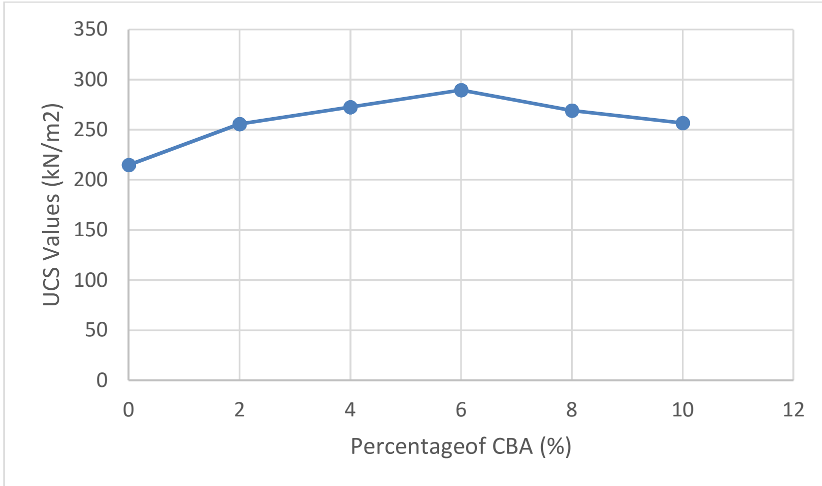

Fig. 3.5 Summary of UCS value against Cow Bone Ash Content

4 Conclusion

From the laboratory test results conducted on the natural untreated lateritic soil sample, the soil has a very good moisture content according to Underwood (1967) which proposed that soil that has a moisture content between 5%-15% is suitable for engineering material. Also the soil is classified as silty clay with high plasticity and was identified as A-6 soil on the AASHTO classification system with group index of 1.59.

On the specific gravity test, the result is comparable according to Lab Report Cover (Pozzolan, 2012) of Indian Institute of Technology Delhi that specific gravities ranges from a low value of 1.90 for a sub bituminous ash to a high value of 2.96 for an iron rich bituminous ash. Also, the ASTMC-218 ranges for pulverized fuel ash is between (1.9 – 2.4), and the specific result of Calcined Cow Bone fall within the specified range.

On the compaction test carried out, the ideal moisture content was achieved at 0% replacement as 13.7% and the maximum dry density was achieved at 0% replacement as 1.87 g/cm^3. However, there is a decrease in MDD and increase in OMC throughout as the percentage of ash increases.

There was a significant increase in the CBR value for lateritic soil sample with increase in percentage of Cow Bone Ash (CBA). However, increase in the percentage of cow bone ash resulted in an increase in the CBR value.

The study concludes that the use of CBA to a maximum of 8% as an additive in stabilization of lateritic soil is effective and therefore recommends its use in light and medium trafficked roads.

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Beyond the Binomial: A New Framework for Probability Analysis Using Kifilideen's Trinomial Distribution with Mathematical Induction for Its Negative Powers

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Abstract

Traditional probability analysis relies on the binomial distribution, which is restricted to events with only two possible outcomes, such as success-failure or pass-fail. However, many real-world scenarios involve three distinct outcomes, such as win-draw-loss in sports, good-semi-good-bad in manufacturing, and rich-middle-poor in economic stratification. Binomial models fail to fully represent such systems, leading to incomplete and biased probability analysis. This research introduces Kifilideen's Trinomial Distribution, a novel probability model that effectively accounts for events with three possible outcomes. Binomial probability models overlook intermediate outcomes, while multinomial model lack an optimized structure for trinomial systems. This framework provides a structured, mathematically grounded solution. A mathematical model was developed using matrix methods and combinatorial probability principles, extending the binomial framework to handle three-outcome events. Additionally, mathematical induction was applied to validate the model for negative powers, ensuring consistency and expanding its predictive capabilities. The model was tested across real-world applications, including product classification, economic categorization, and academic performance analysis. Results demonstrate that Kifilideen's Trinomial Distribution provides a more accurate and complete representation of probabilistic systems compared to traditional binomial models. The derived formulas for negative powers were mathematically validated using mathematical induction, reinforcing the model's reliability. By addressing the limitations of binomial probability models, this research presents Kifilideen's Trinomial Distribution as a superior framework for analyzing three-outcome events. The model enhances probability calculations in diverse fields, making it a valuable tool for decision-making, risk assessment, and predictive analytics. Its mathematical structure establishes a strong foundation for further advancements in applied probability, statistics, and computational modeling.

Introduction

Binomial system is an analytical framework that considers two possible outcomes of an event, representing its extreme cases (Goss, 2011; Aljohani, 2016; Flusser and Francia, 2020; Stroud and Booth, 2020). Binomial system is applied in binomial distribution to solve problems related to probability problems (Phillips, 2006; Gordon, 2013). Probability is a branch of applied mathematics that deals with random experiments (Macrae *et al.*, 2016; Trunkenwald *et al.*, 2022). Two of the pioneering mathematicians in the field of probability are French mathematician, Blaise Pascal (1623 – 1662) and Russian mathematician, Andrei Nikolaevitch Kolmogorov (1903 – 1987) (Lightner, 1991; Nualart, 2004; Lazes, 2016; Jahic, 2019). According to Debnath (2015), in binomial distribution, for any particular event there are two possible chances which are success and failure or pass and fail of such event. So, if the probability of passing an event is p and the probability of failing the event is q from a large population then for certain n number of people or objects or entities selected at random from the large population the binomial distribution is presented as:

$$[p+q]^n = {}_{n,0}{}^{n}_{0}Cp^nq^0 + {}_{n-1,1}{}^{n}_{1}Cp^{n-1}q^1 + {}_{n-2,2}{}^{n}_{2}Cp^{n-2}q^2 + {}_{n-3,3}{}^{n}_{3}Cp^{n-3}q^3 + \cdots + {}_{3,n-3}{}^{n}_{n-3}Cp^3q^{n-3} + {}_{2,n-2}{}^{n}_{n-2}Cp^2q^{n-2} + {}_{1,n-1}{}^{n}_{n-1}Cp^1q^{n-1} + {}_{0,n}{}^{n}_{n}Cp^0q^n$$

(1)

Such that $p + q = 1$

(2)

That is the probability of passing an event $+$ Probability of failing the event $= 1$

(3)

$P_r\ (Pass) + P_r\ (Fail) = 1$

(4)

For Term T_1 for $t = 1$ in (1) indicates the probability of n pass and 0 fail for the random selection of the n people or objects or entities of the population. For Term T_2 for $t = 2$ (1) indicates the probability of $(n - 1)$ pass and 1 fail for the random selection of the n people or objects or entities of the population. For Term T_3 for $t = 3$ in (1) indicates the probability of $(n - 2)$ pass and 2 fail for the random selection of the n people or objects or entities of the population. The trend above for Term T_1 for $t = 1$, Term T_2 for $t = 2$ and Term T_3 for $t = 3$ is also applicable to all other terms in the binomial distribution.

In real life there exist the mid or intermediary chances or possible outcomes of some events, if not all events, making the possible outcomes of such events to three. In any such scenario or instance of three possible outcomes, a trinomial system of analysis would be applicable. There is need to develop a model to analysis such scenarios of trinomial system. In this paper, Kifilideen trinomial theorem distribution model was used in analyzing trinomial systems. Kifilideen trinomial theorem distribution model is applicable and utilized in the field and area of Mathematics, Physics, Chemistry, Biology, Agriculture, Transportation, Social Science, Engineering, Finance, Sport, Industry, and Computer Science. Kifilideen trinomial theorem distribution model extends the scope of analysis of binomial theorem distribution model to three possible outcomes of event. The mathematical model of the Kifilideen trinomial distribution invented in this paper can be used to determine the probability of the combination of different n output involving three possible categories of outcomes of event. The Kifilideen matrix visualizes and helps to indicate all possible power combinations present in any particular Kifilideen trinomial theorem distribution of positive power of n. The Kifilideen matrix can be fully utilized in the analysis of any Kifilideen trinomial theorem distribution (Osanyinpeju, 2021a). The Kifilideen trinomial system is varied along three parameters of two extreme ends (say, either pass, p or fail, q) and an intermediary, r (which is neither pass nor fail). The power combination of these variables (p, r and q) indices tells more about the confidence level ascertained.

Sighting various examples of binomial and trinomial systems; examinational system can be used as a case study where students can either be categorized as above average students $(+)$ scoring (from $50 - 100$ marks) or below average students $(-)$ scoring (from $0 - 49$ marks) in a situation of binomial system while for trinomial system, the students are divided into three categories which are above average students $(+)$ scoring (from $60 - 100$ marks), below average students $(-)$ scoring (from $0 - 30$ marks) and average students $(/)$ scoring (from $40 - 59$ marks). In case of the trinomial system of analysis, lesser effort is put in for the average students to migrate from that level to above average level when compare to the below average students which require two steps and massive effort to migrate to the above average level. Any little relaxation can easily make the average students to fall to below average level unlike the above average students which take time to drop to below average level when relaxed.

More so, in case of defect of manufacture products, products are classified into two categories which are good $(+)$ or bad $(-)$ products for binomial system where the good products are useful and the bad products cannot be utilized at all. It should be known that in manufacturing of products, some products can be categories as semi – good or undecided whether good or bad $(/)$ that is they have features of both good and bad. These kinds of products are not totally bad and can be useful and manageable in some area. These kinds of products cannot be grouped under good or bad but can be categorized as semi – good with efficiency from $40\ to\ 60\ \%$. Under the Kifilideen trinomial theorem distribution model, there are three categories of possible outcomes of products which are good $(+)$, semi – good $(/)$ and bad $(-)$ products. For example, in laptop computer system production one category of the laptops produced has good appearance and all the hardware and software are working optimally. This category is classified under good $(+)$ product. Another categories of the laptops produced has bad appearance but all the hardware and software are working optimally. This category can be classified under semi – good or undecided $(/)$ products. The last category of the laptops produced has bad appearance and all the hardware and software are not working properly. This category can be classified under bad products. In production of substance, substance can be categories as solid and liquid when dealing with binomial system but in some cases products manufacture can come in form of semi – solid (for examples tooth paste, gel, and body cream). So for Kifilideen trinomial distribution analysis model, products of

substances from a company can be analysed under the categories of solid, liquid and semi – solid. Kifilideen trinomial theorem distribution model gives room for mid – way.
In agricultural banking sector there exist trinomial system. Agricultural banking sector gives loan to farmers to boost agricultural produces. In order for the bank not to run at lost they do ask farmer to produce collateral which replace the loan if the farmer is unable to pay back the loan. First category of farmers is farmers that have enough or adequate collateral $(+)$ to obtain the loan. Second category of farmers is farmers that lack or do not have any collateral $(-)$ neither in form of land, car nor any other assets to present so they are not qualified at all for the loan. The third category of farmers is farmers that have collaterals but are inadequate $(/)$ or not enough to obtain loan. This category of farmers is given partial consideration, they may be given the loan or not. They are under the category maybe. In obtaining loan from bank as regard collateral, there are three sets of farmers which are those that have adequate collateral, inadequate collateral and lack collateral. When agricultural banks are dealing with farmers in area of loan, there are trinomial systems of farmers they encountered with.

More so, analysis of binomial distribution in social classes, people are categories into rich $(+)$ or poor $(-)$ but there are also some categories of people that are middle class $(/)$ which these people cannot be categories as been rich or poor because they have some attribute of rich and poor. The rich people $(+)$ live extravagent life and have more than enough. The poor people $(-)$ lack basic needs and live below standard of living. The middle class $(/)$ lives a moderate life. So, Kifilideen trinomial theroem distribution helps to analysis these three categories of classes which are rich $(+)$, middle $(/)$ and poor $(-)$ classes.
In classification of materials based on conductivity, materials are classified into conductors and insulators for which analysis of binomial distribution would be useful. It is known that there are also existence of some materials which cannot be classified as conductors $(+)$ or insulators $(-)$ which are called semi – conductors or metalloids $(/)$ examples are silicon and germanium. Semi – conductors are materials which electrical and thermal conductivity lies between conductors and insulators. In putting semi – conductors into analysis with conductors and insulators, Kifilideen trinomial theorem distribution model would be useful. Kifilideen trinomial theorem distribution model gives room for mid – way.

In secondary school and tertiary institutions, students end up into three categories. The first categories of students are students who get to the last level of education, succeed and obtain certificates with high grade $(+)$. The second categories of students are students who manage to get to the last level of education, although fail out but obtain certificates containing low grades $(-)$. Certificates were given to the second categories of students because they were able to meet up with the minimum requirements. The last categories of students are students who started the program or admitted but latter on drop out or were unable to get to the last stage $(/)$ of the program. These sets of students would not have certificate that they attended the institution although they have acquired one skill or the other from the institution. The school has also benefited from such students for the school fees paid by the students for the time been they are in the institution. These set of students are also valuable to the institution because the little knowledge acquire in the institution can be used by such students to add value to the society at large. This logic indicate that secondary school and tertiary institutions build trinomial system of students.

Furthermore, in transportation system, raw and finished goods such as crude oil, electronics, gold, limestone, cotton and cocoa can be imported or exported by country through three different modes of transportation which are land, sea and air. In analysis of importation and exportation of raw and finished goods by a country Kifilideen trinomial theorem distribution model would be needed to carry out such analysis.

Primary colours are trinomial system of colours in nature which when mixed together gives white light (Anyakoha, 2016). The primary colours are Red $(+)$, Green $(/)$ and Blue $(-)$. For any random selection of the primary colours there are three possible outcomes which are red, green and blue which are trinomial in nature. To analysis random selection from a set of primary colours, Kifilideen trinomial theorem distribution model can be utilized. More so, secondary colours are also trinomial system of colours which are cyan (Green and Blue), Magneta (Blue and Red) and Yellow (Green and Red) (Okeke et al.,1987).

(Primary colours)	G +	B +	R	$\rightarrow$	White light
	+	+	+		
(Secondary colours)	M	Y	C		
	$\downarrow$	$\downarrow$	$\downarrow$		
	White light	White light	White light		

Figure 1: The analysis of the types of colours into trinomial system

The analysis of the types of colours into trinomial system in Figure 1 above can be understood and memorized using the code General Manager (GM), Buy (BY), RiCe (RC) which is presented in the Figure. Where G is green colour, M is magneta, B is blue, Y is yellow, R is Red and C is Cyan. Addition of Green and Magenta gives white light making green to be complementary colour to magneta, addition of Blue and Yellow gives white light making blue a complementary colour to yellow and Red and Cyan gives white light making red complementary colour to cyan (Farinde et al., 2016).

More so, substances can come in three forms which are white, coloured and black substances. White substances are substance which contain all colours or spectra (red, orange, yellow, blue. green, indigo and violet). Black substances are substances which lack colours or without presents of colours while coloured substances are substances which have at least one colour or spectrum but not all colours are presents in it. To analysis these sets of substances, Kifilideen trinomial theorem distribution model would be appropriate.

In wiring system, some connections are done using binomial system where two wires are used which are live having colour red $(+)$ and neutral having colour blue $(-)$ while some connections are done using trinomial system where three wires are used which are live having colour red $(+)$, earth having colour green $(/)$ and neutral having colour blue. For three wiring system of connections, Kifilideen trinomial theroem distribution model is applicable and appropriate in the analysis of the wiring system.

All chemical substances are in categories of trinomial system and are categories into three substances which are acidic substances $(+)$, neutral susbtances $(/)$ and basic substances$(-)$. So, any chemical substance produces in chemical industry can be classified under the categories of these three chemical substances. Acidic substance turns blue litmus paper red, neutral substance has no effect on litmus paper and basic substances turn red litmus paper blue. For analysis of these three substances, Kifilideen trinomial theorem distribution model would be useful. This research work presents real life applications of mathematical model of Kifilideen trinomial theorem distribution of positive powers of n.

Probability theory plays a fundamental role in decision-making, risk assessment, and predictive modeling across diverse fields, including engineering, finance, social sciences and natural sciences. Traditionally, probability distributions such as the binomial distribution have been widely applied to analyze events with two possible outcomes, such as success or failure, pass or fail, and win or loss. However, many real-world scenarios involve three possible outcomes, requiring a more advanced probability model. For instance, in electoral analysis, a political party's performance may result in win, loss, or disqualification, but conventional binomial models fail to account for disqualifications. Similarly, in sports analytics, a team's match outcome can be win, draw, or loss, yet binomial models can only assess win-loss probabilities. Likewise, in quality control, manufactured products may be good, semi-good, or defective, but binomial probability only distinguishes between good and defective products. These limitations highlight the incompleteness of the binomial approach when applied to three outcome systems.

To address this gap, this paper introduces Kifilideen's Trinomial Distribution, a novel probability model that extends the traditional binomial distribution to handle events with three possible outcomes. Unlike existing probability models such as the multinomial distribution, which deals with multiple categorical outcomes but lack a structured approach for three-outcome systems—this model provides a systematic and mathematically grounded framework for three-outcome probability calculations.

The binomial distribution is efficient but insufficient for three-outcome events, requiring an artificial exclusion of one category to fit its two-outcome structure. The multinomial distribution does not provide optimized combinatorial formulas specifically tailored for trinomial cases. Additionally, existing trinomial models in probability theory often lack structured formulations and negative power extensions, limiting their applicability in certain predictive scenarios. Kifilideen's Trinomial Distribution overcomes these limitations by:

1. Providing a structured probability framework specifically designed for three-outcome systems.
2. Extending combinatorial probability analysis using mathematical induction for negative powers, making it applicable in predictive modeling.
3. Offering more accurate probability calculations in real-world applications such as election predictions, sports outcomes, product classifications, and economic stratification.

This study aims to formulate and validate Kifilideen's Trinomial Distribution as a new framework for three-outcome probability analysis, demonstrate its mathematical consistency through induction, and apply it to real-world probability problems. The developed model is expected to enhance statistical decision-making and expand the scope of probability analysis beyond binomial constraints.

Mathematical induction method was adopted in developing the formulas of the components of the Kifilideen's Trinomial Theorem of negative powers of n. The constituents of the Kifilideen's Trinomial Theorem are power combination, group, row, column, position, period and terms (Osanyinpeju, 2020a; Osanynipeju, 2020b; Osanyinpeju, 2020c, Osanyinpeju, 2021b, Osanyinpeju, 2022). Mathematical induction is not a method for making discoveries but a rigorous approach to proving established facts. There is need to present mathematical induction of the mathematical fact of this Trinomial Theorem of negative powers of n so as to inbuilt more confidence in the established fact. The mathematical induction would help to buttress and show how the Kifilideen's Formulas of the negative powers of n are generated. The mathematical induction would also help to support and prove that the developed formulas for the constituents of Kifilideen's Trinomial Theorem of negative powers of n are valid and true. This study makes available the mathematical induction of Kifilideen's Trinomial Theorem of negative powers of n adopting series and sequence ideology. This research work also develops Alternate General Kifilideen's Power Combination Formula, Alternate General Kifilideen's Term Formula and Alternate General Kifilideen's Position Formula for the negative powers of n which conformed but not the same with the one developed for the positive powers of n counterpart.

Materials and Methods

A mathematical model for Kifilideen's Trinomial Distribution was formulated and analyzed using matrix methods and combinatorial probability principles. Additionally, mathematical induction was used to derive formulas for the theorem's negative powers, ensuring the model's consistency and reliability.

Mathematical Model of Kifilideen's Trinomial Distribution of Positive Powers of n

Taking the total number of objects/items/people/entities of an event as $n(T)$, if there exists three possible categories of outcomes for the event where the number of occurrence of the first category (say, pass category) of outcome in the total number of population is $n\ (P)$, the number of occurrence of the second category (say, indecisive or intermediary category) of outcome in the total number of population is $n\ (R)$, the number of occurrence of the third category (say, fail category) of outcome in the total number of population is $n\ (Q)$, then Kifilideen's Trinomial Distribution Model would be useful or applicable.

Table 1. Breakdown of categories of trinomial system in various areas.

S/N	First Category	Second Category	Third Category
1.	True	Indecisive	False
2.	Pass	Inconclusive or withdraw	Fail
3.	On	Intermediate	Off
4.	Magnified Image	Same size as the Object	Diminished Image
5.	Solid	Semi – Solid	Liquid
6.	Win	Draw	Loss
7.	Metal	Metalliod	Non – Metal
8.	Accelerate	Constant motion	Decelerate or Retardate
9.	Conductor	Semi – Conductor	Insulator
10.	Land	Sea	Air
11.	Solid	Liquid	Gas
12.	Constructive	Neutral/No change or effect	Destructive
13.	Elevation	Stationary	Depression
14.	Supersaturated	Saturated	Undersaturated
15.	Good	Semi – Good	Bad
16.	Above Average	Average	Below Average
17.	Rich Class	Middle Class	Poor Class
18.	Up	At rest	Down
19.	Positive	Neutral	Negative
20.	Live	Earth	Neutral
21.	Acid	Neutral	Base
22.	Uniform	Indecisive	Non – Uniform
23.	Alive	Coma (Between live and death)	Dead

Let the probability of first category, say pass $= P_r(pass) = p$ (5)

Let the probability of second category, say indecisive $= P_r\ (indecisive) = r$ (6)

Let the probability of third category, say fail $= P_r\ (fail) = q$ (7)

Then,

$p = \frac{n(P)}{n(T)}$, $r = \frac{n(R)}{n(T)}$ and $q = \frac{n(Q)}{n(T)}$ (8)

Note: $p + r + q = 1$ and $n(P) + n(R) + n(Q) = n(T)$ (9)

Say: p —true/pass/win/rich class/good/conductor/on/uniform acceleration
r —intermediate/indecisive/draw/middle class/median/inconclusive/uniform velocity
q —false/fail/loss/poor class/insulator/bad

Tables 1 above shows the break down categories of trinomial system in various areas. Examples of first category of a trinomial system are true, pass, on, magnified image, solid, win, metal, accelerate, conductor, supersaturated, constructive, up, alive, positive, elevation and rich class. Examples of the second category of the trinomial system are draw, intermediate, indecisive, same size as object, average, inconclusive, withdraw, semi – solid, metalliod, saturated, at rest, coma, middle class, stationary, and semi – conductor while examples of third category of trinomial system are false, fail, off, Diminished Image, loss, non – metal, decelerate, destructive, depression, poor class, down, dead, negative and below average.

If n objects/people/entities/items are selected from the total population of objects/items/people/entities of an event, then, the mathematical model to represent the trinomial system of all possible combination of the n objects/items/people/entities selected is given as:

$$[p+r+q]^n \qquad (10)$$

Using Kifilideen's Trinomial Distribution Model of positive powers of n we have:

$$[p+r+q]^n = {}_{n,0,0}^{\;\;n}Cp^n r^0 q^0 + {}_{n-1,1,0}^{\;\;\;\;n}Cp^{n-1} r^1 q^0 + {}_{n-2,2,0}^{\;\;\;\;n}Cp^{n-2} q^0 + {}_{n-3,3,0}^{\;\;\;\;n}Cp^{n-3} q^0 + \cdots + {}_{n-1,0,1}^{\;\;\;\;n}Cp^{n-1} r^0 q^1$$
$$+ {}_{n-2,1,1}^{\;\;\;\;n}Cp^{n-2} r^1 q^1 + {}_{n-3,2,1}^{\;\;\;\;n}Cp^{n-3} r^2 q^1 + {}_{n-4,3,1}^{\;\;\;\;n}Cp^{n-4} r^3 q^1 + \cdots + {}_{0,n-1,1}^{\;\;\;\;n}Cp^0 r^{n-1} q^1 + \cdots + \cdots + \cdots + {}_{0,0,n}^{\;\;n}Cp^0 r^0 q^n$$

(11)

So, if the probability of passing an event is p, the probability of indecisive of the event is r and the probability of failing the event is q from a large population then for certain n number of people or object or items or entities selected at random from the large population the Kifilideen's Trinomial Distribution Model is presented as (11). The summation of the series of (11) would give 1.

Such that $p + r + q = 1$

(12)

That is, probability of pass of event $+$ probability of indecisive of event $+$ Probability of fail of the event $= 1$ (13)

$$P_r\,(Pass) + P_r\,(Indecisive) + P_r\,(Fail) = 1$$

(14)

For Term T_1 for $t = 1$ in (11) indicates the probability of n pass, 0 indecisive and 0 fail for the random selection of the n people or objects or items or entities of the population. For Term T_2 for $t = 2$ in (11) indicates the probability of $(n-1)$ pass, 1 indecisive 0 fail for the random selection of the n people or objects or entities of the population. For Term T_3 for $t = 3$ in (11) indicates the probability of $(n-2)$ pass and 2 indecisive and 0 fail for the random selection of the n people or objects or entities of the population. For last Term T_t for $t = t$ in (11) indicates the probability of 0 pass, 0 indecisive n fail for the random selection of the n people or objects or entities of the population. The trend above for Term T_1 for $t = 1$, Term T_2 for $t = 2$, Term T_3 for $t = 3$ and lasr Term T_t for $t = t$ is also applicable to all other terms in the Kifilideen's Trinomial Distribution Model.

Mathematical Induction of Kifilideen's Power Combination formula of Negative Powers of n of Kifilideen's Trinomial Theorem

Kifilideen's Power Combination Formula 1

$$C_P = 9t - 110a - 9m + n00 \qquad (15)$$

Where C_P is the power combination of term, t, t is the term of the power combination , a and m are the migration column and row factors respectively and n is the value of the negative power of Kifilideen's Trinomial Theorem.

Proof:

Figure 2 below shows Kifilideen's Matrix of negative power of n (where $n = -6$ for the sample Figure below), of Kifilideen trinomial theorem while Figure 3 indicates the arrangement of the terms in each group for negative power of n (where $n = -6$ for the sample Figure 3 below), of Kifilideen trinomial theorem. From Figure 2 it is observed that the difference in value between the first member of power combination in one group and another first member of power combination in the next or proceeding group is $110.$ For example; for group 1, the first power combination, fm_{g_1} is -600 and for group 2, the first power combination, fm_{g_2} is -710. So, the common difference in power combination, D is $-710-(-600) = -110$

That is, $D =$ Common difference in power combination $= fm_{g_2} - fm_{g_1} = -700-(-600) = -110$ (16)

Also, for group 2, the first power combination, fm_{g_2} is -710 and for group 3, the first power combination, fm_{g_3} is -820. So, the common difference in power combination, D is $-820-(-710) = -110$

That is, $D =$ Common difference in power combination $= fm_{g_3} - fm_{g_2} = -820-(-710) = -110$ (17)

More so, the difference in value between one power combination and the proceeding power combination down a particular group is $9.$ For illustration; considering group 3, the members of the power combination serially are -820, -811, and -802. The common difference, d down the group is:

$d = -811-(-820) = -802-(-811) = 9$ (18)

This information procured in (17) and (18) were used to formulate the mathematical induction of the power combination formula of the negative power of 6 of the Kifilideen's Trinomial Theorem. The mathematical induction of the power combination of the negative power of 6 of the Kifilideen's Trinomial Theorem is given as follow:

Group 1 Term T_1 for $t = 1$, $C_P = -600 = -600 - 110 \times 0 + 9 \times 0$ (19)

$C_P = -600 = -600 - 110 \times 0 + 9 \times (1-1)$ (20)

$C_P = -600 = 9 \times 1 - 110 \times 0 - 9 \times 1 - 600$ (21)

Group 2 Term T_2 for $t = 2$, $C_P = -710 = -600 - 110 \times 1 + 9 \times 0$ (22)

$C_P = -710 = -600 - 110 \times 1 + 9 \times (2-2)$ (23)

$C_P = -710 = 9 \times 2 - 110 \times 1 - 9 \times 2 - 600$ (24)

Term T_3 for $t = 3$, $C_P = -701 = -600 - 110 \times 1 + 9 \times 1$ (25)

$C_P = -701 = -600 - 110 \times 1 + 9 \times (3-2)$ (26)

$C_P = -701 = 9 \times 3 - 110 \times 1 - 9 \times 2 - 600$ (27)

Group 3 Term T_4 for $t = 4$, $C_P = -820 = -600 - 110 \times 2 + 9 \times 0$ (28)

$C_P = -820 = -600 - 110 \times 2 + 9 \times (4-4)$ (29)

$C_P = -820 = 9 \times 4 - 110 \times 2 - 9 \times 4 - 600$ (30)

Term T_5 for $t = 5$, $C_P = -811 = -600 - 110 \times 2 + 9 \times 1$ (31)

$C_P = -811 = -600 - 110 \times 2 + 9 \times (5-4)$ (32)

$C_P = -811 = 9 \times 5 - 110 \times 2 - 9 \times 4 - 600$ (33)

Term T_6 for $t = 6$, $\quad C_P = -802 = -600 - 110 \times 2 + 9 \times 2$ (34)

$$C_P = -802 = -600 - 110 \times 2 + 9 \times (6 - 4) \quad (35)$$

$$C_P = -802 = 9 \times 6 - 110 \times 2 - 9 \times 4 - 600 \quad (36)$$

$$\left|\begin{array}{cccc}
g_1 & g_2 & g_3 & g_q \\
kif & kif & kif & kif \\
-600 & & & \\
 & -710 & & \\
 & -701 & -820 & \\
 & & -811 & . \\
 & & -802 & .. \\
 & & & \cdots \\
 & & & \cdots \\
 & & & \cdots
\end{array}\right|$$

Figure 2. Kifilideen's Matrix of negative power of 6 of Kifilideen's Trinomial Theorem

$$\left|\begin{array}{cccc}
g_1 & g_2 & g_3 & g_q \\
T_1 & & & \\
 & T_2 & & \\
 & T_3 & T_4 & \\
 & & T_5 & . \\
 & & T_6 & .. \\
 & & & \cdots \\
 & & & \cdots
\end{array}\right|$$

Figure 3. Arrangement of the terms in each group for negative power of 6 of Kifilideen's Trinomial Theorem.

In Summary; the mathematical induction of the power combination of the negative power of 6 of the Kifilideen's Trinomial Theorem is given as follow;

Group 1, Term T_1 for $t = 1$, $\quad C_P = -600 = 9 \times 1 - 110 \times 0 - 9 \times 1 - 600$ (37)

Group 2, Term T_2 for $t = 2$, $\quad C_P = -710 = 9 \times 2 - 110 \times 1 - 9 \times 2 - 600$ (38)

Term T_3 for $t = 3$, $\quad C_P = -701 = 9 \times 3 - 110 \times 1 - 9 \times 2 - 600$ (39)

Group 3, Term T_4 for $t = 4$, $\quad C_P = -820 = 9 \times 4 - 110 \times 2 - 9 \times 4 - 600$ (40)

Term T_5 for $t = 5$, $C_P = -811 = 9 \times 5 - 110 \times 2 - 9 \times 4 - 600$ (41)

Term T_6 for $t = 6$, $C_P = -802 = 9 \times 6 - 110 \times 2 - 9 \times 4 - 600$ (42)

. . .
. . .
. . .

Group g; Term T_t for $t = t$; $C_P = kif = 9 \times t - 110 \times a - 9 \times m - 600$ (43)

Following the trend in (37) to (42), we can deduce that the mathematical induction of the power combination of the negative powers of n of the Kifilideen's Trinomial Theorem is given as:

For Term T_t for $t = t$ $\quad C_P = kif = 9t - 110a - 9m + n00$ (44)

Where C_P is the power combination of Term T_t for $t = t$; t is the term of the power combination, a and m are the migration column and row factors respectively; k, i and f are the first, second and third components of the power combination; and n is the negative power of Kifilideen's Trinomial Theorem.

To derive an equation for a and m, we have the mathematical induction of the power combination of the negative power of 6 of the Kifilideen's Trinomial Theorem as given below;

$$C_P = 9 \times \mathbf{t} - 110 \times a - 9 \times \mathbf{m} + n00 = kif \quad (45)$$

Group 1; Term T_1 for $t = 1$, $C_P = 9 \times \mathbf{1} - 110 \times 0 - 9 \times \mathbf{1} - 600 = -60\mathbf{0}$ (46)

Group 2; Term T_2 for $t = 2$, $C_P = 9 \times \mathbf{2} - 110 \times 1 - 9 \times \mathbf{2} - 600 = -71\mathbf{0}$ (47)

Term T_3 for $t = 3$, $C_P = 9 \times \mathbf{3} - 110 \times 1 - 9 \times \mathbf{2} - 600 = -70\mathbf{1}$ (48)

Group 3; Term T_4 for $t = 4$, $C_P = 9 \times \mathbf{4} - 110 \times 2 - 9 \times \mathbf{4} - 600 = -82\mathbf{0}$ (49)

Term T_5 for $t = 5$, $C_P = 9 \times \mathbf{5} - 110 \times 2 - 9 \times \mathbf{4} - 600 = -81\mathbf{1}$ (50)

Term T_6 for $t = 6$, $C_P = 9 \times \mathbf{6} - 110 \times 2 - 9 \times \mathbf{4} - 600 = -80\mathbf{2}$ (51)

Minus **Gives**

$$\boldsymbol{t} \quad - \quad \boldsymbol{m} \quad = \quad \boldsymbol{f}$$

Taking the value of the power combination as kif. Where k, i and f are the first, second and third digits of the power combination. From the mathematical induction in (46) to (51) we can deduce that:

$$t - m = f \quad (52)$$

Where t is the term of the power combination, m is the migration row factor and f is the third component of the power combination.

Also, from the mathematical induction in (46) to (51); Table 1 is worked out below. Table 1 shows the values of a and m for group, g for negative power of 6 or any n of Kifilideen's Trinomial Theorem. It can be noticed from Table 1 that: $a = g - 1$ (53)

To evaluate m, we have: $m = 1 + 1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10 + \cdots + a$ (54)

Taking $m = 1 + \theta$ (55)

Where $\theta = 1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10 + \cdots + a$ (56)

From (56), 1^{st} term $= v = 1$, $d = T_2 - T_1 = 2 - 1 = 1$ and $l = a$ and $w = a$ (57)

Where v is the first term, d is the common difference, T_1 is the first term, T_2 is the second term, l is the last term, w is the number of terms and a is the migration column factor. The series of θ in (58) is Arithmetic progression A.P. From the sum of A.P. given by Macrae (2001) we have:

$$S_w = \frac{w}{2}(v + l) \quad (58)$$

Where v and l are the first and last terms of the series, θ respectively in (56), S_w is the series of θ and w is the number of terms of θ.

$$S_w = \theta = \frac{a}{2}(1 + a) \quad (59)$$

Table 1. Values of a and m for group, g for negative power of -6 or any $-n$ Kifilideen trinomial theorem

g	a	m
1	0	$1 = 1^{+0} = 1$
2	1	$1 + 1 = 1^{+1} = 2$
3	2	$1 + 1 + 2 = 2^{+2} = 4$
.	.	.
.	.	.
.	.	.
g	$g - 1$	$1 + 1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10 + \cdots + a$

Put (59) in (55), we have: $m = 1 + \theta = 1 + \frac{a}{2}(1 + a) = \frac{a^2+a+2}{2}$ (60)

Since from (53), we have $a = g - 1$ (61)

$$m = \frac{(g-1)^2+(g-1)+2}{2} = \frac{g^2-g+2}{2} \quad (62)$$

Generally, from the mathematical induction for negative powers of n for Kifilideen's Trinomial Theorem; we have:

$$C_P = kif = 9t - 110a - 9m + n00 \quad (63)$$

The migration column factor, $a = g - 1$ (64)

The migration row factor, $m = \frac{a^2+a+2}{2}$ or $m = \frac{g^2-g+2}{2}$ (65)

Kifilideen's Power Combination Formula 2

$$C_P = 9(t - 1) - \frac{9}{2}(n - k)^2 - \frac{229}{2}(n - k) + n00 \quad (66)$$

Where C_P is the power combination of Term T_t for $t = t$, t is the term of the power combination, k is the first component of the power combination; and n is the negative power of Kifilideen's Trinomial Theorem.

Proof:

The mathematical induction of the power combination of the negative power of $\mathbf{6}$ of the Kifilideen's Trinomial Theorem from (37) to (42) is given as follow;

$$C_P = 9 \times t - 110 \times \boldsymbol{a} - 9 \times m + \boldsymbol{n}00 = \boldsymbol{k}if \quad (67)$$

Group 1; Term T_1 for $t = 1$, $C_P = 9 \times 1 - 110 \times \mathbf{0} - 9 \times 1 - \mathbf{6}00 = -\mathbf{6}00$ (68)

Group 2; Term T_2 for $t = 2$, $C_P = 9 \times 2 - 110 \times \mathbf{1} - 9 \times 2 - \mathbf{600} = -\mathbf{7}10$ (69)

Term T_3 for $t = 3$, $C_P = 9 \times 3 - 110 \times \mathbf{1} - 9 \times 2 - \mathbf{6}00 = -\mathbf{7}01$ (70)

Group 3; Term T_4 for $t = 4$, $C_P = 9 \times 4 - 110 \times \mathbf{2} - 9 \times 4 - \mathbf{6}00 = -\mathbf{8}20$ (71)

Term T_5 for $t = 5$, $C_P = 9 \times 5 - 110 \times \mathbf{2} - 9 \times 4 - \mathbf{6}00 = -\mathbf{8}11$ (72)

Term T_6 for $t = 6$, $C_P = 9 \times 6 - 110 \times \mathbf{2} - 9 \times 4 - \mathbf{6}00 = -\mathbf{8}02$ (73)

Gives

Minus **Minus**

$\boldsymbol{a} \quad - \quad \boldsymbol{n} \quad = \; -\boldsymbol{k}$

Taking the value of the power combination as kif. Where k, i and f are the first, second and third digits of the power combination. From the mathematical induction in (68) to (73) we can deduce that;

$$a - n = -k \quad (74)$$

$$a = n - k \quad (75)$$

Where a is the migration column factor, k is the first component of the power combination and n is value of the negative powers of Kifilideen's Trinomial Theorem.

From (65), The migration row factor,

$$m = \frac{a^2+a+2}{2} = \frac{(n-k)^2+(n-k)+2}{2} \quad (76)$$

For further deduction for the power combination for the negative powers of n for the Kifilideen trinomial theorem, we have:

From (63), $C_P = 9t - 110a - 9m + n00$ (77)

$$C_P = 9t - 110(n-k) - 9\left(\frac{(n-k)^2+(n-k)+2}{2}\right) + n00 \quad (78)$$

$$C_P = 9(t-1) - \frac{9}{2}(n-k)^2 - \frac{229}{2}(n-k) + n00 \quad (79)$$

Where C_P is the power combination of Term T_t for $t = t$, t is the term of the power combination; k is the first component of the power combination; and n is the negative power of Kifilideen's Trinomial Theorem.

Kifilideen's Power Combination Formula 3

$$C_P = -110a + 9(t-m) + n00 \quad (83)$$

$$a = \frac{-1+\sqrt{8t-7}}{2} \text{ and } m = \frac{a^2+a+2}{2}$$

Where C_P is the power combination of term, t, t is the term of the power combination , a and m are the migration column and row factors respectively and n is the value of the negative powers of Kifilideen's Trinomial Theorem.

Proof:

The mathematical induction of the negative power of – 6 for the Kifilideen trinomial theorem is given as:

Group 1; Term T_1 for $t = 1$, $C_P = -600 = -110 \times 0 - 9(1-1) - 600$
(84)
Group 2; Term T_2 for $t = 2$, $C_P = -710 = -110 \times 1 - 9(2-2) - 600$
(85)
Term T_3 for $t = 3$, $C_P = -701 = -110 \times 1 - 9(3-2) - 600$
(86)
Group 3; Term T_4 for $t = 4$, $C_P = -820 = -110 \times 2 - 9(4-4) - 600$
(87)
Term T_5 for $t = 5$, $C_P = -811 = -110 \times 2 - 9(5-4) - 600$
(88)
Term T_6 for $t = 6$, $C_P = -802 = -110 \times 2 - 9(6-4) - 600$
(89)
. . .
. . .
. . .
Group g; Term T_t for $t = t$; $C_P = kif = -110 \times a - 9(t-m) - 600$
(90)
Following the trend in (84) to (90), we can deduce that the mathematical induction of the power combination of the negative powers of n of the Kifilideen's Trinomial Theorem is given as:
For Term T_t for $t = t$; $C_P = kif = -110a - 9(t-m) + n00$
(92)
From Figure 3, Term T_1 for $t = 1$ belong to group 1, g_1; Term T_2 for $t = 2$ and Term T_3 for $t = 3$ belong to group 2, g_2; Term T_4 for $t = 4$, Term T_5 for $t = 5$, and Term T_6 for $t = 6$ belong to group 3, g_3;..., respectively. Considering only the first term of each group (m value of each group), we have:
$g = 1$, $t = 1 = 1^{st}$ term
(93)
$g = 2$, $t = 1 + 1 = 2^{nd}$ term
(94)
$g = 3$, $t = 1 + 1 + 2 = 4^{th}$ term
(95)

..
..
..

$g = g$, $t = 1 + 1 + 2 + 3 + 4 + \cdots + (g-1)$
(96)
Taking $t = 1 + \mu$
(97)
Where $\mu = 1 + 2 + 3 + 4 + \cdots + (g-1)$
(98)
From the (99), 1^{st} term $= x = 1$, last term $= z = g - 1$ and $u = g - 1$
(99)
Where x is the first term of the series, μ in (98), z is the last term of μ and u is the number of terms of μ. Using sum of arithmetic progression formula presented by Macrae (2001), we have

$$S_u = \mu = \frac{u}{2}(x + z) \quad (100)$$

$$S_{g-1} = \mu = \frac{(g-1)}{2}(1 + g - 1) = \frac{g\,(g-1)}{2}$$
(101)

Put (103) in (98), $$t = 1 + \mu = 1 + \frac{g\,(g-1)}{2}$$
(102)

$$g^2 - g + 2 - 2t = 0$$
(103)

Using quadratic formula, $g = \frac{1 \pm \sqrt{(-1)^2 - 4(1)(2-2t)}}{2 \times 1} = \frac{1 \pm \sqrt{8t-7}}{2}$ (104)

Since g is positive in value, $g = \frac{1+\sqrt{8t-7}}{2}$ (105)

Recall from (53), $a = g - 1, g = a + 1 = \frac{1+\sqrt{8t-7}}{2}$ (106)

From (106), $a + 1 = \frac{1+\sqrt{8t-7}}{2}$, $a = \frac{-1+\sqrt{8t-7}}{2}$ (107)

Recall from (65), $m = \frac{a^2+a+2}{2}$ (108)

For group 1, putting $t = 1$ for Term T_1 in (107) a whole number of 0 can be obtained for a (that is $a = 0$). Inserting $a = 0$ in (108) the value of $m = 1$ is arrived at. Group 2 contains Term T_2 and Term T_3 where values for m and a are $m = 2$ and $a = 1$, putting $t = 2$ for Term T_2 in (107) a whole number of 1 can be achieved for a (that is $a = 1$) and putting $t = 3$ for Term T_3 in (107) a decimal value of 1.5615 can be attained for a. Since the value of a in group 2 is 1, so the whole number part of the value of a attained for $t = 3$ is considered. Inserting $a = 1$ in (108) value of $m = 2$ is arrived at. Subsequently Group 3 contains Term T_4, Term T_5 and Term $T_6$where values for m and a are $m = 4$ and $a = 2$, putting $t = 4$ for Term T_4 in (107) a whole number of 2 can be obtained for a (that is $a = 2$) and putting $t = 5$ for Term T_5, $t = 6$ for Term T_6 in (107) decimal values of 2.3722 and 2.7016 are work out respectively for a. Since the value of a in group 3 is 2, so the whole number part of the value of a attained for $t = 5$, $t = 6$ are considered. Inserting $a = 2$ in (108) value of $m = 4$ is secured. The trend above as calculated for group 1, group 2 and group 3 is also applicable to all the other groups.

Generally, $a = \frac{-1+\sqrt{8t-7}}{2}$ (109)

which can be used to acquire the value of a for any given term of Kifilideen's Trinomial Theorem of negative powers of n and $m = \frac{a^2+a+2}{2}$ (110)

which can be used to obtained the value of m once the value of a is known.

In summary, the following can be deduced from the mathematical induction above,

$$C_P = -110a + 9(t-m) + n00 \quad (111)$$

$$a = \frac{-1+\sqrt{8t-7}}{2} \text{and} \quad m = \frac{a^2+a+2}{2}$$

Mathematical Induction of Kifilideen's Term Formula of Negative Powers of n of Kifilideen's Trinomal Theorem

Kilifideen Term Formula 1

$$t = \frac{(n-k)^2+(n-k)+2+2f}{2} \quad (112)$$

Proof:

The mathematical induction of the Kifilideen'a Term Formula 1 of the negative powers of n of the Kifilideen's Trinomial Theorem (using the negative power of 6) is given as follow:

$$C_P = 9 \times \boldsymbol{t} - 110 \times a - 9 \times \boldsymbol{m} + n00 = kif \quad (113)$$

Group 1; Term T_1 for $t = 1$,
$$C_P = 9 \times \mathbf{1} - 110 \times 0 - 9 \times \mathbf{1} - 600 = -60\mathbf{0} \tag{114}$$
Group 2; Term T_2 for $t = 2$,
$$C_P = 9 \times \mathbf{2} - 110 \times 1 - 9 \times \mathbf{2} - 600 = -71\mathbf{0} \tag{115}$$
Term T_3 for $t = 3$,
$$C_P = 9 \times \mathbf{3} - 110 \times 1 - 9 \times \mathbf{2} - 600 = -70\mathbf{1} \tag{116}$$
Group 3; Term T_4 for $t = 4$,
$$C_P = 9 \times \mathbf{4} - 110 \times 2 - 9 \times \mathbf{4} - 600 = -82\mathbf{0} \tag{117}$$
Term T_5 for $t = 5$,
$$C_P = 9 \times \mathbf{5} - 110 \times 2 - 9 \times \mathbf{4} - 600 = -81\mathbf{1} \tag{118}$$
Term T_6 for $t = 6$, $C_P = 9 \times \mathbf{6} - 110 \times 2 - 9 \times \mathbf{4} - 600 = -80\mathbf{2}$ (119)

Minus **Gives**

$$\boldsymbol{t} \quad - \quad \boldsymbol{m} \quad = \quad \boldsymbol{f}$$

Taking the value of the power combination as kif. Where k, i and f are the first, second and third digits of the power combination. From the mathematical induction in (114) to (119) we can deduce that:

$$t - m = f \tag{120}$$

Where t is the term of the power combination, m is the migration row factor and f is the third component of the power combination. Table 2 illustrates the mathematical induction for the Kifilideen's Term Formula 1 for negative powers of n of Kifilideen's Trinomial Theorem (using negative power of 6). Recall from (75) and (76), the migration group factor, a and migration row factor, m are given as:

$$a = n - k \text{ and } m = \frac{(n-k)^2+(n-k)+2}{2} \tag{121}$$

Therefore,
$$t - m = f \tag{122}$$

$$t - \frac{(n-k)^2+(n-k)+2}{2} = f \tag{123}$$

$$t = \frac{(n-k)^2+(n-k)+2f+2}{2} \tag{124}$$

Table 2. Mathematical induction for the Kifilideen's Term Formula 1 for negative powers of n of Kifilideen's Trinomial Theorem (using negative power of 6).

Group, g	Power combination, C_P (kif)	Migration column factor, a ($a = g - 1$) Or ($a = n - k$)	Migration row factor, m $\left(m = \frac{a^2+a+2}{2}\right)$	Term, t $(t = m + f)$
1	$-60\mathbf{0}$	$1 - 1 = 0$ Or $-6 - -6 = 0$	$\frac{0^2+0+2}{2} = \mathbf{1}$	$\frac{0^2+0+2}{2} + 0 = 1 + \mathbf{0} = 1$
2	$-71\mathbf{0}$	$2 - 1 = 1$ Or	$\frac{1^2+1+2}{2} = \mathbf{2}$	$\frac{1^2+1+2}{2} + 0 = \mathbf{2} + \mathbf{0} = 2$

		$-6 - -7 = 1$		
	-701	$2 - 1 = 1$ Or $-6 - -7 = 1$	$\frac{1^2 + 1 + 2}{2} = \mathbf{2}$	$\frac{1^2 + 1 + 2}{2} + 1 = \mathbf{2} + \mathbf{1} = 3$
3	-820	$3 - 1 = 2$ Or $-6 - -8 = 2$	$\frac{2^2 + 2 + 2}{2} = \mathbf{4}$	$\frac{2^2 + 2 + 2}{2} + 0 = \mathbf{4} + \mathbf{0} = 4$
	-811	$3 - 1 = 2$ Or $-6 - -8 = 2$	$\frac{2^2 + 2 + 2}{2} = \mathbf{4}$	$\frac{2^2 + 2 + 2}{2} + 1 = \mathbf{4} + \mathbf{1} = 5$
	-802	$3 - 1 = 2$ Or $-6 - -8 = 2$	$\frac{2^2 + 2 + 2}{2} = \mathbf{4}$	$\frac{2^2 + 2 + 2}{2} + \mathbf{2} = \mathbf{4} + \mathbf{2} = 6$
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
g	$ki\boldsymbol{f}$	$a = g - 1$ Or $a = n - k$	$m = \frac{a^2 + a + 2}{2}$ Or $m = \frac{(n-k)^2 + (n-k) + 2}{2}$	$t = \frac{a^2 + a + 2}{2} + f$ Or $t = \frac{(n-k)^2 + (n-k) + 2}{2} + f$ Or $t = \frac{(n-k)^2 + (n-k) + 2f + 2}{2}$

In summary, the mathematical induction of the Kifilideen's Term Formula 1 for negative powers of n of Kifilideen's Trinomial Theorem is given as: $t = \frac{(n-k)^2+(n-k)+2f+2}{2}$
(125)

Kilifideen's Term Formula 2

$$t = \frac{(n-k)^2+3(n-k)-2i+2}{2}$$

(126)

Proof:
The mathematical induction of the Kifilideen's term formula 2 of the negative powers of n of the Kifilideen's Trinomial Theorem (using the negative power of 6) is given as follow:

Minus **Result 2**

$$C_P = 9 \times \boldsymbol{t} - 110 \times \boldsymbol{a} - 9 \times \boldsymbol{m} - n00 = \ k\boldsymbol{i}f \quad (127)$$

Group 1; Term T_1 for $t = 1$,
$$C_P = 9 \times \mathbf{1} - 110 \times \mathbf{0} - 9 \times \mathbf{1} - 300 = -3\mathbf{0}0 \quad (128)$$
Group 2; Term T_2 for $t = 2$,
$$C_P = 9 \times \mathbf{2} - 110 \times \mathbf{1} - 9 \times \mathbf{2} - 300 = -4\mathbf{1}0 \quad (129)$$
Term T_3 for $t = 3$,
$$C_P = 9 \times \mathbf{3} - 110 \times \mathbf{1} - 9 \times \mathbf{2} - 300 = -4\mathbf{0}1 \quad (130)$$
Group 3; Term T_4 for $t = 4$,
$$C_P = 9 \times \mathbf{4} - 110 \times \mathbf{2} - 9 \times \mathbf{4} - 300 = -5\mathbf{2}0 \quad (131)$$
Term T_5 for $t = 5$,
$$C_P = 9 \times \mathbf{5} - 110 \times \mathbf{2} - 9 \times \mathbf{4} - 300 = -5\mathbf{1}1 \quad (132)$$
Term T_6 for $t = 6$, $C_P = 9 \times \mathbf{6} - 110 \times \mathbf{2} - 9 \times \mathbf{4} - 300 = -5\mathbf{0}2$ (133)

Minus **Result 1**

Taking the value of the power combination as kif. Where k, i and f are the first, second and third digits of the power combination. From the mathematical induction in (130) to (135) we can deduce that:

$$Results\ 1 = Results\ 2 \quad (134)$$

$$t - m = a - i \quad (135)$$

Where t is the term of the power combination, a is the migration column factor, m is the migration row factor and i is the second component of the power combination. Table 3 demonstrates the mathematical induction for the Kifilideen's Term Formula 2 for negative powers of n of Kifilideen's Trinomial Theorem.

Recall from (75) and (76), the migration column factor, a and migration row factor, m are given as:

$$a = n - k \text{ and } m = \frac{(n-k)^2 + (n-k) + 2}{2} \quad (136)$$

Therefore,
$$t - m = a - i \quad (138)$$

$$t - \frac{(n-k)^2 + (n-k) + 2}{2} = (n - k) - i \quad (139)$$

$$t = \frac{(n-k)^2 + 3(n-k) - 2i + 2}{2} \quad (140)$$

Table 3. Mathematical induction for the Kifilideen Term Formula 2 for negative powers of n of Kifilideen Trinomial Theorem (using negative power of 6).

Group g	Migration column factor a $(a = g - 1)$ Or $(a = n - k)$	Migration row factor m $\left(m = \frac{a^2 + a + 2}{2}\right)$	Power combi nation C_P (kif)	Term t $(t = m + a - i)$
1	$1 - 1 = 0$ Or $-6 - -6 = 0$	$\frac{0^2 + 0 + 2}{2} = \mathbf{1}$	-600	$\frac{0^2 + 0 + 2}{2} + 0 - \mathbf{0} = \mathbf{1} + 0 - \mathbf{0} = 1$
2	$2 - 1 = 1$ Or $-6 - -7 = 1$	$\frac{1^2 + 1 + 2}{2} = \mathbf{2}$	-710	$\frac{1^2 + 1 + 2}{2} + 1 - \mathbf{1} = \mathbf{2} + 1 - \mathbf{1} = 2$
	$2 - 1 = 1$ Or $-6 - -7 = 1$	$\frac{1^2 + 1 + 2}{2} = \mathbf{2}$	-701	$\frac{1^2 + 1 + 2}{2} + 1 - \mathbf{0} = \mathbf{2} + 1 - \mathbf{0} = 3$
3	$3 - 1 = 2$ Or $-6 - -8 = 2$	$\frac{2^2 + 2 + 2}{2} = \mathbf{4}$	-820	$\frac{2^2 + 2 + 2}{2} + 2 - \mathbf{2} = \mathbf{4} + 2 - \mathbf{2} = 4$
	$3 - 1 = 2$ Or $-6 - -8 = 2$	$\frac{2^2 + 2 + 2}{2} = \mathbf{4}$	-811	$\frac{2^2 + 2 + 2}{2} + 2 - \mathbf{1} = \mathbf{4} + 2 - \mathbf{1} = 5$
	$3 - 1 = 2$ Or $-6 - -8 = 2$	$\frac{2^2 + 2 + 2}{2} = \mathbf{4}$	-802	$\frac{2^2 + 2 + 2}{2} + 2 - \mathbf{0} = \mathbf{4} + 2 - \mathbf{0} = 6$
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.

g	$a = g - 1$ Or $a = n - k$	$m = \dfrac{a^2 + a + 2}{2}$ Or $m = \dfrac{(n-k)^2 + (n-k) + 2}{2}$	kif	$t = \dfrac{a^2 + a + 2}{2} + a - i$ Or $t = \dfrac{(n-k)^2 + (n-k) + 2}{2} + (n-k) - i$ Or $t = \dfrac{(n-k)^2 + 3(n-k) - 2i + 2}{2}$

Also, the mathematical induction from Table 3, the Kifilideen's Term Formula 2 for negative powers of n of Kifilideen's Trinomial Theorem (using negative power of 6 or any value of negative power of n) is given as

$$t = \frac{(n-k)^2 + 3(n-k) - 2i + 2}{2}$$
(141)

In summary, the mathematical induction of the Kifilideen general term formula 2 for negative powers of n of Kifilideen trinomial theoremis given as: $t = \frac{(n-k)^2 + 3(n-k) - 2i + 2}{2}$
(142)

Mathematical Induction of Kifilideen's Position Formula of Negative Powers of n

Kifilideen's Position Formula 1

$$R_{member} = F_{member} + 9(p - 1)$$
(143)

Where R_{member} is the power combination of the required member in which position is to be determined, F_{member} is the power combination of the first member of the group in which the required member belong and p is the position of the required member.

Proof:

In Figure 2, the power combination of the first member, F_{member} in groups $1,2,3,4 \ldots$, are $-600, -710, -701, -820, \ldots$, respectively. The mathematical induction of the Kifilideen's Position Formula for negative powers of n of Kifilideen's Trinomial Theorem is presented as follow:

Group 1, Term T_1 for $t = 1$ $p = 1,$ $C_P = -600 = -600 + 9(1 - 1)$
(144)
Group 2, Term T_2 for $t = 2,$ $p = 1,$ $C_P = -710 = -710 + 9(1 - 1)$
(145)
Term T_3 for $t = 3,$ $p = 2,$ $C_P = -701 = -710 + 9(2 - 1)$
(146)
Group 3, Term T_4 for $t = 4,$ $p = 1,$ $C_P = -820 = -820 + 9(1 - 1)$
(147)
Term T_5 for $t = 5,$ $p = 2,$ $C_P = -811 = -820 + 9(2 - 1)$
(148)
Term T_6 for $t = 6,$ $p = 3,$ $C_P = -802 = -820 + 9(3 - 1)$
(149)

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. . . .
. . . .

Group g, Term T_t for $t = t, \quad p = p, \qquad C_P = R_{member} = F_{member} + 9(p-1)$ (150)

Where R_{member} is the power combination of the required member in which position is to be determined, F_{member} is the power combination of the first member of the group in which the required member belong and p is the position of the required member. It is observed from (144) to (150) that to obtain the position of the power combination of the required member of a group, the power combination of the first member of that group is needed. In summary, the mathematical induction of the Kifilideen's Position Formula for negative powers of n of Kifilideen trinomial theorem is given as:

$$R_{member} = F_{member} + 9(p-1) \quad (151)$$

Kifilideen's Position Formula 2

$$C_P = \quad kif = n00 - 110(a) + 9(p-1) \quad (152)$$

Proof:

The mathematical induction of the Kifilideen's Position Formula 2 for negative power 6 of Kifilideen Trinomial Theorem is presented as follow:

Group 1, Term T_1 for $t = 1, \quad p = 1, \quad C_P = -600 = -600 - 110(0) + 9(1-1)$ (153)

Group 2, Term T_2 for $t = 2, \quad p = 1, \quad C_P = -710 = -600 - 110(1) + 9(1-1)$ (154)

Term T_3 for $t = 3, \quad p = 2, \quad C_P = -701 = -600 - 110(1) + 9(2-1)$ (155)

Group 3, Term T_4 for $t = 4, \quad p = 1, \quad C_P = -820 = -600 - 110(2) + 9(1-1)$ (156)

Term T_5 for $t = 5, \quad p = 2, \quad C_P = -811 = -600 - 110(2) + 9(2-1)$ (157)

Term T_6 for $t = 6, \quad p = 3, \quad C_P = -802 = -600 - 110(2) + 9(3-1)$ (158)

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. . . .
. . . .

Group g, Term T_t for $t = t, \quad p = p, \qquad C_P = \quad kif = -600 - 110(a) + 9(p-1)$ (159)

In summary, for negative power of n of Kifilideen's Trinomial Theorem, the Kifilideen's Position Formula is stated as follow:

$$C_P = \quad kif = n00 - 110(a) + 9(p-1) \quad (160)$$

Where k, i and f are the first, second and third digits of the power combination, a is the migration column factor, n is the value of the negative power of the Kifilideen's Trinomial Theorem and p is the position of the power combination to be determined.

Mathematical Induction of Kifilideen's Power Combination Row Column Formula of Negative Power of n

$$CP_{rc} = kif = n00 - 110(c-1) + 9(r-c) \quad (161)$$

$$r = 2f + i + 1, c = f + i + 1, c = a + 1 = g$$

$$n - c + 1 = k, \quad p = r - c + 1$$

Where k, i and f are the first, second and third digits of the power combination, a is the migration column factor, n is the value of the negative power of the Kifilideen's Trinomial Theorem, g is the group the power combination belong to, r and c are the row and column the power combination belong to and p is the position of the power combination to be determined.

Proof:

Figure 4 shows the Kifilideen's Matrix for negative power of 6 of Kifilideen's Trinomial Theorem. For close study of the Kilifideen's Matrix of the negative power of 6 Trinomial Theorem; the migration column value is 110 and the migration row value is 9. This idea forms the basis of the mathematical induction for the Kifilideen's Power Combination Row Column Formula of the negative power of n of Kifilideen's Trinomial Theorem.

The mathematical induction of the Kifilideen's Power Combination Row Column Formula for negative power 6 of Kifilideen's Trinomial Theorem is illustrated as follow:

$$\boldsymbol{n} \quad - \quad (\boldsymbol{c}-\boldsymbol{1}) \quad = \quad \boldsymbol{k}$$

Minus **Gives**

Group 1, Term T_1 for $t = 1$ $\quad C_{1\,1} = -600 - 110(1-1) + 9(\mathbf{1-1}) = -60\mathbf{0}$ (162)

Group 2, Term T_2 for $t = 2$, $\quad C_{2\,2} = -600 - 110(2-1) + 9(\mathbf{1-1}) = -71\mathbf{0}$ (163)

Term T_3 for $t = 3$, $\quad C_{3\,2} = -600 - 110(2-1) + 9(\mathbf{2-2}) = -70\mathbf{1}$ (164)

Group 3, Term T_4 for $t = 4$, $\quad C_{3\,3} = -600 - 110(3-1) + 9(\mathbf{3-3}) = -82\mathbf{0}$ (165)

Term T_5 for $t = 5$, $\quad C_{4\,3} = -600 - 110(3-1) + 9(\mathbf{4-3}) = -81\mathbf{1}$ (166)

Term T_6 for $t = 6$, $\quad C_{5\,3} = -600 - 110(3-1) + 9(\mathbf{5-3}) = -80\mathbf{2}$ (167)

. . .

. . .

. . .

Group g, Term T_t for $t = t$, $\quad C_{r\,c} = -600 - 110(\boldsymbol{c}-\mathbf{1}) + 9(\boldsymbol{r}-\boldsymbol{c}) = \boldsymbol{kif}$ (168)

. . ..

Gives

$$(\boldsymbol{r}-\boldsymbol{c}) \quad = \quad \boldsymbol{f}$$

g_1	g_2	g_3	…
$CP_{rc} = kif$	$CP_{rc} = kif$	$CP_{rc} = kif$	$CP_{rc} = kif$
$CP_{11} = -600$			
	$CP_{22} = -710$		
	$CP_{32} = -701$	$CP_{33} = -820$	
		$CP_{43} = -811$	
		$CP_{53} = -802$	.
			..
			…

Figure 4. the Kifilideen's Matrix of negative power of 6 of Kifilideen's Trinomial Theorem

In summary, for negative powers of n of Kifilideen's Trinomial Theorem, we have:

Group g, Term T_t for $t = t$, $\quad C_{r\,c} = n00 - 110(\boldsymbol{c}-\mathbf{1}) + 9(\boldsymbol{r}-\boldsymbol{c}) = \boldsymbol{kif}$ (169)

Also, from (162) to (169), we can deduce that:

$$n-(c-1)=k, \qquad n-c+1=k \tag{170}$$

More so,

$$r-c=f, \quad r=c+f \tag{171}$$

Note always,

$$n=k+i+f \tag{172}$$

Put (172) in (170), we have:

$$k+i+f-c+1=k \tag{173}$$

So,

$$c=f+i+1 \tag{174}$$

Put (174) in (171), we have:

$$r=f+i+1+f \tag{175}$$

$$r=2f+i+1 \tag{176}$$

Comparing (152) and (169), we have:

$$C_P = \quad kif = n00-110(a)+9(p-1) \tag{177}$$

$$C_{r\ c} = n00-110(\boldsymbol{c-1})+9(\boldsymbol{r-c}) = \boldsymbol{kif} \tag{178}$$

Comparing the coefficient of -110:

$$a=c-1, c=a+1=g \tag{179}$$

Comparing the coefficient of $+9$:

$$p-1=r-c, \qquad p=r-c+1 \tag{180}$$

Therefore, it can be deduced that the mathematical induction of Kifilideen power combination row column formula from (162) to (180) for negative powers of n of Kifilideen's Trinomial Theorem is given as:

$$CP_{rc} = \quad kif = n00-110(c-1)+9(r-c)$$
$$r=2f+i+1, \ c=f+i+1, c=a+1=g$$

$$n-c+1=k, \ p=r-c+1$$

Results

Real Life Applications of Mathematical Model of Kifilideen's Trinomial Distribution

The real-life applications of mathematical model of Kifilideen's Trinomial Distribution of positive power of n is presented as follows:

(1) A car company produces three colours of cars which are red, green and blue. If the probability of a car selected at random is red is $\frac{1}{6}$ and the probability that the car selected at random is blue is $\frac{1}{3}$. If 4 samples of the cars are selected at random, determine the probability that three of the cars are red.

Solution

Let the probability of red car $= P_r\,(red) = p$, Let the probability of green car $= P_r\,(green) = r$ and Let the probability of blue car $= P_r\,(blue) = q$

$p = \frac{1}{6}$ and $q = \frac{1}{3}$

From $p+r+q=1$ in (12), we have

$\frac{1}{6} + r + \frac{1}{3} = 1$

$r = \frac{1}{2}$

For $n=4$ number of car selected at random, the all possible power combinations are presented in the Kifilideen's Matrix of positive power of 4 in Figure 5. For the probability that three of the cars are red $(n(P)=3)$ the possible power combinations from the Kifilideen matrix in Figure 5 are 310 and 301.

Probability of three red cars$= P_r(3\ reds, 1\ green\ and\ 0\ blue) + \ P_r(3\ reds, 0\ green\ and\ 1\ blue)$

Probability of three red cars $= {}_{310}^{\ 4}Cp^3r^1q^0 + {}_{301}^{\ 4}Cp^3r^0q^1 = \frac{4!}{3!1!0!}\left(\frac{1}{6}\right)^3\left(\frac{1}{2}\right)^1\left(\frac{1}{3}\right)^0 + \frac{4!}{3!0!1!}p^3r^0q^1 =$ 0.0154

PRQ	PRQ	PRQ	PRQ	PRQ
400				
310				
220	**301**			
130	211			
040	121	202		
	031	112		
		022	103	
			013	
				004

Figure 5. Kifilideen's Matrix of positive power of 4 for $n = 4$ number of car selected at random showing all the possible power combinations.

In this example, a company produces three colours of cars—red, green, and blue. The probability of selecting a red car is given, and the goal is to determine the probability that three out of four randomly selected cars are red.

Comparison with Existing Probability Models:

1. Binomial Distribution Limitation: the binomial distribution is commonly used for probability analysis where events have only two possible outcomes (e.g. red vs. not red). However, in this case, the company produces three different car colours. Using a binomial model would force the analysis into a two-category system, such as:

- Read (Success) vs. Not Red (Failure)
- Red vs. (Green + Blue combined)

This oversimplifies the problem, distorting the actual probability of each colour and leading to an incomplete and potential misleading analysis.

2. Multinomial Distribution Limitation: the multinomial distribution is capable of handling more than two outcomes, but it does not provide a structured framework for systematically evaluating trinomial systems with specific probability conditions-such as determining the likelihood of a particular number of red cars among a given sample. Its application relies on generalized probability expressions without an optimized combinatorial structure for trinomial cases.

Advantages of Kifildieen's Trinomial Distribution

Kifilideen's Trinomial Distribution overcomes these limitations by providing:

1. A structured probability framework that directly incorporates three outcomes without oversimplifying the data
2. A more accurate representation of real-world scenarios where three distinct outcomes are naturally present.

By applying Kifilideen's Trinomial Distribution, the probability that three of the four selected cars are red is accurately calculated without distorting the original dataset. This demonstrates the model's superiority over binomial and multinomial approaches, particularly in cases where three outcomes must be analyzed without artificial categorization or approximation.

(2) A bulb producing company observes three categories of bulb after production which are good (of extreme quality) bulbs, semi – good (of medium quality) bulbs and bad (of very low quality) bulbs. The

probability of selecting a good and semi – good bulbs at random from the bulbs produce by the company are 0.5 and 0.2 respectively. If 5 samples of bulbs are selected at random. Find the probability that at most 2 bulbs selected are good.

Solution

Let the probability of good bulbs $= P_r\,(good) = p$, Let the probability of semi – good bulbs $= P_r\,(semi\ good) = r$, and Let the probability of bad bulbs $= P_r\,(bad) = q$

$p = 0.5$ and $r = 0.2$

From $p + r + q = 1$ in (12), we have

$0.5 + 0.2 + q = 1$

$q = 0.3$

For $n = 5$ number of bulbs selected at random, the all possible power combinations are presented in the Kifilideen's Matrix of positive power of 5 in Figure 6. For the probability that at most 2 bulbs selected are good ($n(P) = 0, n(P) = 1\ and\ n(P) = 2$), then the possible power combinations from the Kifilideen matrix in Figure 6 are 230, 140, 050, 221, 131, 041, 212,122, 032, 203, 113, 023, 104, 014 and 005 and for the probability that at least 3 bulbs selected are good ($n(P) = 3, n(P) = 4\ and\ n(P) = 5$), the possible power combinations from the Kifilideen's Matrix in Figure 4 are 500, 410, 320, 401, 311 and 302.

Note: The probability of at most 2 good bulbs $+$ the probability of at least 3 good bulbs $= 1$

Since the probability of at the least 3 good bulbs as lesser power combination, so we have:

PRQ	PRQ	PRQ	PRQ	PRQ	PRQ
500					
410					
320	**401**				
230	**311**				
140	221	**302**			
050	131	212			
	041	122	203		
		032	113		
			023	104	
				014	
					005

Figure 6. Kifilideen's Matrix of positive power of 5 for $n = 5$ number of bulbs selected at random showing all the possible power combinations.

Probability of at most 2 good bulbs $= 1 -$ the probability of at least 3 good bulbs

Probability of at most 2 good bulbs $= 1 - \left({}_{500}^{\ \ 5}Cp^5r^0q^0 + {}_{410}^{\ \ 5}Cp^4r^1q^0 + {}_{320}^{\ \ 5}Cp^3r^2q^0 + {}_{401}^{\ \ 5}Cp^4r^0q^1 + {}_{311}^{\ \ 5}Cp^3r^1q^1 + {}_{302}^{\ \ 5}Cp^3r^0q^2\right)$

Probability of at most 2 good bulbs $= 1 - \left(\frac{5!}{5!0!0!}(0.5)^5(0.2)^0(0.3)^0 + \frac{5!}{4!1!0!}(0.5)^4(0.2)^1(0.3)^0 + \frac{5!}{3!2!0!}(0.5)^3(0.2)^2(0.3)^0 + \frac{5!}{4!0!1!}(0.5)^4(0.2)^0(0.3)^1 + \frac{5!}{3!1!1!}(0.5)^3(0.2)^1(0.3)^1 + \frac{5!}{3!0!2!}(0.5)^3(0.2)^0(0.3)^2\right)$

Probability of at most 2 good bulbs $= 1 - (0.03125 + 0.0625 + 0.0500 + 0.09375 + 0.15 + 0.1125)$

Probability of at most 2 good bulbs $= 1 - 0.5000 = 0.5000$

In this example, a manufacturing company produce three categories of bulbs: good (high-quality), semi-good (moderate quality), and bad (defective). The objective is to determine the probability that at most two of the five randomly selected bulbs are good using Kifilideen's Trinomial Distribution.

Comparison with Existing Probability Models

1. Binomial Distribution Limitation: the binomial distribution is often used in quality control to classify products into two categories—typically good vs. bad. If applied to this case, the binomial model would combine semi-good and bad bulbs in to a single category (e.g. 'not good'), resulting in a binary classification (good vs. not good). However, this misrepresents the company's actual production classification because:

- Semi-good bulbs are not entirely defective—they may still function under certain conditions
- Bad bulbs are completely defective, making them different from semi-good ones.

This forced two-category analysis in binomial probability leads to an incomplete and inaccurate representation of the actual production data, limiting quality assessment precision.

2. Multinomial Distribution Limitation: the multinomial distribution can account for multiple categories (good, semi-good, bad), but it does not provide a structured probability framework for trinomial cases where a specific number of outcomes must be analyzed. It applies a general probability formula, which is not optimized for structured trinomial event analysis, making probability calculations more complex and less systematic.

Advantages of Kifilideen's Trinomial Distribution

Kifilideen's Trinomial Distribution addresses these issues by:

1. Preserving the true classification of bulbs (good, semi-good, bad) without forcing an artificial binary division.
2. Providing a structured combinatorial probability framework, allowing for an accurate probability assessment of different categories.
3. Eliminating the need for assumptions that simplify or distort real-world data.
4. Enhancing decision-making in quality control by offering more precise probability insights into the proportion of different bulb types in a production batch.

By applying Kifilideen's Trinomial Distribution, the probability that at most two bulbs in a random selection of five are good is calculated without compromising the integrity of the three-category classification. This demonstrates the model's superiority over binomial and multinomial distributions in cases where three distinct outcomes must be analyzed systematically and accurately.

(3) In a group of 40 people, 30 people are interested in attending a party, out of those 30 people 16 people later attended while the rest could not make it to the party. If 4 samples of people are selected at random from the group of the people, determine the probability that one person show interest but did not attend the party.

Solution

Let the total number of people in the group $= n(T)$, Let the number of people that show interest and attended $= n(P)$, Let the number of people that did not show interest at all $= n(R)$, and Let the number of people that show interest but did not attend $= n(Q)$

$n(T) = 40, n(P) = 16,$ $n(R) = 40 - 30 = 10$ and $n(Q) = 30 - 16 = 14$

Let the probability of people that show interest and attended $= P_r\ (interested\ and\ attended) = p$

Let the probability of people that did not show interest at all $= P_r\ (not\ interested) = r$

Let the probability of people that show interest but did not attend $= P_r\ (interested\ but\ not\ attended) = q$

$p = \frac{n(P)}{n(T)} = \frac{16}{40} = \frac{2}{5}$, $r = \frac{n(R)}{n(T)} = \frac{10}{40} = \frac{1}{4}$ and $q = \frac{n(Q)}{n(T)} = \frac{14}{40} = \frac{7}{20}$

For $n = 4$ number of people selected at random, the all possible power combinations are presented in the Kifilideen's Matrix of positive power of 4 in Figure 7. To determine the probability that one person show interest but did not attend the party $(n(Q) = 1)$, we consider the power combinations from the Kifilideen's Matrix in Figure 7: 301, 211, 121 and 031.

PRQ	PRQ	PRQ	PRQ	PRQ
400				
310				
220	**301**			
130	**211**			
040	**121**	202		
	031	112		
		022	103	
			013	
				004

Figure 7. Kifilideen's Matrix of positive power of 4 for $n = 4$ number of people of selected at random showing all the possible power combinations.

Probability that one person show interest and did not attend the party$=$ P_r (3 interested and attended,0 not interested and 1 interested but not attended)$+$ P_r (2 interested and attended,1 not interested and 1 interested but not attended)$+$ P_r (1 interested and attended,2 not interested and 1 interested but not attended)$+$ P_r (0 interested and attended,3 not interested and 1 interested but not attended)

Probability that one person show interest and did not attend the party$=$ ${}_{301}^{\;\;4}Cp^3r^0q^1 + {}_{211}^{\;\;4}Cp^2r^1q^1 + {}_{121}^{\;\;4}Cp^1r^2q^1 + {}_{031}^{\;\;4}Cp^0r^3q^1 =$

$$\frac{4!}{3!0!1!}\left(\frac{2}{5}\right)^3\left(\frac{1}{4}\right)^0\left(\frac{7}{20}\right)^1 + \frac{4!}{2!1!1!}\left(\frac{2}{5}\right)^2\left(\frac{1}{4}\right)^1\left(\frac{7}{20}\right)^1 + \frac{4!}{1!2!1!}\left(\frac{2}{5}\right)^1\left(\frac{1}{4}\right)^2\left(\frac{7}{20}\right)^1 + \frac{4!}{0!3!1!}\left(\frac{2}{5}\right)^0\left(\frac{1}{4}\right)^3\left(\frac{7}{20}\right)^1$$

Probability that one person show interest and did not attend the party$=$ $0.0896 + 0.168 + 0.105 + 0.021875 = 0.384475$

In this example, a group of 30 individuals expressed interest in attending a party. Out of these, 16 eventually attended, while the remaining 14 did not. The objective is to determine the probability that one of the four randomly selected individuals showed interest but ultimately did not attend using Kifilideen's Trinomial Distribution.

Comparison with Existing Probability Models

1. Binomial Distribution Limitation: The binomial distribution is commonly used in event attendance analysis but is restricted to two outcomes, such as:

- Attended (Success) vs. Not Attended (Failure)

However, this classification ignores an important intermediate group—those who initially showed interest but later failed to attend. Applying the binomial model would force the analysis into a two-category system, combining those who never intended to attend with those who planned to attend but ultimately didn't. This approach misrepresents the actual event dynamics because:

- Those who never showed interest (uninvolved individuals) are different from those who intended to attend but couldn't.
- The probability of actual attendance is influenced by this intermediate category, which binomial distribution fail to account for.

Such an oversimplified binary approach introduces bias into the probability calculations and provides an incomplete representation of attendance behavior.

2. Multinomial Distribution Limitation: The multinomial distribution can handle multiple categories but does not provide a structured probability framework tailored for trinomial systems where specific conditional probabilities must be analyzed. It applies a generalized probability expression, which lack the optimized combinatorial structure necessary for trinomial event probability assessments.

Advantages of Kifilideen's Trinomial Distribution

Kifilideen's Trinomial Distribution overcomes these limitations by:

1. Accurately representing all three distinct group: Attended, Showed Interest but Did Not Attend, and Did Not Show Interest.
2. Providing a structured framework that allows precise calculation of probabilities without artificial grouping or assumption-based estimations.
3. Enhancing decision-making for event planning, as understanding why people who showed interest didn't attend can help improve engagement strategies.
4. Delivering more accurate predictive modeling in scenarios such as marketing campaigns, voter turnout analysis, and behavioral studies.

By applying Kifilideen's Trinomial Distribution, the probability that one of the four randomly selected individuals showed interest but did not attend is accurately determined without losing critical distinctions in attendance behavior. This demonstrates the superiority of Kifilideen's model over binomial and multinomial approaches, especially category significantly influences decision-making.

(4) In a community there are three set of social classes which are the poor, middle and rich classes. The probability a person pick at random from the community is a middle class is 0.2 and that of the poor class is 0.7. If three sample of people are picked from the community at random, find the probability that (i) the three sample of people picked are poor class (ii) two people are poor and one person is rich in the three sample of people picked (iii) none of the three sample of people are poor class

Solution

Let the probability of rich class people= $P_r\ (rich) = p$, Let the probability of middle class people= $P_r\ (middle) = r$, and Let the probability of poor class people= $P_r\ (poor) = q$

$r = 0.2$ and $q = 0.7$

From $p + r + q = 1$ in (12), we have

$p + 0.2 + 0.7 = 1$

$p = 0.1$

For $n = 3$ number of people selected at random, the all possible power combinations are presented in the Kifilideen's Matrix of positive power of 3 in Figure 8.

PRQ	PRQ	PRQ	PRQ
300			
210	201		
120	111		
030	021	102	
		012	
			003

Figure 8: Kifilideen's Matrix of positive power of 4 for $n = 4$ number of car selected at random showing all the possible power combinations.

(i) For the probability that the three sample of people picked are poor class $(n(Q) = 3)$ the possible power combination from the Kifilideen matrix in Figure 8 is **003.**
The probability that the three sample of people picked are poor class$= P_r(0\, rich, 0\, middle$ and 3 poor)$= {}_{003}^{3}Cp^0r^0q^3 = \frac{3!}{0!0!3!}(0.1)^0(0.2)^0(0.7)^3 = 0.3430$

(ii) For the probability that the two people are poor and one person is rich in the three sample of people picked $(n(Q) = 2,\ n(P) = 1$ and $n(R) = 0$ together) the possible power combination from the Kifilideen's Matrix in Figure 7 is **102**.
The probability that two people are poor and one person is rich in the three samples of people picked $= P_r(1\, rich, 0\, middle$ and 2 poor)$= {}_{102}^{3}Cp^1r^0q^2 = \frac{3!}{1!0!2!}(0.1)^1(0.2)^0(0.7)^2 = 0.147$

(iii) For the probability that none of the three samples of people are poor class ($n(Q) = 0$) the possible power combinations from the Kifilideen matrix in Figure 7 are **300**, **210**, **120** and **030**.

The probability that none of the three samples of people are poor class $= P_r$(3 rich, 0 middle and 0 poor) $+\ P_r$(2 rich, 1 middle and 0 poor) $+\ P_r$(1 rich, 2 middle and 0 poor) $+P_r$(0 rich, 3 middle and 0 poor)

The probability that none of the three samples of people are poor class $= {}_{300}^{3}Cp^3r^0q^0 + {}_{210}^{3}Cp^2r^1q^0 + {}_{120}^{3}Cp^1r^2q^0 + {}_{030}^{3}Cp^0r^3q^0 =$
$\frac{3!}{3!0!0!}(0.1)^3(0.2)^0(0.7)^1 + \frac{3!}{2!1!0!}(0.1)^2(0.2)^1(0.7)^0 + \frac{3!}{1!2!0!}(0.1)^1(0.2)^2(0.7)^0 + \frac{3!}{0!3!0!}(0.1)^0(0.2)^3(0.7)^0$
Probability that one person show interest and did not attend the party $= 0.0007 + 0.0060 + 0.0120 + 0.0080 = 0.0267$

In this example 4(iii), a community consists of three distinct social classes: rich, middle class, and poor. The probability of selecting a middle-class individual at random is 0.2, while the probability of selecting a poor individual is 0.7. The objective is to determine the probability that none of the three randomly selected individuals are from the poor class using Kifilideen's Trinomial Distribution.

Comparison with Existing Probability Models
1. Binomial Distribution Limitation: the binomial distribution is commonly applied to social class analysis, but it can only handle two possible categories, such as:
- Rich (Success) vs. Not Rich (Failure)
- Poor (Failure) vs. Not Poor (Success)

This forces the middle class into an artificial category, either merging them with the poor or the rich. However, this misrepresents the social structure because:
- The middle class is not as wealthy as the rich but is financially stable enough to afford basic necessities.
- The poor, on the other hand, struggle to meet basic needs, making them fundamentally different from the middle class.

By ignoring or misclassifying the middle class, binomial models introduce bias and fail to capture the true distribution of social classes, leading to inaccurate probability estimations in studies related to wealth distribution and social mobility.
2. Multinomial Distribution Limitation: the multinomial distribution allows for multiple categories, but it lacks a structured probability framework to systematically analyze trinomial events, such as determining the likelihood of specific social class compositions in a given sample. It applies general probability expressions but does not offer an optimized approach for trinomial systems.

Advantages of Kifilideen's Trinomial Distribution
Kifilideen's Trinomial Distribution provides a more accurate and structured probability framework by:
1. Preserving the distinct classification of social classes (rich, middle class, poor) without merging or eliminating the middle class.

2. Allowing direct probability calculations for each class without approximation or forced binary grouping. 3. Providing a structured combinatorial approach for determining the probability of different class distributions in a random selection.
4. Enhancing social and economic analysis by offering a realistic probability model for studies on income inequality, policy development, and market segmentation.
By applying Kifilideen's Trinomial Distribution, the probability that none of the three randomly selected individuals belong to the poor class is determined without distorting the three-category classification. This demonstrates the superiority of Kifilideen's model over binomial and multinomial approaches, particularly in socioeconomic studies where accurate classification is crucial for decision-making and policy analysis.

(5) The probability that a club A would win, draw and loss a match with club B are $\frac{1}{9}, \frac{5}{36}$ *and* $\frac{3}{4}$ respectively. If two matches were played with club B, find (i) the probability that club A losses the two matches (ii) the probability that club A does not the loss two matches (iii) the probability that club A loss one match and draw one.

Solution
(i) Let the probability of club A win$= P_r\,(win) = p$, Let the probability of club A draw$= P_r\,(draw) = r$, and Let the probability of club A loss$= P_r\,(loss) = q$

$p = \frac{1}{9}, r = \frac{5}{36}$and $q = \frac{3}{4}$
For $n = 2$ number of matches played, the all possible power combinations are presented in the Kifilideen's Matrix of positive power of 2 in Figure 9. For the probability that club A losses the two matches ($n(Q) = 2$) the possible power combinations from the Kifilideen matrix in Figure 9 are **002**.

PRQ	PRQ	PRQ
200		
110		
020	**101**	
	011	
		002

Figure 9. Kifilideen's Matrix of positive power of 2 for $n = 2$ number of matches showing all the possible power combinations.

The probability that club A losses the two matches$= P_r$(0 win, 0 draw and 0 loss)$= {}_{002}^{\;\;2}Cp^0r^0q^2 = \frac{2!}{0!0!2!}\left(\frac{1}{9}\right)^0\left(\frac{5}{36}\right)^0\left(\frac{3}{4}\right)^2$
The probability that club A losses the two matches $= 0.5625$

(ii) The probability that club A does not loss the two matches $= 1 -$ the probability that club A losses the two matches $= 1 - 0.5625 = 0.4375$

Or

For the probability that club A losses the two matches $(n(Q) = 2)$ the possible power combination from the Kifilideen's Matrix in Figure 4 is **002** while for the probability that club A did not loss two matches $(n(Q) = 0, n(Q) = 1)$ the possible power combinations from the Kifilideen's Matrix in Figure 4 are **200**, **110**, **020**, **101** and **011**.

The probability that club A does not loss the two matches $= {}_{200}{}^{2}_{0}Cp^2r^0q^0 + {}_{110}{}^{2}_{0}Cp^1r^1q^0 + {}_{020}{}^{2}_{0}Cp^0r^2q^0 + {}_{101}{}^{2}_{1}Cp^1r^0q^1 + {}_{011}{}^{2}_{1}Cp^0r^1q^1 = \frac{2!}{2!0!0!}\left(\frac{1}{9}\right)^2\left(\frac{5}{36}\right)^0\left(\frac{3}{4}\right)^0 + \frac{2!}{1!1!0!}\left(\frac{1}{9}\right)^1\left(\frac{5}{36}\right)^1\left(\frac{3}{4}\right)^0 + \frac{2!}{0!2!0!}\left(\frac{1}{9}\right)^0\left(\frac{5}{36}\right)^2\left(\frac{3}{4}\right)^0 + \frac{2!}{1!0!1!}\left(\frac{1}{9}\right)^1\left(\frac{5}{36}\right)^0\left(\frac{3}{4}\right)^1 + \frac{2!}{0!1!1!}\left(\frac{1}{9}\right)^0\left(\frac{5}{36}\right)^1\left(\frac{3}{4}\right)^1$

The probability that club A does not loss the two matches $= 0.0123457 + 0.0308642 + 0.0192901 + 0.1666667 + 0.2083333 = 0.4375$

(iii) For the probability that club A losses one and draw one $(n(R) = 1, n(Q) = 1$ and $n(P) = 0$ altogather) the possible power combinations from the Kifilideen's Matrix in Figure 4 is 011.

The probability that club A loss one and draw one$= P_r$(0 win, 1 draw and 1 loss) $= {}_{011}{}^{2}_{1}Cp^0r^1q^1 = \frac{2!}{0!1!1!}\left(\frac{1}{9}\right)^0\left(\frac{5}{36}\right)^1\left(\frac{3}{4}\right)^1$

The probability that club A loss one and draw one $= 0.20833$

In this example 5(i), a sports team competes in two matches, where the possible outcomes are win, draw, or loss. The objective is to determine the probability that the team loses both matches using Kifilideen's Trinomial Distribution.

Comparison with Existing Probability Models

1. Binomial Distribution Limitation: the binomial distribution is commonly used in sports analytics, but it only accounts for two possible outcomes, such as:

- Win vs. Loss
- Win vs. Not Win (which includes both draws and losses as a single category)

However, this approach fails to recognize the strategic significance of draws, which are fundamentally different from outright losses. In reality:

- A draw is a boundary between winning and losing—a slight improvement in performance could turn a draw into a win, while a minor decline could turn it into a loss.
- If a team has a high percentage of draws, it indicates potential for future wins with minimal adjustments in strategy.
- If a team has a high percentage of losses, significant effort is required to turn those into wins, as the performance gap is larger.

By grouping draws with losses, the binomial model misrepresents team performance, leading to biased probability calculations that fail to capture a team's true competitive potential.

2. Multinomial Distribution Limitation: the multinomial distribution allows for multiple outcomes (win, draw, and loss) but does not offer a structured combinatorial framework for trinomial probability assessments. It applies a general probability formula without an optimized approach for systematically evaluating the likelihood of specific outcomes in a small sample of matches.

Advantages of Kifilideen's Trinomial Distribution

Kifilideen's Trinomial Distribution overcomes these limitations by:

1. Explicitly distinguishing between win, draw, and loss, ensuring a more realistic and structured performance analysis.
2. Providing a combinatorial probability approach, allowing for precise calculations that reflect the competitive dynamics between win, draw, and loss.
3. Offering better predictive insights—if a team has a high probability of drawing games, minor improvements in performance could lead to a significantly higher win rate in the future.
4. Aiding strategic decision-making for coaches, analysts, and sports managers by giving a clearer picture of the effort required to shift a team's performance toward more wins.

By applying Kifilideen's Trinomial Distribution, the probability that the team loses both matches is determined without misclassifying draws as losses, ensuring a more accurate evaluation of team performance and future potential. This demonstrates the model's superiority over binomial and multinomial approaches, particularly in sports analytics where small performance margins can significantly impact future results.

(6) The probability that a farmer has adequate collateral to obtain loan from agricultural bank is $\frac{2}{3}$ and the probability that a farmer lack collateral to obtain loan from agricultural bank is $\frac{7}{30}$. If three farmers are selected at random, determine the probability that two farmers have adequate collateral to obtain loan from the agricultural bank.

Solution

Let the probability of adequate collateral$=P_r$ (adequate collateral)$=p$, Let the probability of inadequate$=P_r$ (inadequate)$=r,$ and Let the probability of lack$=P_r$ (lack)$=q$

$p=\frac{2}{3}$and $q=\frac{7}{30}$

From $p+r+q=1$ in (12), we have
$\frac{2}{3}+r+\frac{7}{30}=1$
$r=\frac{1}{10}$
For $n=3$ number of farmers selected at random, the all possible power combinations are presented in the Kifilideen'a Matrix of positive power of 3 in Figure 10. For the probability that two farmers have adequate collateral to obtain loan from the agricultural bank $(n(P)=2)$ the possible power combinations from the Kifilideen matrix in Figure 10 is 210 and 201.
The probability that two farmers have adequate collateral to obtain loan from the agricultural bank $=P_r$(2 adequate, 1 inadequate and 0 lack)$+P_r$(2 adequate, 0 inadequate and 1 lack) $={}_{210}^{3}Cp^2r^1q^0+{}_{201}^{3}Cp^2r^0q^1$

PRQ	PRQ	PRQ	PRQ
300			
210	**201**		
120	111		
030	021	102	
		012	
			003

Figure 10. Kifilideen matrix of positive power of 3 for $n=3$ number of farmers selected at random showing all the possible power combinations

The probability that two farmers have adequate collateral to obtain loan from the agricultural bank $=\frac{3!}{2!1!0!}\left(\frac{2}{3}\right)^2\left(\frac{1}{10}\right)^1\left(\frac{7}{30}\right)^0+\frac{3!}{2!0!1!}\left(\frac{2}{3}\right)^2\left(\frac{1}{10}\right)^0\left(\frac{7}{30}\right)^1=0.1333333+\ 0.3111111=0.4444444$

In this example, farmers applying for loans are classified into three categories:
1. Farmers with adequate collateral (fully eligible for the loan).
2. Farmers with no collateral (completely ineligible).
3. Farmers with inadequate collateral (partially eligible, may be considered based on policy discretion).
The objective is to determine the probability that two out of three randomly selected farmers have adequate collateral using Kifilideen's Trinomial Distribution.

Comparison with Existing Probability Models

1. Binomial Distribution Limitation: the binomial distribution is often used in financial eligibility analysis but is restricted to two categories, such as:

● Eligible (Success) vs. Not Eligible (Failure)

● Has Collateral vs. No Collateral

However, this approach fails to differentiate between farmers with inadequate collateral and those with no collateral at all. In reality:

● Farmers with inadequate collateral show some level of commitment and financial stability, making them different from those with no collateral at all.

● Farmers without any collateral provide no assurance to the lender, making them completely ineligible under most policies.

● Grouping both together under "Not Eligible" ignores the possibility that farmers with partial collateral could still qualify under alternative loan conditions.

By oversimplifying the categorization, the binomial model introduces bias, leading to unfair assessments and misrepresentations of loan eligibility.

2. Multinomial Distribution Limitation: the multinomial distribution allows for multiple categories (adequate, inadequate, and no collateral), but it lacks a structured probability framework optimized for trinomial systems. It applies a general probability formula, which is not specifically designed for structured trinomial probability analysis in decision-making processes like loan approvals.

Advantages of Kifilideen's Trinomial Distribution

Kifilideen's Trinomial Distribution provides a more accurate and structured probability model by:

1. Distinguishing between adequate, inadequate, and no collateral, ensuring fairer financial assessments.
2. Providing a structured combinatorial approach, allowing for more precise probability calculations.
3. Helping lenders make more informed decisions by considering the likelihood of partially eligible farmers securing loans.
4. Improving financial policy planning by offering deeper insights into the distribution of loan applicants.

By applying Kifilideen's Trinomial Distribution, the probability that two of the three randomly selected farmers have adequate collateral is determined without unjustly grouping inadequate-collateral farmers with completely ineligible farmers. This demonstrates the model's superiority over binomial and multinomial approaches, particularly in financial and policy-driven decision-making where fairness and precision are critical.

Utilization of the Kifilideen's Formulas developed for the Negative Power of n of Kifilideen Trinomial Theorem

(1) For a trinomial expression of $[x + y + z)^{-3}$ and the 27th term of the Kifilideen trinomial expansion of the trinomial expression, determine the following:

(i) the power combination of the 27th term

(ii) the group the 27th term belong to

(iii) the row and column in which the 27th term belong

(iv) the position of the 27th term in the group it belong to

Solution

(i) Using the Kifilideen Power Combination formula for negative powers of n,

$$C_P = 9t - 110a - 9m + n00$$

Determining the Kifilideen migration column factor, a for 27th term, we have:

$$a = \frac{-1+\sqrt{8t-7}}{2} = \frac{-1+\sqrt{8\times 27-7}}{2} = \mathbf{6}.73$$

The migration column factor, $a = 6$

The Kifilideen migration row factor, m for 27th term, we have:

$$m = \frac{a^2+a+2}{2} \quad = \frac{6^2+6+2}{2} = 22$$

The migration row factor, $m = 22$

So, $C_P =$
$9t - 110a - 9m + n00$

$$n = \text{negative power of the trinomial expression} = -3$$
$$C_P = 9 \times 27 - 110 \times 6 - 9 \times 22 - 300$$
$$= -915$$

(ii) Using the Kifilideen's Group Formula for negative power of n, we have:

$$g = \frac{1+\sqrt{8t-7}}{2} = \frac{1+\sqrt{8\times 27-7}}{2} = 7.73$$

The group, $g = 7$

Therefore 27th term belongs to group 7 in the Kifilideen matrix of the negative power of – 3

(iii) From $C_P = kif = -915$,

$$k = -9, i = 1 \text{ and } f = 5$$

From $n - c + 1 = k$

$$-3 - c + 1 = -9$$
$$c = 7$$

Or

From
$c = a + 1 = g$

$$c = 6 + 1 = 7$$
$$c = 7$$

From $r = 2f + i + 1$

$$r = 12$$

Therefore, the 27th term is found in column 7 and row 12 of the Kifilideen matrix of the negative power of 3.

(iv) From (203), the position of the 27th term in the group it belongs to is determined as:

$$p = r - c + 1$$
$$p = 12 - 7 + 1$$
$$p = 6$$

Or

Using Kifilideen's Position Formula for negative power of n,

$$C_P = \quad kif = n00 + -110(a) + 9(p-1)$$

The migration column factor, $a = 6$, Power combination = $C_P = -915$ and value of the negative power of the Trinomial Theorem = -3

$$C_P = \quad kif = -300 + -110(6) + 9(p-1)$$
$$= -915$$
$$p = 6$$

Therefore, the 27th term is in position 6 in the group 7 of the Kifilideen's Matrix of the negative power of – 3.

(2) The power combination of the t^{th} term of Kifilideen trinomial expansion of the trinomial expression $\left[\frac{x^{-9}y^4}{4z^2} + 1 - yz^2\right]^{-n}$ is -732. Determine the following:

(i) the value of the power of the trinomial expression

(ii) the t^{th} term of the power combination

Solution

(i) For $C_p = kif = -732$

From, $n = k + i + f$

$$k = -7, i = 3 \text{ and } f = 2$$

We have: $n = -7 + 3 + 2$

$$n = -2$$

(ii) Using the Kifilideen's Power Combination Formula for negative power of n,

$$C_P = 9(t-1) - \frac{9}{2}(n-k)^2 - \frac{229}{2}(n-k) + n00$$

$$-732 = 9(t-1) - \frac{9}{2}\left(-2-(-7)\right)^2 - \frac{229}{2}\left(-2-(-7)\right) - 200$$

$$t = 18^{\text{th}} \text{ term}$$

(3) The power combination of the t^{th} term of Kifilideen trinomial expansion of the trinomial expression $(s + r + v)^{-6}$ is given as -811. Obtain the t^{th} term of the power combination

Solution

The Kifilideen migration column factor, a is obtained as:

$$a = n - k$$

$n =$ value of the negative power of the trinomial expression $= -6$

From $C_P = kif = -811$

$$k = -8$$

So, $a = n - k$

$$a = -6 - (-8)$$

$$a = 2$$

The Kifilideen migration row factor, m is obtained as

$$m = \frac{a^2+a+2}{2} = \frac{2^2+2+2}{2} = 4$$

Using the Kifilideen's Power Combination Formula for negative power of n,

$$C_P = -110a + 9(t-m) + n00$$

$$-811 = -110 \times 2 + 9(t-4) - 600$$

$$t = 5^{\text{th}} \text{ term}$$

(4) The power combination of the t^{th} term of Kifilideen trinomial expansion of the trinomial expression $\left[4 - \sqrt{\frac{6}{5x}} - y^2\right]^{-4}$ is $-20\,,4,5$. Determine using the Kifilideen general term formula the t^{th} term of the power combination.

Solution

From the question,

$$C_P = kif = -20,7,9 \text{ and } n = -4$$

$$k = -20,\ i = 7 \text{ and } f = 9$$

Using Kifilideen Term Formula 1 for negative powers of n, we have:

$$t = \frac{(n-k)^2+(n-k)+2f+2}{2}$$

$$t = \frac{(-4-(20))^2+(-4-(-20))+2\times9+2}{2}$$

$$t = 146^{\text{th}} \text{ term}$$

Or

Using Kifilideen Term Formula 2 for negative power of n, we have:

$$t = \frac{(n-k)^2+3(n-k)-2i+2}{2}$$

$$t = \frac{(-4-(-20))^2+3(-4-(-20))-2\times7+2}{2}$$

$$t = 146^{\text{th}} \text{ term}$$

Conclusion

This study introduces Kifilideen's Trinomial Distribution, a novel probability model designed to extend the traditional binomial analysis to events with three possible outcomes. Unlike conventional binomial distributions that only account for two extreme possibilities, this model effectively incorporates intermediate outcomes, making it more suitable for real-world probability analysis in diverse fields such as engineering, economics, quality control, and sports analytics. A mathematical framework for the proposed distribution was formulated using combinatorial probability principles and matrix methods. Additionally, mathematical induction was applied to derive and validate the model for negative powers, further reinforcing its theoretical foundation. The results demonstrate that Kifilideen's Trinomial Distribution successfully captures the probability distributions of three-outcome events, providing a more accurate and comprehensive probability analysis compared to existing binomial and multinomial approaches. The proposed model offers several advantages over existing probability methods:

1. Enhanced Accuracy: It fully accounts for three possible event outcomes, eliminating biases inherent in binomial models that overlook intermediate cases.
2. Mathematical Consistency: the use of mathematical induction validates the model for both positive and negative power expansions.
3. Broad Applicability: the model is adaptable to real-world problems such as election forecasting, sport predictions, product quality classification, and economic stratification.

The findings of this research establish Kifilideen's Trinomial Distribution as a significant advancement in probability analysis. Future research could explore extensions to higher-order multinomial scenarios, optimization of computational techniques for large datasets, and integration of the model into machine learning framework for predictive analytics. By addressing the limitations of traditional binomial and multinomial distributions, this study provides a robust, structured, and practical approach for analyzing three-outcome probabilistic systems, marking a substantial contribution to the field of probability theory and applied mathematics.

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Development of Call Setup Success Rate Prediction Model using Ensemble Algorithm

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Abstract

The poor quality of services (QoS) experienced by mobile network users may be a result of network providers relying on the troposphere for transmission of signals without first evaluating and characterizing the area of the conveyance of the signals. The knowledge of which weather variables have an impact on signal propagation is expedient to define network vulnerability. This study developed a machine learning model using bagged tree and LS Boosting algorithms after employing a suitable feature selection algorithm. Hyperparameter optimization using the Bayesian technique was employed to obtain an optimal model. The performance of the models was then compared using mean average error, mean squared error, r-squared, and prediction speed. The models were further used to predict call setup success rates using new data. Results show that the bagged tree algorithm performed better based on figures of metric as well as prediction values.

Keywords: Quality of Service, Mobile Network, Call set-up success rate, drop call rate, signal.

1. Introduction

The introduction of the Global System for Mobile Communications (GSM) in Nigeria in 2001 has significantly improved the quality of life for Nigerians (Bakare *et al.,* 2017). However, with the expansion of mobile services, it has become essential for mobile communication operators to accurately measure the quality of service (QoS) of their networks and continuously improve them to stay competitive (Brooks and Hestnes, 2010; Banović-Ćurguz and Ilišević, 2019).

Poor QoS often results from network operators' reliance on sending signals through the troposphere without proper evaluation and characterization of this atmospheric layer. The troposphere, the lowest part of the Earth's atmosphere, has a direct impact on human life and weather. It extends to approximately 10 km at the poles and up to 17 km at the equator (Sassen and Wang, 2012).

Understanding how weather conditions impact signal propagation is critical, as adverse weather can impair network performance. Such knowledge enables the forecasting, simulation, and design of high-performance communication systems, requiring detailed information on radio wave transmission characteristics across different environments. Mobile network providers must balance network operations, QoS, and radio coverage to achieve optimal performance in diverse conditions (Agbo *et al.,*2021; Vadukkoot *et al.,* 2022; Jeremiah and Onuu, 2022).

The structure of the radio refractive index, N, in the lower atmosphere, helps identify weather parameters likely to affect signal propagation, as expressed in Equation 1 (Thayer, 1974):

$$N = 77.6\frac{P}{T} + 72\frac{e}{T} + 3.75 \times 10^5 \frac{e}{T^2} \qquad (1)$$

where t is the temperature in Celsius, T is the temperature in kelvin, P is the pressure (hPa), $e = \frac{H.e_s}{100}$, H is the relative humidity (%), e_s: saturation vapor pressure (hPa) at the temperature t (C).

Studies indicate that tropospheric variables, including wind speed, relative humidity, and temperature, interact with signals during transmission (Ali *et al.*, 2023; Mantovani *et al.*, 2015). The Call Setup Success Rate (CSSR) measures the likelihood of successful call initiation by a mobile station and is a key metric for evaluating network performance. CSSR is calculated immediately after the assignment of the traffic channel (TCH), irrespective of whether the call is later dropped by the calling or called party (Awofolaju *et al.,* 2023).

The Call Setup Success Rate (CSSR) measures the success rate of call setup or the probability of calls successfully initiated by a mobile station. This occurs immediately after the traffic channel (TCH) assignment, irrespective of whether the call is later dropped by either the calling or receiving party. CSSR is a critical indicator in assessing network performance; a low CSSR indicates that the mobile station is unlikely to successfully initiate a call, negatively affecting the user experience. High CSSR values, on the other hand, indicate better cell performance. This high CSSR is achieved when the Stand-alone Dedicated Channel (SDCCH) seizure and TCH allocation are smoothly acquired for call setup. The CSSR can be calculated as shown in Equation 2:

$$\boldsymbol{CSSR} = \frac{\boldsymbol{Number\ of\ successful\ TCH\ assignment}}{\boldsymbol{Total\ number\ of\ call\ attempts}}\ \boldsymbol{x\ 100}\% \qquad (\mathbf{2})$$

Rattaro *et al.,* (2021) used Random Dot Product Graphs and Graph Neural Networks to predict the state of a channel on a given link by measuring other links, reducing signaling overhead. Their proposed graph-based machine learning methods outperformed traditional approaches in channel state prediction, achieving a root mean square error (RMSE) of 10 dB and an accuracy of 73% using a dataset of RSSI measurements from real-world Wi-Fi providers. However, they noted that the computational complexity of these methods might pose limitations in practical applications.

Popoola and Areo (2020) developed a quality-of-service (QoS) prediction model using an artificial neural network (ANN) to evaluate the efficiency of services provided by the GSM network in Nigeria. While their model performed well, it did not reach optimal accuracy compared to the manual approach of the Nigerian Communications Commission (NCC). They suggested that using advanced machine learning techniques, such as deep learning or ensemble learning, could further improve the model's accuracy.

Oje and Edeki (2021) utilized a walk-test methodology to measure KPIs related to internet accessibility on the 4G network among users subscribed to various mobile network operators (MNOs) at the University of Ilorin. They collected data using TEMS Investigation 16.3.4 and TEMS Discovery Device 10, conducting tests that involved file uploads, data downloads, and video streaming at different locations. MNO4 provided the best overall quality and throughput, whereas MNO1 had the poorest service but maintained minimal coverage at all test sites. Extending the study to include other universities or public spaces could help determine if the results are consistent or vary based on geographical and network conditions.

Kuboye, *et al.,* (2023) proposed a model to predict traffic congestion in LTE networks using machine learning. The model was divided into stages including data preparation, model splitting, classification, evaluation, and tuning. The k-nearest neighbor (k-NN) algorithm yielded the best performance among the methods tested. The study suggested that future models could use online machine learning techniques to continuously collect data from network operators, enhancing real-time traffic predictions and helping providers minimize congestion.

Krasniqi *et al.,* (2019) evaluated the key performance indicators (KPIs) of a 24-cell 4G/LTE network cluster in Kosovo. The study revealed that the availability KPI was below the threshold (>99%), signaling a need for improvement. They proposed that future research should analyze QoS across the entire 4G/LTE network in Kosovo, as well as address challenges that operators may encounter during the transition to 5G.

Eghonghon (2017) used network statistics to assess the QoS of a cellular network during a church event, focusing on CSSR and Drop Call Rate and comparing the results with NCC benchmarks. The findings showed that the provider's KPIs fell short of NCC recommendations, particularly under high-traffic conditions, highlighting the need for service improvements. The study recommended comparing the QoS of different providers within the same area and assessing networks across various regions.

Chamorro (2020) analyzed the quality parameters of a 4G-LTE base station in rural Peru, focusing on KPIs such as signal level, signal-to-noise ratio, and quality. The study found that the base station’s KPIs met ITU's E-800 recommendations, ensuring optimal coverage and network access in rural areas. They suggested that future research should investigate how environmental factors, such as weather and terrain, impact the performance of base stations.

Accurate information about the QoS is essential in evaluating telecommunication network. Classical methods like linear regression and logistic regression have been employed for the prediction of QoS. However, employing advanced algorithms could improve the prediction accuracy of QoS. Hence, this paper employed bagging and LS boosting algorithms with their ensemble in the prediction of QoS. The objectives are to model the bagging and LS boosting algorithm using MATLAB R2022a and subsequently evaluating the model with RMSE, MAE and R-squared. The study revealed the importance of ensemble model in enhancing the performance of the machine learning models..

2. Materials and Methods

2.1 Dataset Description

Historical data of CSSR, and meteorological parameters such as temperature, wind speed, relative humidity, and surface pressure were collected from the archives of the Nigerian Meteorological Agency (NIMET) and Nigerian Communication Commission (NCC) in comma-separated values (CSV) using Modern Era Retrospective Analysis for Research and Applications version 2 (MERRA – 2). The data collected spanned over seven years from January 1, 2016 to December 31, 2022, and the summary dataset is represented in Table 1.

Table 1: Dataset Summary

Statistics	CSSR	Surface Pressure*(kPa)*	Relative Humidity *(%)*	Avg Temp *(K)*	Avg Wind Speed *(m/s)*
count	432	432	432	432	432
mean	99.04	98.49	84.37	25.93	4.71
Std	0.73	1.61	7.29	7.08	8.67
Min	91.9	96.63	48.56	18.12	2.40
25%	98.95	96.94	81.56	24.43	3.22
50%	99.3	98.12	86.88	25.54	3.62
75%	99.48	100.16	89.44	26.66	4.11
max	99.7	101.08	91.69	82.44	82.44

2.2 Feature Selection

Feature selection is the main step in machine learning-based model development (Naheed *et al*, 2020). To obtain a good model, the feature selection algorithm chooses the most relevant features from the feature vector and discards the irrelevant ones.

2.3 Ensemble Model

Ensemble modelling involves the use of different basic machine learning models, although as a single model, to forecast an outcome. Reduction of the generalization error of the forecast is the inspiration for using ensemble models. The general principle of ensemble methods is to construct a linear combination of some model fitting methods, instead of using a single fit of the method.

2.4 Bagging Tree Algorithm

The Bagging Tree (BT) algorithm creates a bootstrapped sample, on which either a regression algorithm or classification algorithm is applied. For regression, an average is taken and computed over all the outputs forecasted by the individual learners. For classification, the most voted class (hard-voting) is considered as the output, else the highest average of all the class probabilities (soft-voting). Mathematically, BT prediction can be represented as in Equation 3.

$$\widehat{Y_{bag}} = \widehat{X_1} + \widehat{X_2} + \widehat{X_3} + \cdots + \widehat{X_n} \quad (3)$$

where $\widehat{Y_{bag}}$ is the output of the bagging tree and $\widehat{X_1}, \widehat{X_2} \ldots \widehat{X_n}$ are the input.

2.5 LSBoost Algorithm

Unlike bagging, the LSBoost (LSBT) algorithm trains the basic machine-learning models consecutively and gives weights to all the training records. The training set for the subsequent iteration will be overrepresented by the training records that are difficult to categorize thanks to the boosting process.

Every training record has a weight assigned by boosting, and depending on how tough the classification is, boosting must adaptively adjust the weight. This results in the creation of a basic learners' group, skilled at classifying both simple and complex records. By using a straightforward voting aggregation, the model's basic learners are all pooled.

2.6 Hyperparameter Optimization

Hyperparameter optimization aims at finding the optimal collection of hyperparameters for a model to reduce the loss function and, ultimately, increase accuracy on given independent data. Hyperparameter tuning is important in machine learning-based model development and several researchers have employed various optimization strategies (Raji *et al.*, 2022; Liao *et al.*, 2022; Awofolaju *et al.*, 2024a; Awofolaju *et al.*, 2024b), including the Bayesian method employed in this study. Bayesian optimization is a form of sequential model-based optimization (SMBO) strategy that improves the sampling approach for subsequent tests. Table 2 shows the model optimization using Bayesian hyperparameter tuning. Finding the highest value at the sample point for an unknown function f is the goal of Bayesian optimization and it is represented mathematically in Equation 4 as:

$$x^* = \arg\max f(x) \quad x \in A \quad (4)$$

where A represents the x search space.

Table 2: Model optimization using Bayesian Hyperparameter Tuning

Hyper-parameter	Range value	Optimized value
Ensemble method	Bagged, LSBoost	Bagged
Number of learners	10-500	12
Learning Rate	0.001-1	0.01
Minimum leaf size	1-346	344
Number of Predictors to Sample	1-8	6

2.7 Evaluation Metrics

Forecast model errors are typically calculated using the RMSE and MAE approaches. However, four indicators were utilized in this study to compare the effectiveness of CSSR prediction models. The details of MAE, RMSE, R-squared, and model prediction speed are displayed in the sections below.

2.7.1 Mean Absolute Error (MAE)

The average of the absolute error between the observed value and the projected value for a model is provided in Equation 5 for a given observation value O_i, experimental value P_i , and sample size n .

$$MAE = \frac{1}{n}\sum_{i=1}^{n}(|O_i - P_i|) \tag{5}$$

As MAE tends to zero, the model is good, however, when the value of MAE increases, the performance of the model is bad.

2.7.2 Root Mean Square Error (RMSE)

RMSE means a value determined by squaring the error between the observed value Oi and the predicted value Pi and averaging it, as depicted in Equation 6:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2} \tag{6}$$

As the value of RMSE increases, the prediction performance deteriorates.

2.7.3 R-Square

The R-squared is given in Equation 7 as:

$$R^2 = \frac{(\sum_{i=1}^{n}(O_i - P_i)(O_i{}' - P_i{}'))^2}{\sum_{i=1}^{n}(O_i - P_i)^2 \sum_{i=1}^{n}(O_i{}' - P_i{}')^2} \tag{7}$$

Where $O_i{}'$ *and* $P_i{}'$ are the mean of the observed and experimental values respectively.

3. Result and Discussion

3.1 Exploratory Data Analysis

Figure 1 shows the distribution of CSSR for different regions under different weather conditions namely: relative humidity, average temperature, average wind speed, and surface pressure. A significant effect can be observed from the change in relative humidity. Figure 2 shows the Feature Importance of the CSSR Prediction Model.

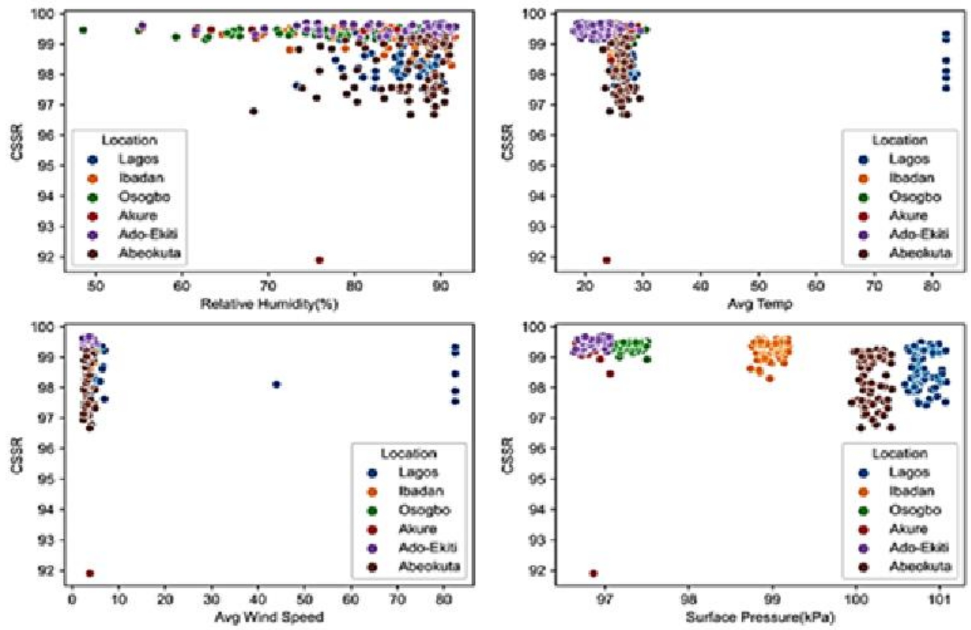

Figure 1: Exploratory Data Analysis (a) CSSR versus change in relative humidity for several regions (b) CSSR versus average temperature (c) CSSR versus average wind speed and (d) CSSR versus surface pressure.

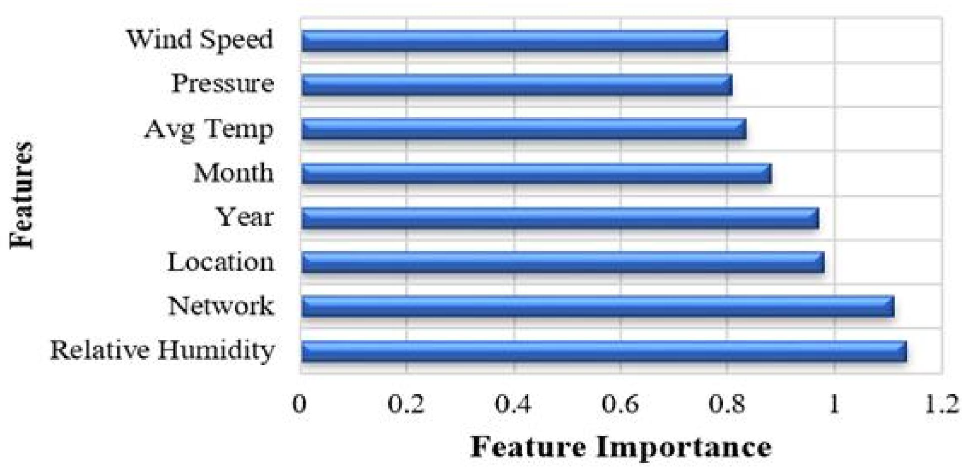

Figure 2: Feature Importance on CSSR Prediction Model

3.2 Experimental Results

The experimental environment of this study was based on MATLAB R2022a (Regression learning Application). In this study, two ensemble-based algorithms trained using historical datasets to predict CSSR were applied. To analyze the performance of the proposed models, Figure 3, Figure 4, Figure 5 and Figure 6 compared the performance of the models based on RMSE, MAE, R-squared, and prediction speed respectively. BT algorithm performed better than LSBT based on all the figures of metrics considered. It can also be seen that the effect of Principal Component Analysis (PCA) on the model is very insignificant. However, optimizing the model by Bayesian hyperparameter turning produces a better model. Figure 7 and Figure 8 present the prediction of CSSR using the two models: LSBT and BT respectively. The BT model predicted the CSSR accurately for the 2nd 7th, 18th, and 20th months. The overall prediction performance of BT as shown in Fig.7 is better than that of LSBT as shown in Fig.8. the optimized ensemble model in Figure 3 had the least RMSE of 372 while the LS boost had the highest RMSE of 397. Evaluating using RMSE highlight the importance of optimizing machine learning models. Though, the optimized ensemble model using MAE did poorly. This could be attributed be attributed to the insufficient trainings of the ensemble models.

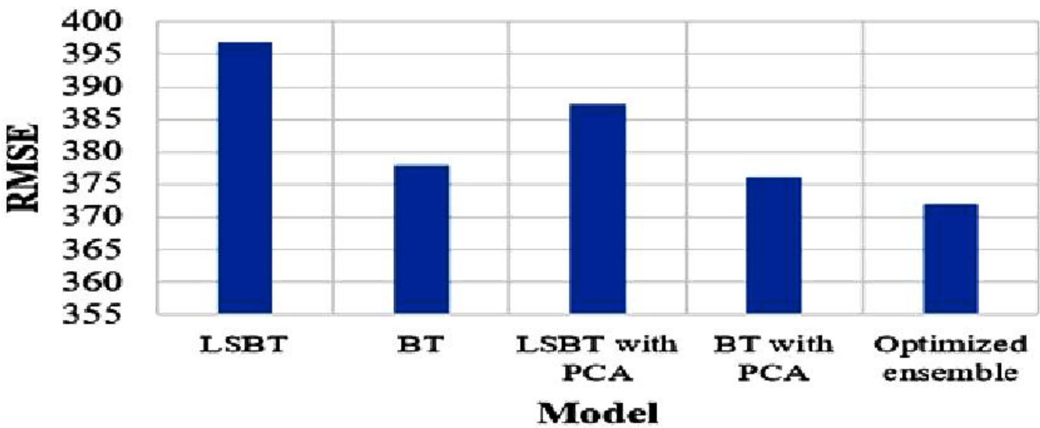

Figure 3: Performance of Models using RMSE

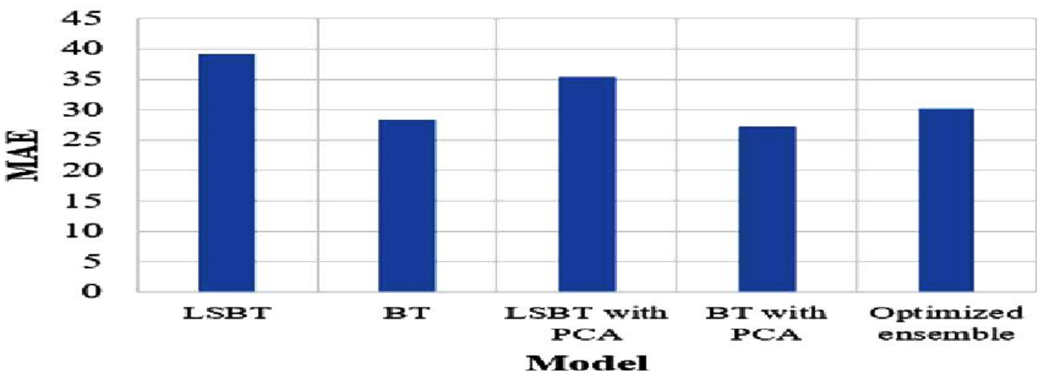

Figure 4: Performance of Models using MAE

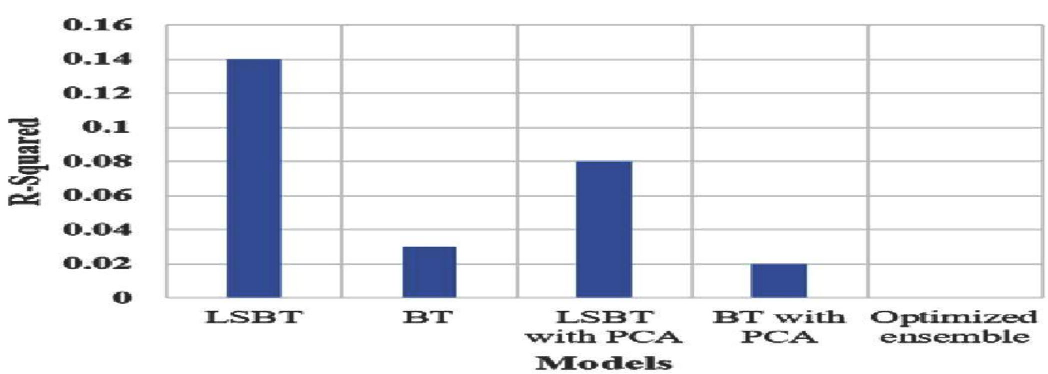

Figure 5: Performance of Models using R-squared

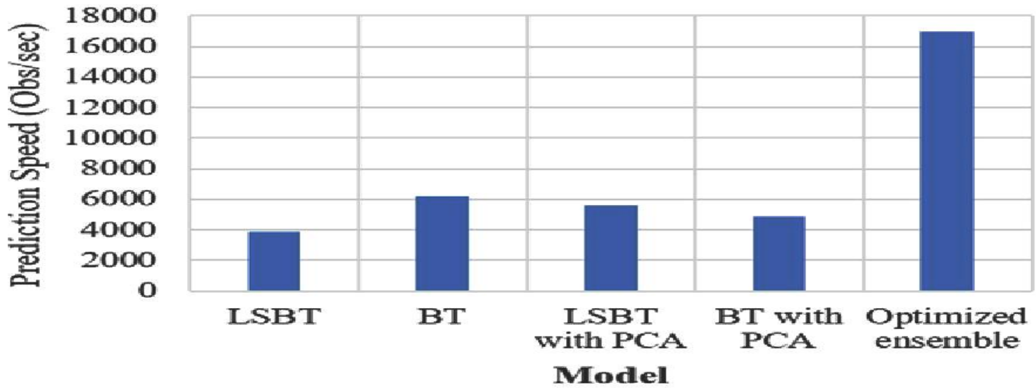

Figure 6: Performance of Models using Prediction Speed

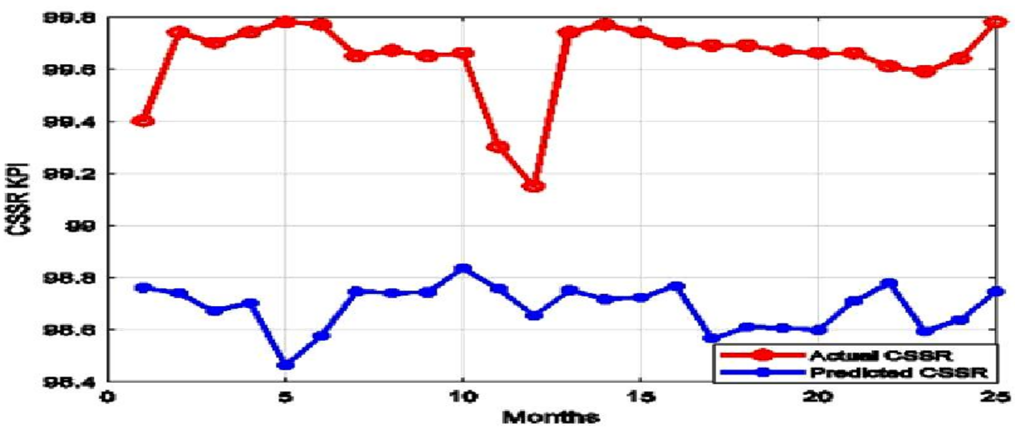

Figure 7: CSSR Prediction using LSBT

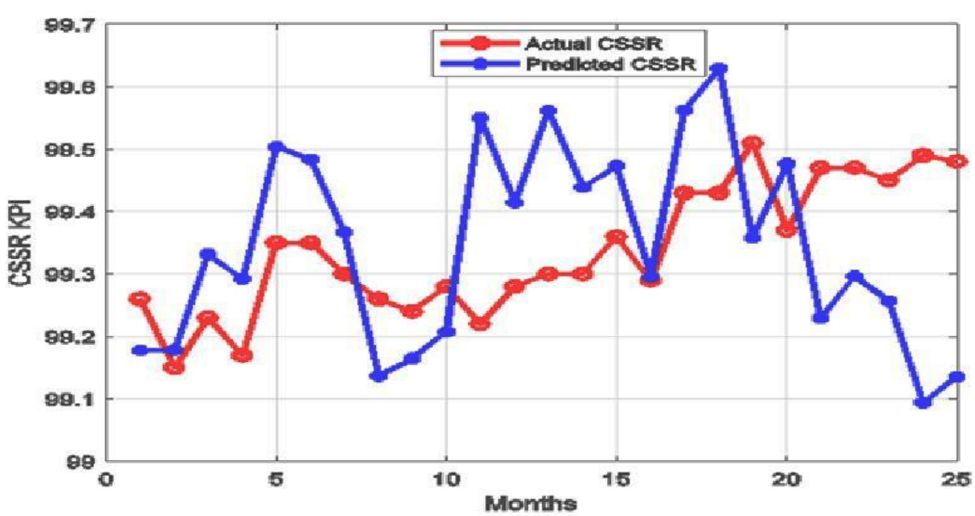

Figure 8: CSSR Prediction using BT

4. Conclusions

This study aimed to develop a machine learning model for predicting CSSR, a key performance indicator for quality of service (QoS) and end-user experience (QoE) in telecommunications. Based on the findings, it is concluded that:

(i) Meteorological parameters such as temperature, wind speed, relative humidity, and surface pressure significantly influence CSSR,

(ii) The BT algorithm outperformed the LSBT algorithm in predicting CSSR after data preprocessing and hyperparameter optimization,

(iii) The proposed model can effectively establish CSSR and has a considerable impact on the design, development, and deployment of radio communication systems.

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OPERATIONAL CHARACTERIZATION OF ROAD NETWORKS OF OSOGBO METRAPOLITAN CITY, SOUTH-WESTERN NIGERIA

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Abstract

Rapid increase of vehicles in Osogbo metropolis has created traffic congestion problem that significantly affected the traffic flow and traffic safety of the transport network thereby having impact on its land use efficiency and livability. Limited studies only considered operational characteristics of road network using traffic volume/flow for transportation planning of Osogbo metropolis. The road networks of three Central Business Districts (CBD) namely; Oke-fia, Oja-Oba and Stadium covering the regional capital of Osun State in Nigeria were selected from Osogbo Transport Network (OTN). Traffic analysis of the three selected CBDs was carried out through traffic count conducted at the morning and evening peak hours using video recording camera placed at the approach views. The Level of Service (LOS) of E (unstable flow near capacity), C (constrained constant flow with attention required by driver) and B (reasonably free flowing) were obtained for Oke-fia, Oja-Oba and Stadium respectively. The highest traffic volume was obtained in Oke-Fia road network followed by Oja-Oba road network and lastly Stadium road network with LOS of E, C and B respectively. This study indicates that Oke-fia and Oja-Oba networks have unsatisfactory operational conditions with traffic congestion while Stadium network is fair but they generally indicated an opposite variation in trip pattern for weekdays and weekend trips. Land use factor and Bus rapid transit are recommended for future transport planning of the study area.

Keywords: Level of Service, Central Business Districts, Road network, Traffic flow.

Introduction

The development of transport in the overall activities of a nation is the ability to deliver an improved, efficient, effective, affordable, accessible, safe, reliable and an integrated transport system which will prosper the economic, social and political segments of the nation. Where transportation infrastructures meet mobility requests and enable access to markets and services, economic opportunities are likely to emerge. Given its significance, transportation has a major environmental impact (Adeniran and Yusuf, 2016).

Nigeria's transportation networks have progressed at a comparatively slow rate and have encountered many issues over the years since independence. Inadequacies in this field have had a profound impact on urban centers across the world, and as a result, have had a significant impact on the development of the nation both economically and socially. It is not an over statement to state that transportation is a critical component and major driver of growth, both economically and socially (Popoola, 2020). The development of developing countries exemplifies this perspective held by transportation engineers, researchers and professionals. The economic condition of advanced countries like the United States of America and Germany, as well as other African countries like South Africa, is being studied to see how successful transportation planning affects economic and social growth (Popoola, 2020).

The position of social, economic and household activities, as well as employment centers in urban areas is influenced by transportation network structures. It has an effect on travelers' accessibility and destination choices. There is a need to establish a strategy for city road network growth that considers equity in road network supply and its effect on urban development through an interactive planning process to incrementally create a road network that leads to a city's sustainable and balanced urban development pattern (Sairam and Saijay, 2020).

The study is limited to Osogbo Metropolitan city and its road network as the case study. Three selected Central Business Districts (CBD) namely Oke-fia, Oja-Oba and Stadium were only considered as places majorly associated with congestion.

Methodology

Study Area

The research took place in Osogbo Metropolitan City (OMC), the capital of Osun State. The road networks of three Central Business Districts covering the regional capital of Osun state in Nigeria were selected from Osogbo Transport Network (OTN) which was obtained using Geographic Information System (GIS) software.

Osogbo has high traffic density and is one of the state's most important road transport users as being expected from the capital city of a state (Adedotun *et al*., 2016). The city is situated on a latitude of 7°48"20' North and a longitude of 4°34'20" East. Osogbo has been the administrative hub of Osogbo and Olorunda Local Government Areas with a population of 306,228 people; it remains one of the most populated cities in the State (Oyeniyi, 2015).

It has grown from a small center to a massive hub with numerous radial exit routes. The city now has numerous types of intra-urban road networks which include Ayetoro road, West bypass, Old garage-Ogooluwa Road, East bypass, Station road Alekuwodo road, Ota-Efun road, Odi-Olowo road, Oke-Fia road and so on (Adedotun *et al*., 2016).

According to Osun State Ministry of Works and Transport, Osogbo, there are about 1914 roads in Osogbo city which includes both major and minor. The paved minor roads are 74 in number constituting 4% of the total number of roads while unpaved minor roads are 1808 in number constituting 96% out of the total number of roads in Osogbo. It is also noted that 29 major (90.6%) roads are paved while 3 (9.4%) are unpaved out of the total number of roads in the urban city (State Ministry of Works and Transport, Osogbo, Osun state, 2021).

Traffic Studies

The traffic counting was done using Video recorder to collect the data at three Central Business Districts namely Oke-fia, Oja-Oba and Stadium Intersections for 14 days consecutively at peak hours in the morning and evening. This enables the determination of the number of vehicles, vehicle types as well as more substantial information such as traffic volume, traffic flow and level of service.

Video recordings, data extraction and analysis

A tripod stand fixed with 14 mega pixel digital video camera was used to capture traffic (at every second) at the road approaches from a point of view. The video camera was positioned in such a way that the video does not block the flow of traffic. The video recorder was placed on the road at the approach view for 14 days in a row, for peak hours in the morning and in the evening.

Traffic analysis

The sum of vehicles flowing at a specific point on a road over a given period of time is referred to as traffic volume. Normally, traffic does not arrive at a junction at a constant or uniform rate according to Rogers (2003). At times, traffic can arrive at a faster rate than the design reference flow (DRF) while at other times; traffic may arrive at a slower rate. Count intervals may vary from 5 minutes to a year.

This is conventionally assigned as vehicles per hour. This was computed by converting the total count to Passenger Car Unit (P.C.U) by multiplying the number of each vehicle type with its regular Percentage Car Equivalent (PCE). The performance of the intersections was measured (Level of Service) using Peak hour factor and volume- capacity ratio as stipulated in HCM (2010).

Result and Discussion

Intersection Inventory

The inventory of the intersections selected at three Central Business Districts (CBD) from Osogbo road network namely Oke-fia, Oja-Oba and stadium CBDs were illustrated in Figures 1a - 1c respectively. The daily traffic count for the intersections is presented in Appendix A. Oke-fia intersection is a five leg intersection which contains the north bound (Lameco road), west bound (Estate road), south bound (Alekuwodo road), south-east bound (Old Garage road) and east bound (GRA road) routes respectively as shown in Figure 1a. The surface of the road is of asphaltic concrete. The vehicles predominantly plying the road are; special utility vehicles (SUVs), passenger cars, motorcycles, buses and trucks. The five legs converging at the intersection which are two double-carriage ways (two lanes each) and three single-carriage way (one lane each) have no pavement markings.

Oja-Oba intersection is a four legged type as shown in Figure 1b, namely; Sabo road (east bound), Station road (north bound), Osogbo-Ilesha road (south bound), and Isale Osun road (west bound). The carriageway is of flexible pavement type and there are no road signs and markings, the four legs converging at the intersection are single-carriage ways (one lane each). The vehicles predominantly plying the road are; special utility vehicles (SUVs), passenger cars, motorcycles, buses and trucks. Stadium intersection is a four leg intersection which comprises of north bound (Ikirun road), west bound (Lameco road), south bound (Ayetoro road) and east

Figure 1a: Oke-fia Intersection
Source: Author's field work, 2021.

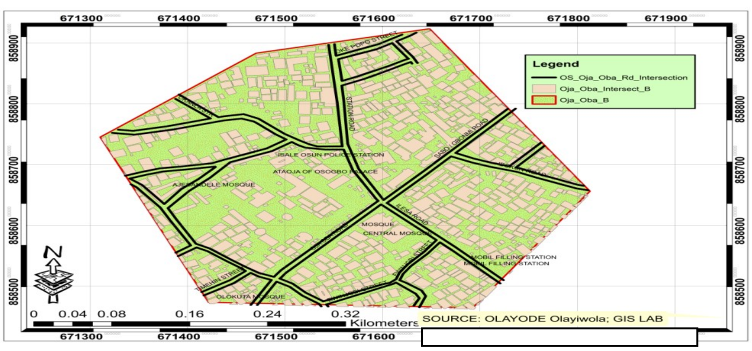
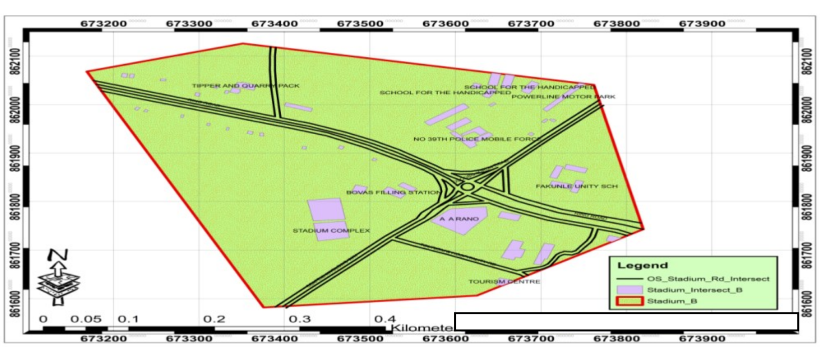


Figure 1b: Oja-Oba Intersection
Source: Author's field work, 2021.



Source: Author's field work, 2021.

(Testing ground road) bound respectively as shown in Figure 1c. The surface of the road is of asphaltic concrete. All the four legs converging at the intersection are double-carriage way (two lanes each) and they have no pavement markings. The vehicles predominantly plying the road are; special utility vehicle (SUV), passenger car, motorcycles, buses and trucks.

Traffic Characteristics

The traffic characteristics of Oke-fia, Oja-Oba and Stadium intersections are shown in Figures 2a, 2b and 2c respectively. The selected CBD intersections exhibit heterogeneous traffic characteristics as shown in Figures 4.2a-4.2c respectively. This agrees with the findings of Osuolale *et al.* (2019). At Oke-fia intersection, the highest percentage of vehicle type recorded is bikes with 47.96% in the South bound, 35.75% in the East bound, 34.34% in the West bound, 33.52% in the South-East bound and 21.63% in the North bound of the total stream flow per each approaches followed by buses, cars, SUV and lastly trucks as shown in Figure 2a. This is not consistent with Osuolale *et al.* (2019) and Huseyin *et al.* (2019). This shows that the intersection is dominated by public transport which plies the road, it has been established from the travel behavior of the city that bikes and buses are the dominant means of transport which mostly contributed to public transport. This is caused by the commercial activities surrounding the intersection.

At Oja-Oba intersection, the highest percentage of vehicle type recorded is buses with 49.42% in the South bound, 46.78% in the East bound, 40.76% in the West bound and 46.78% in the North bound of the total stream flow per each approaches followed by bikes, cars, SUV and lastly trucks as shown in Figure 2b. This is in contrast to Osuolale *et al.* (2019) and Huseyin *et al.* (2019). This shows that the intersection is dominated with public transport which plies the road, it has been established from the travel behavior of the city that bikes and buses are the dominant means of transport which mostly contributed to public transport. This is caused by the commercial activities surrounding the intersection.

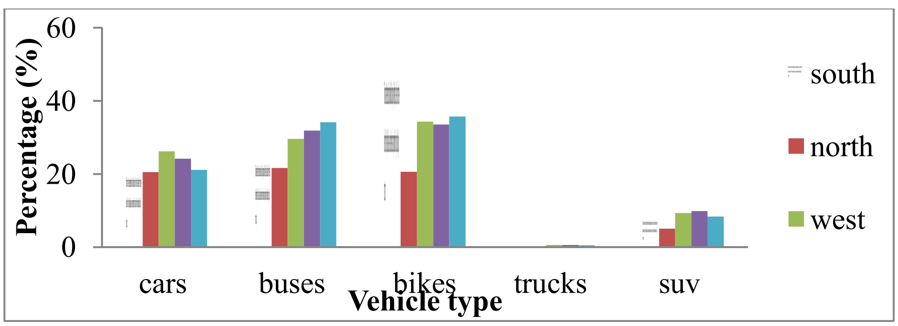


Figure 2a: Modal Choice at Oke-fia Intersection

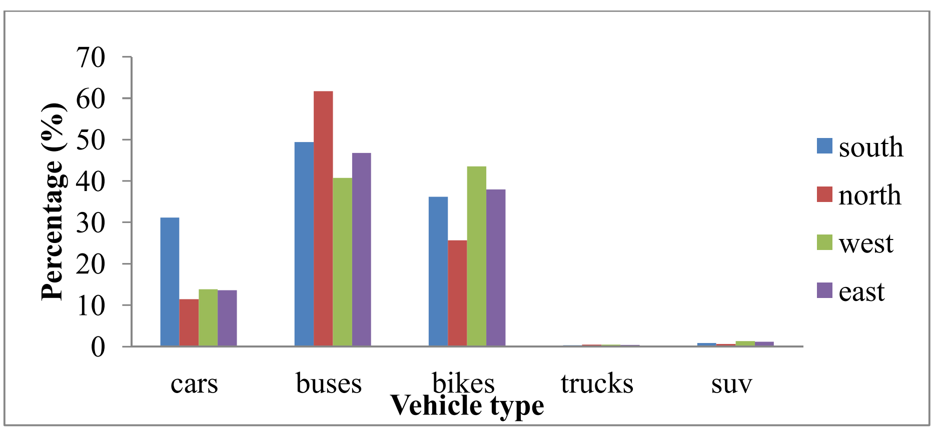


Figure 2b: Modal Choice at Oja-Oba Intersection

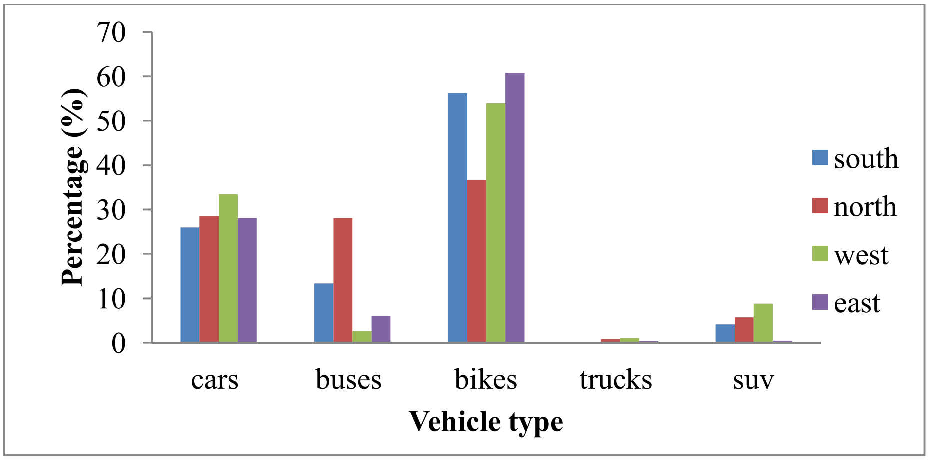


Figure 2c: Modal Choice at Stadium Intersection

At Stadium intersection, the highest percentage of vehicle type recorded is bikes with 56.26% in the South bound, 60.82% in the East bound, 53.98% in the West bound and 36.73% in the North bound of the total stream flow per each approaches followed by cars, buses, SUV and lastly trucks as shown in Figure 2c. This is in contrast to Osuolale *et al.* (2019) and Huseyin *et al.* (2019). This shows that the intersection is composed of public and private transports which ply the road, it has been established from the travel behavior of the city that cars mostly contributed to private transport while bikes and buses mostly contributed to public transport. This is caused by the commercial and educational activities surrounding the intersection.

Traffic volume studies

The average hourly flow (AHF) for South bound (SB), North bound (NB), West bound (WB), East and South-East bound (SEB) are 764, 1197, 616, 381 and 1059 veh./hr. respectively at Oke-fia intersection and this is shown in Table 1a. The highest volume recorded for the NB was anticipated as the traffic is moving towards another state urban city (Ogbomosho) in couples with several urban towns along the road. The SB also has potential traffic volume as it serves as a major traffic collector for the remaining bounds linking to the core city of Osogbo and also shut down of near intersection (Ola-Iya) for ongoing fly over construction.

Table 1a: Average Daily Traffic (ADT) and Average Hourly Flow (AHF) of Oke-fia Intersection

ROAD SECTION	PCU	ADT (pc/day)	AHF (pc/d/hr)
North bound (Lameco road)	67020	4787	1197
East bound (GRA road)	21305	1522	381
West bound (Estate road)	34510	2465	616
South bound (Alekuwodo road)	42794	3057	764
South-East (Old Garage Road)	59271	4234	1059

At Oja-Oba intersection, the AHF for South bound (SB), North bound (NB), West bound (WB) and East are 854, 892, 594 and 517 veh./hr. respectively and this is shown in Table 1b. The highest volume was recorded for the NB which was due to the traffic moving towards another urban city (Ilesa) which eventually led to another state urban city (Akure) in conjunction with different urban towns along the road,. The SB also recorded high traffic volume as it serves core commercial centers (Station road and Old garage) as well as Teaching Hospital of the State University which is a also traffic generating place.

The AHF for South bound (SB), North bound (NB), West bound (WB) and East are 1004, 763, 455 and 379 veh./hr respectively at Stadium intersection and this is shown in Table 1c. The highest volume recorded for the SB is envisaged, as it is the major traffic collector at the intersection also moving towards the commercial centre. The NB is found with high traffic volume as it is approaching another urban town (Ikirun), availability of car parks and open market.

Level of Service (LOS)

The Volume-Capacity ratio (V/C) for the South bound (SB), North bound (NB), West bound (WB), East (EB) and South-East bound (SEB) of Oke-fia intersection are 0.94, 1.23, 0.79, 0.49 and 1.39 with LOS of E, F, D, B and F respectively as specified by HCM (2010). The average V/C at the intersection is 0.97 which puts the LOS to be E, that is, unstable flow near capacity and its LOS often changes to F (the worst condition) very quickly because of disturbance (road conditions, accidents e.t.c) in traffic flow and this is in accordance with Musaib and Sonia (2018). The geometric configuration of the intersection contributed negatively to its LOS, there was no shoulder, no channelization and the three approaches were single carriage ways.

Table 1b: Average Daily Traffic (ADT) and Average Hourly Flow (AHF) of Oja-Oba Intersection

ROAD SECTION	PCU	ADT (pc/day)	AHF (pc/day/hr)
North bound (Station road)	49917	3566	892
East bound (Sabo road)	28959	2069	517
West bound (Isale-Osun road)	33279	2377	594
South bound (Ilesa-Garage road)	47819	3416	854

Table 1c: Average Daily Traffic (ADT) and Average Hourly Flow (AHF) of Stadium Intersection

ROAD SECTION	PCU	ADT (pc/day)	AHF (pc/day/hr)
North bound (Ikirun road)	42711	3051	763
East bound (Testing ground road)	25499	1821	455
West bound (Lameco road)	21212	1515	379
South bound (Ayetoro road)	56233	4017	1004

Similarly, the V/C for the South bound (SB), North bound (NB), West bound (WB) and East Bound (EB) of Oja-Oba intersection are 0.87, 0.98, 0.58 and 0.52 with LOS of D, E, C and B respectively as specified by HCM (2010). The average V/C at the intersection was 0.74 which made the LOS to be C and showed a constrained constant flow below speed limits with additional attention required by the drivers to maintain safe operations, comfort and convenience levels of the driver decline noticeably and this is in accordance with Musaib and Sonia (2018). The geometric configuration of the intersection contributed negatively to its LOS, there was no shoulder, no channelization and all four approaches were single carriage ways.

Also, the V/C for the South bound (SB), North bound (NB), West bound (WB) and East (EB) of Stadium intersection are 0.54, 0.45, 0.19 and 0.23 with LOS of B, B, A and A respectively as specified by

HCM (2010). The average V/C at the intersection is 0.35 which places the level of service (LOS) to be B and this indicates reasonably free flowing conditions but with some influence by others and this is in accordance with Musaib and Sonia (2018). The geometric configuration of the intersection contributed positively to its LOS, there was shoulder, right channelization and all four approaches were double carriage ways.

Conclusion

The operational characteristics show the network is heterogeneous, the highest traffic volume (4017veh/hr) was obtained in Oke-Fia road network with LOS E followed by Oja Oba road network (2857veh/hr) with LOS C and lastly Stadium road network (2601veh/hr) with LOS B.

This study indicates that Oke-fia and Oja-Oba networks have unsatisfactory operational conditions with traffic congestion while Stadium network is fair but they generally indicated an opposite variation in trip pattern for weekdays and weekend trips.

Bus Rapid Transit which has the potential to boost traffic flow and minimize congestion should be introduced at some main nodes in the OMC transport network.

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INFLUENCE OF BRITISH STANDARD LIGHT COMPACTION ENERGY ON LATERITIC SOIL STABILIZED WITH COAL BOTTOM ASH

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Abstract

Lateritic soil is generally known to have low bearing strength due to the high presence of clay content in it, while researchers have utilized several additives to improve its engineering properties, this study focuses on determining the influence of the British Standard Light (BSL) compaction effort on a lateritic soil collected from a trial pit in Osogbo, Osun state in Nigeria and stabilized with coal bottom ash (CBA). The CBA used for the determination of compaction energies was up to 40% by weight of the lateritic soil and the index properties tests such as particle size distribution, specific gravity as well as Atterberg limits tests were carried out on both the stabilized and unstabilized soils. California Bearing ratio test (CBR) was also carried out to determines the effect of CBA on the strength properties of the lateritic soil. Upon stabilizing the soil with CBA, the results showed a decrease in percentages of fine fraction upon addition of CBA ranging from 41.14% to 0.20% with the addition of 0% to 40% CBA., decrease in the plasticity index from 19.6% to 12.0%, decrease in maximum dry density (MDD) from 1.81 to 1.48, with an increase in optimum moisture content (OMC) from 13.0% to 13.6% (BSL). There is however significant increase in the California bearing ratio {Unsoaked CBR – from 20% to 46% (BSL) and the Soaked CBR – from 8% to 19% (BSL), which indicates improvement in the soil strength. The study showed that the modified soil at CBA content of 10% met the requirements of the Nigerian General Specifications of not more than 35% passing sieve No.200, maximum plasticity (PI) index of 12%, and liquid limits (LL) of a maximum of 50% which can be recommended for use as a subgrade material for road construction.

Keywords: California bearing ratio, Compactive efforts, Stabilization, Unconfined compressive strength.

Introduction

The growing need for constructing cost-effective civil engineering structures at a relatively low cost especially in developing countries like Africa has challenged road authorities to look into the use of lateritic soils not only as a sub-grade fill material for buildings and roads but also as an alternative base material for low traffic roads [6].

Lateritic soil being a product of a humid tropical weathering process is generally known to have a low bearing capacity and have gaps in the soil grading curves largely due to the large quantity of clay contents present in them. However, its strength is affected and renders the stability unreliable especially where there is moisture [3].

In Nigeria, there are over one hundred and ninety-four thousand kilometers (194,394 *km*) of the road network which include paved and unpaved inter-state highways and access roads. Furthermore, there are also three thousand nine hundred and eighty-four kilometers (3,984 km) of operated railway track [20]. However, by the mid-1990s, most of the roads and rail lines deteriorated due to poor investment and sustainability culture [19]. Lateritic soil with principal material rich in iron and aluminium oxides and hydroxides (sesquioxides), which comes in red, brown, yellow and purple colours with red colour being the dominant colour is the most commonly used soil for road construction in Nigeria [7].

Soil stabilizing agents used by highway engineers and researchers in an attempt to stabilize weak soil include but not limited to lime, fly ash, Portland cement, cement kiln dust, cassava peels ash, blast furnace slags, rice husk, banana leaves ash, bitumen or tar, polymers, fiber reinforcement, solid waste, aggregates, organic matter [3], [4], [8], [9]etc. mostly for their pozzolanic nature with coal bottom ash being recently explored as a potential admixing agent for use in both concrete and soils.

Coal bottom ash (CBA) is a by-product of coal combustion and there are proven coal reserves of about 639 million metric tonnes of coal in Nigeria while the inferred reserves are about 2.75 billion metric tonnes [10]. Coal has not been fully utilized to its potentials since it had been abandoned after the discovery of oil in the country. However, it is being used as energy fuel in cement production, foundries and bakery industries, also serve as an important raw material in tyre and battery manufacturing. The coal is gradually finding its foot as a source of fuel for power stations [10]. The potential for coal utilization in the country shows that coal bottom ash may be available in the country in larger quantities in the future. and will provide a proper alternative to the use of the ash as against taking them to landfills as is being done in other countries, thus preventing potential contamination of the soil in the environment. CBA had been confirmed by researchers to have pozzolanic properties [16] and had also been utilized as a partial replacement of aggregates in concrete [18]. This study aims at evaluating the influence of compactive effort on lateritic soil stabilized with coal bottom ash

Materials and Method

Disturbed samples from a trial pit at the Stadium area along Osogbo-Ikirun road in Osogbo, Osun state was collected and air-dried at Osun State Geotechnics and Structures laboratory. The trial pit was dug between the range of 1-1.5m depth. The coal bottom ash used for this study was obtained by incinerating coal from Lafia-obi coal mine, Lafia-obi, Nassarawa State by open burning until sand residual was obtained and then pulverizing till the desired ash content was achieved.

Test Methods

The following laboratory tests such as particle size distribution, atterberg limits, specific gravity, natural moisture content, and compaction tests were carried out on the natural and stabilized soils using the British Standard Light (BSL) compaction effort for both the natural and stabilized soils. These laboratory tests were carried out in accordance with the procedures specified by the British Standard Institution [11] and [12] and Federal Republic of Nigeria General Specification [14].

Results and Discussion

Index properties of Natural Soil

The natural moisture content of the soil sample has 15.4% with a specific gravity of 2.64. The values fall within the range of specific gravity of solid of light coloured sand, which is mainly made up of quartz as predominant mineral [6].

The soil sample is classified as A-7-5 subgroup soil [1] or SMH based on USCS classification. It is reddish-brown in colour, has a liquid limit of 54.9% and plasticity index of 19.6%. The percentage passing sieve No.200 was 41.14%. The index properties of the soil sample are shown in Table 1.

Table 1.1: Index properties of Soil samples.

Soil Properties	**Soil Sample**
Natural Moisture Content	15.4%
Specific gravity	2.64
% passing 75µm Sieve	41.14%
Liquid Limit	54.9%
Plasticity Index	19.6%
AASHTO Classification	A-7-5(4)
Colour	Reddish-Brown

Oxide Composition of CBA and Soil

The oxide composition of the CBA and soil sample used in this study is shown in Table 1.2 which indicates a high amount of CaO in the CBA that helps in cementing the soil particles together, while other major oxides that indicates the pozzolanic nature of the CBA are also high. The addition of SiO_2 + Fe_2O_3 + Al_2O_3 of CBA is 63.978 > 50, it is thus classified as a Class C pozzollan according to [5]. The ratio of $SiO_2/(Fe_2O_3 + Al_2O_3)$ of the soil sample is 1.76 which shows that they are soils of weak laterization and kaolinized profile according to Schellmann scheme for classification of weathering products [17].

Table 1.2: Oxide composition of the CBA and Soil sample used in the study

Oxide	CBA (%)	Soil Sample
CaO	10.789	0.1055
SiO_2	40.805	55.30
Al_2O_3	12.384	21.93
Fe_2O_3	11.062	9.561
MnO	1.3589	0.07728
K_2O	0.1369	1.3634
TiO_2	1.5944	0.9466
MgO	3.850	2.66
SO_3	16.788	0.1736
P_2O_5	0.2860	0.1781
BaO	0.144	0.0066
L.O.I	N/A	7.40

Particle Size Distribution of Soil-CBA Mixture

In the soil sample as shown in figure 1.1, there were marked reductions in the percentage of the soil passing BS sieve No.200 from 41.14% at 0% CBA content to 0.20%, 1.00%, 1.00% and 1.20% at 10, 20, 30 and 40% respectively. The soil upon modification with CBA improved from an A-7-5 soil to A-2-7 on a general classification and the soil became well-graded upon addition of CBA

The reductions in the proportion of fines were as a result of bonding of clay to silt sizes of the ash to form pseudo-sand sizes and of sand sizes to form larger sand sizes. The coal bottom ash content caused the mixture to flocculate and agglomerate more, hence, got coarser and thus enabled the clay fraction to form larger soil sizes. This agrees with the findings of [13], who indicated that the mixture gave a better graded particle size distribution than the constituent soil.

Specific gravity

The specific gravity of the soil mixture decreases with increase in CBA content as shown if figure 1.2. The specific gravity of the natural soil sample(2.64) which is higher than that of CBA(2.22) is the main contributing factor to the reduction in the specific gravity of the stabilized soil with increasing CBA content which decreases from 2.64 at 0% CBA to 2.45 at 40% CBA. [15] and [13] both emphasized the effect that lower specific gravity of CBA had on the natural soil.

Atterberg limits

The soil is of high plasticity because the liquid limit is above 50% but the reduction in the plasticity indices with the addition of CBA is an indication of soil improvement. Above view is agreed upon in the findings of [9].

The liquid limit on treatment with CBA reduced from 54.9% for the natural soil to the lowest value of 53.0% at 10% CBA. The plastic limit value increased from 35.3% for the natural soil to a peak value of 42.8% at 10% CBA while the Plasticity index value reduced from 19.6% for the natural soil to the lowest value of 10.2% at 10% CBA. The Atterberg limits curves for the Soil/CBA mixture are shown in Figure 1.3.

The general reduction in liquid limit and plasticity indices with CBA content can be as a result of the mixture which flocculates the soil particles together and reduces the clay size fraction and hence the soil surface area. It later increases as a result of the increase in the moisture content necessary for the hydration process of the mixture to occur [15].

Compaction Characteristics

The compaction result of the stabilized soil sample is shown in Figures 1.4 and 1.5, for the BSL compactive, the MDD value of the natural soil is 1.81 Mg/m^3.and treated with CBA, showed a gradual decrease in the MDD to the lowest value of 1.48 Mg/m^3 at 40% CBA content. The equivalent OMC increased from 13.0% for the natural soil to 13.6% at 10% CBA content before it tapered down to 12.8% at 40% CBA content.

The decrease in MDD with coal bottom ash content agrees with the findings of [15] as well as [13], which might be attributed to effect of the particle size distribution (the enhancement of the flocculation and agglomeration of clay particles which caused reduction in the surface area of the soil) and specific gravities of the mixtures with the ash having a lower specific gravity of 2.20 which in turn decreases the dry density of the mixture. The increase in OMC may not be unconnected to the large amount of water required for the hydration of the CBA to take place because of its pozzollanic properties and the flocculation of the soil after treatment with coal bottom ash which resulted in the water that had become separated from the particles concentrated in the voids between the bonded particles and as a result caused the increment in the OMC [2].

California Bearing Ratio

The variation of the CBA on the CBR values of the soil samples are shown in Figures 1.6 and 1.7 for unsoaked and soaked conditions as applicable to all the three compaction energies.

Generally, the CBR increases with increase in CBA treatment for the compaction energy levels considered which could be because of agglomeration of the soil after treatment with CBA which made the soil more closely packed together and then spiking up the strength of the soil.

The CBR however generally declined after reaching its peak mostly and this may be connected to the fact that the specific gravity of CBA is lower than that of the soil and even though it increases the bearing ratio of the soil up to a certain level, the quantity of the CBA in the soil beyond that level became too much in the mixture which got the strength reduced as well as the soil's bearing ratio. This observation agrees with the findings of [15], [13], and [2].

Under the un-soaked conditions as shown in figure 1.6, for the BSL effort, the CBR of the soil on treatment with CBA increased from 20% at 0% CBA to the peak value of 46% achieved at 10% CBA before it tapered down which does not meet the suitability limit for road base construction of minimum of 80% un-soaked CBR value according to [14].

Under the soaked conditions as shown in figure 1.7, for the BSL compaction effort, the CBR increased from 8% at 0% CBA till the peak value of 19% was achieved at 10% CBA content after which it tapered down.

Mineralogy and Micro-analysis of Soils

The X-ray diffraction on the soil sample shows that the soil contains a mixture of Kaolinite, Annite, Geothite and Quartz with the latter being predominant.

The micrograph of the naturally treated soils shows inter-grain porosity induced by drying and microstructure alteration. This could be as a result of no significant pozzolanic reaction taking place during the curing period. However, the micrographs of the treated soil show the aggregation of the soil samples and the soil samples became more closely packed thereby removing excess pores in the soil which helps to increase the strength of the soils which may not be unconnected to the agglomeration and flocculation of the soil as well the pozzolanic reaction that occurs during the period of curing.

Conclusion

The soil sample used in the study was classified as A-7-5(4) soil which is highly clayey with 41.14% of the natural soil passing the BS No. 200 sieve. Upon modification with CBA, the particle size of the fines fraction decreased and the gradation of the CBA modified soil improved by becoming better graded.

Based on the recommendations of the Nigerian General Specifications, The modified soil with 10% CBA content met the value of not more than 35% passing sieve No 200 (0.075mm aperture) and 12% maximum plasticity index value for use as subgrade material.

The oxide composition test carried out also shows that CBA used in the study is a Class C pozzolan. The maximum dry density of the CBA modified soil reduced with higher CBA content for the BSL compactive effort considered while the optimum moisture content increases with increase in the CBA content. The soaked and un-soaked California bearing ratio of the natural soil improved for the compactive energy level considered in the study.

The X-ray diffraction on the soil samples shows that the sample contains a mixture of Kaolinite, Annite, Rutile and Quartz with the latter being predominant. The micro-analysis of the soil shows that on treatment with CBA, the soil became more closely packed thereby removing excess pores in the soil which helps to increase the strength of the soils.

The result of this study conducted shows that the maximum content of lateritic soil modified with 10% CBA content exhibits better results and thus can be used as a subgrade material for road construction works .

Appendix

Figure 1.1: Particle size analysis for Soil-CBA mixtures

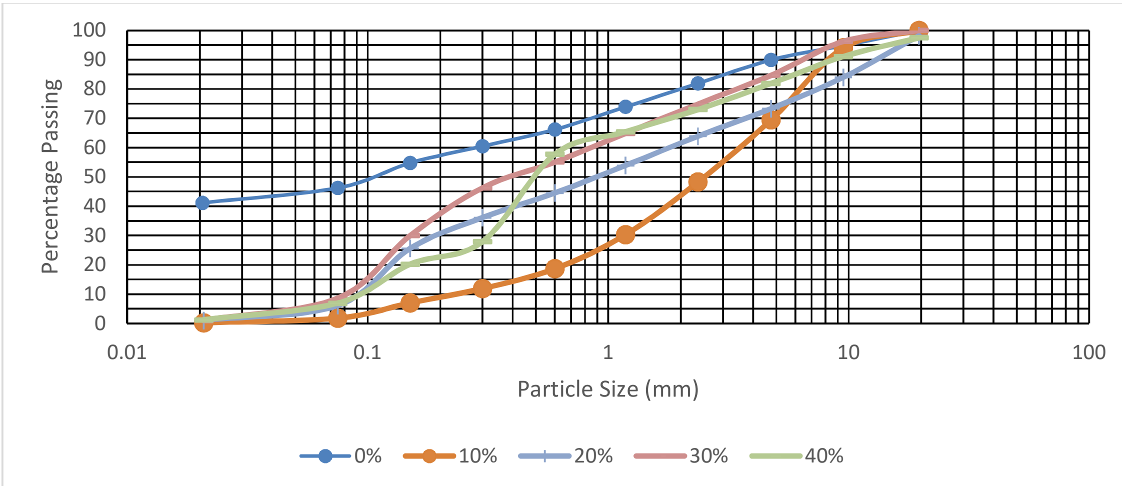


Figure 1.2: Variation of Specific gravities of soils stabilized with CBA contents.

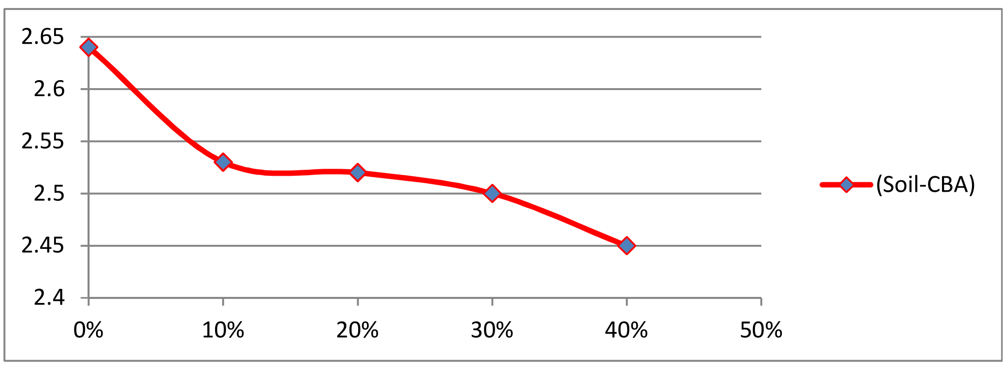


Figure 1.3: Variation of Atterberg limits of soils stabilized with CBA contents.

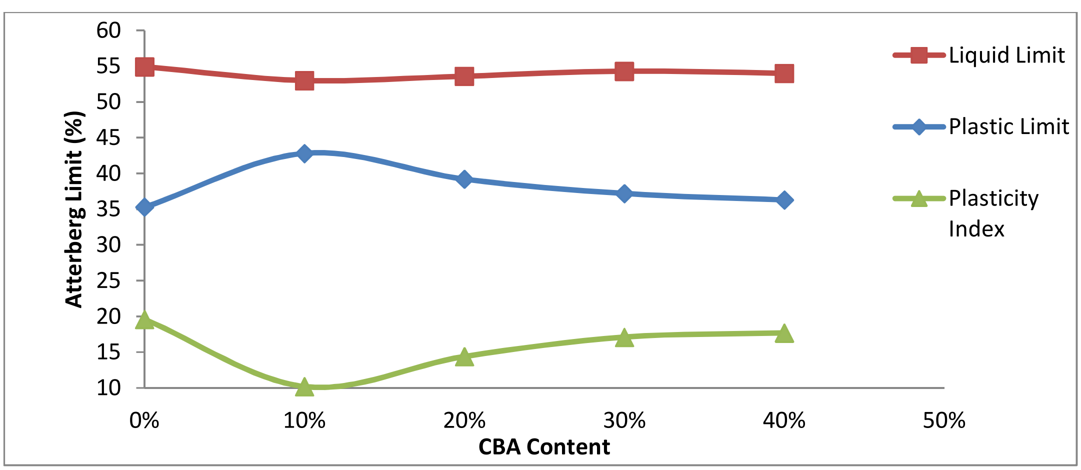


Figure 1.4: Variation of Maximum Dry Densities of lateritic soil-CBA mixture

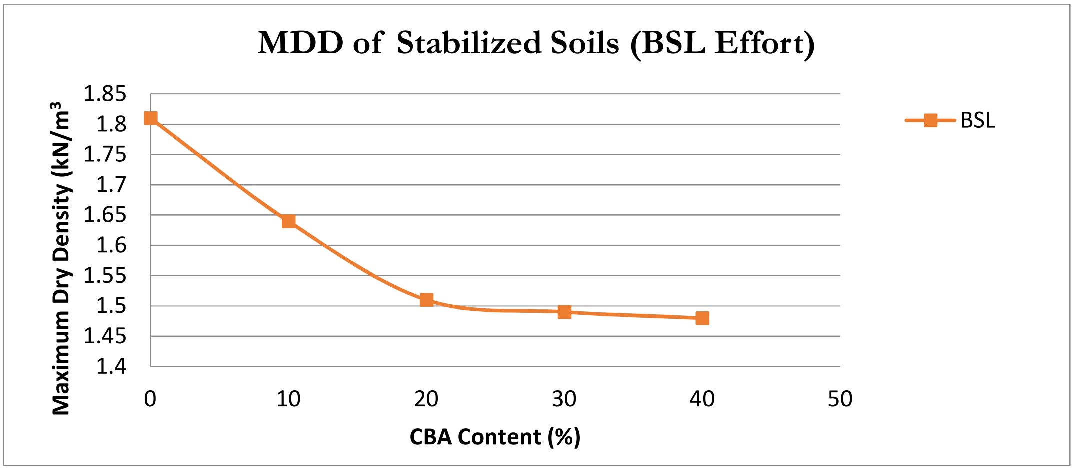


Figure 1.5: Variation of Optimum Moisture Content (OMC) of lateritic soil-CBA mixture.

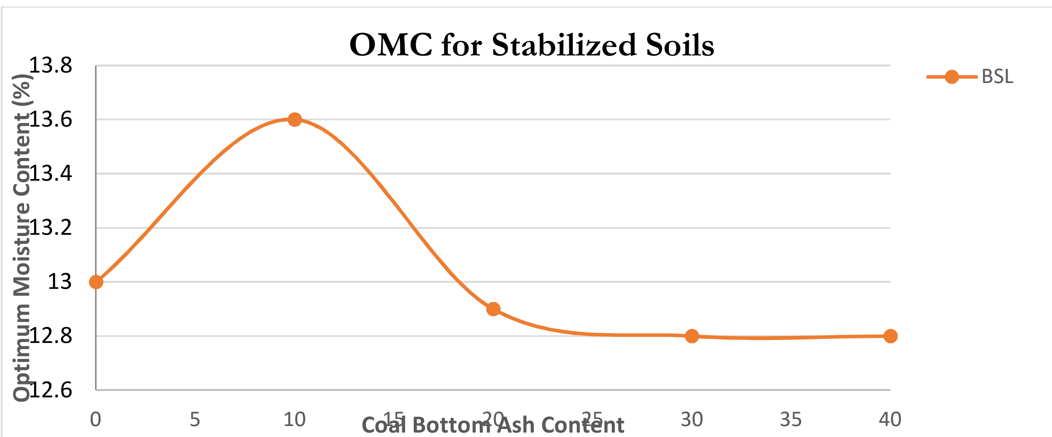


Figure 1.6: Variation of California Bearing Ratio (CBR) of lateritic soil-CBA mixture (Unsoaked Conditions).

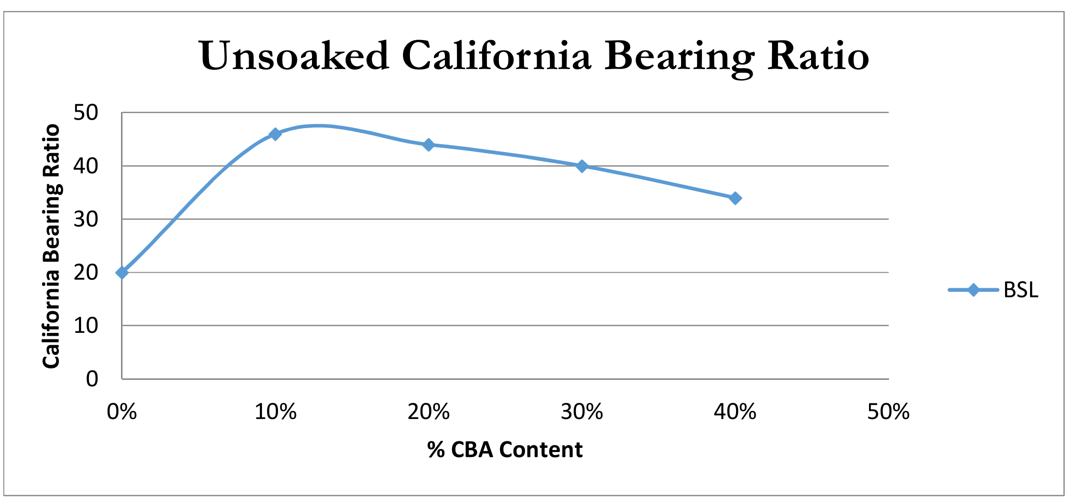


Figure 1.7: Variation of California Bearing Ratio (CBR) of lateritic soil-CBA mixture (Soaked Conditions).

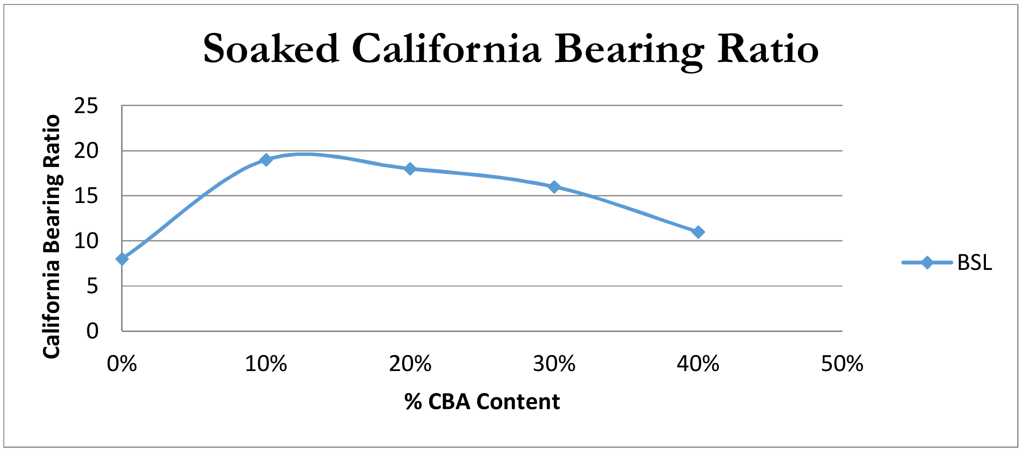
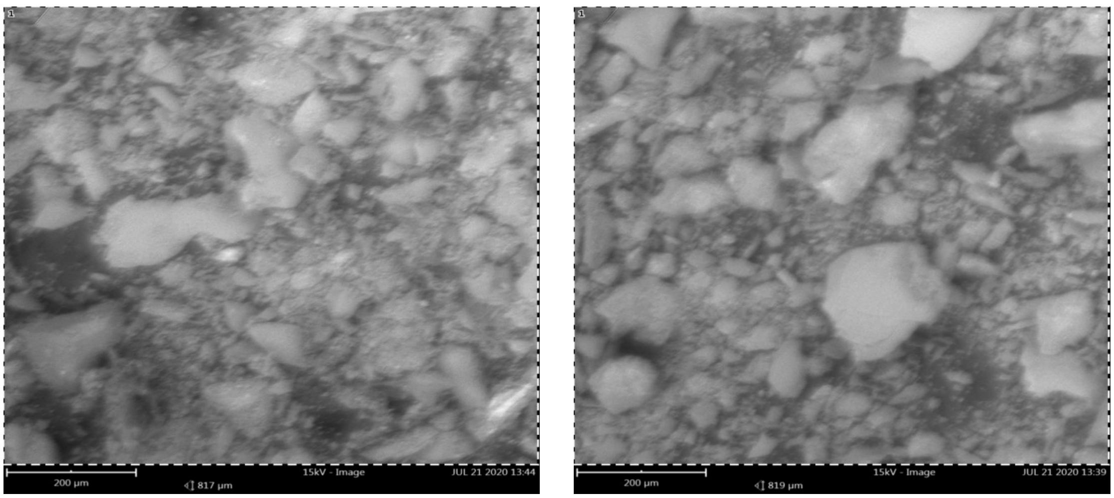


Plate 1.0: Micrograph of lateritic soil before (a) and after treatment (b)



(a) **(b)**

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Concrete Decarbonization Techniques For Climate Change Impact Mitigation: A review

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Abstract

The annual production of concrete stands at 25 billion tons (about 3.8 tons per capital) globally. This has raised the cement production significantly leaving a heavy deposit of carbon dioxide (CO_2) which contributes to climate change. The weighty threat posed to the living creatures by the anthropogenic CO_2 accounting for 75% of global greenhouse gas necessitates their removal through creative conversion into a sustainable product. Decarbonizing this sector is necessary to reduce the environmental impact and conserve biodiversity. Moreso, CO_2 capture by sequestration techniques in concrete have proven to be credible strategy for cutting carbon emissions. Moreover, the benefits of sequestering CO_2 waste in fresh concrete, where it reacts with portlandite to form stable solid calcium carbonate–enhances the concrete strength and durability. The credible methods of capturing industrial CO_2 at production and utilizing the same for sustainable and environmental concrete production are presented in this review paper. The successful implementation of these techniques necessitates collaboration among scholars, industry players, and policymakers, cutting their environmental impact by keeping global warming well below 2 ℃ and pursuing to keep temperature rise to 1.5 ℃ via responsible act.

Keywords: Concrete, Sequestration, Decarbonization, Mineral carbonation, Carbon capture and utilization, Climate change.

Introduction

Concrete is widely used building material due to its durability, versatility, and sufficient availability (Andreas *et.al.,* 2014). The energy-intensive manufacturing of cement, involving the calcination of limestone and the emission of carbon dioxide (CO_2), constitutes approximately 8% of worldwide CO_2 emissions. These CO_2 emissions are 75% of global total greenhouse gas (GHG), encompassing all sources of CO_2, not alone cement. A growing initiative aims to reduce the carbon footprint of concrete in the construction sector, given its significant impact on biodiversity and global warming (Radovic*,* 2024). Moreover, 90–95% of GHG emissions linked to concrete manufacture stem from cement. The release of CO_2 from cement industry surpasses the global emission from aviation industry (Liu, 2020). According to Shim (2016), cement industry contributes around 5% global CO_2 emissions, with 50% steming from chemical process and 40% from fuel combustion, and that cement production involves heating limestone in a kiln to approximately 2,700 ℃ with the aid of coal combustion leading to substantial CO_2 release into the environment. The necessity of carbon neutrality for a safer future mandates the decarbonization of the cement sector.

In recent years, practicability of supplementary cementitious materials (SCMs) as replacement constituents in concrete have proven to be a suitable alternative for cement, lowering the weighty carbon footprint. Efforts are being directed to cut the carbon footprint from different industry sectors and its influence on climate systems. Sethi (2011) estimated that industrial CO_2 cumulate 64% of the total GHG emission. However, cementitious construction materials such as coal ash (CA) can be introduced to lower cement potent, and aid formation of calcite during the direct carbonation process of fresh concrete resulting to CO_2 capture by the concrete leading to carbonate mineralization in the cementitious matrix and beneficial for the concrete strength improvement (Andreas *et.al.,* 2014).

Carbonation of Concrete

Concrete holds weighty potential as a medium for CO_2 sequestration. Carbonation in concrete serves as a decarbonisation technique, with a technologically advanced method to capture and utilise waste CO_2 from industrial processes, thereby producing a valuable product like concrete instead of pollutants that contaminate the environment. Concrete demonstrates a significant capacity for carbon dioxide capture and storage. This potential arises from its impressive carbonation reactivity to trap carbon dioxide equivalent to the emissions generated by the decomposition of limestone in cement production (Monkman*,* 2016). To reduce CO_2 in the building industry, it is important to look at technological methods that collect and store waste CO_2 (Singh and Vishal, 2023). One promising strategy for achieving carbon cut in the building industry is carbon capture, utilisation, and storage (CCUS), which has recently received global attraction. As a promising strategy for CO_2 sequestration after combustion, mineral carbonation has newly gained prominence as an important part of CCUS technology. A prevalent method for achieving a carbon-free sector is the conversion of carbon dioxide into solid inorganic carbonates (Xuan*,* 2018). The environment is perceived vulnerable from the activities of the heat absorbing gas, CO_2. However, concrete can be viewed as a symbiotic entity with a self-sustaining capacity to conserve the industrial CO_2 off the atmosphere by locking it permanently without further release, thereby limiting its ash potent as a response to climate action: SDG 13. The mechanical characteristics of concrete can be affected by the carbonation process, which occurs when stable nano-sized crystals, specifically calcite ($CaCO_3$), are generated within the concrete by the chemical reaction between moisture, calcium oxide (CaO), and CO_2.

The sequestered CO_2 either by direct carbonation (Figure 2) or atmosphere is forever trapped in the concrete, enhance concrete strength by approximately 15%. The study further asserted that:

i. A cubic meter of carbonated concrete saves 7-11 kg of CO_2 from diffusing into the atmosphere.
ii. Precast concrete permanently sequestered 12-18 kg of CO_2 per cubic meter.
iii. Average building built with CO_2 mineralized concrete would save closely 680 metric ton of embodied carbon which translate to carbon absorbed by 889 acres of forest in a year, and eliminate approximately 50,000 cars producing carbon emissions off the road in a day with an average 4.6 metric tons/year.

Hamad (2021) reported analysis of carbonated concrete by X-ray diffraction (XRD) indicates the presence of calcite ($CaCO_3$) resulting from the aqueous carbonation process described in equations 1 and 2, which shows the complete conversion of the original portlandite ($Ca(OH)_2$) into calcite, Figure 1.

The Chemical Reaction Process:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O \qquad 1$$

$$Ca_3Al_2(OH)_{12} + 3CO_2 \longrightarrow 3CaCO_3 + 2Al(OH)_3 + 3H_2O \qquad 2$$

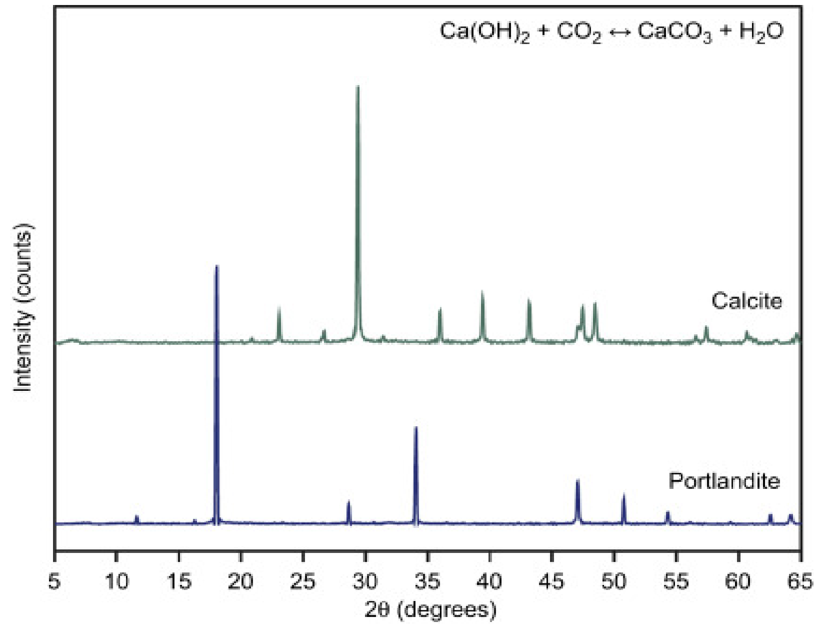

Figure 1. XRD Image of Mineralized CO_2 Concrete

Source: Hamad (2021)

Figure 2. Accelerated Carbonation of Concrete

Source: (Pu, 2021)

Carbon Capture and Storage Technique

Carbon capture and storage (CCS) is an emerging technology that cut CO_2 emissions stemming from human activities. In attempt to phase out CO_2, it is responsible to collect it from various sources, including power plants and industrial activities. Subsequently, the CO_2 in the collection chamber needs to be compressed to a supercritical level and subsequently transfer safely to underground geological formations (Leung, 2014). The CCS technique is considered a highly promising approach for cutting down component of greenhouse gas (GHG) and its ecological impact. The implementation could result to huge success to climate change adaptation efforts (Yoro and Daramola, 2020). However, adoption of CCS promises to eliminate carbon release associated with concrete industry and its emissions from the cement industry can be captured and sequestered in depleted oil and gas reserves (Gur, 2022). These technologies are currently at the infant stages of development and deployment. Their implementation in the cement sector offers permanent solution to issues of global warming (Bokka and Lau, 2023). Although, CCS systems implementation in the sector faces technological, economic, and regulatory consequences.

One of the proposed methods around CO_2 issues in cement production is post-combustion capture, which involves capturing CO_2 from the flue gases generated during the production process (Ismayilli, 2019). The captured CO_2 can then be utilized by infusion into the fresh concrete forming a nano-sized mineral through a process called CO_2 mineralization (i.e. carbonation), which involves the chemical reaction of CO_2 with calcium and magnesium silicate minerals to produce stable carbonates (Miller, 2021), that can benefit concrete properties. This method not only cut the carbon footprint of concrete production but also helps to sequester CO_2 which accounts for about 15% improvement in concrete strength, also preventing its release into the atmosphere (Neeraj and Yadav, 2020). Also, CCS techniques have the potential to eliminate over 90% of CO_2 emissions from power plants and industrial facilities, and the air. The voluntary carbon market presents an opportunity for manufacturers to generate financial gains through the sale of carbon credits. The valuation of these credits is reliant upon their anticipated cost savings during the manufacturing process, and utilization of carbon capture can potentially yield marketable goods or services, but it is not a guaranteed means of reducing emissions or providing a net benefit to the climate, as there may be indirect and other factors to consider (Vakurov. and Abrosimov, 2018). Furthermore, Table 1 adapted presents technology roadmap and carbon dioxide removal (CDR) Impact phases in concrete production, however, the computation dwell on three key Cs; Carbon capture, Carbon utilization, and Carbon removal mechanisms.

Table 1. Technology Roadmap and CDR Impact

Products	CO_2 Utilized (Mt)	Impact of Reduced Cement (Mt)	Net Impact (Mt)
Ready Mix Concrete (RMC)	4.2	126.1	130.3
Reclaimed Water (RW)	65.3	229.6	294.9
Mansory and Precast (MP)	0.4	12.3	12.7
Reclaimed Aggregate (RA)	95.8	-	80.7
Cumulative Totals	166	368	519

The technology roadmap underscores the critical role of CDR in reducing emissions in the concrete industry. Ready-mix concrete demonstrates significant potential, with 4.2 million tons of CO_2 utilized and 126.1 million tons saved through reduced cement usage, resulting in a net impact of 130.3 million tons of CO_2 mitigation. Reclaimed water (RW) presents peak efficiency, with a gross impact of around 295 million tons, showcasing its significance for production that is sustainable. The innovative drives do not only cut energy consumption but also enhance resource utilization, which align with the sustainable development goal (SDG) 13: Responsible Consumption.

Additionally, reclaimed aggregates (RA) and precast concrete strengthen the case for CDR. RA add to a net CO_2 impact of 95.8 million tons by lowering waste and supporting circular economy. Also, precast concrete, though with a smaller net impact of 12.7 million tons, demonstrates precision and reduced material wastage, critical for sustainable construction. These methods put together achieve a total reduction of 519 million tons of CO_2, indicating strong shift towards clean concrete solution. However, the roadmap strengthens the practicability and need of integrating these technologies to meet SDG goals and address climate challenges efficiently.

Alkaline Activator Blended Carbon-dioxide in Concrete

Studies have shown that the use of waste CO_2 from industrial processes as a raw material for producing innovative concrete. The approach holds promise for extracting valuable resources from waste (Humbert and Castro-Gomes, 2019). The use CO_2 gas from industrial processes introduce as additive in concrete can reduce water cement ratio, and carbon footprint of concrete cut down by up to 50% (Adesina 2020). Also, production of alkali activated concrete using waste CO_2 can decrease the carbon footprint of concrete (Awoyera, 2020). Many studies advocate CO_2 as an activator for geopolymer binder which could lessen the global carbon impact on the environment and by incorporating them into the mix for improved mechanical properties and durability (Das, 2022). According to Mohan (2020), concrete's durability and compressive strength were enhanced by direct accelerated CO_2 carbonation, which also had a less carbon footprint. Kanagaraj (2023) studied the applicability of recycled CO_2 as a foaming agent in the development of lightweight concrete and the result shows enhanced mechanical properties of lightweight concrete. Also, Gao (2021) investigated carbonated slag as a potential alternative to cement in concrete production. The study submitted that carbonated slag contributes mechanical properties and durability of concrete, while lowing its carbon footprint. According to studies, a reaction between CO_2 and magnesium oxide can produce a mineral that can be used as a cement substitute. Moreover, adding CO_2 as an activator during the creation of geopolymer concrete can improve its strength-durability integrity and lower its overall carbon emissions (Pasupathy, 2021).

Capacity and Suitability of Carbonated Material in Concrete

The metric for assessing advances towards CO_2 sequester is crucial. The idea of carbon sequestration capacity of materials measures the amount of CO_2 absorbed relative to the initial mass of the material before chemical carbonation (Jang and Lee, 2016), as shown in Eq. (3). However, assessment of CO_2 uptake capacity employs techniques like the mass gain method, mass curve method, and thermogravimetric analysis (Liu, 2018).

$$CO2\ uptake\ = MCO2\ \div MC\ \times 100 \qquad 3$$

In the equation above, M_{CO2} and Mc respectively signifies the mass of CO_2 captured after post carbonation treatment and the initial mass of material prior carbonation treatment. Also, carbonation efficiency denoted by equation (4) presents important information to measure the carbonation effect of materials. It identifies CO_2 mass effectively sequestered (M_{CO2}) by a material under specific conditions relative to the theoretical CO_2 captured (M_{th}) which was computed using Steinour's or Huntzinger's equation (Montes-Hernandez, 2009). Across materials exposed to carbonation conditions, translates to higher carbonation capacity and greater carbonation efficiency denotes improved mineral CO_2 sequestration (Ebrahimi, 2017).

$$CO2 - eff - MCO2 \div \text{Mth} \times 100 \quad 4$$

Draw Back of Modern CO_2 Sequestration Method

Technological procedures of carbon sequestration have been proposed as a potential solution to reducing the concentration of atmospheric CO_2. Numerous challenges associated with the techniques need to be addressed for acceptability across the globe. For example, carbon capture and storage technologies can be expensive, and the cost is often passed on to consumers, making it difficult for the technologies to be adopted on a large scale (Gur, 2022). The issue of leakage; CO_2 that is stored underground can potentially leak back into the atmosphere due to natural fractures in rock formations or as a result of human error during injection, thereby negating the benefits of carbon capture and storage (Liu and Meng, 2021). Also, over time, the danger about the long-term viability of carbon storage sites; over time, reaction of CO_2 with minerals in the storage site can lead to mineral dissolution and potentially releasing the CO_2 back into the atmosphere.

Another setback is that CCS technologies need a huge amount of energy to operate, which can result in rise of the carbon footprint of the process and could be problematic if the energy used is derived from fossil fuels, as it would basically result in a carbon-intensive process. Also, there are social and political challenges associated with execution of modern carbon sequestration technique. Some communities may be resistant to having carbon storage sited in their territory, particularly if it holds perception that the site could be hazardous. Moreso, there may be challenges with securing regulatory approval for CCS (Kua and Tan, 2023). While these technologies have been successfully demonstrated at small scales, it is unclear whether they can be implemented on a large scale across board to have a meaningful impact on global CO_2 emissions. Nevertheless, the approach holds strong conviction in cutting atmospheric CO_2 for cleaner concrete (Vakurov and Abrosimov, 2018).

Mechanism of CO_2 Sequestration in Concrete

Li and Wu, (2022) highlight the movement of mineral ions (mostly Ca^{2+}) from solid to liquid by leaching, the dissolution of CO_2 and the formation of carbonate ions, and the orchestration of carbonation reactions that lead to the formation of calcite particles. These steps not only set up the process of sequestration, but also determine how well the materials work and how much they can hold. More importantly, liquid, or moisture, is always a part of the first two stages (Rostami, 2011). In the first phase of orchestrating calcium ion leaching, total calcium content, particle size, and microstructural details of the raw natural materials are important and increasing the temperature can enhance the process of calcium leaching. However, calcite particle precipitation thickens the calcite layer, serving as a barrier against calcium leaching. The precipitation of calcite particles leads to the formation of a thicker calcite layer as seen (Figure 3), serves as a protective barrier against subsequent calcium leaching, and the kinetics of carbonation reactions are primarily influenced by temperature. Yet, during the mineral sequestration process, the production of carbonate ions in liquid is affected by CO_2 concentration, temperature, and pressure (Lekakh, 2008; Rostami, 2011).

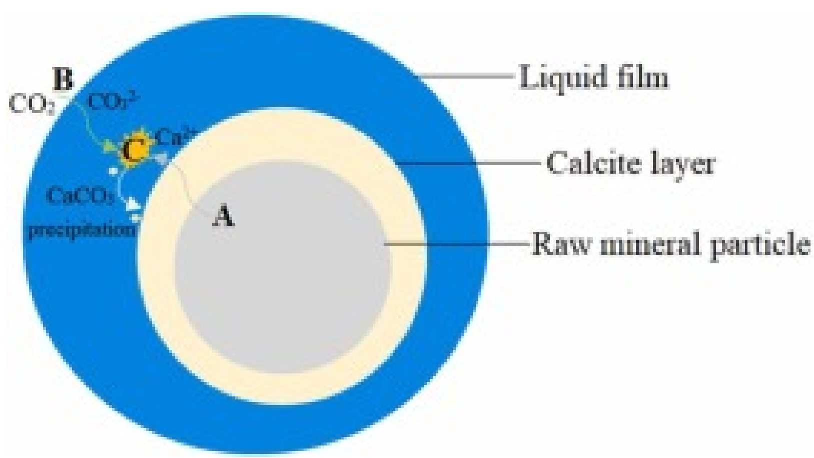

Figure 3: Mineral CO_2 Sequestration Layers
Source: Rostami, (2011)

Mineral Carbonation

The process of sequestering CO_2 involves its reaction with specific minerals such as olivine, serpentine, or basalt, resulting in the formation of stable carbonate minerals (Neeraj and Yadav, 2020). Also, the reaction between CO_2 and metal oxides, such as magnesium and calcium oxides, or silicate minerals resulting in the formation of carbonates that are insoluble and thermodynamically stable (Yunsung, 2022). Mineral carbonation serves as a potential solution for carbon capture and storage (CCS) in cases where geological sequestration is not feasible, particularly for smaller to medium emitters. However, large-scale CO_2 injection initiatives are currently in progress, establishing underground CO_2 sequestration in sedimentary rocks as the most developed method for depositing CO_2 obtained from point sources, and conceivably through direct air capture (DAC). Also, the process enables the stable and non-toxic conversion of atmospheric CO_2 into a carbonate product that can be stored indefinitely, the product can be further utilized and commercialized. Review suggested that utilization of Iron (Fe)-rich mine waste material for mineral carbonation presents a viable approach for the dual purpose of carbon capture and storage which facilitate mineral precipitation for carbonation (Snæbjornsdottir, 2020).

Bio-based Cements

Biocement synthesizes a naturally existing limestone compound by combining elements of carbon and calcium, while diminishing the reliance on heat and fossil fuels. Bio-based cements have been identified as a viable alternative for conventional Portland cement due to their lower CO_2 emissions during the manufacturing process. Diverse biomasses, including agricultural waste, are utilized in the production of bio-base cements, and the mechanical properties have been observed to be comparable or even superior to those of Portland cement (Mohammadjavad, 2022). For example, concrete tiles derived from bio-based materials exhibit a durability that match-up that of traditional concrete tiles by a factor of 300%, while also emitting reduced amount of CO_2, up to 95%. Also, the utilization of microalgae in the production of bio-cement according to studies shows significant decrease in CO_2 emissions and conserve up to 95 percent of the water utilized during manufacturing, as opposed to traditional Portland cement (Babatunde, 2024).

Biogenic CO_2 sequestration

Biogenic CO_2 sequestration involves utilization of microorganisms such as bacteria and fungus for the precipitation of calcium carbonate in concrete; a method that can effectively sequester CO_2 while simultaneously enhancing the mechanical and durability characteristics of concrete. However, by the investigation of Yuze (2023), it has been observed that concrete specimens subjected to CO_2 sequestration demonstrate a potentially greater compressive strength and exhibit high early strength in comparison to those without CO_2. For instance, biogenic precipitation of calcium carbonate improved the compressive strength and durability of concrete. Essentially, biogenic CO_2 sequestration process can significantly mitigate climate change through carbon sequestration, carbon neutrality, and negative emissions, thereby reducing atmospheric CO_2 levels (Sumit, 2020).

Limitation on Current Studies and Future Research Directions

To advance CO_2 sequestration strategies in concrete in addressing climate change efforts, it is imperative to confront current constraints and investigate prospective alternatives advised below:

i. Limited long-term data: Due to the novelty of CO_2 sequestration techniques aimed at decarbonizing concrete, there exists an absence of long-term data on their efficacy and resilience. Long-term studies should assess the efficacy, durability, and carbon sequestration potential of diverse methodologies to acquire knowledge pertaining to the longevity and efficacy of the subject under prolonged exposure to challenging circumstances.

ii. Scalability challenges: While various CO_2 sequestration techniques exhibit potential, their implementation on a large scale may encounter challenges. Effective implementation necessitates addressing concerns such as resource availability, cost-effectiveness, and technological feasibility.
iii. Economic feasibility and policy implications: Research is necessary to examine the economic feasibility of CO_2 sequestration methods, their focus into existing policy and regulatory frameworks. This will facilitate the extensive utilization and incentivize industry-wide implementation.
iv. Artificial Intelligence: Artificial intelligence and machine learning can enhance the design of mineral carbonation reactors. These advancements may enhance the viability and cost-effectiveness of implementing CO_2 sequestration techniques on a larger scale.

Conclusions

Ultimately, the Review concluded that carbon elimination won't solved itself. Making the environment greener is our collective shared responsibility at every stage of our existence. However, preservation of a sustainable future for our planet and safeguarding of the welfare of both current and future generations is contingent upon our capacity to proficiently manage climate change via efficient policies and solutions. In view of this, concrete industry is among many sectors that must collaborate in addressing the issue of climate change. The implementation of CO_2 sequestration techniques can mitigate the environmental impact emission associated with concrete production and decrease heat absorbing gas. Adoption of these practices can aid in the global pursuit of mitigating temperature rise and fostering a sustainable future through sustained research, innovation, and collaborative efforts for the complete realization of CO_2 sequestration in mitigating carbon emissions in the concrete industry. However, stakeholders possess the capability to construct facilitative frameworks, stimulate sustainable methodologies, and disseminate awareness regarding the importance of decarbonization. Beside global warming mitigation, CO_2 sequestration facilitates sustainable economic growth and yields favourable environmental outcomes.

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Adsorption-Based Removal of Synthetic Dyes Using Corncob-Derived Cellulose

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Abstract

Dye wastewater, especially from the textile industry, poses a significant environmental challenge due to the complex and non-biodegradable nature of synthetic dyes such as Congo red. Conventional dye removal methods are often costly and inefficient, underscoring the need for affordable, eco-friendly alternatives. This study explores the use of cellulose derived from corncob, an abundant agricultural by-product, as a low-cost adsorbent for dye remediation. Corncob was pre-treated through washing, drying, milling, and successive chemical treatments with 3 wt.% sodium hydroxide, sodium chlorite, and hydrogen peroxide to isolate cellulose. Adsorption experiments were designed using the Central Composite Design of Response Surface Methodology, employing Design Expert software (v13.0.1) to optimize the agitation speed (140-180 rpm) and contact time (30, 45, and 60 minutes) for maximum removal efficiency (Re) and adsorption capacity (qe). Batch adsorption was conducted at room temperature, and the residual concentration of Congo red was measured at 498 nm using a UV-Vis spectrophotometer. Under optimal conditions, a maximum adsorption capacity of 0.76 mg/g and removal efficiency of 76.05% were achieved. This study demonstrates that corncob-based cellulose offers a sustainable, eco-friendly, and cost-effective solution for industrial wastewater treatment, supporting cleaner production practices in the textile industry.

Keywords: Corncob, Cellulose fiber, Adsorption, Congo red

Introduction

The extensive use of synthetic dyes in the textile industry poses serious environmental concerns, with dye-laden wastewater frequently discharged into water bodies. Synthetic dyes, such as Congo red, are non-biodegradable and can be toxic or carcinogenic, impacting aquatic ecosystems and human health (Kumar et al., 2020; Yaseen & Scholz, 2019). Traditional dye removal methods, like coagulation, oxidation, and filtration, often involve high operational costs and complex processes, limiting their feasibility on a large scale (Oller et al., 2011; Samsami et al., 2020). Adsorption has become a preferred alternative due to its efficiency, simplicity, and adaptability. However, the high cost of conventional adsorbents, such as activated carbon, restricts their widespread application (Bhatnagar & Sillanpää, 2010).

Research has increasingly focused on low-cost adsorbents derived from agricultural byproducts, which are sustainable, affordable, and effective for dye adsorption (Rafatullah et al., 2010). Corncob, an abundant agricultural waste, has shown promise as an eco-friendly adsorbent due to its high cellulose content and porous structure, which enhance its dye adsorption potential (Miyah et al., 2016; Zhang et al., 2020). Despite initial studies, there remains a need to optimize the adsorption performance of corncob cellulose to assess its practical application.

This study investigates the use of corncob-derived cellulose as an adsorbent for Congo red dye. The corncob was chemically treated to isolate cellulose, enhancing adsorption capabilities. A Central Composite Design

(CCD) approach within the Response Surface Methodology (RSM) was used to optimize conditions such as agitation speed and contact time. The Langmuir isotherm model was applied to analyze adsorption behavior.

By demonstrating the efficacy of corncob-based cellulose for dye removal, this study supports the development of affordable, eco-friendly wastewater treatment solutions using agricultural waste, promoting sustainable practices in the textile industry.

Materials and Method

2.1. Materials

(i) **Corncob**: The corncob used as a raw material for cellulose extraction was sourced locally from agricultural fields. As an agricultural by-product, it was chosen for its abundance, renewability, and high cellulose content (Miyah et al., 2016; Zhang et al., 2020).
(ii) **Reagents**: Sodium hydroxide (NaOH), sodium chlorite ($NaClO_2$), acetic acid (CH_3COOH), and hydrogen peroxide (H_2O_2) were used for the pre-treatment and purification of corncob cellulose. Congo red dye was selected as the target pollutant for the adsorption experiments.
(iii) **Equipment**: The equipment used included a hot plate stirrer, UV-Vis spectrophotometer, magnetic stirrer, oven, pH meter, and rotary shaker. The UV-Vis spectrophotometer was particularly crucial for determining the residual concentration of Congo red in the dye solution at a wavelength of 498 nm.

2.2. Preparation of Corncob-Derived Cellulose

(i) **The raw corncob** was pre-treated by washing thoroughly to remove impurities, followed by drying and milling to obtain a fine powder. This powder was then sieved to achieve uniform particle size, enhancing consistency in cellulose extraction (Saha et al., 2016).
(ii) **Alkaline Treatment**: Corncob powder (400 g) was treated with a 3 wt.% sodium hydroxide (NaOH) solution at 70°C for 4 hours with constant stirring. This step aimed to remove lignin and hemicellulose, increasing the cellulose content in the final adsorbent (Thompson et al., 2019).
(iii) **Delignification and Bleaching**: The alkaline-treated corncob was washed with distilled water to neutrality, then subjected to a 10 wt.% sodium chlorite ($NaClO_2$) solution and acetic acid (CH_3COOH) in a 1:10 ratio for 24 hours. Finally, the sample was treated with hydrogen peroxide (H_2O_2) at a 10% concentration to further purify the cellulose. After each chemical treatment, the sample was rinsed to neutrality and dried at atmospheric temperature (Thompson et al., 2019; Yin et al., 2018).

2.3. Experimental Design and Optimization

(i) **Design of Experiments (DOE)**: Central Composite Design (CCD) within the Response Surface Methodology (RSM) framework was utilized to optimize two critical parameters: agitation speed (140-180 rpm) and contact time (30, 45, and 60 minutes). The software Design Expert (v13.0.1) generated experimental runs to identify the best combination of these parameters for optimal removal efficiency (R_e) and adsorption capacity (q_e) (Silva, 2024).
(ii) **Adsorption Experiment**: Batch adsorption experiments were conducted at room temperature. For each run, a fixed amount of cellulose was mixed with a 100 mL solution of Congo red dye at a concentration of 1000 mg/L. The samples were agitated in a rotary shaker at the specified speeds and contact times, per the experimental design.
(iii) **Measurement of Dye Removal**: After adsorption, the samples were filtered, and the residual dye concentration in the filtrate was measured using a UV-Vis spectrophotometer at a wavelength of 498 nm. Adsorption capacity (q_e) and removal efficiency (R_e) were calculated based on the initial and final dye concentrations using the following formulas:

(iv) **Adsorption Capacity**:

$$q_e = \frac{C_o - C_e}{Mass} \times Volume$$

(v) Removal Efficiency:

$$R_e = \frac{C_o - C_e}{C_o} \times 100\%$$

where C_0 is the initial dye concentration, C_e is the equilibrium dye concentration, V is the volume of solution, and W is the weight of the adsorbent (Aksu, 2005).

Results and Discussion

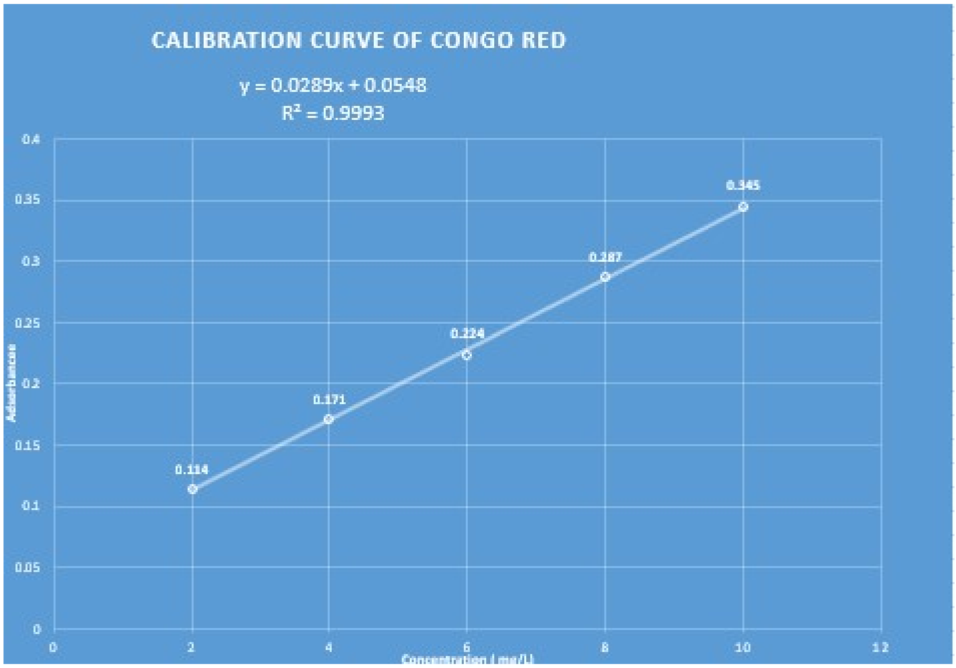
This study evaluated the adsorption efficiency of cellulose derived from corncob for removing Congo red dye from synthetic wastewater. Using the Central Composite Design (CCD) of Response Surface Methodology, optimal conditions for adsorption were determined by analysing the effects of agitation speed and contact time on removal efficiency (R_e) and adsorption capacity (q_e).

3.1 Adsorption Performance of Corncob-Derived Cellulose

(i) **Adsorption Capacity and Removal Efficiency**: Under optimal conditions—an agitation speed of 180 rpm and a contact time of 60 minutes—the cellulose exhibited a maximum adsorption capacity (q_e) of 0.76 mg/g and a removal efficiency (R_e) of 76.05%.
(ii) **Table 4.1**: This table presents the experimental data showing various concentrations of Congo red dye and corresponding adsorbance values, which were used to assess the adsorption performance.

Table 1: Table of Concentration vs Adsorbance

Concentration (mg/L)	Adsorbance
2	0.114
4	0.171
6	0.224
8	0.287
10	0.345



Graph of Concentration vs Adsorbance

This data was further analysed using UV-Vis spectroscopy at a wavelength of 498 nm to determine residual dye concentrations post-adsorption.

3.2 Optimization of Adsorption Parameters Using Central Composite Design (CCD)

The CCD approach within the Design Expert software facilitated the evaluation of optimal agitation speeds and contact times. The statistical analysis confirmed that both factors significantly influenced adsorption efficiency and capacity.

Table **2**: Adsorption Capacity and Removal Efficiency for Various Experimental Runs

Run	Agitation (rpm)	Time (min)	Adsorption Capacity	Removal Efficiency
1	180	60	0.760554	76.0554
2	160	60	0.642907	64.2907
3	140	60	0.646367	64.6367
4	180	45	0.649827	64.9827
5	160	45	0.514879	51.4879
6	140	45	0.570242	57.0242
7	180	30	0.504498	50.4498
8	160	30	0.428374	42.8374
9	160	45	0.52872	52.872
10	140	30	0.449135	44.9135

The highest adsorption capacity and removal efficiency were observed at an agitation speed of 180 rpm and a contact time of 60 minutes, with values of 0.76 mg/g and 76.05%, respectively.

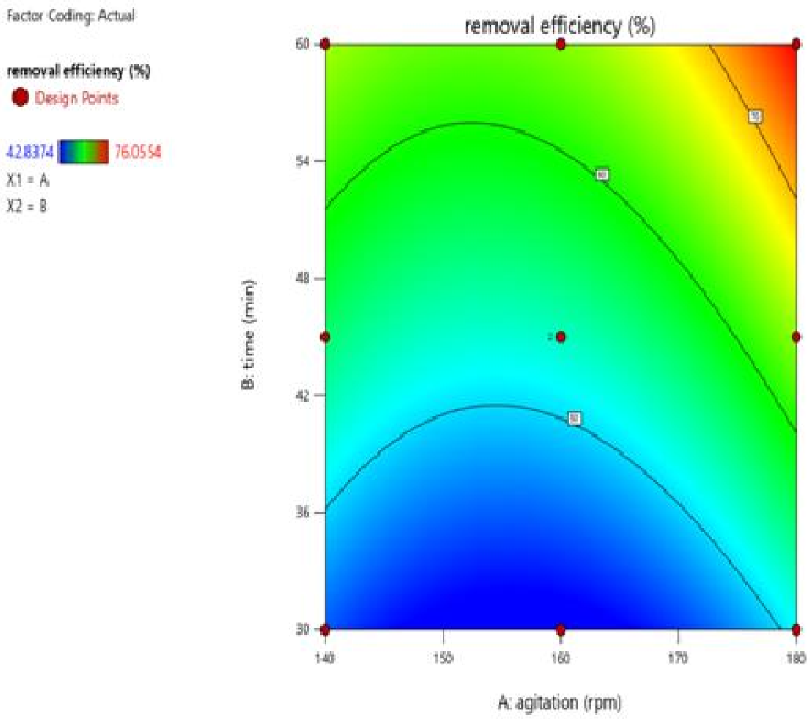


Figure 1: Contour Plot of Removal Efficiency as a Function of Agitation Speed and Contact Time

Figure 1 illustrates the impact of agitation speed and contact time on removal efficiency, showing that optimal values are achieved at higher speeds and longer contact times.

3.2.1 Effect of Contact Time, Adsorbent Dosage, and Agitation Speed

(i) **Contact Time**: Adsorption capacity increased with longer contact time, peaking at 60 minutes, beyond which the adsorption reached equilibrium.
(ii) **Agitation Speed**: Higher speeds enhanced dye molecule diffusion, leading to higher removal efficiency, though excessively high speeds could lead to dye desorption.
(iii) **Adsorbent Dosage**: Increasing dosage improved removal efficiency but had diminishing returns beyond optimal levels.

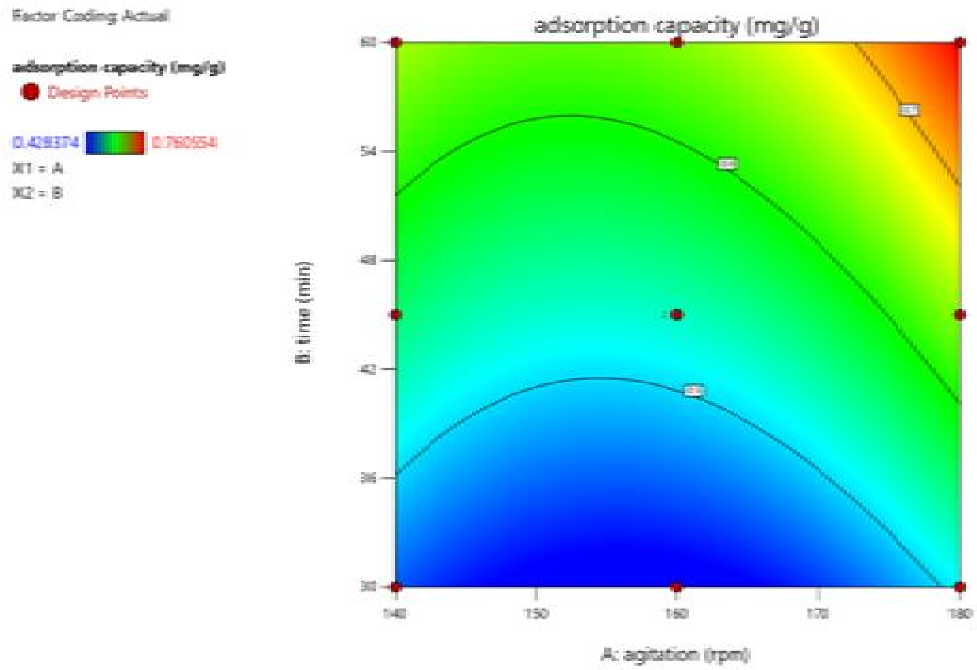


Figure 2: Contour Plot of Adsorption Capacity as a Function of Agitation Speed and Contact Time

Figure 2 illustrates the effects of varying agitation speeds and contact times on adsorption capacity showing maximum adsorption at higher speeds and longer times.

Conclusion

This study demonstrates the effectiveness of corncob-derived cellulose as a sustainable and cost-effective adsorbent for the removal of Congo red dye from wastewater. Optimal conditions of 180 rpm agitation speed and 60 minutes contact time yielded a maximum adsorption capacity of 0.76 mg/g and a removal efficiency of 76.05%. The adsorption kinetics followed a pseudo-second-order model, suggesting that chemisorption is the dominant adsorption mechanism.

The results highlight the potential of agricultural by products, such as corncob, as eco-friendly alternatives to conventional adsorbents for treating dye-laden industrial wastewater. By repurposing corncob waste, this study offers an affordable solution for textile and other dye-intensive industries, contributing to cleaner production practices. Future research could focus on regeneration and reuse of corncob cellulose and explore its application for other pollutants, expanding its utility in sustainable wastewater treatment.

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Design of an Automated Crop Monitoring System

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ABSTRACT

As the need for efficient and sustainable agricultural practices increases, integrating Internet of Things (IoT) technologies into farming have become crucial. The increasing global demand for food, coupled with resource scarcity and environmental concerns, has necessitated the adoption of advanced farming technologies. Smart agricultural systems, powered by the Internet of Things (IoT), provide an efficient means to enhance crop yield, improve resource utilization, and reduce manual labor. This paper outlines the design and development of an automated crop monitoring system utilizing the ESP8266 microcontroller as the microcontroller and sensors for control and automation. The system continuously monitors environmental factors, including temperature, humidity, and soil moisture through a series of sensors. Automating processes such as irrigation helps enhance both crop yield and the efficient use of resources. Experimental data supports the system's ability to facilitate real-time monitoring and execute automatic control actions, contributing to advancements in smart farming techniques. As agriculture faces mounting pressures from climate change and an ever-growing population, the role of technology in ensuring food security cannot be overstated. The implementation of IoT in agricultural practices not only streamlines farming operations but also promotes sustainability by minimizing waste and optimizing resource management. This automated crop monitoring system serves as a model for how innovative technologies can be effectively deployed in the agricultural sector. By gathering and evaluating real-time data, farmers are equipped to make well-informed choices, resulting in stronger and more adaptable agricultural methods. Furthermore, the insights gained from this research could inspire future developments in smart agriculture, paving the way for scalable solutions that address both current and emerging challenges in food production.

Keywords: *Cloud Platform: Arduino Cloud, Sensors: DHT11, Soil sensor, BH1750, Rain detector Sensor, Controller: ESP8266*

Introduction

The agriculture sector faces significant challenges due to increasing population pressures, climate change, and limited natural resources. Ensuring the efficiency and sustainability of farming operations has thus become critical. Smart farming technologies, particularly those involving IoT, offer promising solutions by enabling real-time monitoring and control of crop conditions. Agriculture is a fundamental pillar of Nigeria's economy, providing employment for a large segment of the population and playing a key role in the nation's GDP. However, traditional farming practices are often inefficient, leading to wasted resources, suboptimal crop yields, and increased labor costs. Additionally, climate variability and unpredictable weather patterns further complicate farming operations, putting pressure on farmers to adopt more sustainable and efficient agricultural practices.

In recent years, the integration of IoT technology into farming, commonly referred to as smart agriculture, has emerged as a viable solution to these challenges. By enabling real-time monitoring and automation of farming processes, IoT-based systems help farmers make data-driven decisions, improve crop management, and optimize the use of resources such as water and energy. These technologies are particularly relevant in Nigeria, where unpredictable rainfall and limited access to irrigation infrastructure pose significant obstacles to food production. The Automatic Crop Monitoring System discussed in this paper uses the ESP8266 microcontroller as the central hub, integrating environmental sensors and a cloud platform to monitor and manage critical crop growth factors. The system autonomously adjusts irrigation according to live soil moisture readings and other environmental factors, ensuring crops receive the ideal amount of water while conserving resources. This paper focuses on developing an automated crop monitoring system powered by the ESP8266 microcontroller.

The system collects and processes environmental data, automating key farming tasks such as irrigation, with a goal of improving crop production and reducing manual intervention. The integration of IoT in farming helps optimize resource use, contributing to sustainable agriculture. In addition to improving resource efficiency, IoT-based agriculture systems contribute to better risk management and decision-making in farming. By providing farmers with real-time data on weather conditions, soil health, and crop growth, these systems enable proactive responses to changing conditions. A drop in temperature or unexpected rainfall is detected, farmers will be alerted to automatically adjust irrigation schedules to prevent crop damage.

This degree of automation not only decreases reliance on manual labor but also strengthens crop resilience to climate fluctuations, leading to more stable yields. Furthermore, IoT systems can store and analyze historical data, helping farmers identify trends and optimize practices for future planting cycles. In the context of Nigerian agriculture, these capabilities are essential for adapting to climate challenges, securing food production, and supporting the livelihoods of farmers. This establishes IoT as an influential means of revolutionizing traditional agriculture, fostering a more sustainable and resilient sector

Literature Review

The integration of IoT into agriculture, often referred to as smart farming, has garnered considerable attention over the past decade due to its potential to improve agricultural productivity, conserve resources, and reduce labor. Several research studies have explored different IoT-based solutions for automating crop monitoring and irrigation systems. The application of Internet of Things (IoT) technologies in agriculture has gained significant attention in recent years due to its potential to improve productivity, reduce resource waste, and enhance sustainability. Various researchers have proposed solutions that integrate IoT devices, such as sensors and microcontrollers, to automate agricultural monitoring and irrigation systems.

IoT in Agriculture for Precision Farming

IoT-based precision farming systems have been designed to address specific environmental challenges, such as water scarcity and soil degradation. For example, the work of Abbas et al. (2021**)** focuses on a low-cost smart irrigation system using Arduino and soil moisture sensors. The system automates irrigation by controlling water pumps based on real-time soil moisture data, resulting in improved water usage efficiency. However, the system relies on a basic cloud platform with limited data analytics capabilities, which restricts the farmer's ability to predict future irrigation needs based on historical data-Integrated Smart Farming Systems

Cloud computing has also been a significant advancement in smart farming. In their study, Patil et al. (2020) the system relies on a basic cloud platform with limited data analytics capabilities, which restricts the farmer's ability to predict future irrigation needs based on historical data. Their system utilized an Arduino microcontroller and wireless sensor networks to gather environmental data and transmit it to a cloud platform for real-time monitoring. While effective, the system did not incorporate automated control mechanisms such as irrigation or ventilation, leaving the responsibility for decision-making solely on the user.

IoT-Based Smart Agriculture Systems

Numerous studies have concentrated on creating IoT-driven solutions for real-time crop monitoring and irrigation automation. For instance, Zhang et al. (2020) proposed a smart farming system utilizing a network of sensors to monitor environmental parameters such as temperature, humidity, and soil moisture, controlled via a cloud-based platform. This system employed a Raspberry Pi as a central controller and communicated with a mobile application for remote access. While this system demonstrated the efficiency of IoT in optimizing irrigation schedules, it required significant computational resources, making it less accessible for small-scale farmers. A prominent use of IoT in agriculture is the deployment of automated irrigation systems. Kumar et al. (2020) proposed an IoT-based automated irrigation system using ESP8266, soil moisture sensors, and cloud storage. The system could monitor the moisture levels and control the water pumps automatically when moisture levels were low. Their system showed significant improvements in water usage. However, it lacked the ability to regulate other environmental factors like temperature and light

Soil Moisture-Based Automated Irrigation

The integration of soil moisture sensors into irrigation systems has been explored in multiple studies. Gutiérrez et al. (2018) developed a system that utilizes a combination of soil moisture and weather data to automate irrigation decisions. Their system was implemented using Arduino, which reads moisture levels from the soil and employs a simple thresholding method to control irrigation. However, this system lacked cloud integration, limiting its scalability and ability to provide remote monitoring and control.

ESP32-Based IoT Systems

The ESP8266 microcontroller has been widely adopted in IoT systems due to its low cost and built-in Wi-Fi connectivity. For example, Kumar et al. (2019) implemented an IoT-based greenhouse monitoring system using ESP8266 to track temperature, humidity, and soil moisture levels. Data was transmitted to the cloud using Firebase, allowing farmers to monitor conditions and adjust irrigation through a web interface. While this system proved effective in reducing water consumption and optimizing greenhouse conditions, it was primarily designed for small-scale operations.

Cloud-Based Agriculture Monitoring

Cloud platforms, such as Thing-Speak and Arduino Cloud, have become essential components of IoT agriculture systems. Research by Malik et al. (2021) utilized Thing-Speak to collect and analyze data from sensors deployed on farms, visualized through a web interface. The use of cloud platforms enabled farmers to monitor environmental conditions remotely and adjust irrigation settings in real time based on sensor data. However, the system faced challenges regarding network connectivity and data latency in rural areas, which limited its effectiveness.

IoT for Small-Scale Farming in Developing Countries

IoT adoption in small-scale farming, particularly in developing countries, has been slower due to infrastructure limitations and cost concerns. To address this issue, Sharma et al. (2020) developed a low-cost automated irrigation system using ESP8266 and Blynk for real-time monitoring of soil moisture. This system was designed for smallholder farmers in rural India, where access to advanced farming tools is limited. The research demonstrated that IoT solutions could be tailored to meet the specific needs of farmers in resource-constrained environments. This approach closely aligns with the goals of the proposed system for Nigerian agriculture, aiming to offer an affordable, scalable solution for crop monitoring

Proposed Solution

Building on the limitations of these systems, our approach integrates the ESP8266 microcontroller equipped with various environmental sensors to monitor soil moisture, temperature, humidity, and light intensity. By transmitting data to the Arduino IoT Cloud, we provide real-time monitoring and remote-control capabilities, enabling farmers to automate irrigation based on real-time environmental data. The modular design of this system enables easy scalability and the integration of additional sensors or control systems, offering a flexible solution for both small and large-scale farming operations.

METHODOLOGY

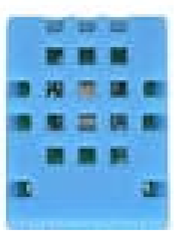
System Design

The proposed system uses a modular design, where each functional block operates independently and is integrated with the ESP8266 microcontroller. The key components of the system include the ESP8266, environmental sensors, a wireless communication module, actuators for irrigation, and a cloud platform for data visualization and control.

Hardware Components

ESP8266 Microcontroller: The ESP8266 serves as the core processing unit, responsible for collecting sensor data, executing control algorithms, and communicating with the cloud platform. It was selected for its integrated Wi-Fi capability, low power consumption, and suitability for IoT applications.

DHT11 Temperature and Humidity Sensor: This sensor monitors the ambient temperature and humidity around the crops. It helps regulate irrigation based on weather conditions, ensuring that water is not wasted during periods of high humidity or rainfall.



Soil Moisture Sensor: The soil moisture sensor measures the volumetric water content in the soil. It is critical for determining when crops require irrigation. The system is configured to activate the water pump when the soil moisture level drops below a predefined threshold, ensuring that crops receive adequate water without over-irrigation.

BH1750 Light Intensity Sensor: This sensor tracks the light intensity in the crop field, which is crucial for photosynthesis. By monitoring light levels, the system can adjust irrigation schedules to coincide with periods of high sunlight, when plants require more water.

Actuators: The system uses water pump as actuators. These devices are controlled by the ESP8266 based on real-time sensor data to manage irrigation and air circulation around the crops.

Communication and Cloud Integration

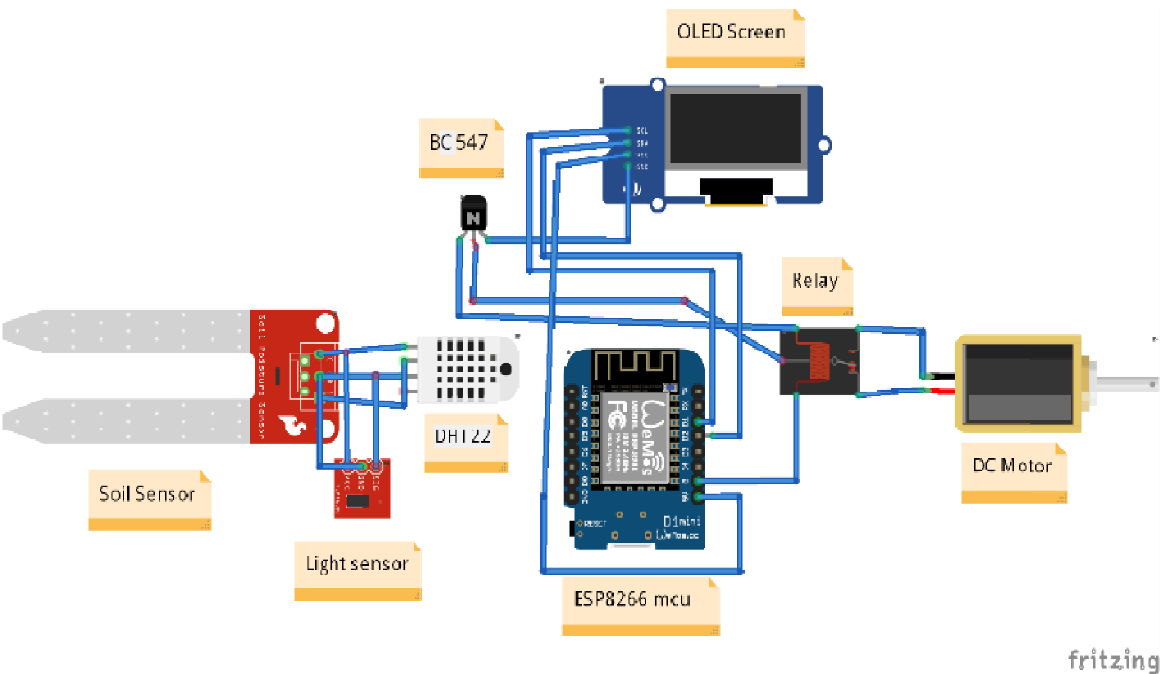
Data collected by the ESP8266 from the environmental sensors is transmitted to the Arduino IoT Cloud. The cloud platform provides a user-friendly interface for farmers to monitor real-time environmental data from their mobile devices or computers. Through the platform, users can visualize data trends, receive notifications when environmental conditions deviate from set parameters, and manually control the irrigation system if needed. The cloud platform also allows for remote access, enabling farmers to manage their crops from any location. This functionality is particularly beneficial for farmers with large plots of land or those managing multiple farms.

Modular Design Concept

The system's modular design ensures that each component operates independently while being seamlessly integrated into the overall system. For instance, the sensors continuously collect data, which is then processed by the ESP8266. Depending on the sensor readings, the system automatically adjusts irrigation and environmental controls without human intervention. The modularity of the design allows for easy expansion, enabling additional sensors or actuators to be added as needed.

System Architecture and Implementation

The architecture of the system centers on the ESP8266 microcontroller, which manages data collection, processing, and communication. A network of sensors and wireless modules supports the ESP8266, allowing for efficient environmental monitoring and remote system control. This smart farming setup includes the DHT11 sensor for temperature and humidity, a soil moisture sensor for soil water content, and the BH1750 sensor for light intensity.

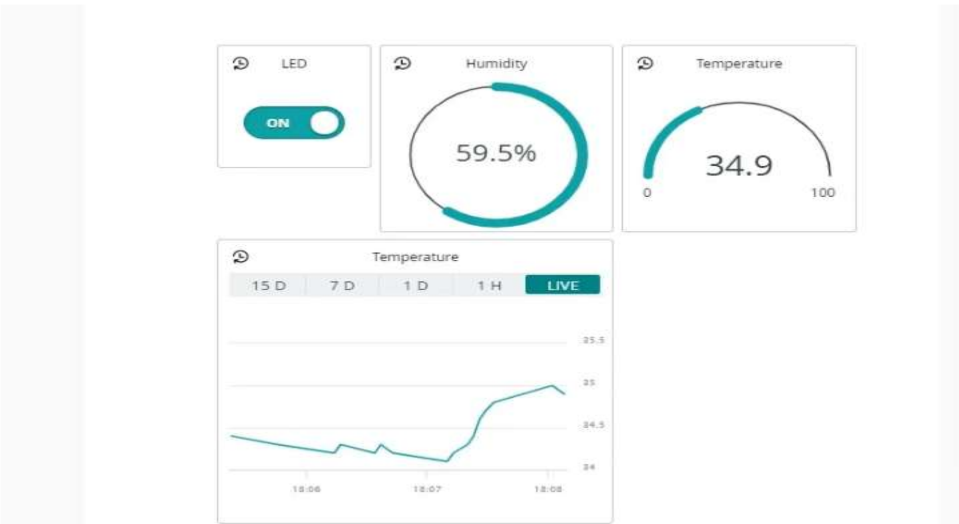


Data Collection

The ESP8266 microcontroller continuously receives real-time data from the various sensors. The DHT11 provides temperature and humidity information, enabling the system to assess weather conditions and potential crop stress. The soil moisture sensor monitors the water content in the soil, ensuring that crops receive the necessary hydration. Meanwhile, the BH1750 light sensor collects data on light intensity, which is vital for understanding and responding to the photosynthetic needs of the plants. This setup allows for comprehensive environmental tracking to optimize crop growth.

Communication and Cloud Integration

Once the ESP8266 collects sensor data, it transmits the information to the Arduino IoT Cloud platform via its built-in Wi-Fi module. This cloud platform stores and visualizes data in real time, allowing farmers to remotely monitor environmental conditions and control the irrigation system using a web interface or mobile app. If adjustments to the irrigation thresholds are needed, they can be made remotely, providing flexibility and control.



Automated Irrigation System

The system includes an automated irrigation feature that triggers water pumps based on soil moisture thresholds. When the soil moisture falls below a preset level, such as 30%, the ESP8266 activates the pumps through connected relays or other actuators to water the crops. This mechanism helps prevent under-watering and reduces labor.

Power Management and Sustainability

To support remote and potentially off-grid locations, the system is designed to operate on sustainable power sources. Solar panels are used to power up the system, storing energy in a rechargeable battery that can maintain system function even in low-light conditions. This power setup minimizes dependency on the grid and contributes to a sustainable agricultural solution, reducing the carbon footprint.

RESULTS

The system was tested on a small-scale farm in Nigeria over a period of four weeks. The primary goal of the experiment was to assess the system's ability to monitor environmental conditions and automate irrigation based on real-time data.

Data Monitoring

Throughout the testing period, the system monitored temperature, humidity, soil moisture, and light intensity. The following table shows the average sensor readings and actions taken by the system.

	Parameter	Average Value	Threshold	Action Taken
1	Temperature (°C)	28°C	N/A	None
2	Humidity (%)	65%	N/A	None
3	Soil Moisture (%)	26%	<30%	Irrigation
4	Light Intensity (lx)	4200 lx	N/A	None

The system successfully triggered irrigation when the soil moisture levels dropped below 30%. Additionally, the cloud platform provided real-time updates and notifications, allowing the farm manager to monitor the farm remotely.

Water Usage Efficiency

The system improved water usage efficiency by automating irrigation based on soil moisture levels. This reduced water waste and ensured that crops were irrigated only when necessary. Over the testing period, water consumption was reduced by 25%, demonstrating the system's effectiveness in conserving resources.

Conclusions

The design and development of an automated crop monitoring system, utilizing IoT technology and powered by the ESP8266 microcontroller, represent a promising solution for addressing the challenges facing modern agriculture. This study successfully integrated various environmental sensors, including temperature, humidity, soil moisture, and light intensity sensors, with an IoT-enabled cloud platform to monitor and manage critical crop growth factors in real time. By automating irrigation based on real-time data, this system has demonstrated the potential to improve water efficiency, reduce manual labor, and ultimately enhance crop yield. The results obtained from this system indicate that the integration of IoT into agricultural practices can significantly benefit resource-constrained environments, such as those in developing countries. In Nigeria, where rainfall patterns are unpredictable, and irrigation resources are limited, this system offers a scalable, efficient, and cost-effective approach to crop monitoring and resource management. By leveraging cloud technology and IoT, the system provides farmers with actionable insights, enabling data-driven decisions that contribute to sustainable farming practices.

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Assessing the Efficacy of Crumb Rubber as a Filler in Asphaltic Concrete

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Abstract

Roadway construction plays a fundamental role in the development and connectivity of societies across the globe. Asphaltic concrete stands as the predominant material employed in this process due to its versatility, and ease of construction. However, Warm Mix Asphaltic Concrete (WMA) has performance issues which necessitate the need for its improvement. In response to these issues, various asphalt modification techniques have been explored, with Crumb Rubber (CR) emerging as a promising solution. This study evaluated the effectiveness of CR as a modifier in WMA concrete production. The WMA samples were produced using 60/70 penetration grade of bitumen with an additive (sasobit) which was added to the bitumen at 3.5 wt. % of the bitumen. The convention mineral filler was modified by incorporating CR which was varied at a proportion of 0 – 50 wt. % at 5% interval of the filler. The index properties of the bitumen, aggregates and filler were investigated. Marshall properties (stability, flow and Marshall quotient) were evaluated on the WMA concrete samples. Index properties of bitumen, aggregates and filler were found to satisfy the required specifications for a quality WMA concrete production. The results revealed an increase in the Marshall properties with increasing CR content. The study identified the optimum replacement level of CR at 20 wt. %, which resulted in the maximum stability, flow and Marshall quotient of 16.5 kN, 5.75 mm and 3.98 kN/mm, respectively. This study institute the potential of CR at 20 wt. % maximum to enhance properties of asphaltic concrete and stimulate sustainability.

Keywords: Asphaltic concrete, Crumb rubber, Marshall properties, Sasobit, Warm Mix Asphalt.

Introduction

Asphaltic concrete is made up of coarse aggregates, fine aggregates, mineral filler and bitumen. The qualities of the constituent materials determine the overall performance of an asphaltic concrete mix (Wong *et al.,* 2022). Bitumen is the binder of asphaltic concrete, and the primary source is petroleum. In a bid to produce asphaltic concrete that has a better performance, there is the need to develop low-cost, environmentally friendly, and sustainable construction materials. This has necessitated Mashaan *et al.* (2014); Ajagbe *et al.* (2018); Akinleye *et al.* (2020a); (2020b); Wang *et al.,* (2020); Salami *et al.* (2023a); 2023b to carry out investigations on alternative materials that are capable of giving an enhanced performance. Roadway construction plays a fundamental role in the development and connectivity of societies across the globe. Thus, roadway is still the most common mode of transport for goods and services around the world (Hassan *et al.,* 2024). The most common type of road pavement structure is asphaltic concrete pavement (Bello and Atilola, 2015). Review of literature revealed that, performance of asphaltic concrete can be enhanced by using additives to suit pavement requirements (Choudhary *et al.*, 2018; Ajagbe *et al.,* 2018; Akinleye *et al.,* 2020a;2020b; Deng *et al.,* 2023; Salami *et al.,* 2023a). Hot Bitumen Mix (HBM) requires a high production temperature, which causes harmful gaseous emissions to be discharged. As a result of HBM's negative impacts, research into Warm Bitumen Mix (WBM) production which has a lower production temperature is necessary. To reach a maximum temperature drop of 30°C, the bitumen production temperature must be lowered by adding a special additive called sasobit. Sasobit is a South African indigenous substance. The manufacturer of Sasobit recommended adding 3% of the additive to a solution with a maximum temperature reduction aim of 30°C. In contrast, the current investigation used the 3.5% sasobit content recommended by (Salami *et al.,* 2023b). The rationale for its adoption is that (Salami *et al.,* 2023b) established the best mixture for Nigerian conditions by varying the percentage of organic component (sasobit) using locally accessible ingredients.

Crumb Rubber (CR), derived from recycled tyres, acts as a modifier that can improve the flexibility, crack resistance, and durability of asphalt pavements (Wang *et al.,* 2020). Each year, millions of scrap tyres are discarded, posing a significant environmental and logistical problem (Venudharan *et al.,* 2014; Manupati *et al.,* 2024). Stockpiling these tyres takes up valuable land, and improper disposal can lead to environmental hazards like fires and water pollution. The modification of asphaltic concrete with CR has a dual benefit: it addresses waste tyre disposal while possibly enhancing asphaltic concrete performance. The process of integrating CR into asphalt mixtures entails grinding old tyres into small particles ranging in size from coarse aggregates to fine powders. These particles are then mixed into the asphalt binder, either wet (with CR) or dry (including CR precisely to the aggregates). Furthermore, crumb rubber may improve rutting resistance by raising the asphalt's viscosity at high temperatures, making it more resistant to permanent deformation under traffic (Losa *et al.,* 2012). Wang *et al.* (2012) reported that CR modification can offer environmental advantages by utilizing recycled tire material, reducing the demand for virgin materials in asphaltic concrete production. As a result of lower production temperature of WMA, CR and WMA concrete are compactible which assist in mitigating concerns about potential harmful emissions that might occur when heating CR. The WMA technology enhance the interaction and dispersion of CR particles within the bitumen. This improved distribution can optimize the performance benefits of the CR (Azzam *et al.,* 2015; Heidari *et al.,* 2018).

Saeed *et al.* (2019) investigated the effect and influence of CR on the performance and characteristics of wet-applied asphalt pavements. The study established that the asphalt mixtures with varied percentages of CR mixed by the wet process were examined. The research demonstrated that CR greatly increases the rigidity modulus, rutting resistance, and pavement resistance to moisture damage. According to reports, adding 20% to 24% of CR modifiers to conventional asphaltic concrete mixtures produces the best results among various CR polymer percentages. As a result, Peng *et al.* (2023) reported that WMA incorporating CR improves a CR binder's softening point and penetration index, reduces its viscosity at high temperatures, increases binder stiffness, reduces traffic noise, lowers overall maintenance costs, and increases pavement life by increasing the fatigue resistance of the asphalt pavement. Furthermore, Ameri *et al.* (2023) examined the influence of CR on the fatigue performance of WMA concrete. The study made WMA concrete with 2.5% sasobit by weight of bitumen. Using a wet modification procedure, a CR of size passing a 0.150 mm filter was added to WMA concrete mixtures at 0, 10, 15, and 20% by weight of virgin bitumen. According to the study, the fatigue resistance of the WMA concrete improved.

This research explored the efficacy of CR as conventional filler modifier in WMA concrete production. The convention mineral filler was modified by incorporating CR which was varied at a proportion of 0 – 50 wt. % at 5% interval of the filler. The index properties of the bitumen, aggregates and filler were analyzed. Marshall properties (stability, flow and Marshall quotient) were evaluated on the WMA concrete samples. The outcomes of this research have the potential minimize waste from landfills, enhance sustainable development, and strengthen the efficacy of flexible pavement.

Materials and Method

The materials and method adopted during the research are spelt out in the subsequent sections.

2.1 Materials

Reynolds Construction Company Limited, based in Ilorin, Nigeria, supplied the bitumen. The bitumen was classed as 60/70 grade of penetration which is also referred to as VG-30 grade. Fig. 1a shows a bitumen sample. As shown in Fig. 1b, quarry dust obtained from quarry site within Osun State, Nigeria served as fine aggregate in this study. The quarry dust was sieved to ensure the maximum size does not exceed 4.75 mm before it was used, while the material used for mineral filler in the asphalt production was quarry dust sieved using a US sieve No. 200 (75 μm), crushed stone of size 10-20mm was used as the coarse aggregate in the production. Fig. 1c and 1d present the samples of mineral filler and coarse aggregate, respectively. The sasobit used was supplied by Reynolds Construction Coy Ltd., Ibadan, Nigeria. Fig. 1e displays a sasobit sample. The CR is shown in Fig. 1f. The 1 mm CR was sourced from Free Recycling Limited Nigeria located at Wire-land Cable, Apata, Ibadan, Nigeria. The waste tyre was shredded using an industrial machine into smaller sizes of 1 mm size.

2.2 Method

A total of 33 Asphaltic concrete samples were created, with each proportion having three trials. The percentage of CR applied ranges between 0 and 50% at 5% intervals. The asphaltic concrete samples were made from 1200 gramme of aggregates and filler. This study used the dry alteration process, which comprises combining the CR with standard mineral filler in a dry state. To produce WBM, 3.5% sasobit was added to the bitumen. Bitumen samples were subjected to a range of experimental tests, including ductility, specific gravity, penetration, viscosity, softening point, loss on heating, flash point, and fire point. The experimental protocols followed the ASTM D113-86, established standardized testing method. The data collected for this inquiry were analyzed using the Federal Ministry of Works' (FMW) road and bridge specifications, 2016.

Figure 1: Materials utilized during the research (a) Bitumen sample (b) Fine aggregate sample (c) Conventional mineral filler sample (d) Coarse aggregate sample (e) Sasobit sample (f) Crumb rubber sample

Results and Discussion

3.1.1 Index properties of bitumen

The purpose of these tests is to ensure that the bitumen used in producing the asphaltic concrete samples is within the required standard specifications. The index properties of bitumen are shown in Table 1. As shown in the Table, the penetration, softening point, ductility, flash point, fire point and specific gravity fall within the range specified by ASTM D113-86. (1986), ASTM D36-2002. (2002), ASTM D445-06. (2006), ASTM D5-06. (2006), ASTM D5-97. (1997), ASTM D70-03. (2003), and ASTM D92-02. (2002) and FMW (2016) standards.

Table 1: Index Properties of Bitumen

Standard	Penetration (mm)	Softening (?)	Ductility (cm)	Flash Point (?)	Fire point (?)	Specific Gravity
Results Obtained	68	55	99	246	288	0.98
FMW	60-70	48-56	≤100	Min.250	Min.250	1.01-1.06
ASTM	60-70	47-58	-	Min. 230	Min. 230	0.97-1.06
BIS	-	-	≥75	-	-	-
AI	-	>50	5-100	-	-	-

N.B.: FMW is Federal Ministry of Works (2016); ASTM is American Society of Testing and Materials, D5-97 for penetration, D36-95 for softening, and D2041 for specific gravity; BIS is Bureau of Indian Standards (1986); and AI is Asphalt Institute (1991).

3.1.2 Properties of aggregate

The index properties of aggregates are shown in Table 2. Results obtained for the aggregate crushing value, aggregate impact value, flakiness index, elongation index, and specific gravity fall within the range specified by standards for a quality concrete production. Table 2 reveals the aggregate crushing value was 15.07%, matching FMW (2016) and ASTM (2018) 30% maximums. According to Ajagbe *et al.* (2015); Ahmed *et al.* (2020) and Yu *et al.* (2022), aggregates below 30% contain crushing resistance components. This study shows crushing resistance with aggregate crushing values below 30%. Aggregate impact value is 16.35%. Rehman *et al.* (2020) reported that aggregates under 20% impact contain impact-resistant components. Thus, this sample's aggregate impact is below 20%, demonstrating impact resistance. This study's aggregate effect value is below FMW (2016) and ASTM (2018) maximums of 30, 45, and 30%. This study's asphalt mixture material passes the requirement. The flakiness index was 29.75%. This is below FMW (2016)'s 35% asphalt concrete limit. This study's flakiness index is below ASTM (2018) and BS (1992) maximums of 45 and 40%. So crushed rock flakiness index fulfils FMW (2016) and ASTM (2018). The aggregate utilized in this study's asphalt mixtures meets the requirement. The asphalt concrete elongation index is 28.96%, below FMW (2016) limit 35%. It also fulfils ASTM (2018)'s 45–50% limit. The specific gravities of coarse, fine, and mineral filler were 2.9, 2.7, and 1.8. The FMW (2016) and ASTM (2018) regulations limit material specific gravity to 3.0. All values are below 3.0. The aggregate utilized in this study's bitumen mixtures meets the requirements specified by various standards.

3.1.3 Properties of the CR-modified WMA concrete

Table 3 lists the parameters of mixes with 5% – 50% CR. This includes bulk specific gravity, volume of voids (Vv), voids in mineral aggregate (VMA), and bitumen-filled voids. Bulk specific gravity measures asphaltic concrete's density. The reported values are 2.03–2.18 g/cm^3. The CR percentage raises bulk specific gravity marginally. Higher bulk specific gravity suggests a denser mixture, which can increase durability and deformation resistance. Void volume is the space in asphaltic concrete that is not occupied by solid elements. The reported values are 4.51% – 8.52%. Stability and durability are improved by a more compact mixture with fewer air voids. The AI defined 3-5% voids, FMW 3 - 8%. The VMA represents the coarse and fine aggregates' area in asphalt. The reported values are 18.02% – 21.56%. Higher VMA values indicate better aggregate distribution and interlocking, improving stability and rutting resistance (Akinleye *et al.,* 2020a). Bitumen binder-filled void spaces in asphalt mixtures are called VFB. The reported values are 60.25% – 79.07%. A higher VFB implies more bitumen, which improves mixture binding and cohesiveness (Salami *et al.,* 2023a; 2023b). The FMW specified 65 - 82% gap filled with bitumen, while AI specified 65 - 80%.

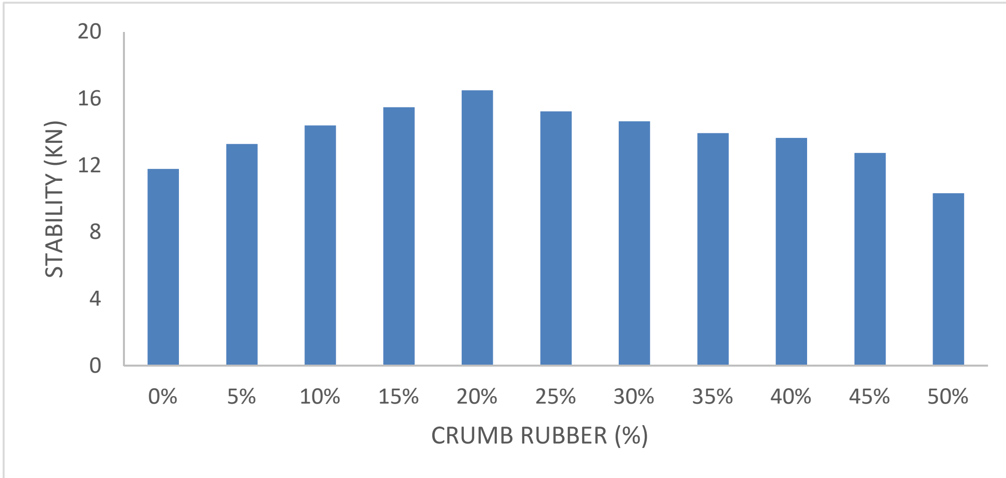
Table 2: Index Properties of Aggregates for Asphaltic Concrete Mixes

Tests	Results Obtained	FMW, 2016 Specification	ASTM, 2018 Specification	BS, 1992 Specification	Remarks
Aggregate Crushing value (CA)	15.07%	30% Maximum	30% Maximum	30% Maximum	Satisfactory
Aggregate Impact value (CA)	16.35%	30% Maximum	45% Maximum	30% Maximum	Satisfactory
Flakiness Index (CA)	29.75%	35% Maximum	45% Maximum	40% Maximum	Satisfactory
Elongation Index (CA)	28.96%	35% Maximum	45% Maximum	50% Maximum	Satisfactory
Specific Gravity (CA)	2.9	3 Maximum	3 Maximum	3 Maximum	Satisfactory
Specific Gravity (FA)	2.7	3 Maximum	3 Maximum	3 Maximum	Satisfactory
Specific Gravity (Filler)	1.8	3 Maximum	3 Maximum	3 Maximum	Satisfactory

N.B.: FMW is Federal Ministry of Works Specifications for Roads and Bridges, 2016; ASTM is American for Testing and Materials, 2018; BS is British Standard, 1992; CA is Coarse Aggregates; FA is Fine Aggregates; and N/A is Not Available.

Table 3: Properties of CR-Modified WMA Asphaltic Concrete

Crumb Rubber Percentage	Bulk Specific Gravity (g/cm^3)	Volume of the Void (Vv)	Void in Mineral Aggregate (VMA)	Void filled with Bitumen (VFB)	Stability (kN)	Flow (mm)	Marshall Quotient (kN/mm)
0	2.03	4.75	18.18	73.89	11.8	3.25	3.63
5	2.06	4.56	18.02	74.71	13.3	3.5	3.80
10	2.09	6.67	19.83	66.38	14.4	3.85	3.74
15	2.12	7.28	20.36	64.24	15.5	4.05	3.83
20	2.12	5.06	18.45	72.58	16.5	4.15	3.98
25	2.13	4.51	21.56	79.07	15.3	4.65	3.28
30	2.13	6.93	20.06	65.46	14.7	5.15	2.85
35	2.15	5.42	18.76	71.10	14.0	5.25	2.66
40	2.17	8.52	21.42	60.25	13.7	5.25	2.60
45	2.18	5.55	18.88	70.58	12.8	5.5	2.30
50	2.18	5.37	18.72	71.33	10.4	5.75	1.80



a. Marshall stability

The stability value is used to assess strength in resisting external loads. Kumar and Kumar (2023) recommended that the Marshall test be used to evaluate asphalt designs, specifically HMA. Fig. 2a clearly shows the stability results of 11 samples of CR asphalt mixes ranging from 0% (control) to 50% with a 5% gap. Stability evaluates the asphaltic concrete mixture's resistance to distortion under applied load. The stability values range between 10.4 kN and 16.5 kN. The stability increases as the crumb rubber content increases which is in tandem with the findings of Ameri *et al.,* 2023. Sample 5, which included 20% crumb rubber tyre, achieved the greatest stability value. Higher stability ratings indicate increased load-bearing capability and resistance to rutting and cracking (Mashaan *et al.,* 2014). All CR mixes' stability met the FMW, 2016 (≥3.5) standard.

b. Marshall flow

Table 1, like the Marshall stability test findings, shows the Marshall flow values of all combinations that are within the range of values permitted by AS2150-2005 Standards (2005). Flow measures the deformation of an asphalt mixture under a given load. The reported flow values range from 3.25 to 5.75 mm, as shown in Figure 2b. Lower flow values indicate less deformation and increased resistance to rutting (Ameri *et al.,* 2023). The flow for all crumb rubber tyre mixtures met the criteria of 2 - 6 mm flow specified in the FMW (2016).

c. Marshall Quotient

The Marshall quotient is a ratio of stability to flow that indicates the overall performance of an asphaltic concrete mixture. Figure 3 shows the reported Marshall quotient values, which range from 1.80 to 3.98 kN/mm. Higher Marshall quotient values suggest increased resistance to deformation and overall performance (Choudhary *et al.,* 2020). The Marshall properties of the mixtures show that the addition of CR changed the qualities of the asphaltic concrete. The differences in bulk specific gravity (GM), volume of voids, VMA, VFB, stability, flow, and Marshall quotient indicate that the crumb rubber tyre component influences the compactness, workability, and performance of the asphalt mix.

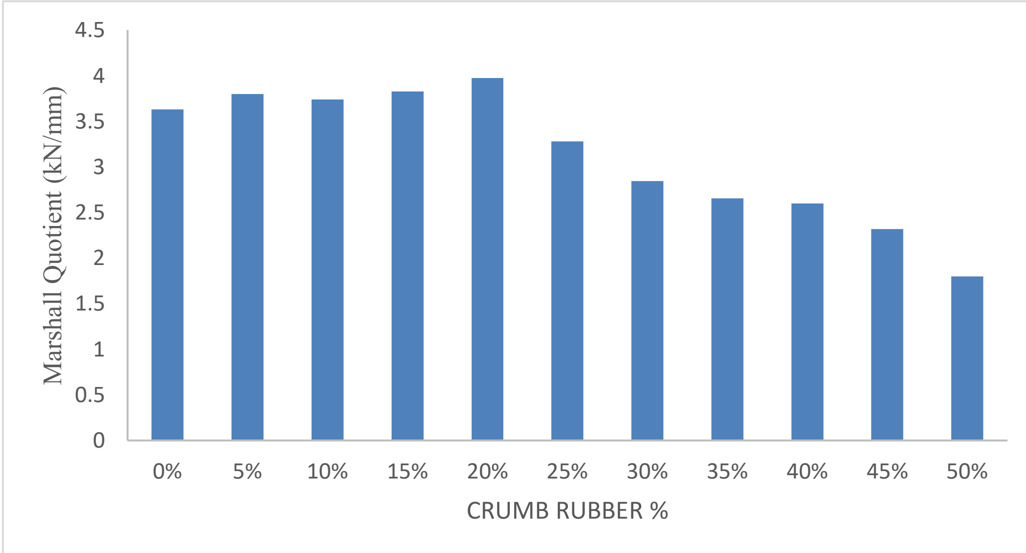
(a) 

Figure 2a: Stability of CR-modified WMA concrete mixtures

b: Flow of CR-modified WMA concrete mixtures

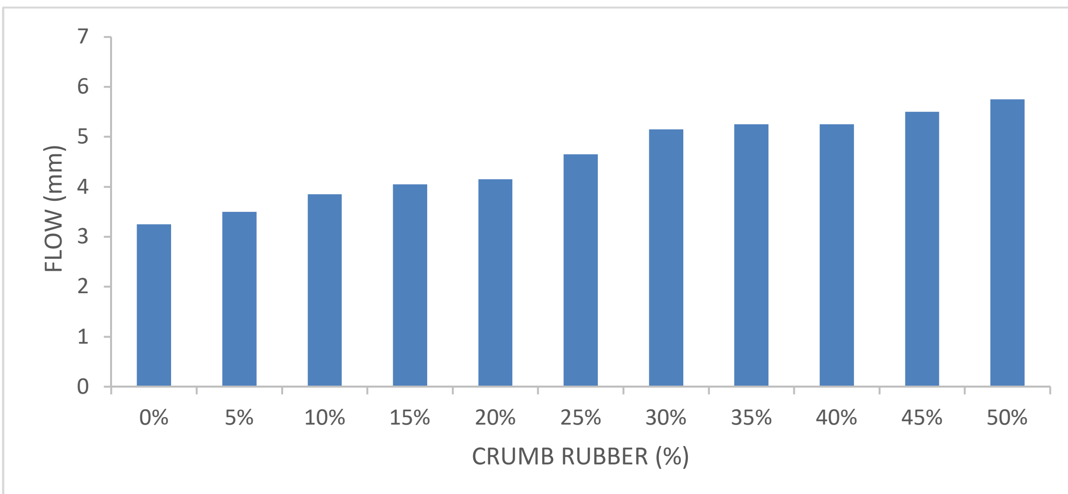


Figure 3: Marshall Quotient of CR-modified WMA concrete mixtures

Conclusion

This study evaluated the efficacy of CR as a mineral filler in WMA concrete production with quarry dust as a conventional filler. The index properties of bitumen, aggregate and mineral filler satisfy the required specifications which indicates their suitability for a quality asphaltic concrete production. Investigation from this study revealed an increase in the Marshall properties (stability, flow and Marshall quotient) with increasing CR content. The study identified the optimum replacement level of CR at 20 wt. %, which resulted in the maximum stability, flow and Marshall quotient of 16.5 kN, 5.75 mm and 3.98 kN/mm, respectively. This finding is significant as it demonstrates that exploring CR at 20 wt. % optimal substitution improves the WMA concrete and stimulate environmental sustainability. Since the Marshall quotient values increase as the CR content increases, this implies that the CR-modified WMA concrete has an improved resistance to rutting and deformation.

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Factors Influencing the Level of Awareness of the Built Environment Professionals on Climate Change Effects in Lagos State, Nigeria

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Abstract

The purpose of this paper is to examine factors influencing the level of awareness of the built environment professionals on climate change effects in Lagos state. Data were obtained from 163 built environment professionals in the study area. A stratified technique was employed in the selection of built environment professionals for survey because professionals are stratified according to their designation. D*escriptive and inferential statistical analysis were employed to analyze the data. The paper has one major finding: it examined the factors influencing the level of awareness of the built environment professionals on climate change effects in the study area. The study focused on registered built environment professionals in Lagos state and this limited the generalization of the findings. Moreover, there was also limited availability of literature with respect to factors influencing the level of awareness of the built environment professionals on climate change effects. The result suggests the need to improve the awareness of built environment professionals on climate change through seminars, workshops and continuous professional development programme (CPD). There are many studies that investigate factors influencing the level of awareness of climate change effects from different sectors, however, this is the first study to the authors' knowledge that examines the factors influencing the level of awareness of the built environment professionals on climate change effects in Lagos state, Nigeria.*

Keywords: Factors, Level of awareness, Built Environment Professionals, Climate Change, Nigeria

Introduction

The built environment touches all aspects of our lives encompassing the buildings we live in, the distribution system that provides us with water and electricity, and the roads, bridges, and transportation systems we use to get from place to place. Built environment has greatly contributed to climate change through construction processes and production of construction materials such as cement and steel (Pomponi & Moncaster, 2016). The activities in the built environment destroys natural habitat and ecosystem, consume excessive amount of water and energy, and produces excessive wastes. These fundamentally contribute to carbon emissions, harm nature and contribute to climate change, which results into ugly consequences (Opoku, 2019). Generally, climate change awareness is influenced by certain number of factors including the geographical location, winds and ocean currents, humidity, temperature, topography, solar radiation, latitude & elevation and the interactions of various air masses (Putra et al., 2022).

The ongoing campaign and efforts to reduce the effects of climate change, a recent report by International Energy Agency (IEA) (2023) showed that carbon dioxide emissions increase by 0.9% or 321 Mt in 2022 and reach a new all-time high of 36.8 Gt. This among others is caused by energy combustion, industrial production processes, cooling and heating demands, transport, electricity, steel and cement production. Climate change increasingly threatens the social, economic and natural systems, thereby hindering progress towards achieving sustainable development (Fuso Nerini et al., 2019). Climate change describes gradual changes in all the interconnected weather elements on our planet. It describes the significant variation in the average global weather condition and it is a situation that explains the patterns of how weather condition is warm, wet, or dry over several decades or longer (Hulme, 2015).

Profile of the Built Environment Professionals

The construction and consulting organization require professionals that are environmentally sensitive to sustain the built environment for future generation. This is necessary due to the rising environmental degradation from various construction activities. There are several studies on causes and effects of climate change likewise the mitigating measures to the effects of climate change (Schneider, 2019). However, there are death of literature on the profiles of built environment professionals (BEP), particularly about the professionals that are aware of climate change. Adenuga et al. (2022) opined that the profiles of the respondents are to provide an insight into the credibility of the responses gathered. The respondents with engineering, building technology, and quantity surveying backgrounds contributed more to the study, with 62.1%, 19.5%, and 10.3%, respectively. This imply that the participation of professions in the construction field is fit to express a reliable opinion that would afford the study comprehensive information sufficient to reach a conclusion as regards the phenomenon under discussion.

Factors Influencing the Level of Awareness of the Built Environment Professionals on Climate Change Effects

This section provides information on factors that influence people' awareness of climate change. Kuit and Waarts (2014) opined that education, experience, sex, age and membership of relevant professional bodies/organisations are among the factors that influence the level of awareness of climate change. Similarly, Buckland and Campbell (2021) identified gender, age, access to extension service, participation in groups/organizations, climate change perceptions as parts of the factors that influence awareness of climate change. According to Oduniyi (2016), factors influencing climate change awareness were identified as occupation, age and education. In another study, Zhu (2021) found that education level, experience access to modern technologies are among the factors that influence awareness of climate change. Helm et al. (2018) also identified environmental concern, social-demographic characteristics and financial self-efficacy as factors influencing the level of awareness of climate change.

Furthermore, Ung et al. (2015) found that self-efficacy also applied to a financial management context, referring to the perceived ability to accomplish a financial goal. Thus, it can be expected that, as the household's financial self-efficacy increases, so does their confidence to execute measures related to climate change, despite their objective level of financial resources.

In Nigeria, climate change is influenced by its geographical location, winds and ocean currents, humidity, temperature, topography, solar radiation, latitude & elevation and the interactions of various air masses (Putra et al., 2022). According to Thaker et al. (2019), age, education level, urban or rural location, income, access to communications, experiencing temperature changes and engagement on environmental matters were identified as factors that are linked to the awareness of climate change among the built environment professionals. In another research work, Lee et al. (2015) established that socio-demographic characteristics, educational attainment, understanding the anthropogenic cause of climate change are the strongest predictors of climate change awareness. Table 1 provide information on factors influencing the level of awareness of built environment professionals on climate change effects.

Method

This paper examines factors influencing the level of awareness of built environment professionals on climate change effects in Lagos state, the whole study employed a quantitative research method in data collection and analysis. The study was conducted on built environment professionals who are registered with Lagos state government. Among the professionals are architects, quantity surveyors, builders, estate surveyors and valuers, land surveyors, urban and regional planners and engineers in Lagos State. The questionnaire survey was structured into two (2) sections. Section A explored the profile of the built environment and this include professional designation, professional membership, professional registration, highest academic qualification, years of work experience, nature of business organization, business operations/specializations, years of establishment, size of employees, annual revenues and financial worth of assets, section B explored the factors influencing the level of awareness of built environment professionals on climate change effects in

Table 1: Factors Influencing the Level of Awareness of the Built Environment Professionals on Climate Change Effects

No.	Factors	Sources/Authors
1	Socio demographic factors like sex, age, race, education and income	Zhu (2021); Oduniyi (2016); Kuit & Waarts (2014);
2	Membership of relevant professional bodies/organisations	Buckland & Campbell (2021); Kuit & Waarts (2014);
3	Access to modern technologies	Zhu (2021)
4	Perception of change in local temperature	Zhu (2021)
5	Participation in groups or associations	Buckland & Campbell (2021)
6	Access to information on climate	Oduniyi (2016)
7	Type of occupation	Oduniyi (2016)
8	Concerns for environment	Helm *et al.* (2018)
9	Personal financial worth or value	Helm *et al.* (2018)
10	Geographical location	Putra *et al.* (2022)
11	Access to information through media	Thaker*et al.*(2019)
12	Engagement on environmental matters	Thaker*et al.*(2019)
13	Experiencing temperature changes	Thaker*et al.*(2019)
14	Educational attainment	Lee *et al.* (2015)
15	Understanding the anthropogenic cause of climate change	Lee *et al.* (2015)
16	Winds & ocean currents	Putra *et al.* (2022)
17	Humidity	Putra *et al.* (2022)
18	Temperature	Putra *et al.* (2022)
19	Topography	Putra *et al.* (2022)
20	Solar radiation	Putra *et al.* (2022)
21	Latitude & elevation	Putra *et al.* (2022)
22	Interactions of various air masses	Putra *et al.* (2022)

Lagos state. Data were obtained through well-structured questionnaires. A total of one hundred and sixty-three (163) questionnaires were administered to built environment professionals in Lagos State,

Nigeria. A stratified random-sampling technique was employed in the selection of built environment professionals for survey because professionals are stratified according to their designation.
To develop the data collection instrument, a review of the literature was carried out to find studies on factors influencing the level of awareness of built environment professionals on climate change effects. A made up of factors influencing the level of awareness of built environment professionals on climate change effects was also constructed from the literature review. These formed the research constructs. The variables in the constructs were made up of 22 variables on factors influencing the level of awareness of built environment professionals on climate change effects. The research instrument (survey) focused on the factors influencing the level of awareness of built environment professionals on climate change effects.

To determine the sample frame for the qualitative strand of the research, a list of registered built environment professionals was obtained from the various professional bodies of the built environment in Lagos state. Data about factors influencing the level of awareness of built environment professionals on climate change effects were obtained from the professionals with the use of a structured questionnaire.

Data collected from the quantitative strand were analyzed using descriptive and inferential statistical methods. Examples of descriptive statistical tools in this study include charts, frequency distributions, means scores, and standard deviation, whereas inferential statistical tools include analysis of variance (ANOVA) and factor analysis. Through means scores, and standard deviation, factor analysis, factors influencing the level of awareness significance indices were developed and ranked to determine professionals perception of factors influencing the level of awareness of built environment professionals on climate change effects. The significance index of factors compares the differences in the opinions of the professionals. This was achieved through ANOVA, confidence level ($P<0.05$) were considered.

Data Analysis and Discussion

The data collected in the study were presented and analyzed under the following sub-heading:

Examination of factors influencing the level of awareness of BEPs on climate change

This study examined the factors influencing the level of awareness of built environment professionals on climate change effects in the study area. The factors influencing the level of awareness of built environment professionals were assessed and the result obtained is presented in the Table 2 The result showed the mean score, ranking and ANOVA of the 22 identified factors.

Result on Table 2 showed that the high ranked factor influencing the level of awareness on climate change by respondents who are architects are Perception of change in local temperature (MS= 3.24), Age (MS= 3.20), Temperature (MS= 3.16), income (MS= 3.16), understanding the anthropogenic cause of climate change (MS= 3.16), sex (MS= 3.16), gender (MS= 3.12), experiencing temperature changes (MS= 3.08), membership of relevant professional bodies (MS= 3.04), type of occupation (MS= 3.04) and participation in groups or association (MS= 3.00). Ranked low by the same category of respondents are access to modern technologies (MS= 2.92), personal financial worth or value (MS= 2.92), latitude and elevation (MS= 2.84), engagement on environmental matters (MS= 2.80), geographical location (MS= 2.76), solar radiation (MS= 2.76), level of education (MS= 2.76), interactions of various air masses (MS= 2.72), winds and ocean currents (MS= 2.68), concerns for environment (MS= 2.64), topography (MS= 2.64), access to information on climate (MS= 2.48) and humidity (MS= 2.32).

From the group of respondents who are builders, ranked high among the factors influencing the level of awareness are membership of relevant professional bodies (MS= 3.39), Age (MS= 3.39), personal financial worth or value (MS= 3.22), concerns for environment (MS= 3.17), income (MS= 3.11), access to information on climate (MS= 3.11), winds and ocean currents (MS= 3.11), latitude and elevation (MS= 3.11), interactions of various air masses (MS= 3.11), sex (MS= 3.11), gender (MS= 3.11), access to modern technologies (MS= 3.06), experiencing temperature changes (MS= 3.06), solar radiation (MS= 3.06), Temperature (MS= 3.00), Perception of change in local temperature (MS= 3.00) and humidity (MS= 3.00). Ranked low by this group of respondents are understanding the anthropogenic cause of climate change (MS= 2.94), topography (MS= 2.94), geographical location (MS= 2.94), participation in groups or association (MS= 2.83), type of occupation (MS= 2.83), engagement on environmental matters (MS= 2.78) and level of education (MS= 2.72).

Engineers' result shows that the high ranked factors are engagement on environmental matters (MS=3.43), latitude and elevation (MS= 3.35), Age (MS= 3.35), type of occupation (MS= 3.35), level of education (MS= 3.30), understanding the anthropogenic cause of climate change (MS= 3.30), membership of relevant professional bodies (MS= 3.30), access to modern technologies (MS= 3.22), interactions of various air masses (MS= 3.17), experiencing temperature changes (MS= 3.13), solar radiation (MS= 3.13), concerns for environment (MS= 3.04), income (MS= 3.00) and winds and ocean currents (MS= 3.00). Ranked low by this same group of respondents are temperature (MS= 2.96), Perception of change in local temperature (MS= 2.91), access to information on climate (MS= 2.83), sex (MS= 2.83), geographical location (MS= 2.83), humidity (MS= 2.83), gender (MS= 2.74), personal financial worth or value (MS= 2.70), participation in groups or association (MS= 2.65) and topography (MS= 2.94).

Table 2: Examination of Factors influencing the level of awareness of BEP on Climate Change effects

		Overall			ARCs		BLDRs		ENGRs		QSs		SURVs		ESVRs		TPLRs		ANOVA	
SN	Factors	M	SD	R	M	R	M	R	M	R	M	R	M	R	M	R	M	R	F	Sig.
1	Experiencing temperature changes	3.25	1.00	1	3.08	8	3.06	13	3.13	10	3.67	1	3.20	9	3.14	4	2.94	12	1.96	0.07
2	Access to modern technologies	3.23	1.08	2	2.92	12	3.06	12	3.22	8	3.47	3	3.60	3	3.14	3	3.19	5	0.98	0.44
3	Temperature	3.18	1.12	3	3.16	3	3.00	15	2.96	15	3.44	4	3.30	6	2.96	13	3.31	2	0.85	0.54
4	Age	3.17	0.89	4	3.20	2	3.39	2	3.35	3	3.02	19	3.50	4	3.11	7	2.94	13	0.96	0.45
5	Level of education	3.15	1.06	5	2.76	18	2.72	24	3.30	5	3.42	5	3.30	8	3.21	1	3.06	9	1.70	0.12
6	Understanding the anthropogenic cause of CC	3.12	0.99	6	3.16	5	2.94	18	3.30	6	3.16	14	2.80	18	3.07	10	3.13	7	0.42	0.86
7	Perception of change in local temperature	3.10	0.99	7	3.24	1	3.00	15	2.91	16	3.12	17	3.30	7	3.07	9	3.19	6	0.34	0.92
8	Engagement on environmental matters	3.09	1.09	8	2.80	15	2.78	23	3.43	1	3.47	2	2.70	20	2.93	14	2.94	11	2.20	**0.05**
9	Latitude & elevation	3.07	1.03	9	2.84	14	3.11	7	3.35	2	3.12	17	3.00	15	3.07	8	2.88	16	0.61	0.73
10	Participation in groups or associations	3.05	1.11	10	3.00	11	2.83	21	2.65	23	3.12	16	3.70	1	3.18	2	3.13	8	1.30	0.26
11	Solar radiation	3.04	1.12	11	2.76	17	3.06	13	3.13	11	3.26	7	2.60	22	2.89	16	3.25	3	0.98	0.44

12	Gender	3.04	0.93	12	3.12	7	3.11	11	2.74	21	2.88	22	3.00	15	3.11	6	3.56	1	1.56	0.16
13	Concerns for environment	3.01	1.07	13	2.64	21	3.17	4	3.04	12	3.26	7	3.00	12	2.93	15	2.81	18	1.06	0.39
14	Type of occupation	3.01	1.05	14	3.04	10	2.83	22	3.35	4	3.14	15	3.20	9	2.68	22	2.81	19	1.21	0.31
15	Interactions of various air masses	3.01	1.04	15	2.72	19	3.11	9	3.17	9	3.16	12	2.70	20	3.00	12	2.94	15	0.76	0.60
16	Membership of relevant Professional bodies	3.00	1.10	16	3.04	9	3.39	1	3.30	7	2.91	21	2.60	24	2.82	19	2.88	16	1.11	0.36
17	Access to information on climate	3.00	1.05	17	2.48	23	3.11	6	2.83	17	3.26	10	3.10	11	3.14	5	2.94	13	1.75	0.11
18	Personal financial worth or value	2.99	1.07	18	2.92	12	3.22	3	2.70	22	3.21	11	3.00	13	2.79	20	3.06	10	0.93	0.47
19	Income	2.96	1.11	19	3.16	4	3.11	5	3.00	13	2.77	23	2.90	17	2.79	21	3.25	3	0.71	0.64
20	Humidity	2.94	1.05	20	2.32	24	3.00	17	2.83	20	3.30	6	3.70	2	2.89	17	2.63	22	3.83	**0.00**
21	Winds & ocean currents	2.93	1.02	21	2.68	20	3.11	7	3.00	14	3.26	9	3.00	14	2.64	23	2.56	23	1.89	0.09
22	Geographical location	2.90	1.07	22	2.76	16	2.94	20	2.83	18	2.98	20	3.40	5	2.86	18	2.75	20	0.54	0.78
23	Topography	2.86	1.06	23	2.64	22	2.94	19	2.65	24	3.16	13	2.60	22	3.07	11	2.38	24	1.80	0.10
24	Sex	2.83	0.99	24	3.16	6	3.11	10	2.83	18	2.60	24	2.80	19	2.61	24	2.75	21	1.32	0.25

ARCs- Architects; BLDRs- Builders; ENGRs- Engineers; QSs- Quantity Surveyors; SURVs- Surveyors; ESVRs- Estate Surveyors and Valuers; TPLRs- Town Planners. M-Mean; SD- Standard Deviation; R- Ranking. Significant factors with p-value ≤ 0.05.

Ranked high by the group of respondents whose designation is Quantity surveyor are experiencing temperature changes (MS= 3.67), engagement on environmental matters (MS=3.47), access to modern technologies (MS= 3.47), Temperature (MS= 3.44), level of education (MS= 3.42), humidity (MS= 3.30), concerns for environment (MS= 3.26), solar radiation (MS= 3.26), winds and ocean currents (MS= 3.26), access to information on climate (MS= 3.26), personal financial worth or value (MS= 3.21), interactions of various air masses (MS= 3.16), topography (MS= 3.16), understanding the anthropogenic cause of climate change (MS= 3.16), type of occupation (MS= 3.14), participation in groups or association (MS= 3.12), latitude and elevation (MS= 3.12),Perception of change in local temperature (MS= 3.12) and Age (MS= 3.02). The low ranked factors are geographical location (MS= 2.98), membership of relevant professional bodies (MS= 2.91), gender (MS= 2.88), income (MS= 2.77) and sex (MS= 2.60).

From the perspective of the respondents that are Surveyors, result shows that participation in groups or association (MS= 3.70), humidity (MS= 3.70), access to modern technologies (MS= 3.60), Age (MS= 3.50), geographical location (MS= 3.40), Temperature (MS= 3.30), Perception of change in local temperature (MS= 3.30), level of education (MS= 3.30), type of occupation (MS= 3.20), experiencing temperature changes (MS= 3.20), access to information on climate (MS= 3.10), concerns for environment (MS= 3.00), personal financial worth or value (MS= 3.00), winds and ocean currents (MS= 3.00), latitude and elevation (MS= 3.00) and gender (MS= 3.00) are ranked high while income (MS= 2.90), understanding the anthropogenic cause of climate change (MS= 2.80), sex (MS= 2.80), engagement on environmental matters (MS=2.70), interactions of various air masses (MS= 2.70), topography (MS= 2.60), solar radiation (MS= 2.60) and membership of relevant professional bodies (MS= 2.60) are ranked low.

From the group of respondents who are Estate surveyors and valuers result shows that high ranked factors are level of education (MS= 3.21), participation in groups or association (MS= 3.18), access to modern technologies (MS= 3.14), experiencing temperature changes (MS= 3.14), access to information on climate (MS= 3.14), gender (MS= 3.11), Age (MS= 3.11), latitude and elevation (MS= 3.07), Perception of change in local temperature (MS= 3.07), understanding the anthropogenic cause of climate change (MS= 3.07), sex (MS= 2.80), topography (MS= 3.07) and interactions of various air masses (MS= 3.00). Ranked low by this group of respondents are temperature (MS= 2.96), engagement on environmental matters (MS=2.93), concerns for environment (MS= 2.93), solar radiation (MS= 2.89), humidity (MS= 2.89), geographical location (MS= 2.86), membership of relevant professional bodies (MS= 2.82), personal financial worth or value (MS= 2.79), income (MS= 2.79), type of occupation (MS= 2.68) and winds & ocean currents (MS= 2.64).

Town planners result shows that ranked high among the factors influencing the level of awareness are gender (MS= 3.56), Temperature (MS= 3.31), income (MS= 3.25), solar radiation (MS= 3.25), access to modern technologies (MS= 3.19), Perception of change in local temperature (MS= 3.19), understanding the anthropogenic cause of climate change (MS= 3.13), participation in groups or association (MS= 3.13), level of education (MS= 3.06) and personal financial worth or value (MS= 3.06). Others are engagement on environmental matters (MS=2.94), experiencing temperature changes (MS= 2.94), access to information on climate (MS= 2.94), Age (MS= 2.94), interactions of various air masses (MS= 2.94), latitude and elevation (MS= 2.88), membership of relevant professional bodies (MS= 2.88), concerns for environment (MS= 2.81), type of occupation (MS= 2.81), geographical location (MS= 2.75), sex (MS= 2.75), humidity (MS= 2.63), winds & ocean currents (MS= 2.56) and topography (MS= 2.38) that are ranked low.

The factors influencing the level of awareness of BEP on climate change are experiencing temperature changes, access to modern technologies, temperature, age, level of education, understanding the anthropogenic cause of climate change. The result agrees with Thaker *et al.* (2019) that age, education level and experiencing temperature changes were identified as factors that are linked to the awareness of climate change among built environment professionals. In addition, the result corroborates the previous studies that concluded that education level, experience and access to modern technologies are among the factors that influence awareness of climate change (Zhu *et al.*, 2021).

On further testing of the respondents' opinions using ANOVA to compare differences in opinions among the groups, Table 2 showed that at 5% confidence level (P 0.05), there were significant differences in the perception of professionals on humidity and engagement on environmental matters with significant differences of 0.00 and 0.05 respectively. However, there are no significant differences in perception of professionals on other factors that influence the level of awareness on climate change.

To further explore the attributes of the factors influencing the level of awareness of climate change. Table 3 presents the results obtained from the application of KMO and Bartlett's test of sphericity conducted. The value of KMO varies from 0 to 1, and a minimum value of 0.5 is advised for factor analysis to proceed (Field 2013). Also, with the Bartlett's test of sphericity significant at < 0.05. The results obtained from analysis shows (KMO = 0.812) which met this condition. This shows that the responses given by the respondents on factors influencing the level of awareness of climate change are valid and suitable for factor analysis.

Table 3: KMO and Bartlett's Test of Factors Influencing the Level of Awareness of Climate Change

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.812
Bartlett's Test of Sphericity	Approx. Chi-Square	1039.467
	Df	276
	Sig.	.000

To further foster the adequacy of the sample size, communality which describe the total amount of original variables shared with all the other variables in the analysis which is useful in determining the final variables extracted was first established. The average communality of the variables after extraction was 0.58. Hence, the communality from Table 4 are significant due to the conventional rule that extraction value (eigenvalues) of more than 0.5 at the initial iteration indicates significance for further analysis.
After establishing that data collected were suitable for conducting factor analysis, the data were subjected to factor analysis. Results were obtained by extracting eigenvalues of factors influencing the level of awareness of climate change with the total initial Eigenvalues greater than 1.0. Seven (7) out of twenty-four (24) components met this criteria as shown in Table 4

Considering the seven extracted components, it cumulatively explained 58.271% of the variation in the data. The total variance explained by each component extracted shows that the first principal component accounted for 24.860% of the observed variance and the seven (7) components accounted 58.271% of the observed variance. The cumulative percentage of variance explained by the seven (7) components was accounted for by 58.271%. This shows that 58.271% of the common variance shared by twenty-four (24) variables can be accounted for by seven (7) components.

Table 4: Communalities of Factors Influencing the Level of Awareness of Climate Change

	Initial	Extraction
Sex	1	0.747
Age	1	0.578
Gender	1	0.583
Income	1	0.660
Membership of relevant professional bodies/organisations	1	0.446
Access to modern technologies	1	0.741

Perception of change in local temperature	1	0.600
Participation in groups or associations	1	0.655
Access to information on climate	1	0.559
Type of occupation	1	0.539
Concerns for environment	1	0.627
Personal financial worth or value	1	0.355
Geographical location	1	0.534
Engagement on environmental matters	1	0.485
Experiencing temperature changes	1	0.595
Level of education	1	0.558
Understanding the anthropogenic cause of climate change	1	0.646
Winds & ocean currents	1	0.507
Humidity	1	0.617
Temperature	1	0.641
Topography	1	0.613
Solar radiation	1	0.568
Latitude & elevation	1	0.552
Interactions of various air masses	1	0.578

Average= 0.58

Table 5: Total Variance Explained of Factors influencing the level of awareness of Climate Change

	Initial Eigenvalues			Extraction SS Loadings			Rotation SS Loadings		
Factors	Total	% of Var	Cum %	Total	% of Var	Cum %	Total	% of Var	Cum %
1	5.966	24.860	24.860	5.966	24.860	24.860	2.506	10.442	10.442
2	1.771	7.378	32.238	1.771	7.378	32.238	2.500	10.418	20.860
3	1.517	6.321	38.559	1.517	6.321	38.559	2.044	8.518	29.379
4	1.403	5.848	44.406	1.403	5.848	44.406	1.975	8.229	37.607
5	1.185	4.938	49.345	1.185	4.938	49.345	1.890	7.876	45.484
6	1.135	4.728	54.073	1.135	4.728	54.073	1.563	6.514	51.997
7	1.008	4.198	58.271	1.008	4.198	58.271	1.506	6.273	58.271
8	.955	3.977	62.248						
9	.927	3.864	66.112						
10	.872	3.633	69.745						

11	.839	3.496	73.241
12	.751	3.131	76.371
13	.718	2.993	79.365
14	.671	2.796	82.161
15	.610	2.543	84.704
16	.525	2.188	86.892
17	.516	2.148	89.040
18	.462	1.924	90.964
19	.442	1.841	92.806
20	.390	1.624	94.429
21	.382	1.590	96.020
22	.353	1.471	97.490
23	.340	1.416	98.906
24	.262	1.094	100.000

Extraction Method: Principal Component Analysis.

Further analysis of data collected as presented in Table 6 describe the rotated component matrix which revealed the components with their corresponding loading variables as well as the accompanying loading values. The rotation revealed that seven (7) components sharing twenty-four (24) variables with loading values ranging between 0.403 and 0.815. component 1 has five (5) loading variables, component 2 has six (6) loading variables, component 3 has two (2) loading variables and component 4 has three (3) loading variables each. Also, component 5 and 6 have three (3) loading variables each while component 7 has two (2) loading variables.

Table 6: Rotated Component Matrix of Factors influencing the level of awareness of Climate Change

	C1	C2	C3	C4	C5	C6	C7
Demographic & climatic factor							
Age	0.527						
Engagement on environmental matters	0.492						
Solar radiation	0.678						
Latitude & elevation	0.660						
Interactions of various air masses	0.711						
Social factor							
Membership of relevant Professional bodies		0.611					
Access to information on climate		0.621					
Type of occupation		0.640					

Personal financial worth or value		0.403					
Level of education		0.566					
Understanding the anthropogenic cause of CC		0.568					
Physical factor							
Concerns for environment			0.701				
Experiencing temperature changes			0.697				
Environmental factor							
Participation in groups or associations				0.603			
Temperature				0.731			
Topography				0.628			
Economic factor							
Gender					0.734		
Income					0.682		
Geographical location					0.524		
Climatic factor							
Sex						0.815	
Perception of change in local temperature						0.595	
Winds & ocean currents						0.481	
Technological factor							
Access to modern technologies							0.770
Humidity							0.565

The Table 6 shows the name of various components which are derived based on the factors with the highest factor loading. Critical examination of inherent relationship among various factors were considered in naming the components.

Components 1 with Eigenvalue of 5.966 and 24.860% of variance was named demographic factor. It consists of five variables with high loading values. The loading variable contained in social factor group are age (0.527) engagement on environmental matters (0.492), solar radiation (0.678), latitude and elevation (0.660), interaction of various air masses (0.711). Component 2 with eigenvalue of 1.771 and 7.378% of variance is named social factors. It consists of six variables, the loading variable are membership of relevant professional bodies (0.611), access to information on climate (0.621), type of occupation (0.640), personal financial worth or value (0.403), level of education (0.566), understanding the anthropogenic cause of climate change (0.568).

Component 3 has eigenvalue of 1.517 and 6.321% of variance and it is named physical factor. It comprises of two variables which are concerns for environment (0.701) and experiencing temperature changes (0.697). Components 4 has eigenvalue of 1.403 and 5.848% of variance comprising of three variables. It is named environmental factor. It comprises of three loading variables which are participation in groups or association (0.603), temperature (0.731) and topography (0.628). Component 5 with eigenvalue of 1.185 and 4.938% of variance is name economic factor. It consists of gender (0.734), income (0.682) and geographical location (0.524).

Component 6 has eigenvalue of 1.135 and 4.728% of variance and it is named climatic factor. it comprises of sex (0.815), perception of change in local temperature (0.595) and winds & ocean currents (0.481). Component 7 has eigenvalue of 1.008 and 4.198% of variance. It comprises two loading variables and it is named technological factor. The loading variables are access to modern technologies (0.770) and humidity (0.565). Considering the loading values of these variables, the variables with the highest value include sex, access to modern technologies, gender, temperature, concern for the environment and interaction of various air masses. This result agrees with the findings of the mean score of this study. Therefore, it can be inferred that sex, access to modern technologies, gender, temperature, concern for the environment and interaction of various air masses are important factors that influence the level of awareness of built environment professionals on climate change. These findings agrees with some of the conclusions of previous studies that found out sex, access to modern technologies, gender, temperature, concern for the environment and interaction of various air masses are important factors that influence the level of awareness of built environment professionals on climate change (Zhu *et al*., 2021; Putra *et al*., 2022; Helm et al., 2018).

Discussion of Findings

The paper examined the factors influencing the level of awareness of BEPs on climate change. The result revealed that experiencing temperature changes, access to modern technologies, temperature, age, level of education, understanding the anthropogenic cause of climate change, perception of change in local temperature and engagement in environmental matters are moderately ranked as factors influencing the awareness of climate change. These factors are classified as demographic and climatic, social, physical and environmental factors. However, results revealed that the opinion of the built environment professionals on the factors varies across different designations.

Conclusion

This paper examine the factors influencing the level of awareness of built environment professionals on climate change effects in Lagos state, Nigeria. The whole study employed a quantitative research method in data collection and analysis. The study was conducted on built environment professionals who are registered with Lagos state government. Among the professionals are architects, quantity surveyors, builders, urban & regional planners, estate surveyors & valuers, surveyors, and engineers. Data collected from the quantitative strand were analyzed using descriptive and inferential statistical methods. Examples of descriptive statistical tools in this study include charts, frequency distributions, means scores, and standard deviation, whereas inferential statistical tools include analysis of variance (ANOVA) and factor analysis. The factors were measured and the result revealed that built environment professional's opinion of the factors influencing the level of awareness varies across different designations. Therefore, the study recommends the need to improve the level of awareness of built environment professionals on climate change through seminars, workshops and continuous professional development programme (CPD).

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APPRAISAL OF OPEN DEFECATION PRACTICES IN OSOGBO TOWN, NIGERIA.

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Abstract

Open defecation remains a significant public health concern in Osogbo town, despite efforts to improve sanitation. This study appraises the prevalence and determinants of open defecation practices in the town with a focus on the objectives. The objectives of the study include; examining the awareness, and identify potential solution to address open defecation in the study area.A single approach method was used which is the primary sources of data was used for the study. The primary sources of data was obtained from the administration of questionnaire which was administered to the selected areas to examine the residents engagement in the study area. The study shows that respondents were aware of open defecation risks to health and environment, majority recognized risks such as disease spread (66%), water contamination (68.6%), and environmental degradation (67.3%) in the study area. The analysis shows that lack of access to toilet (44.9%), lack of proper knowledge of Hygiene (39.7%), and poor maintenance of existing facilities in the study areas. The findings highlight the need for improved access to sanitation facilities, awareness campaigns, and community-led initiatives, and developing eco-friendly sanitation system to address open defecation in Osogbo town.This study contributes to the development of effective strategies for reducing open defecation and promoting a healthier environment in urban areas.

Key words: Open defecation, Osogbo town, Sanitation, Awareness, Public health.

Introduction

The act of defecation perpetrated by an individual or groups of people in an open space, water bodies, bushes, etc. is defined as open defecation.The issue of open defecation is peculiar to some parts of Nigeria and with Osogbo town being the case study, this work will understudy the peculiarities between location and proper sanitation, Global sanitization status and its impact, cultural and religious perception of open defecation in Osogbo town, Nigeria. In recognition with this 12 local government areas (LGA's) in five states declared open defecation free in Nigeria (Vanguard newspaper,2023). As of 2021 Nigeria population is over 211 million, an estimated number of people who defecate in the open is of 24% of Nigeria population which is about 48 million of people (WASH, UNICEF 2021). All sustainable development goal (SDG) regions saw a drop in the number of people practicing open defecation, except for sub-Saharan Africa, where high population growth led to an increase in open defecation from 204 million to 220 million, and in Oceania, where the practice increased from 1 million to 1.3million.

Statement of the research problem

The practice of open defecation has resulted in the spread of cholera, typhoid and other intestinal worms, tracheotomy, and other diseases (WHO, 2022). Open defecation is a major environmental health problem facing many countries in sub-Saharan Africa. The reasons for open defecation are varied. It can be a voluntary, semi-voluntary or involuntary choice. Most of the time, a lack of access to a toilet is the reason. However, in some places even people with toilets in their houses prefer to defecate in the open.(Cavil; Chambers; Vernon (2015).

Aim

This aim provides a clear direction for this research outlining the key objectives and scope of the study, It also highlights the importance of understanding the complex factors contributing to open defecation practices and identifying effective solutions to address this critical public health issue. The aim will be achieved through the following objectives:

a) Examine the awareness of open defecation risk to health and environment.

b) Focus on potential solution to address open defecation.

The study area

Osogbo town, which is located in Osun State, Nigeria. Osogbo is the capital of Osun State and is home to approximately 500,000 people (www.mampower.com).Osogbo the capital of Osun lies on coordinates 7°46' North 4°34'East with an area of 47kmsq.

The sanitation situation in Osogbo is as follows: - About 60% of the population in Osogbo have access to improved sanitation facilities. The remaining 40% of the population rely on open defecation or unimproved sanitation facilities. The majority of the improved sanitation facilities in Osogbo are pit latrines, and there is a lack of access to sewerage and septic systems. There is a significant gap between urban and rural areas in terms of access to improved sanitation facilities. Water supply in the town is largely dependent on groundwater, which is often contaminated.

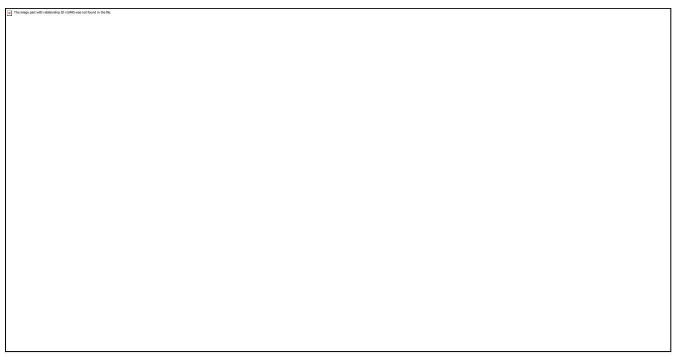

Figure 1.1. Map of Nigeria, showing osun state.

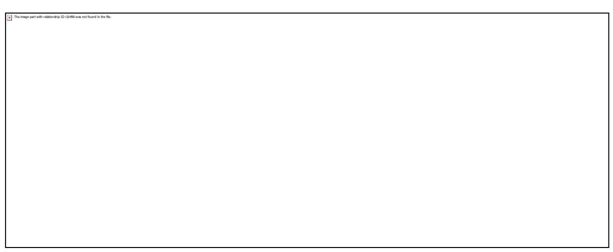

Figure 1.2. Map of Osun State, showing Osogbo and olorunda local government area.

Research methodology

This chapter provides an explanation of, and an argument in support of, the methodology that was used to investigate open defecation practice in Osogbo town, Nigeria. This city is mainly covered by two Local Government Areas (LGAs); Osogbo and Olorunda and the two contains 26 political wards delineated for electoral purposes. In conclusion, we will go through the empirical methodology, which will include the sources and type of data required, Sample size, Sample procedures, Technique and Method of data analysis.

Sources and Types of Data

There are two sources of data. This research made use of the one sources of data which are primary and secondary. The primary data were obtained through questionnaires and were complemented with reconnaissance surveys, personal interviews, and observational methods. The questionnaire was used to collect information based on the aim and objectives of the work, and the data required was based on quantitative and qualitative data. Secondary data was obtained from textbooks, journals, periodicals; published and unpublished works, maps, and internet materials, geo-spatial data.

Sampling Frame

The sample frame for this study consists of 26 political wards in the city of Osogbo, which were stratified into residential zones. This stratification comprised seven wards in the traditional zone, ten wards in the transitional zone and nine wards in the sub-urban zone, due to homogeneity of residential zone. In each selected building, the focus was on any adult from age 18 years and above. The benchmark of 18years is premised on the age as appoint of legal transition into adulthood. The benchmark has been used in previous Nigerian studies such as Daramola (2015), and the benchmark of maximum age for questionnaire administration is below age 70 years. The selected areas are listed in Table 2.2 with their respective populations.

Sampling Procedure

Sampling which is the selection of a subset of individual from within a statistical population to estimate the characteristics of the whole population. Stratified sampling was used in the accusation of information from this study area. Stratified sampling is a method of sampling in which the population will be divided into parts or homogeneous groups (Strata) on the basis of the political division into wards, so as to curtail a non-biased sample. To ensure sufficient collection of information, systematic/simple random sampling was used in each selected ward so as to distribute the sample more evenly over the population.

High density residential areas in the traditional zones; which comprises of 7 political wards

Asubiaro, Islae-Osun, Isale-Aro, Fagbesa, Araromi, Matanmi, Akindeko, Oke-Fia, Ita-Olokan, Isale-Agbara, Ayepe, Oke-Baale, Gbeja, Popo, Sabo, Iludun, Station Road, Alekunwodo, Obelawo, Gbonmi, Agowande, Atelewo, Egbatedo, Ayetoro, Igbona, OdiOlowo, Olu-Ode, Oja-oba

Medium density residential areas in the transitional zones; which comprises of 10 political wards

Ogo-Oluwa, Salvation Army, Dada Estate, Capital, John Mackay, Costain, Fiwasaye, Oke-Onitea, Power Line, Omo West Abere, Bolanle, Agunbaelewo, Ofatedo, Iwo Road, Ota Efun, Testing Ground, Kelebe, Ofatedo, Ola Iya, Iyana Camp.

Low density residential areas in the sub-urban zones; which comprises of 9 political wards

Oroki Estate, Kobongbogboe, Alabameta, Dagbolu, Timehin, G.R.A, Osogbo L.G.A., Haleluyah Estate, Owode Ede, Owode Ilesa Garage.

Table 2.1.Showing Osogbo Projected Population and Estimated Households.

S/N	Year	Osogbo Projected Population	Growth Rate	Estimated Number of Households
1	**2021**	**731,000**	**2.38%**	-
2	**2022**	**750,000**	**2.60%**	
3.	**2023**	**772,000**	**2.93%**	**17,026**
4	**2024**	**796,000**	**3.11%**	-

Source: i. United nations –World population prospects

ii. The NBS Estimated Average household size 5 per household

iii. Growth rate of Osogbo @ 2.93% by the Sources; www.manpower.com

Sample Size

The sample size is the unit of study population; it was calculated based on the proportion of study population. in this research, taro yamane formula was used as shown below;

$$n = \frac{N}{1+N(e)^2}$$

Where: n= Sample size

N=population size

E=margin of error (e=error of tolerance) at desired (0.08 at 95% confidence level).

$$n = \frac{38{,}171}{1+(38{,}171)\,(0.08)^2}$$

$$n = \frac{38{,}171}{245}$$

n =156.

To determine the number of percentages of the questionnaires to be administered, the sample size will be divided by the total population and multiplied by 100:

$$\frac{156}{38{,}171} \times 100 = 0.41\%$$

This has also been used by scholars like boluwaji(2017).

Table 2.2. Sample size for selected areas in the study.

S/N	List of Selected areas	Projected Population For 2023	Estimated Number of Households	Sample size @0.41%
1	Alekuwodo	34,701	6,940	28
2	Ayetoro	11,981	2,396	10
3	Isale-Osun	38,763	7,725	31
4.	Asubiaro	11,717	2,343	10
5.	Oja-Oba	30,786	7,752	32
6.	Oke-Ayepe	6,925	1,385	6
7.	Oke-Baale	4,808	961	4
8.	Powerline	6,721	1,344	6
9.	Sabo	27,394	5,478	22
10.	Owode	9,387	1,877	7
	Total	**183,180**	**38,171**	**156**

Table 2.3. Research Methodology Frame.

S/N	OBJECTIVES	SOURCES OF DATA	VARIABLE REQUIRED	METHOD OF DATA ANALYSIS
1.	Examine the awareness of open defecation risk to health and environment.	Primary data	Information from the respondents	Descriptive Statistics E.g percentages,frequency table,graphs and charts.
2.	Focus on potential solution to address open defecation.	Primary data	Information from the respondents	Descriptive Statistics E.g percentages, frequency table,graphs,and charts.

Results and discussion

This chapter contains the analysis, discussion of data collected during the study of open defecation practices in Osogbo town, Nigeria with a view to interpret findings analyze possible planning implications and convey high level results and implications to national decision-makers for sustainable and better environment. This section discusses on the problems associated with open defecation practices in Osogbo town, itemizing the conditions and causes , location site in the study area. all 156 questionnaires were distributed across all the 10 randomly selected areas, which all were filled by the respondents, and we're deemed analyzed.

Examine the awareness of respondents on open defecation risk to health and environment

Table 2.4. Awareness of Open Defecation Risks to health.

S/N	**Awareness of Open Defecation Risks to health**	STATISTICS	**Level of awareness (ratings)**					
			Not at all aware	Slightly aware	Somewhat aware	Moderately aware	Extremely aware	TOTAL
1.	Spread of diseases like cholera, typhoid, hepatitis A	FREQUENCY	4	15	7	27	103	156
		PERCENT(%)	(2.5%)	(9.6%)	(4.5%)	(17.3%)	(66.0%)	(100.0%)
2.	Contamination of drinking-water and food sources diseases	FREQUENCY	2	7	9	31	107	156
		PERCENT(%)	(1.3%)	(4.5%)	(5.8%)	(19.9%)	(68.6%)	(100.0%)
3.	Attraction of flies and insects that spread diseases	FREQUENCY	2	7	10	30	107	156
		PERCENT(%)	(1.3%)	(4.5%)	(6.4%)	(19.2%)	(68.8%)	(100.0%)
4.	Increased susceptibility of children to malnutrition and stunting	FREQUENCY	11	17	18	28	82	156
		PERCENT(%)	(7.1%)	(10.9%)	(11.5%)	(17.9%)	(52.6%)	(100.0%)
5.	Cases of diarrhea, cholera, or other illness caused by open defecation	FREQUENCY	5	18	17	19	97	156
		PERCENT(%)	(3.2%)	(11.5%)	(10.9%)	(12.2%)	(62.2%)	(100.0%)

The data presented in Table 2.4 regarding the awareness status of respondents in the appraisal of open defecation practices in Osogbo town, sheds light on the impact of open defecation practices risk on health in the region. The table includes ratings based on the level of awareness for each factor. The majority of respondents are extremely aware of the risks associated with open defecation, including; Spread of diseases like cholera, typhoid, and hepatitis A (66.0%), Contamination of drinking water and food sources (68.6%),Attraction of flies and insects that spread diseases (68.6%),Increased susceptibility of children to malnutrition and stunting (52.6%). This information is crucial as it signifies that a significant majority of the participants have first-hand experience and awareness about open defecation risk to human health, enabling them to provide valuable insights and feedback based on their actual experiences, knowledge and awareness. Planners should prioritize measures to mitigate the health risk of disease caused by open defecation in the study area. Planning for hygiene protocols and safety measures is essential to protect public health. By analyzing the existing conditions of impact of open defecation risk on health in the study area and considering the planning implications outlined below, authorities can work towards improving sanitation infrastructure, enhancing respondents awareness, and promoting public health and well-being in the community.

Planning implications includes; interventions should focus on reinforcing awareness of open defecation risks, particularly among those with lower awareness levels. Education campaigns should emphasize the link between open defecation and child malnutrition/stunting. Community-based initiatives should prioritize sanitation and hygiene practices to reduce the perceived impact of open defecation on health. Targeted interventions should focus on groups with lower awareness levels, such as younger adults, those with lower education, and lower-income households. Emphasize the importance of proper sanitation practices in reducing child malnutrition and stunting. Encourage community leaders and stakeholders to promote awareness and adoption of proper sanitation practices. By addressing these implications, the community can work towards reducing open defecation practices, improving sanitation and hygiene, and promoting overall health and well-being. However, there are gaps in awareness, particularly among; those who are not at all aware or slightly aware of the risks, those who are less aware of the link between open defecation and child malnutrition/stunting, which has perceived Impact of Open Defecation. A significant proportion of respondents (62.2%) are extremely aware of cases of diarrhea, cholera, or other illnesses caused by open defecation, indicating a perceived direct impact on health. In conclusion, the information on respondents' awareness on the appraisal of open defecation practices in Osogbo town provides valuable context for understanding health related open defecation risk in the region. By addressing these gaps in awareness and reinforcing the importance of proper sanitation practices, the community can work towards reducing open defecation and its associated health risks.

Table 2.5. Awareness of Open Defecation Risks to environment.

S/N	Awareness of Open Defecation Risks to environment	STATISTICS	Level of awareness (ratings)					TOTAL
			Not at all aware	Slightly aware	Somewhat aware	Moderately aware	Extremely aware	
1.	Knowledge about open defecation impact on the quality of the water	FREQUENCY PERCENT(%)	7 (4.5%)	15 (9.6%)	8 (5.1%)	21 (13.5%)	105 (67.3%)	156 (100.0%)
2.	Understanding of open defecation impact on the quality of the soil	FREQUENCY PERCENT(%)	7 (4.5%)	21 (13.5%)	15 (9.6%)	29 (18.6%)	84 (53.8%)	156 (100.0%)
3.	Perception of open defecation impact on the presence of flies and other insects	FREQUENCY PERCENT(%)	3 (1.9%)	9 (5.8%)	10 (6.4%)	29 (18.6%)	105 (67.3%)	156 (100.0%)
4.	Insight of open defecation impact on enviroment appearance	FREQUENCY PERCENT(%)	1 (.6%)	18 (11.5%)	16 (10.3%)	37 (23.7%)	84 (53.8%)	156 (100.0%)

The table 2.5 provides an overview of environmental Awareness of open defecation risk in various locations within the study area detailing information on the respondents awareness of the environmental impacts of open defecation. The table includes ratings based on the level of awareness for each factor. The majority of respondents are extremely aware of the environmental impacts of open defecation, including; water quality degradation (67.3%), soil quality degradation (53.8%), increased presence of flies and insects (67.3%), negative impact on area appearance (53.8%). This information is crucial as it signifies that a significant majority of the participants have first-hand experience and awareness about open defecation risk to the environment, enabling them to provide valuable insights and feedback based on their actual experiences, knowledge, awareness and observations.The findings from Table 3.2 highlight the planning implications include; ensuring emphasize the environmental consequences of open defecation in awareness campaigns. Targeted interventions should focus on groups with lower environmental awareness levels. Promote proper waste management and sanitation practices to mitigate environmental impacts. Encourage community-led initiatives to maintain a clean environment and prevent open defecation. Integrate environmental education into school curricula and community health programs. Provide access to sanitation facilities and promote their use, particularly in high-risk areas. Monitor and evaluate the effectiveness of environmental awareness campaigns and community-based initiatives. Encourage policymakers to prioritize environmental health and sanitation in urban planning and development. By addressing these implications, the community can work towards reducing open defecation practices, mitigating environmental impacts, and promoting a cleaner and healthier environment. However, gaps in awareness persist, particularly among; those who are not at all aware or slightly aware of the environmental impacts, those with lower awareness levels regarding soil quality degradation, which has lead to the environmental concerns. The high level of awareness about the environmental impacts of open defecation suggests that respondents are concerned about the effects on their surroundings, including water and soil quality, and the presence of disease-spreading insects. In conclusion, the information on respondents' awareness on the appraisal of open defecation practices in Osogbo town provides valuable context for understanding the environmental risk tat can be caused by open defecation in the region.

Potential solution to address open defecation practices in Osogbo town

Table 2.6. Solution to address open defecation practices.

ATTRIBUTES	**10 SELECTED POLITICAL WARDS IN OSOGBO**	
	Frequency	**Percent (%)**
Reasons for engaging in open defecation		
Lack of toilets	70	44.9
Insufficient number of toilets	24	15.4
Lack of proper knowledge of Hygiene	62	39.7
TOTAL	**156**	**100.0**
Methods to improve sanitation in your area		
Provision of public toilet	54	34.6
Construction of household toilets	13	8.3
Improved water supply	31	19.9
Raising awareness campaigns against open defecation	58	37.2
TOTAL	**156**	**100.0**
Ways to make toilets more accessible and affordable for everyone		
Subsidies for toilet construction	49	31.4
Subsidies for sanitation products	20	12.8
Voucher system	25	16.0

Community-led total sanitation	62	39.7
TOTAL	**156**	**100.0**
Ways to encourage people use toilet instead of open defecation		
Provide accessible and affordable toilets	54	34.6
Launch awareness campaigns	42	26.9
Implement incentives program	19	12.2
Engage with community leaders and stakeholders	41	26.3
TOTAL	**156**	**100.0**
Effective strategies in addressing open defecation		
Improving access to toilet	49	31.4
Implementing educational programs	19	12.2
Developing Eco-friendly sanitation system	46	29.5
Enhancing infrastructure	42	26.9
TOTAL	**156**	**100.0**

Based on the table 2.6 data, The table 3.3 provided a descriptive analysis of various factors related the potential solutions to address open defecation practices in Osogbo town. Here is an analysis and explanation of the data, along with its planning implications. The appraisal of open defecation practices in Osogbo town is a vital aspect of urban planning and public health. Urban health planners play a significant role in ensuring potential solution to address open defecation practices in all residents thereby contributing to public health and overall quality of life. By evaluating various factors related to such as; Lack of toilets and insufficient knowledge of hygiene are major reasons for open defecation. Community-led initiatives, subsidies for toilet construction, and raising awareness campaigns are suggested solutions. Improving access to toilets, implementing educational programs, and enhancing infrastructure are effective strategies and Most respondents are willing to participate in programs or initiatives to reduce open defecation and authorities can identify areas that require improvement and develop strategies to enhance sanitation infrastructure. The data highlights the need for potential solution to solve the problem associated with open defecation practices are; Provision of public toilets: Construct public toilets, especially in high-density areas. Subsidies for toilet construction: Offer subsidies to households to build toilets. Raising awareness campaigns: Organize awareness campaigns to educate people about the risks of open defecation. Community-led total sanitation: Engage community leaders and stakeholders to promote sanitation practices. Implementing educational programs: Integrate sanitation and hygiene education into school curricula. Enhancing infrastructure: Improve water supply and waste management infrastructure. Incentives programs: Implement incentives for households to build and use toilets. Community engagement: Engage with community leaders and stakeholders to promote sanitation practices. By addressing the root causes of open defecation and implementing these solutions, Osogbo town can reduce open defecation practices and improve sanitation and hygiene outcomes. In terms of planning implications, the appraisal of open defecation practices in Osogbo town highlights; Integrated approach: Implement a combination of solutions to address open defecation practices. Community engagement: Involve community leaders and stakeholders in planning and implementation. Infrastructure development: Improve water supply and waste management infrastructure. Education and awareness: Integrate sanitation and hygiene education into school curricula and conduct awareness campaigns. Incentives and subsidies: Offer incentives and subsidies to households to build and use toilets. Monitoring and evaluation: Regularly monitor and evaluate the effectiveness of initiatives. Policy and legislation: Strengthen policies and legislation to support sanitation and hygiene initiatives. Community ownership: Encourage community ownership and participation in sanitation initiatives. By addressing open defecation practices through a comprehensive and integrated approach, Osogbo town can improve sanitation and hygiene outcomes, reduce health risks, and enhance overall quality of life.

In conclusion the study highlights the need for a multi-faceted approach to address open defecation practices in Osogbo town. The solutions identified include provision of public toilets, subsidies for toilet construction, raising awareness campaigns, community-led total sanitation, implementing educational programs, enhancing infrastructure, and incentives programs. Community engagement and participation are crucial for the success of these initiatives.

Conclusions

The study appraise Open defecation practices persist in Osogbo town in which findings revealed that respondent considered lack of access to toilets, and lack of sanitation facilities as the most major problems faced in the study area. Despite recognizing the risks, residents engage in open defecation due to limited alternatives. Effective strategies to address this issue include improving access to toilets, raising awareness, and community-led initiatives. This study highlights the need for a multifaceted approach to address open defecation in Osogbo town. By understanding the socioeconomic factors and awareness levels of residents, effective strategies can be implemented to improve access to sanitation, raise awareness, and promote behavioral change. Community-led initiatives and affordable sanitation options are crucial to reducing open defecation practices and promoting a healthier environment.

Recommendations

In conformity with the findings of this study, the following recommendations are hereby suggested:

i. Improve access to toilets: Construct public toilets and promote affordable sanitation options.

ii. Raise awareness: Implement campaigns to educate residents about open defecation risks and promote behavioral change.

iii. Community-led initiatives: Engage residents in total sanitation programs and encourage community ownership.

iv. Provide affordable sanitation options: Offer subsidized toilets and sanitation services for low-income households.

v.. Encourage participation: Engage residents in programs and initiatives to reduce open defecation.

Appendix

SECTION A: EXAMINE THE AWARENESS OF OPEN DEFECATION RISK TO HEALTH AND ENVIRONMENT.

i. OPEN DEFECATION RISK TO HEALTH

Awareness of open defecation risk on health

Level of awareness on the impact;

Not at all aware

Slightly aware

Somewhat aware

Moderately aware

Extremely aware

1.Can spread of diseases like cholera, typhoid, hepatitis A be caused by open defecation?
2.Can contamination of drinking water and food sources be caused by open defecation?
3.Can attraction of flies and insects that spread diseases could be through open defecation?
4.Can open defecation caused increased in susceptibility of children to malnutrition and stunting?
5.Can any cases of diarrhea, cholera, or other illness caused by open defecation

ii. OPEN DEFECATION RISK TO ENVIRONMENT
1.Do you have any knowledge about open defecation impact on the quality of the water?
2.Do you have any understanding of open defecation impact on the quality of the soil?
3.Do you have any perception of open defecation impact on the presence of flies and other insects?
4. Do you have any insight about open defecation impact on environment appearance?

SECTION B: POTENTIAL SOLUTION TO ADDRESS OPEN DEFECATION

1. Why do people engage in open defecation? a) Absence of toilets b) Insufficient number of toilets c) Lack of proper knowledge of hygiene d) Lack of toilets

2. What do you think could be done to improve sanitation in your area? a) Provision of public toilets b) Construction of household toilets c) Improved water supply d) Raising awareness campaigns against open defecation

3. What do you think could be done to make toilets more accessible and affordable for everyone? a) Subsidies for toilet construction b) Subsidies for sanitation products c) Voucher system d) Community-led total sanitation

4. What do you think could be done to encourage people to use toilets instead of open defecation? a) Provide accessible and affordable toilets b) Launch awareness campaigns c) Implement incentives program d) Engage with community leaders and stakeholders

5. Which of the following strategies could be effective in addressing open defecation? a) Improving access to toilets b) Implementing educational programs c) Developing Eco-friendly sanitation systems d) Enhancing infrastructure

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Copula Modelling Strategies for Drought Analysis - A Review

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Abstract
The aim of this studies is to review the copula modelling strategies for drought analysis. Though, significant amount of research has been performed on the probabilistic characterisation of drought. However, the majority of drought studies aligns with univariate analysis even though drought is a complex phenomenon that is characterised by a few randomly correlated variables. Copulas are a very powerful tool for quantifying the dependence structure between correlated quantities. In light of the reviewed literatures, it suffices to conclude that meteorological drought are the most investigated drought type, primarily quantified by Frank copula model strategies, in this regard, supported by the claim that Archimedean copula family are the most popular class, though, marred with specific shortcomings that inhibit it speedy transformation in multivariate component. Contrarily, Metaelliptical and Extreme value have relative strength over Archimedeans families. Finding in this studies, revealed need for optimal search of appropriate copula models that best defines the problem within the spectral of copula families, instead of being gullible to Archimedeans. Adequate revelation were given of strength and drawback associated with common copulas. Hence, it is recommended, that related studies should explored trivariate copulas against popular bivariate approaches to strengthen the relationship between three drought variables.
Keywords: Drought, Copula, Climate, Meteorological and Univariate

1.0 Introduction

Given the recent and potential future increases in global temperature and changes in precipitation, climate change may come with changes in the frequency and severity of extreme events such as drought and flood **(**Shiau, 2015**).** Therefore, drought analysis has become a global issue that attracts the attention of various water resources experts. In this context, drought is considered a period of below-average precipitation in a given region, resulting in prolonged shortages in water supply, whether atmospheric, surface water or ground water. It is imperative to note that, drought produces a complex web of impacts capable of transforming itself from one form to another; that is, for instance, from meteorological to hydrological, and perhaps to agricultural (Sergiusz, 2015). Unlike, many sudden natural disasters, sudden natural disasters, droughts result when there is less than normal precipitation over an extended period. The departure from normality can produce serious agricultural, environmental, and socioeconomic damage (Sergiusz, 2015). Since droughts are strictly related to stochastic phenomena, such as precipitation or streamflow, the proper way to investigate droughts is by using probability theory and stochastic process methods (Shiau, 2015). The probabilistic characterization of droughts is important, primarily in regions where accurate water resource planning and management requires detailed knowledge of water shortages due to climate variability (Shiau, 2015). Thus, as reported by (Chowdhury, *et al.,* 2019) the development of models capable of describing such complex phenomena has become a growing area of research interest.

In this regard, Copulas stands out as mapping functions that capture the rank-invariant dependence structure among random variables, which are obtained by joining marginal distribution of any form especially as the case with the dynamics of drought processes. The Copula modelling strategy has received a lot of attention with considerable adoption in flood and drought. This is driven by the fact that univariate drought characteristic analysis, though a well-developed technique applied in water resources for decades, often associated with singular variables has proven inadequate in quantifying drought bivariate nature (Chukwu 2019). .In the past, bivariate distributions are often explored in hydrological extremes studies. For example, bivariate normal distribution Goel, *et al.* (2018), bivariate exponential distribution Bacch**i,** *et al.* (2019), bivariate gamma distribution Yue, *et al.,* (2017) and bivariate extreme value distribution (Shiau, 2015). The major drawbacks of these bivariate distributions as indicated by Frees, *et al.,* (2018), are that the same family is needed for each marginal distribution, requires more data, sophisticated mathematical treatment, and a limited number of available models. However, it is important to note that bivariate distribution cannot be applied to correlated hydrological variables with a different marginal distribution which is common in drought analysis. Hence, in recognition of this, physical models based on a bivariate copula strategy stand out in quantifying drought characteristics. These approaches are fast becoming attractive alternatives and offer various benefits ahead of the traditional statistical approach. Goel (2018) opined that some of the benefits are in line with the guiding principles of hydrological modelling, that is parsimony, modesty, and testability Otache, *et al.* (2020); Invariant under strictly increasing transformations of the random variables (Shiau, 2015). Even at that, there is a complete dearth of documented evidence or extensive review that holistically probes into the pros and cons, of bivariate copula modelling for drought. 2.0 Synoptic Reviews

Lall *et al.* (2016) reported severe drought scenario that lasted for more than 3 years (2013–2015) and was characterized by multidecadal variability, as observed from one of the longest systematic records available in Asia from 1770 to 2015, and hydrological drought was perceived to be the most prominent amidst others. Therefore, was modelled by Gumbel copula. Recently, Mirabbasi *et al.* (2016) conducted a bivariate analysis of drought duration and severity using copulas for Sharafkhaneh station, northwest of Iran investigated some bivariate probabilistic properties of droughts, based on the derived copula-based joint distribution. Several copulas were tested to determine the best fit. The Galambos copula provided the best fit for the observed drought data. The results indicated that the long and severe drought occurrence probability at the Sharafkhaneh station is high and that drought events are a frequent phenomenon in this region.Vyver *et al.* (2018) recently developed a joint deficit index (JDI) based on multivariate probabilities of precipitation over various time scales from 1-12months, and was constructed from empirical copulas. Hence, it examines the Gaussian copula model for the JDI. However, Bootstrap experiments indicate that the Gaussian copula model has advantages over the empirical copula method in the context of drought severity assessment based on: (i) it can quantify droughts outside the range of the empirical copula, (ii) it provides adequate drought quantification, and (iii) provides a better understanding of the uncertainty in the estimation. Ming, *et al.* (2023) employed the standardized precipitation index to identify drought events using China's monthly gridded precipitation dataset from 1961 to 2020. Univariate and copula-based bivariate methods were then used to examine drought duration and severity on 3, 6, and 12-month time scales and Frank copula were used to establish the dependence between drought duration and severity. The main findings were as follows: (1) 3 and 6-month time scales yielded comparable regional drought features, but not 12-month time scales and (2) higher drought severity was associated with longer drought duration.

Liping *et al.* (2020) studied, two drought characteristic variables (the drought duration and severity) and extracted them by using the theory of runs based on four drought indexes (i.e., the percentage of precipitation anomaly, the standardized precipitation index, the standardized precipitation evapotranspiration index and the improved comprehensive meteorological drought index). Further, the built joint distribution model of drought characteristic variables is based on four types of Archimedean copulas. The Frank copula function was found to be the optimal joint distribution function. The results showed that: (1) The area of extreme drought was from northeast to southwest in Yunnan Province from 1960 to 2015. Shiau, *et al.* (2019) employed a clayton copula for a bivariate analysis of drought severity and duration at the Abadan and Anzali gauge stations in Iran. Results revealed that drought severity in a humid region may be more severe if high rainfall fluctuations exist within a region.

Chukwu (2019) analysed hydrological drought severity-duration-frequency for the Sokoto-Rima River basin in Nigeria by employing secondary hydro-meteorological data of the basin. Therefore, modeled severity-duration dependence using bivariate copula. Results show that copula models the dependence between the drought severity and duration. In this regard, the Frank copula of the Archimedean family was adjudged the most suitable model based on minimal AIC (-4.2780) and SIC (8.2780) statistics and at the same time, there is obvious dominance of gamma probability marginal (67%) for severity series and Weibull distribution marginal for the duration (67%); i.e. in all the gauging stations relatively concerning logistic-normal and extreme value probability distributions. Chukwu (2024) established appropriate time-scale resolution for regional drought characterization in northern Nigeria. Explored copula modelling strategies to characterise meteorological drought events as well as engineering mission risk phenomena. The result shows that for modelling the meteorological drought severity-duration relationship, the survival copula of the BB8 class is the best model considering joint probability scenarios while risk, vulnerability, and resilience are the most sensitive variables for engineering mission risk assessment. Musa *et al.* (2022) define drought events by standard precipitation index (SPI 3) series for 24-gauge stations in Ceyhan Basin Turkey considering different elevation levels (high, average, and low). The influence of upper tail dependencies were tested for the selection of the most appropriate copula function. Gumbel and BB1 copulas were regarded as the best copulas for the drought duration and severity series, respectively.

According to Kao (2019) copulas are used to perform a spatiotemporal drought analysis for the Midwestern USA and adopted a copula-based joint deficit index (JDI) for describing overall drought status and compared it to the Palmer drought severity index. The findings of this particular study revealed that the copula-based JDI provides information for drought identification determined on a month-by-month assessment for future drought recovery. It can be inferred from reviewed literature that meteorological droughts are the most extensively investigated drought types primarily quantified by Frank copula, that probably lended credence to the Archimedean copula family as the most referenced copula family. Table 1 gives a brief foregleam of the most probable copula types, mostly associated with three drought classes. However, Table 1 is a product of an extensive review of related literature on the subject of interest, the surmised implication is to give insight or tele-guild researchers on drought class and their relationship with most referenced copula models.

Table 1: Candidate Copulas for Identified Drought Typology

Drought Type	Frequent used Copula		Literature
	First	Second	
Meteorological	Frank	Gumbel	Bifeng *et al.* (2022); Ming, *et al.* (2023) and Musa, *et al.* (2022).
Hydrological	Clayton	Gumbel	Chukwu (2019) and Lall, *et al.* (2016)
Agricultural	Gumbel	C-vine	Wu, *et al.* (2021) and Hasan, *et al.* (2022)

3.0 Conceptualisation of Drought Phenomena in the Context of Copula Models

Since droughts are complex phenomena, one variable cannot provide a comprehensive evaluation of droughts (Shiau *et al.,* 2017). Separate analysis of drought duration distribution and drought severity distributions cannot reveal a significant correlation between them. Instead of using traditional univariate analysis for drought assessment, a better approach for describing drought characteristics is to derive the joint distribution of drought variables (Mishra et al., 2010). For example, Shiau *et al.* (2017) and Cancelliere *et al.* (2010) proposed different methods to investigate the joint distribution of drought duration and drought severity or intensity. Those bivariate distributions have either complex mathematical deri vations or their parameters are obtained by fitting the observed or generated data (Shiau, 2016).

Multivariate distributions using copulas, however, overcame such difficulties. In recent years, copulas have been used for multivariate hydrological analysis. For example, Zhang *et al.* (2017) and (Song *et al.*, 2017b, a) used copula modelling strategies for rainfall frequency analysis and drought frequency analysis respectively. Copula was used extensively in hydrology because of its flexibility, since it is based on a nonlinear relationship between variables and connects both distribution and marginal functions. Design engineers and water resources planners need to know not only the frequency of droughts, but also the risk of having droughts of differing duration, severity, and interval times. For this purpose, a multivariate distribution needs to be determined, to simplify inference procedures and to derive flexible multivariate distributions, copulas were considered the most appropriate and efficient strategy as opined by Cancelliere *et al.* (2010).Previous studies have indicated that copulas perform well for bivariate problems, and in particular, several families of Archimedean copulas, including Frank and Clayton, have been popular choices for dependence models because of their simplicity and generation properties. It suffices to note that, the word copula originated from a Latin word that mean "link" or" ties" together, copula is a probability model that represents the multivariate uniform distribution, that examines the association or dependence between many variables. It is use to understand the joint probabilities of multivariate distribution (Cancelliere *et al.*, 2010). The following proceeding subsection describes the formulation of different classes of copula within their family confines as well as probes into individual strength and attributive shortcomings.

3.1 **Independent Copula**

The simplest copula form is given as:

$$C(u_{1,}u_2) = u_1 u_2 \qquad (1)$$

where u_1 and u_2 are standard uniform random variables (i.e. $u_1 u_2 \epsilon [0, 1]$) Fréchet bounds.

For each copula $C(u_1, \ldots, u_d)$) there exists the bounds

$$\max\left\{\sum_{i=1}^{d} u_1 + 1 - d\right\} \leq C(u) \leq min\{u_1 \ldots u_d\} \qquad (2)$$

Let the lower bound be defined as $F_I(u_I \ldots u_d)$ and upper bounds be $F_U(u_I \ldots u_d)$, The comonotonicity copula is the Fréchet upper bound copula given as

$$F_U(u_I \ldots u_d) = \min(u_I \ldots u_d) \qquad (3)$$

The counter-monotonicity copula is defined as a Fréchet lower bound copula in two dimensions as follows

$$F_U(u_I \ldots u_d) = \max\{u_1 + u_2 - 1, 0\}$$

3.2 Copula Family

3.2.1 Archimedean Copula

Archimedean copulas are generally used as measures of dependence for low dimensional cases with Frank and Clayton copulas as the well-known examples.

I. Clayton copula

Let θ be the dependence parameter restricted on the region (0, ∞). The Clayton copula takes the form

$$\mathrm{C}(\mathrm{u}_{1,}\mathrm{u}_2) = (\mathrm{u}^{-\theta}{}_1 + \mathrm{u}^{-\theta}{}_2 - 1)^{-1/\theta} \qquad (5)$$

As θ → 0, we obtain the product copula, and as θ → ∞ it approaches the two-dimensional minimum copula because the copula attains the Fréchet upper bound, but the Fréchet lower bound is never attained for any value (Chukwu, 2019).

II. Frank copula

Let θ be the dependence parameter that may assume any real value (−∞, ∞). The Frank copula is given as:

$$C(u_{1,}u_2) = -\theta^{-1}\log\left\{1 + \frac{(e^{-\theta u_1 - 1})(e^{-\theta u_2 - 1})}{(e^{-\theta} - 1)}\right\} \qquad (6)$$

The Fréchet lower bound corresponds to −∞, independence equals 0 while Fréchet upper bound corresponds to ∞ (Chukwu, 2019).

III. Ali-Mikhail-Haq (AMH)

The AMH copula is one of the famous two single-parameter Archimedean copulas (Chesneau, 2023). It is clearly exchangeable, i.e., $C_{\ddagger}(u, v, a) = C_{\ddagger}(u, v, a)$ for any (u,v) ∈ $[0,1]^2$, and associative, i.e.,

$C_{\ddagger}\left[C_{\ddagger}(u,v,a),w,a\right] = C_{\ddagger}\left[C_{\ddagger}(u,w,a),a\right]$ for any (u, v, w) $\in [0,1]^3$. In addition, it does not have tail dependence except for $a = -1$, where a is rigid left tail of 0.5. It is positively quadrant-dependent for $a \in |0,1|$ i.e., $C_{\ddagger}(u,v,a) \leq$ uv for any (u, v) $\in [0,1|^2$and negatively quadrant dependent for $a \in |0,1|$ i.e., $C_{\ddagger}(u,v,a) \geq$ uv for any (u, v) $\in [0,1|^2$. On the correlation aspects, the range for the associated medial correlation is [-0:2, 0.3333], and that of the associated Spearman rho is [33- 48 log (2), $4\pi^2$ - 39] ≈ [-0.2711, 0.4784].

The Ali-Mikhail-Haq copula bivariate Archimedean copula was defined by Li *et al.* (2015) as

$$C(u,v) = \frac{uv}{1-\theta(1-u)(1-v)} \tag{7}$$

For (v, u) $\in |0,1|^2$ and its generator is $\varphi(t) = log\left(\frac{1-\theta(1-t)}{t}\right)$

3.2.2 Extreme Value Copula

Emil Gumbel (1891–1966) and Janos Galambos (1940) are two early contributors to extreme-value theory **(**Zhang *et al.,* 2017**).** In the context of copula theory, Roger Nelsen promoted and developed extreme values copula through research, therefore, noted the superiority of the Gumbel and Galambos parametric families as well as affirming it popularity. Gumbel and Galambos families are the only extreme-value copulas that are Archimedean and reciprocal Archimedean, respectively.

1. **Galambos Copula**

The bivariate Galambos copula with parameter $\rho \in (0,1)$ for all $u_1 u_2 \in (0,1)$

$$GA_{\rho}(u_1,\ldots,u_d) = \frac{u_1 u_2}{exp\left[-\left\{|In(u_1)|^{\frac{-1}{\rho}}\right\}+\left\{|In(u_2)|^{\frac{-1}{\rho}}\right\}^{-\rho}\right]} \tag{8}$$

The limiting cases $\rho = 0$ and $\rho = \infty$ correspond to the Frechet–Hoeffding upper bound M and the independence copula Π, respectively. Beyond the fact that both families belong to the class of extreme-value copulas, they have expressions that seem tantalizingly similar.

2. **Gumbel copula**

For $1 \leq \theta < \infty$ the bivariate Gumbel copula is given as good

$$C(u_{1,}u_2) = \exp\left(-((-Inu_1)^{\theta}) + ((-Inu_2)^{\theta})^{1/\theta}\right) \tag{9}$$

When θ=1, the independence copula is obtained in a specific instance, and the limit of this copula is the two-dimensional minimum copula as θ→∞. Therefore, this copula oscillates between perfect dependence and zero dependence with θ as the parameter representing the extent of dependence limited to [1, ∞]. 1 as the θ value coincides with zero dependence. When θ approaches ∞, the Fréchet upper bound is obtained for any value of θ.

3.2.3 Meta-Elliptical Copula

The Gaussian copulas are the copulas of elliptical distributions with the Gaussian (Normal) and student t as well-known examples. The class of metaelliptical copulas was originally introduced by Fang *et al.* (2014). It is derived from the well-known family of elliptical distributions, which is itself an extension of the classical multivariate normal distribution.

1. **Gaussian (Normal) copula**

The Gaussian copula is a distribution over the unit hypercube $[0,1]^d$. It is constructed from a multivariate normal distribution over $\mathbb{R}^d$ by using the probability integral transform. For a given correlation matrix $R \in [-1,1]^{d\times d}$, the Gaussian copula with parameter matrix R can be written as

$$C_R^{Gauss}(u) = \Phi_R\left(\Phi^{-1}(u_1),\ \ldots\ ,\Phi^{-1}(u_d)\right) \tag{10}$$

where Φ^{-1} is the inverse cumulative distribution function of standard normal and Φ_R is the joint cumulative distribution function of a multivariate normal distribution with mean vector zero and covariance matrix equal to the correlation matrix R. While there is no simple analytical formula for the copula function, $C_R^{Gauss}(u)$, it can be upper or lower-bounded, and approximated using numerical integration. In addition, the normal copula attains the Fréchet lower bound when the dependence parameter approaches -1 and attains the upper bound when the dependence parameter approaches 1 (Botev, 2016).

2. Student t

Let *d* be the dimension of a copula, t_v the distribution function of a standard univariate *t* distribution and t_v p the joint density function (df) of the vector $X \sim t_d(v, 0, P)$ with *P* as a correlation matrix. The *d*-dimensional of student *t* copula is given as

$$C_v^t p(u) = t_{v,p}\left(t_v{}^{-1}(u_1), \dots, t_v{}^{-1}(u_d)\right) \quad (11)$$

It is important to note that, only the comonotonicity copulas are special cases of the Gaussian copula. Thus, independent copula is not a special case of this copula because uncorrelated multivariate t-distributed random variables are not independent.

The overall, Table 2.0 gives a vivid breakdown of composite copula family members as a function of strength and associated weakness for each identified copulas.

Copula Family	Strength	Shortcoming
Archimedean	Archimedean family copulas have simple closed-form expressions and most of them can describe a broad range of tail dependence and asymmetric tail dependence which led to their wide usage in hydrological applications (Ming *et al.*, 2023). Notable, symmetrical structure and strong combinatorial ability which other copulas do not have (Christophe, 2024).	Archimedean copula depends on only one or two parameters, their usefulness in real data is limited due to the inflexibility. For example, the dependence structure of each pair of variables within the pseudo-copula is always identical; thus, it is not possible to define different correlations between different variables within the pseudo-copula. (Fang, *et al.*, 2014)
▪ Clayton	Is suitable for the case of positive correlation between variables such as drought duration and severity (Fei *et al.,*2019). Sensitive to the change of the bottom tail (Liping, *et al.*, 2020).	Cannot describe negative dependence adequately (Liping, *et al.*, 2020). Relative weakness in terms of capturing asymmetry relationship, which is commonly encountered in drought and water resource studies, this is due to the symmetric nature of clayton copula (Liping, *et al.*, 2020).
▪ Frank	The lower and upper Fréchet bounds are among the range of allowable dependence unlike other copula families Thus, strong positive or negative dependence can be modelled with Frank copula and captures asymmetric relationships common in drought series (Liping *et al.*, 2020). The middle of the distribution is where the strongest dependence is centered suggesting that this copula is most suitable for data with weak tail dependence (McNeil *et al.*, 2005). Adjudged as the best for the establishment of future drought duration and joint probability of drought characteristics for water resource management (Ishfaq *et al.,* 2024; Liping *et al.*, 2020).	More restricted to low dimensional cases (Liping *et al.*, 2020).

▪ AMH	It is one of the rare copulas to enjoy a simple and comprehensive harmonic mean property (Triantafyllou, 2019). That can combine both positive and negative correlation variables (Christophe, 2024).	Limited to capturing asymmetric dependence features, significant negative correlations, or versatile tail dependence properties (Christophe, 2024)
Extreme Value	Plays an essential role in modelin***g*** the maximum and the minimum of a random variable and deals with the extreme deviations from the mean of the probability distributions. Extreme value copula models help to describe natural limiting, Extreme value copulas may be used to reveal the extreme dependence of the hydrological data (Musa *et al*., 2022).	Limited to extreme deviation from the means of probability distributions. Hence, a scenario that may not commonly surface in the quantification of drought (Sergiusz, 2015).
• Galambos	Appears the best for representing drought parameters, thus enabling comparison between univariate and bivariate return periods (Ishfaq *et al.,* 2024).	Restricted to negative dependence where it droves it second name as a negative logistic copula (Ishfaq *et al.,* 2024)
• Gumbel	Can capture the characteristics of the upper tail on the variable frequency. Much suitable for the case of a positive correlation between variables such as drought duration and severity (Liping *et al*., 2020). Proves superior for modelling joint return periods of drought (Ishfaq *et al.,* 2024).	Not sensitive to the change of the bottom tail (Liping *et al*., 2020). The correlations on the extreme right sides of the distribution are more concentrated (i.e., higher correlation) than those on the extreme left sides of the distribution (Liping *et al*., 2020). Making it undesirable in certain application.
Meta-Elliptical	It is easy to simulate from elliptical copulas, at the same time can capture both positive and negative dependency structures (Fang, *et al*., 2014).	Not having a closed-form expression, radial symmetry, the lower and upper tail-dependence are identical, which might be undesirable in some application (Fang, *et al*., 2014).
• Gaussian	Simple probability density, adjustable degree of dependence between every pair of variables, and interpretable and well-estimable parameters (Christophe, 2024).	One major drawback of Gaussian copula is that it intrinsically lacks the flexibility of ***modelling*** the tail dependence which real data often exhibit (Liping *et al*., 2020).
• Student t	Have well-known conditional distributions, a simple data-generating mechanism and unimodality (Botev, 2016).	It accuracy is marred when perfect normality is required (Botev, 2016).

4.0 Conclusion

Thorough analytic review approach employed here reveals, that copulas are a very powerful tool for quantifying the dependence structure between correlated quantities. Frequency analysis using a copula method does not assume that variables are independent or normal or that they have the same type of marginal distributions (i.e., the marginal distributions of individual variables can be of any form and the variables can be correlated) such is considered as a major advantage of copula techniques. In addition, this submission has shown that any of the copula family models considered here could be used for prediction purposes or quantitative drought analysis. Though the Archimedean family are generally used as measures of dependence for low dimensional cases and champions drought analysis with Frank, Gumbel or logistic and Clayton copulas as well-known examples, that does not dismiss or undermine the potential of other family members. In light of the foregoing, suffices to conclude that meteorological drought are the most extensive investigated drought type, primarily quantified by Frank copula model strategies, in this regarded, supported the claimed that Archimedean Copula family are the most popular family.

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The Effect of Partial Replacement of Fine Aggregate with Owo-Eba, Osogbo Silica Sand on the Strength Properties of Concrete

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Abstract
The high demand for sand in concrete production has led to scarcity and rising costs, while excessive sand mining contributes to environmental issues like climate change, habitat destruction, soil erosion, and water pollution. To mitigate these impacts, silica sand was used as a sustainable alternative to fine aggregate in this study. Concrete mixes were developed with 25 - 100% silica sand replacement in 25% increments, while control mixes had no silica sand. The workability of fresh concrete mixes was determined through slump test. The hardened concrete was evaluated for its mechanical properties, including compressive strength at 7, 28, and 56 days, and tensile and flexural strengths at 28 and 56 days. The results showed that all the concrete mixes had true slump and slump value for concrete ranged from 43 - 27 mm with 0 to 100% silica sand content. The hardened concrete density ranged from 2543 - 2109 kg/m³ at 7 days, 2583 - 2109 kg/m³ at 28 days, and 2607 - 2109 kg/m³ at 56 days. Compressive strength decreased with higher silica sand content, ranging from 10.47 - 1.34 N/mm² at 7 days, 12.42 - 2.77 N/mm² at 28 days, and 14.83 - 4.48 N/mm² at 56 days. Splitting tensile strength ranged from 1.32 - 0.43 N/mm² at 28 days and 1.44 - 0.57 N/mm² at 56 days, while flexural strength ranged from 8.81 - 5.61 N/mm² at 28 days and 9.86-6.1 N/mm² at 56 days. It can be concluded that the optimum of 25% silica sand is adequate as replacement for fine aggregate in concrete production.

Keywords: Concrete, compressive strength, flexural strength, silica sand, split tensile strength

Introduction

The fact that aggregates account for 60-80% of the volume of concrete and 70-85% of the mass of concrete, with fine aggregate accounting for 35-45%, their impact on overall concrete performance, including strength, thermal and elastic, dimensional, and volume stability, cannot be underestimated (Brito and Saikia 2013). Fine aggregate provides dimensional stability in concrete volume, which improves the elastic modulus and abrasion resistance of concrete (Liu *et al*., 2020).

The quality of fine aggregates also affects the proportions of the mixture as well as its hardening capabilities. In addition, the characteristics of the fine aggregates have a considerable bearing on the degree to which the concrete will shrink. The three main sources of sand used in construction are river sand, crushed sand, and pit sand. River sand is usually obtained from river banks, while pit sand is obtained by digging deep pits. On the other hand, crushed sand is obtained by the strategic crushing of rocks (to fine particles) in quarries. The demand for concrete is increasing with the growth in population, the current estimate of concrete being used in the world annually is 5 billion cubic yard which is 8,786 billion tons (Cement Association of Canada, 2002). However, the world is running out of natural sand, which is one of the main constituents of concrete.

Silica sand can be obtained from crushing the natural rocks and stones as it shares a comparable quality with manufactured and river sand (Malathy *et al*., 2022). The earth's crust has the greatest silicas of any mineral.having a significant component of almost all minerals that make rocks. It can be found in many different shapes, including quartz crystals, hills formed by enormous rocks, quartz sand (silica sand), sandstone, quartzite, tripoli, diatomite, flint, opal, and chalcedony forms like agate and onyx (Malathy et al., 2022). Other than as construction materials, silica sand has a high concentration of silica (up to 99% SiO_2) in the form of quartz (Malathy *et al*., 2022).

Previous studies in the past have used several materials as alternative fine and coarse aggregates in making concrete to reduce the use of virgin materials to a great extent. Attri et al. (2021) concluded that 45% replacement of NA with coarse RCA, 100% replacement of river sand with stone crusher and silica dust do not affect significantly the properties of precast concrete blocks. Ren et al. (2022) reported that the addition of silica sand to M20 grade concrete increased the bending resistance at up to 50% replacement of natural sand, and finally, decreases it by up to 70% replacement. (Jignesh and Vaniya, 2015) discovered that at 12% replacement level with silica sand in M20 grade concrete, the concrete cost was reduced around 5% less than conventional concrete. Mao et al. (2022) studied the properties of concrete made with silica sand. Fine silica sand passing through a 75-m micron sieve was used as a partial replacement for cement in the M25 grade concrete up to 25% replacements. Fifteen percent silica sand replacement gave the better compressive, flexural and split tensile strengths compared with the control mix. The reported studies have shown that silica sand has found applications in concrete. However, enough research has not been done on the strength properties after the fine aggregate in the mix has been replaced with silica sand. This study evaluates the effects of partial replacement of fine aggregate with silica sand on the strength properties of concrete.

Materials and Methods

Materials

In this study, sharp sand collected from riverbanks within Osogbo, Nigeria served as fine aggregate. Dangote 3X Portland Limestone Cement, CEM II 42.5N (A-L) obtained from a retail store within Osogbo, Osun State, Nigeria was used as binding material. Silica sand of 2 mm maximum size sourced from Owo Eba, Osogbo, Nigeria (Lat: 7° 43' 44.83" N, Long: 4° 34' 49.30" E) was used as replacement for natural fine aggregate contents in this study. The chemical composition of raw silica sand is shown in Table 1. Crushed granite with maximum size of 4.75 mm and sharp sand with maximum size of 4.75 mm sourced from the construction site within Osun State University, Osogbo, Nigeria, were used as coarse and fine aggregate, respectively in this research work. Potable water was employed in mixing and curing of all materials which conforms to BS EN 1008:2002. The water was collected from the laboratory at Osun State University. The particle size distribution of silica sand, crushed granite and sharp sand are shown in Figure 1.

Table 1: Chemical Composition of Silica Sand

Chemical Constituents	Compositions (%)
SiO_2	95.39
Al_2O_3	2.13
Fe_2O_3	1.87
CaO	0.20
SO_3	0.01
Mg_2O	0.02
MgO	1.53
K_2O	0.36
TiO_2	0.89
$SiO_2 + Al_2O_3 + Fe_2O_3$	99.39

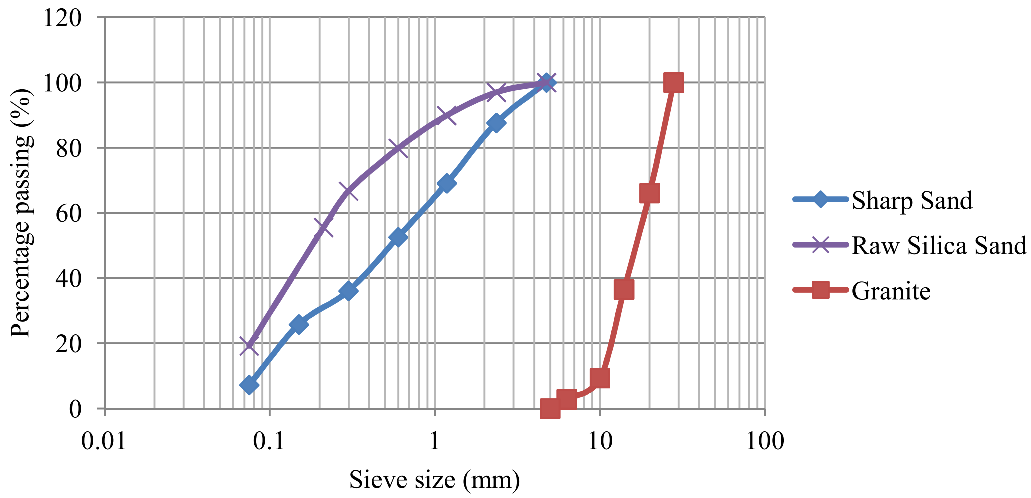

Figure 1: Particle size distribution curves of materials

Concrete mix preparation and specimen's production

All the concrete mixtures were produced by weight-batching with crushed granite, cement, silica sand as the constituent materials. The mix proportion of 1: 1.91: 3.88 (cement: sand: granite) obtained using Building Research and Establishment concrete mix design approach was used and a total number of 5 concrete mixtures were produced. A fixed water- to-binder ratio of 0.63 and total binder constituents of 326 kg/m^3 were prepared with 0, 25, 50, 75 and 100% silica sand as replacement for natural sharp sand by volume. Table 2 shows the details of concrete mix proportion. Concrete constituents were properly mixed on flat, non-absorbent surface. Fine aggregates and cement were thoroughly mixed together before mixing it with the coarse aggregates. The mould used were wooden moulds of 150 mm x 150 mm x 150 mm and plastic mould of 150 mm diameter and 300 mm length which conform to BS EN 12390-1:2000. The moulds were properly oiled for easy demoulding and then filled with concrete. After casting and finishing, all the specimens were allowed to set. The total number of cubes, cylinders and beams casted were 45, 30 and 30 respectively. The specimens were demoulded after 24 hours of casting and cured in tank placed at the laboratory until the testing ages.

Table 2: Details of concrete mix proportion (1 kg/m^3)

Mix ID	RSS (%)	Cement (kg)	RSS (kg)	Sand (kg)	Granite (kg)	Water (kg)
1	0	333	0	636	1291	210
2	25	333	159	477	1291	210
3	50	333	286	286	1291	210
4	75	333	477	159	1291	210
5	100	333	636	0	1291	210

Testing Methods

Slump test was carried out to measure the consistency of fresh concrete. The procedure for carrying out this test was in accordance with ASTM C143 (2015). The compressive strength test was carried out on hardened concrete specimens (150 mm x 150 mm x 150 mm) at the curing ages of 7, 28 and 56 days using Universal Testing Machine (UTM) according to BS EN 12390-3:2019., while the split tensile strength was carried out on hardened concrete specimens (100mm diameter x 200mm height) using the Universal Testing Machine (UTM) according to BS EN 12390-3:2019 at 28 days only with UTM.

RESULTS AND DISCUSSIONS

Workability

The results of the slump of concrete are presented in Table 4.3. Results showed that all the concrete mixes had true slump and slump value were 38, 35, 30 and 27 mm for concrete with 25, 50, 75 and 100% silica sand content, respectively. The slump of fresh concrete decreases with increase with silica sand content. The decrease in the fresh concrete slump observed with concrete with silica sand indicates the decline in the workability which was as a result of the presence of large proportion of silica sand samples (Malathy *et al*., 2022). All the concrete mixes satisfied the requirements of slump (25-50 mm) for concrete suitable for reinforced concrete which allow for manual compaction (Neville and Brooks, 2010).

Table 4.3: Slump of fresh concrete

Silica sand content (%)	Slump value (mm)
0	43
25	38
50	35
75	30
100	27

Compressive strength

The average compressive strength results of the hardened concrete containing silica sand at different percentages are indicated in Figure 2. The compressive strength of the control was 15.47 N/mm² and decreased from 13.53 to 6.34 N/mm² with increase in silica sand contents from 25 to 100% at 7 days of curing. The compressive strength at 28 days for the control was 18.37 N/mm² and decreased from 17.42 to 7.77 N/mm² with increase in silica sand contents from 25 to 100%. At 56 days, the compressive strength of the control is 19.83 N/mm² and decreased from 18.53 to 9.48 N/mm² with increase in silica sand contents from 25 to 100%. These results indicate that the compressive strength of concrete decreased as the silica sand contents increases whereas as the curing ages increases, the concrete density increases. The high fineness of silica sand increases water demand, reducing workability and leading to a strength decline as the substitution rate rises (Malathy *et al*., 2022). However, the increase in concrete's compressive strength with curing age can be attributed to improved particle packing due to the use of fine powders, as well as efficient filling of voids.

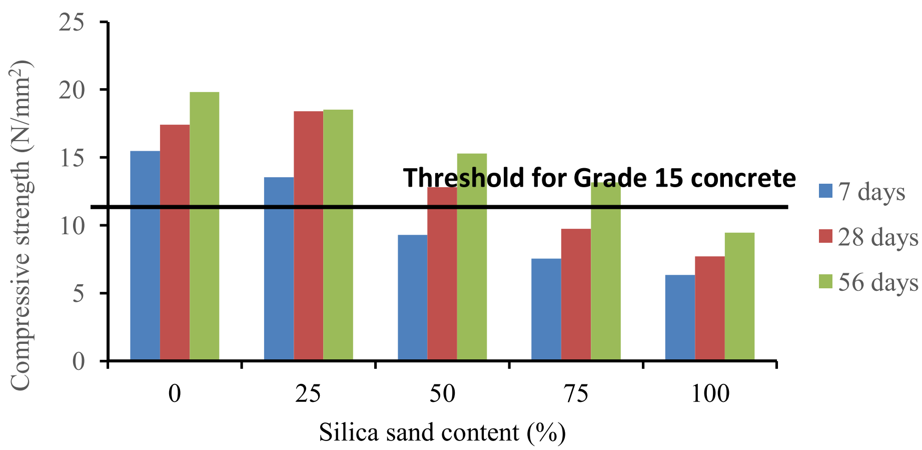

Figure 2: Compressive strength of hardened concrete with silica sand

Split Tensile Strength

The average split tensile strength results of the hardened concrete containing silica sand at different percentages are indicated in Figure 3. At 28 days, the splitting tensile strength of the control is 1.32 N/mm² and ranged from 1.31 to 0.43 N/mm² with increase in silica sand contents from 25 to 100%. The splitting tensile strength at 56 days for the control is 1.44 N/mm2 and ranged from 1.47 to 0.57 N/mm2 with increase in silica sand contents from 25 to 100%. The split tensile strengths of all the concrete with silica sand are lower than that of the control at 28 days. However, at 56 days, the splitting tensile strengths of concrete with 25% silica sand increased by 2.08% with respect to the control whereas it decreases when the substitution rate became higher than 25%. It is evident from the plot that the optimal splitting tensile strength is observed at 25% silica sand addition. The increase in splitting tensile strengths observed at the later age of 56 days indicate that the incorporation of silica sand at the optimum substitution of 25% increase the hydration process and significantly increase the formation of calcium-silicate-hydrate which is responsible for strength development (Sarra, 2022).

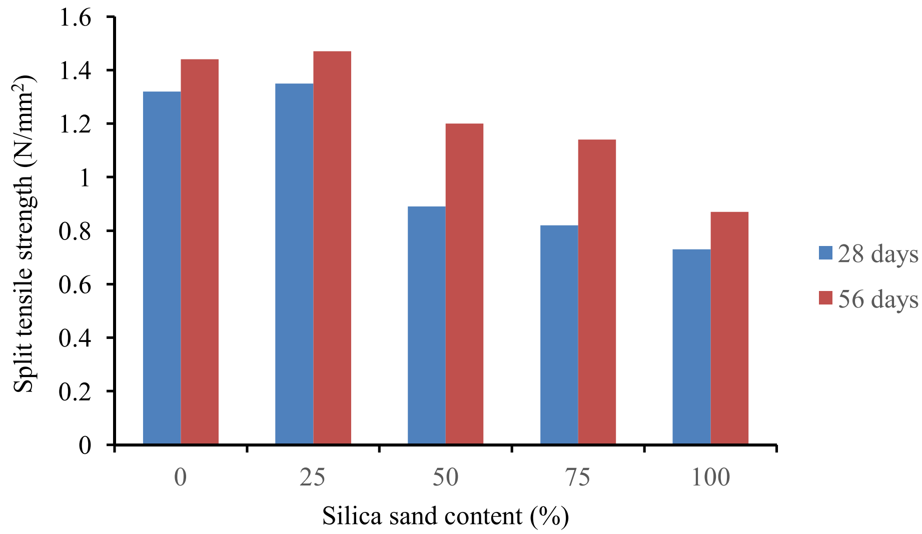

Figure 3: Split tensile strength of hardened concrete with silica sand

Conclusions

The following conclusion were drawn based on the findings from this study.

(i) The chemical composition of silica sand and its specific gravity shows that it can serve as a fine aggregate in concrete production.

(ii) The slump and density of concrete decreases with replacement of fine aggregate with silica sand. The 25% silica sand has the highest slump and density value closer to the control while the 100% silica sand has the lowest slump value.

(iii) The compressive, splitting tensile and strengths of concrete decreases as the silica sand content increases. The maximum strength of the concrete with silica sand is at 25% replacement level and it is relatively closer to the control, this can be applied in the development of durable concrete pavements for highways.

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Evaluation of Compressive Strength of Concrete with Shredded Polystyrene as a Partial Replacement for Natural Fine Aggregate

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Abstract

The use of waste materials in concrete production offers a sustainable solution to environmental challenges while enhancing construction material performance. This study investigates the strength and durability characteristics of lightweight concrete incorporating Expanded Polystyrene (EPS) as a partial replacement for fine aggregate. A 1:2:4 mix ratio with a 0.5 water-cement ratio was adopted, and EPS was added at 0%, 1%, 2%, and 3% replacement levels by weight of natural fine aggregate. Tests were conducted to determine workability, density, compressive strength, and durability after exposure to magnesium sulphate ($MgSO_4$). Preliminary material tests included specific gravity, sieve analysis, crushing value, impact value, and setting time. Results showed that workability, density, and compressive strength decreased as EPS content increased. At 28 days, compressive strengths were 21.3 N/mm², 15.6 N/mm², 6.4 N/mm², and 2.4 N/mm² for 0%, 1%, 2%, and 3% EPS, respectively, with 1% EPS identified as the optimal replacement level. The reduced density of EPS concrete makes it suitable for non-load-bearing lightweight applications such as partitions, panels, and facades. Additionally, its ductile behaviour, impact resistance, and thermal stability make it ideal for environments with large temperature variations and for use in high-rise buildings to reduce structural weight.

Keywords: Compressive Strength, Expanded Polystyrene, Partial Replacement, Sustainable Construction, Waste utilization;

Introduction

Concrete has rapidly developed as one of the most widely used building materials due to its numerous advantages, including affordability, high compressive strength, resistance to rust and fire, ease of use, and durability against decay (Karolina *et al*., 2019). However, rising material costs and environmental concerns have prompted the Nigerian construction industry to explore sustainable alternatives. Excessive exploitation of natural resources for construction has led to environmental degradation and natural disasters, emphasizing the need for eco-friendly materials that ensure long-term sustainability.

Expanded Polystyrene (EPS), a waste product commonly used for packaging, poses significant environmental challenges in terms of disposal and waste management. Utilizing EPS in concrete not only addresses waste disposal issues but also conserves natural resources and reduces the environmental footprint (Vandhiyan *et al*., 2016). Additionally, river sand, the most commonly used fine aggregate in concrete, is becoming scarce due to unsustainable mining practices, which contribute to environmental problems such as water table depletion and habitat destruction (Anjana *et al*., 2019).

EPS offers favorable mechanical and thermal properties, including a specific gravity of 1050 kg/m³, tensile strength of 40 MN/m², and a bending modulus of 3 GN/m². However, its brittleness and environmental impact make it a pressing concern for environmentalists (Karolina *et al*., 2019). Integrating EPS into concrete production presents an innovative solution, addressing both environmental sustainability and the increasing demand for lightweight materials in construction. Concrete remains indispensable in civil engineering and construction, with its mixture of cement, aggregates, and water forming a solid mass characterized by high compressive strength but low tensile strength (Suhad *et al*., 2016). However, the rising costs of construction materials have hindered infrastructure development in many developing countries, including Nigeria (Ede and Ogundiran, 2014; Igba *et al*., 2020). In response, lightweight concrete incorporating EPS can reduce structural self-weight while maintaining adequate strength, making it suitable for innovative building applications

(Jayanth, 2018). This study explores the use of EPS as a partial replacement for fine aggregate in concrete, aiming to mitigate environmental impacts, promote resource conservation, and address the need for lightweight, sustainable building materials. The study seeks to bridge the gap by exposing concrete samples to harsh environmental conditions and evaluating their performance.

Materials and Methods

Materials

The Portland limestone cement (PLC) used was Dangote BlocMaster, grade: 42.5R, having a moisture content of 1.81 % and specific gravity of 3.16. The fine aggregate used was sourced from Zaria Local Government Area, Kaduna State, Nigeria, with a specific gravity as 2.68. The coarse aggregate used has a specific gravity of 2.68. The Expanded Polystyrene (EPS) was obtained from local dumping sites of industrial waste. The EPS was shredded rubbing the bulk EPS solid against the rough surface of a perforated sheet metal figure. The result fine particles of EPS were sieved through a 4.75 mm sieve. Fine particles of EPS passing a 4.75 mm sieve were used as a replacement for fine aggregate for this research (Figure 1).

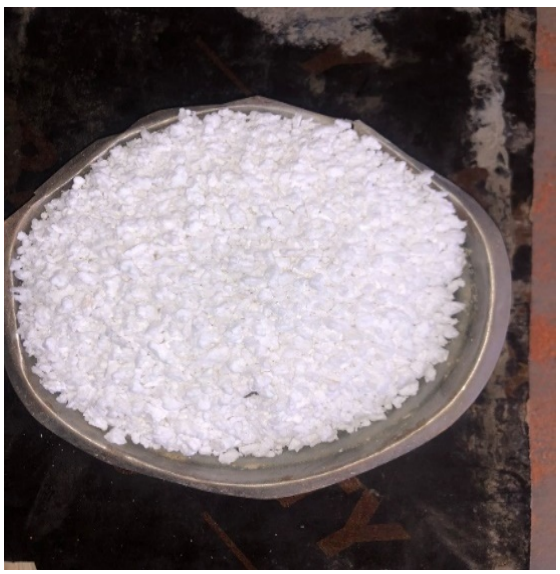

Figure 1: Extended polystyrene (EPS) beads

Figure 2: ESP-concrete cubes samples

Methods

The compressive strength test on EPS-concrete was conducted in conformity with BS EN 12390-3 (2019). The compressive strength test was conducted to compare the strength of EPS concrete to conventional concrete. The density of the specimens produced was computed in accordance BS EN 12390-3 (2019). with A total of 36 cubes (Figure 2) using varying percentages of EPS to partially replace fine aggregate were cast with the same W/C ratio of 0.5. The cubes were tested each for 7, 14, and 28 days after curing. Three cubes were each tested for 7, 14, and 28 days after curing.

Results and Discussions

Density of EPS-Concrete

The results of density at various percentage replacement of fine aggregate with EPS in concrete are presented in Figure 3. The density of the concrete cubes decreases as the EPS replacement percentage increases, with reductions of 2.5%, 19.75%, and 28.38% for 1%, 2%, and 3% EPS replacement, respectively. For applications requiring high density, EPS replacement should be limited to a maximum of 1%.

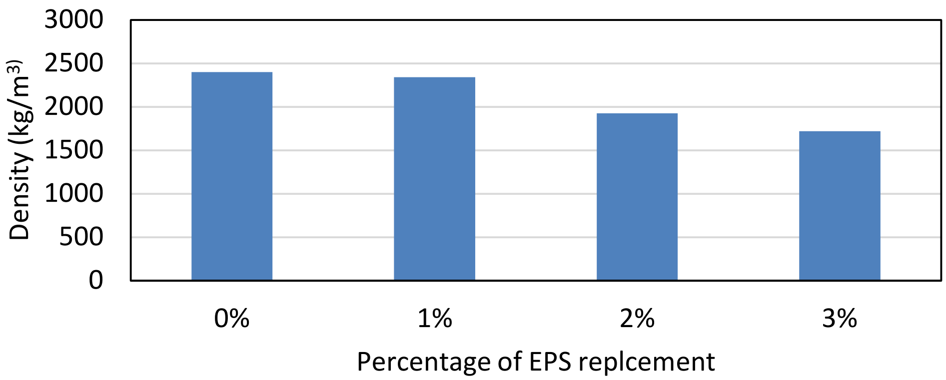

Figure 3: Density of EPS-concrete at various EPS percentage replacement

Compressive Strength of EPS-Concrete

The results of the compressive strength of EPS-concrete for varying percentages of EPS replacement (0%, 1%, 2%, and 3%) at curing ages of 7, 14, and 28 days are presented in Figure 4. For all replacement levels, the compressive strength increases as the curing age progresses from 7 to 28 days as can be observed in Figure 4. This is a typical behavior for concrete as the hydration process continues over time. The 0% EPS replacement (control mix) shows the highest strength gain across all curing ages (15.2 MPa at 7 days to 21.3 MPa at 28 days), indicating that the absence of EPS enhances strength development. Increasing the EPS content reduces compressive strength at all curing ages. For example, at 28 days, compressive strength decreases from 21.3 MPa (0% EPS) to 15.6 MPa (1%), 6.4 MPa (2%), and 2.4 MPa (3%). The reduction in strength is more pronounced at higher percentages of EPS replacement due to EPS's lightweight and non-structural nature, which limits its ability to contribute to concrete's load-bearing capacity. Considering strength loss with EPS content, at 7 days, the strength loss compared to the control mix is approximately 38.2%, 68.4%, and 89.5% for 1%, 2%, and 3% EPS replacement respectively. Similar trends are observed at 14 and 28 days, with increasing EPS leading to significant strength reductions. The use of EPS in concrete offers environmental benefits by repurposing waste materials and reducing the density of concrete. However, its compressive strength limitations must be carefully considered in the design and application of EPS-concrete. These results highlight the trade-off between strength and lightweight properties in EPS-concrete and provide valuable guidance for selecting suitable EPS replacement levels for specific construction needs. The results obtained in this study align with those obtained by Jaydeep (2017); Aasif *et al.* (2018); Gupta *et al.* (2018); and Ashish *et al.* (2020).

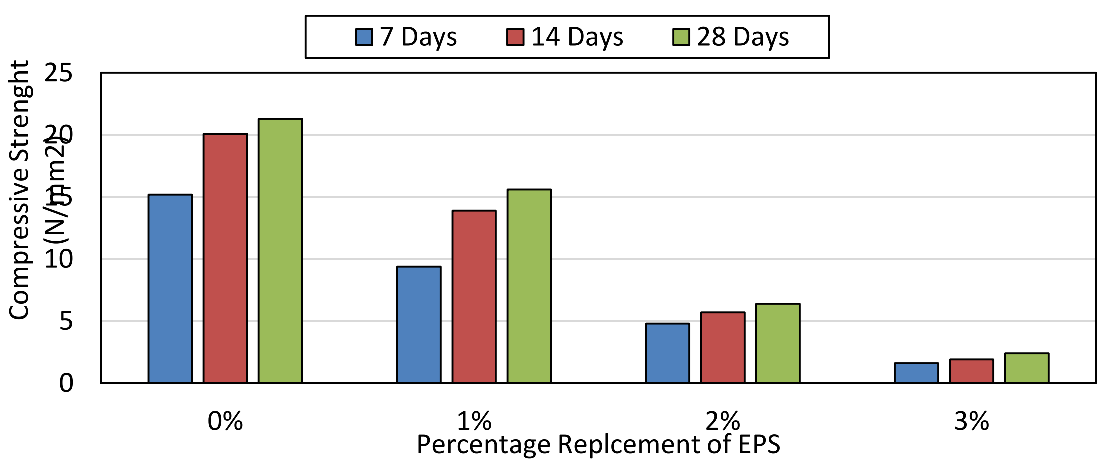

Figure 4: Relationship between Compressive Strength, Percentage of EPS and Curing Age

Durability of EPS-Concrete

The compressive strength test was of EPS-concrete subjected to $MgSO_4$ attack was conducted and compared to normal EPS-concrete (cure in normal water). The result is as shown in Figure 5 for samples cured for 28 days. The percentages of EPS replacement range from 0% to 3%.

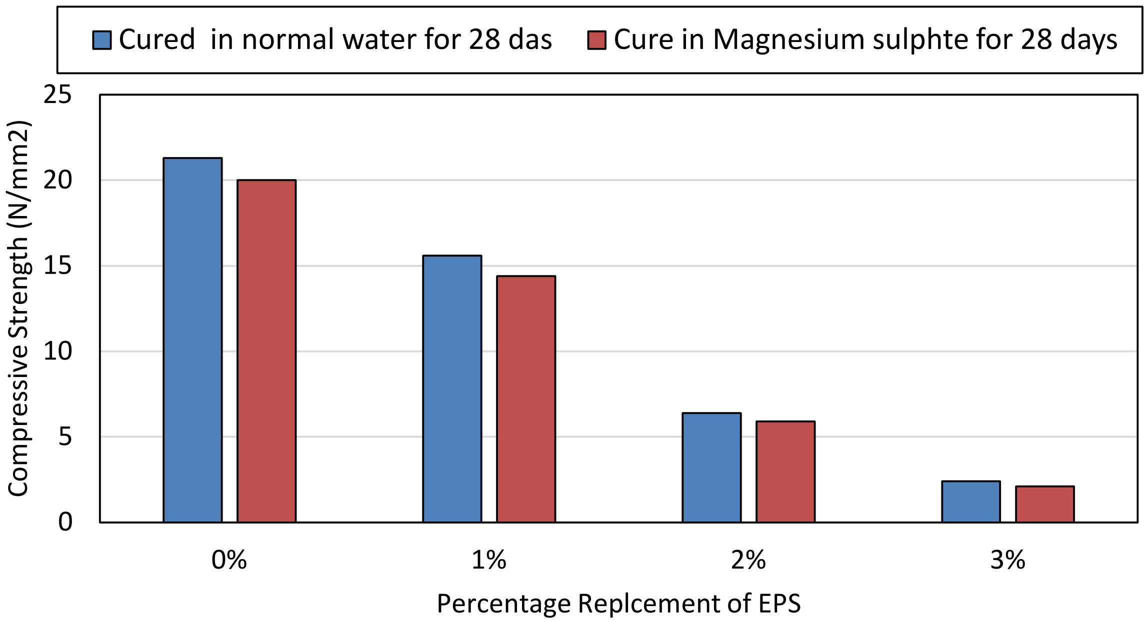

Figure 5: Compressive strength for sample subjected to $MgSo_4$ for 28days

The compressive strength of concrete cured in magnesium sulphate is consistently lower than that of concrete cured in normal water across all EPS replacement levels as can be seen in Figure 5. This reduction is due to the chemical attack of magnesium sulphate, which likely weakened the concrete matrix by reacting with the cementitious materials, leading to decreased structural integrity. Looking at compressive strength trends across EPS replacement: At 0% EPS replacement, the strength decreases from 21.3 N/mm^2 (normal water) to 20 N/mm^2 (magnesium sulphate), representing a 6.1% reduction. At 1% EPS replacement, the strength drops from 15.6 N/mm^2 to 14.4 N/mm^2, showing a 7.7% reduction. At 2% EPS replacement, the strength decreases from 6.4 N/mm^2 to 5.9 N/mm^2, a 7.8% reduction. At 3% EPS replacement, the strength reduces from 2.4 N/mm^2 to 2.1 N/mm^2, indicating a 12.5% reduction. Higher percentages of EPS replacement led to significantly lower compressive strength in both curing conditions. The compressive strength reduction due to magnesium sulphate is more pronounced at higher EPS levels, indicating that concrete with higher EPS content is more vulnerable to chemical degradation.

Conclusions

The results of this project highlight that while the addition of shredded polystyrene can significantly reduce the mass of concrete, it may have some trade-offs in terms of compressive strength. Based on the findings of this research, the following conclusions can be drawn:

i. The optimal replacement level of EPS is found to be 1%, as it effectively balances lightweight properties with strength. This dosage achieves a 28-day compressive strength of 15.6 MPa, demonstrating its ability to maintain adequate structural integrity while reducing weight. The performance remains consistent under both normal and aggressive curing conditions, confirming 1% EPS as the ideal replacement level for achieving these dual objectives.
ii. Higher EPS replacement levels (2% and 3%) result in significant strength reductions, rendering them unsuitable for structural applications requiring high compressive strength. However, these mixes are well-suited for non-load-bearing uses, such as lightweight partitions, panels, or facades, where

compressive strength is not critical. In contrast, EPS-concrete with a 1% replacement achieves a balance between lightweight properties and moderate strength, making it suitable for lightweight structural elements like upper floors or fill materials.

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DETECTION OF GROUNDWATER FLUCTUATION SIGNATORIES IN MINNA METROPOLIS

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Abstract
It is important to note, that detecting groundwater fluctuation signatories and spatiotemporal variations of groundwater level is crucial for understanding the hydrodynamic behaviour and aquifer characteristics. In doing so, this research explored basic statistical tool of central tendency family and simple regression approach. In order to analysis the spatial temporal variation of wet and dry season groundwater pattern. The result shows that Shakwata has the highest maximum static water level (SWL) of 9.250 and mean of 4.800, Kadna maximum of 8.700 and mean of 4.522 and Korokpma maximum static water level of 6.900 and mean of 1.200. These stations are located in southern part of Minna with average elevation of 246.732 m above the sea level, while east, north and central have average elevation of 287.718, 289.268 and 260.191 respective. Shakwata, Kadna and Korokpma have the highest depression, this probably accounted for high recharge level recorded in the candidate stations or area. In the overall, it recommended, that surface elevation is key player that must be given adequate attention in predicting static water level in any groundwater fluctuation analysis within the horizon groundwater studies.
Keywords: Groundwater, Fluctuation, Well depth and Surface elevation

1.0 Introduction

Groundwater is a fundamental asset of the earth surface that is vital in keeping the water level and streams in waterways, lakes and wetlands. Groundwater covers around 95% of the freshwater on our planet, making it essential to human (Mohammady *et al.,* 2017). Das *et al.,* (2020) opined that groundwater covers around 95% of the freshwater on the planet, making it essential to human. Over the past 50 years, groundwater has been widely used for household, technical purposes, irrigation and other uses, which have created massive pressure on the adequacy of groundwater (Faruki *et al.,* 2024). Yearly, 982 m3 of groundwater is removed internationally for different purposes (Yousuf *et al.*, 2018). The water system is vital to food security in many parts of the world and groundwater use, has become a significant source of irrigation water, especially in China and South Asia (Mohammady *et al.,* 2012).Groundwater is a hydrogeological inference task that incorporates a detail study of the geology and hydrogeological conditions of the area, and also the use of indirect surface geophysical methods. The general pattern of groundwater occurrence is dependent upon the physical framework in which groundwater occurs and the hydrologic balance that results from recharge and discharge mechanisms. The local occurrence of groundwater is the consequence of a finite combination of climatic, hydrologic, geologic, topographic and soil forming factors which together form an integrated dynamic system. Understanding these mechanisms will go a long way in ensuring that groundwater is developed optimally for use, costly failure rates will be reduced and groundwater will be protected from contamination and excessive withdrawal (Idris-Nda *et al.* 2015).

Groundwater level fluctuations are indicative for changes in the quantity of water stored underground. Mid and long term analysis of groundwater level fluctuations refer to a specific cycle called water year or hydrological year (HY) (Taylor and Alley, 2002). It is the annual cycle that is associated with the natural progression of the hydrological seasons and depends on climate conditions and differs in different regions of the world. The fundamental explanations for groundwater decay are overexploitation of water, population increment, urbanisation, precipitation change (Sarkar and Kanungo, 2004).These fluctuations serve as natural stresses to aquifers. Response of aquifers to these stresses or controlled stream-stage variations can be used to estimate the hydraulic parameters of aquifers (Sarkar and Kanungo, 2004). The complexity of flow within aquifers may require extensive data and detailed modelling to address contending issues, with adequate attention to accurate analysis of the water balance though complicated by inflows and losses that are difficult to identify, monitor or interpret. However, relatively simple data, such as specific water levels in a carefully designed network of monitoring wells, can be combined with estimates of rainfall input to provide key indications of groundwater dynamics. Long-term declines in water levels are often indicative of overabstraction conditions. Similarly, stable water levels generally indicate that inflows are in balance with outflows.Compared to soft rock aquifer with high yield capacity, hard rock terrain possesses a limited quantity and is mostly concentrated in the weathered zone and fractured zone (Pradhan , 2017).

Different techniques have made to delineate groundwater potential zones and concomitant fluctuations. For example, probabilistic models such as frequency ratio (FR) Ozdemir (2018), multi-criteria decision analysis, that is AHP Pradhan (2017), weights - of – evidence Lee *et al.* (2019), logistic regression Pourghasemi and Beheshtirad, (2015), evidential belief function Mogaji *et al.* (2015), certainty factor, decision tree, artificial neural network model, Shannon's entropy (SE) (Chenini and Mammou, 2017). In recognition of all this, it is important to bring to fore the existence of the following gaps: Periods of record for groundwater data are generally short, and data-quality concerns are not often present, such factors make water-level change and overabstraction assessments based on publicly available information problematic. This is not just a concern for groundwater but is a common feature in many water-resource evaluations exercises. Secondly, most reviewed approaches did not take adequate cognisance of spatio-temporal implication of water-level trend dynamics inference or in the definition of critical and overexploited areas rather dwells on the estimated level of groundwater development within administrative areas as the sole measure. Thirdly, the relationship between precipitation and groundwater level was shallowly investigated and the statistical resources of Pearson, Kendall nor Spearman correlations were not fully harness in this regards. Considering, the specific nature of the study area, there is a complete dearth of studies that attempted classifying the studies area in terms of seemingly hydrogeological similarity. Against this backdrop, It suffices to state, that the implication of the surmised missing link or gap could marred any qualitative groundwater studies.

2.0 Materials and Methods

2.1 Study Area

Niger State is one of the 36 states created in Nigeria with her capital in Minna located between latitude 9° 34'– 9° 37'N and longitude 6° 36'– 6° 39'E (Musa and Egharevba, 2009) with an annual rainfall of 578 mm and a mean temperature of 34°(Figure 1).Niger State is one of the 36 states created in Nigeria with her capital in Minna located between latitude 9° 34'– 9° 37'N and longitude 6° 36'– 6° 39'E. In line with Musa and Egharevba (2009) annual rainfall of 578 mm and a mean temperature of 34°. The onset of rainfall in Minna is mostly March-April and ends towards October-November and mean temperature is of 34 °C (Musa *et al,* 2012). It was classed as guinea savannah that is, comprises of short grasses and scattered tree of tropical climate vegetation belt of Nigeria, having two (2) distinct seasons (wet and dry seasons). Figure 1 shows a detail view of the study location.

2.2 Data Type and Mobilisation

Static water level (SWL) data for Minna town, was obtained from field test, sampling and environmental agencies.

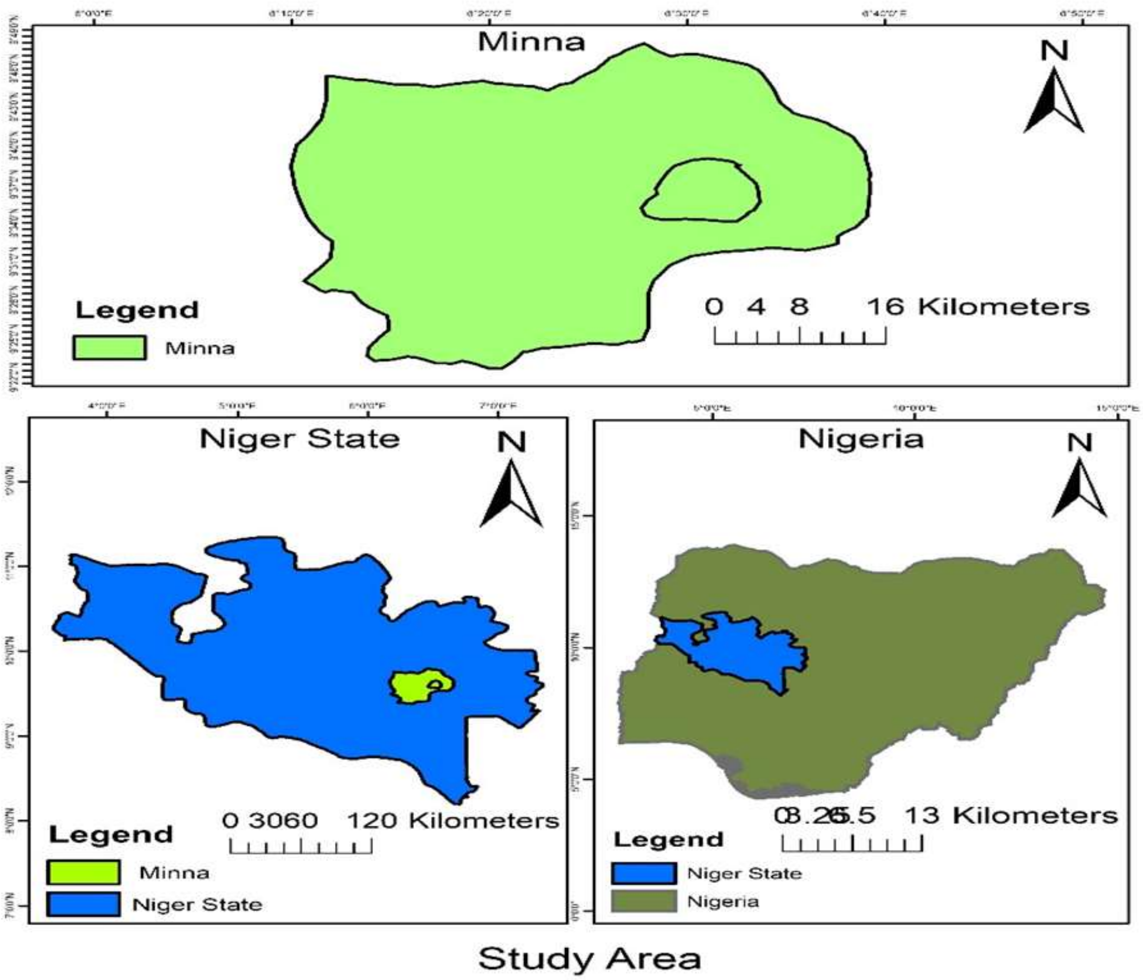

Figure 1: Minna Metropolis Map

2.2 Methods

The entire SWL dataset of Minna was aggregated and the mean, standard deviation and skewness, kurtosis, regression parameters of the dataset was computed using Microsoft excel.

3.0 Results and Discussion

3.1 Spatiotemporal variation analysis of static water level

The monitoring dataset provided in Table 1. The descriptive statistics gives valid insight into the groundwater dynamics of Minna. For instance, Shakwata has the highest maximum static water level (SWL) of 9.250 and mean of 4.800, Kadna maximum of 8.700 and mean of 4.522 and Korokpma maximum static water level of 6.900 and mean of 1.200. These stations are located in southern part of Minna with average elevation 246.732 m above the sea level, while east, north and central have average elevation of 287.718, 289.268 and 260.191 respective. Shakwata, Kadna, Korokpma have the highest depression, probably accounted for high recharge level recorded in the candidate station. In tandem, with the findings of Abdullahi and Iheakanwa (2013) differences in recharge in comparison with flat surface are manifested at the foot of a hill, at such, depths with high reresistivitysistivities may have hard consolidated material like granites, boulders or a dike–like structure, whereas low resistivity could be an indication of zones of fractured/weathered rocks or clays. Abiye (2016) groundwater flows from regions of higher hydraulic head to regions of lower hydraulic head. The velocity of groundwater flow is proportional to the magnitude of the hydraulic gradient and the hydraulic conductivity of the aquifer. Groundwater flows faster where the hydraulic gradient and/or hydraulic conductivity are larger. This likely added strength to the conclusion reached by Mohammed *et al* (2007), that the central and northern parts of the Minna have poor to marginal groundwater potential, and this is supported by the occurrences and concentration of fractures which can constitute weathered/fractured aquifers around these regions unlike the southern. The results indicated that significant increase or decrease in SWL, may distort statistical properties of candidate distribution, for example rainfall maximum of 1.100 m of Bosso estate yielded increased skewness and kurtosis of annual surmised distribution at the 0.875 and 5.940 m respectively. In a similar routine, a reduction of SWL markedly intensified the interaction of the skewness and the kurtosis, while the skewness–kurtosis interaction weakened with decreased of maximum SWL in stations across supposed stations as attested by Odekunle (2018). Moreover, it was observed that the effect of extreme precipitation on the skewness–kurtosis interaction was stronger in; Bosso estate, Ketterengwari, Kadna, Jikpan, Gidan mangoro, Brighter, Tunga market, Saukahuta, Limawa primary school, Bosso Dam, Maitumbi, Taliba road and Tundun Fulani. Faruki *et al* (2024) associated extreme kurtosis and skewness to extreme temperature with concomitant evapotranspiration without no corresponding adequate rainfall depth to replenish the lost soil moisture. Rainfall is principal input to all hydroclimatic/hydrogeology phenomena. Therefore, rainfall pattern count. As noted Odekunle (2018) influence of the dynamics of continental air and maritime air masses which meet along a slanting surface called Inter-Tropical Discontinuity (ITD) may distract the rainfall formation of the region under study vis-à-vis groundwater dynamics. Odekunle (2018) reiterated there are notable varying degrees of convective activity and precipitation that occur at the south of ITD while little or no cloud development or precipitation occur in the Northern part of ITD.

Table 1: Summary statistics of production monitor well

Station	**SWL(m)**						
	Min	**Max**	**Median**	**Mean**	**SD**	**Skew.**	**Kurt.**
Tunga market	0.500	1.500	1.000	0.900	0.418	0.512	-0.612
Sauka kahuta	1.500	4.700	0.700	3.233	0.738	0.875	-0.823
Boss Dam	0.100	1.100	0.500	0.663	0.592	2.252	5.940
Bosso Estate	0.590	1.950	2.050	1.916	0.497	-1.621	3.265
Brighter	0.600	2.500	2.00	1.786	0.773	-1.001	-1.047
Chanchaga	0.760	3.230	1.370	1.510	0.903	0.996	0.462
City gate	1.700	2.400	1.800	1.940	0.249	1.496	2.041
Dutse kura	0.340	1.550	1.115	1.236	0.497	0.085	-0.682
M.I. Wushishi	0.500	1.500	1.300	1.300	0.100	0.00	0.00
Gidan Mangoro	0.700	1.100	1.250	1.290	0.473	-0.005	-1.808
Jikpan 1	0.600	3.260	1.200	1.590	0.964	1.037	-0.477
Kadna	1.800	**8.700**	3.300	4.522	2.331	0.492	-1.374
Ketterengwari	0.100	2.500	1.150	1.229	0.759	0.336	-1.085
Korokpma	0.360	**6.900**	1.200	1.665	1.589	2.221	4.354

Kpakungu	1.100	1.500	1.500	1.785	1.707	1.501	1.507
Limawa primary	0.390	2.590	1.785	1.590	0.629	-0.723	-0.489
Maitumbi	0.100	5.900	2.400	2.725	2.313	0.179	-2.055
Moris junction	0.500	1.600	0.750	0.875	0.316	1.115	0.557
Shakwata	1.900	**9.250**	4.800	5.213	1.983	0.383	0.135
Talba Road	1.300	4.480	2.740	2.838	1.008	-0.111	-0.766
Top medical	1.000	1.100	1.100	1.100	0.082	0.000	0.00
Tundun Fulani	0.800	2.970	2.200	2.410	0.995	0.077	-1.319
Tunga	1.100	3.600	1.400	1.690	0.759	1.376	1.865
Tunga goro	0.300	1.570	0.910	0.902	0.300	0.224	1.575
Maikunkele	0.700	3.480	1.270	1.476	0.748	1.787	3.478

3.2 Dry season spatiotemporal variation analysis of static water level

In the light of the foregoing, investigating spatiotemporal variations of groundwater level is crucial for understanding hydrodynamic behaviour and aquifer characterisation. The distribution and relationship between SWL and well depth are depicted in Figure 2. The results show a concentrated SWL in a wells depth range between 0 and 50 m with few outlier, which is supposedly caused by extreme temperature variation hence, with the SWL height extending from 0 to 9 m. The indicated boundary from the result demonstrates two distinct borders between a less productive aquifer with a SWL greater than 8 m of SWL and a productive aquifer among the depth wells close to SWL equals to zero. Conversely, in the linear regression analysis noted in Figure 3 and Table 2 and Table 3 between the SWL and the topographic surface reveals an R-squared value of 0.4954, with a correlation coefficient (R) of 0.7038 and a statistical significance at the 95% confidence level with a p-value of less than 0.0001. These strong correlations indicate a gravitationally driven aquifer system. This implies that surface elevation might be a substantial factor in predicting SWL within.

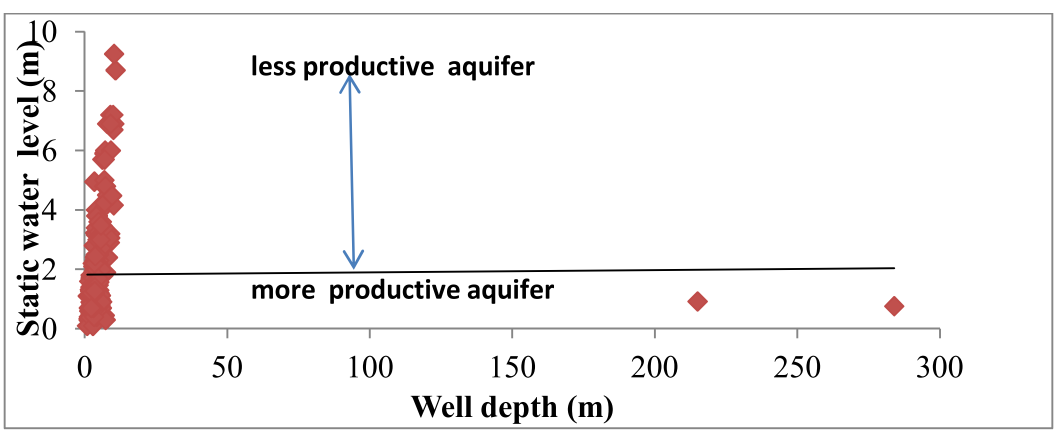

Figure 2: Spatial Distribution of Depth to Static Water for Dry Season

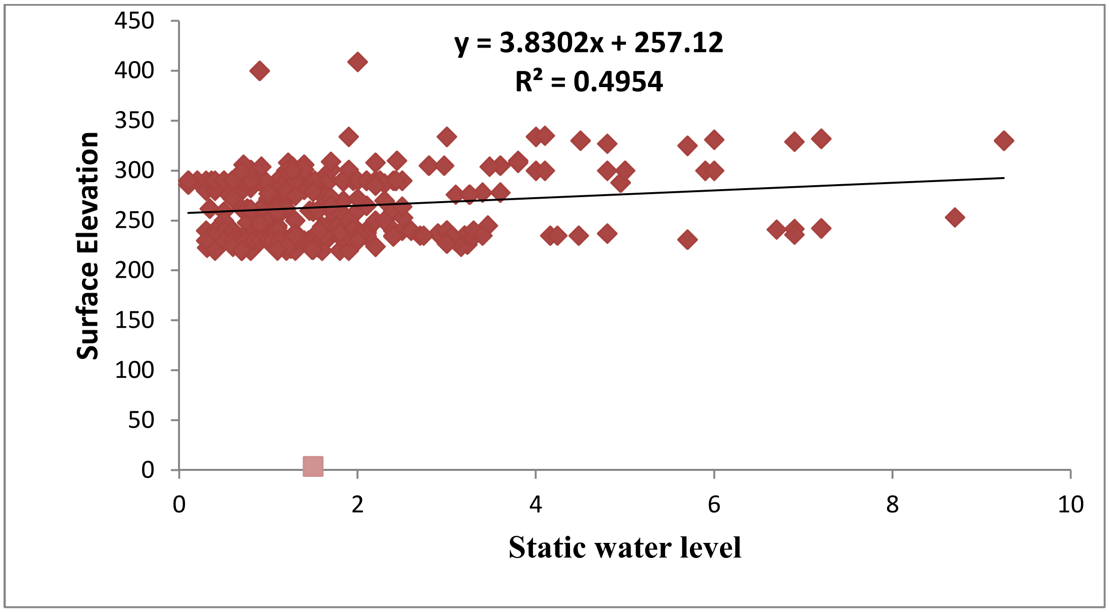

Figure 3: Spatial Distribution of Depth to Static Water for Wet Season

Table 2: SWL Verses Surface Elevation Dry Season

Regression Statistics	
R	0.7038
R Square	0.4954
Adjusted R Square	0.028015797
Standard Error	31.91473789
Observations	294

Table 3: Correlation Analysis for Dry Season

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	257.1407211	2.940991192	87.43335303	1.8893e^{-3}	251.3524934	262.9289
X Variable	3.82829019	1.245657425	3.073309012	0.002316919	1.376685146	6.279895

4.0 Conclusion

It is important to note, that detecting groundwater fluctuation signatories and spatiotemporal variations of groundwater level is crucial for understanding hydrodynamic behavior and aquifer characterization. Findings here indicated that the volume of water yielded in most considered stations and wells were linear function of depth of the well, topography or surface elevation and SWL. Mostly link to gravitationally driving system of the aquifer. For instance, Shakwata has the highest maximum static water level (SWL) of 9.250 and mean of 4.800, Kadna maximum of 8.700 and mean of 4.522 and Korokpma maximum static water level of 6.900 and mean of 1.200. These stations are located in southern part of Minna with average elevation 246.732 m above the sea level, while east, north and central have average elevation of 287.718, 289.268 and 260.191 respective. Shakwata, Kadna, Korokpma have the highest depression, probably accounted for high recharge level recorded in the candidate stations or area. In the overall, it suffices to know, that surface elevation is key player that must be given adequate attention in predicting SWL within groundwater horizon and future groundwater exploration should be tilt towards areas of seemingly rich groundwater zone. It is recommended that adequate thematic layers analysis and studies should done in order to have thorough understanding of exact groundwater potential zone, effective groundwater planning and management in real time.

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Assessment of Ergonomic Hazards and Risk Minimization Practices among Solid Waste Collectors in Port Harcourt Metropolis

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Abstract
Waste generation has continued to witness unprecedented increase globally. The disposal of these wastes presents ergonomic hazards with associated human health implications. These ergonomic hazards include uncomfortable work position, standing long hours, working under extreme heat and cold, frequent lifting of heavy objects, working long hours without breaks and rest periods and exposure to vibrations.This study was carried out to assess ergonomic hazards and risk minimization strategies among solid waste collectors in Port Harcourt Metropolis. The survey research design was deployed for this study. A well-structured questionnaire validated by two professionals in the field of study was distributed to 250 respondents selected from 25 refuse collection centers within the city metropolis. Results from questionnaire analysis revealed that 81.2% of the respondents were in agreement that they undertook their jobs under uncomfortable work positions, 16.0% of the respondents were not in agreement and 2.8% were undecided. 78.0% of the respondents stood long hours on moving vehicles, 79.2% of the respondents frequently lifted heavy objects in the course of their job. 60.4% of the respondents worked under extreme temperature of heat and cold. Furthermore, the study revealed that the heath implications of these ergonomic hazards include carpal tunnel syndrome (30.2%), fatigue and reduced energy levels (28.5%), back and neck pain (18.6%), shoulder, wrist and elbow injuries (13.2%) and stress and mental health issues (9.5%). Research findings also revealed that 68.0% of the waste collectors do not wear personal protective clothing, 75.20% of the waste collectors do not wear safety shoes, 66.8% of the waste collectors do not wear nose masks while 74.8% of the waste collectors do not wear reflective vest. This could be attributed to the inadequate provision of these personal protective equipment by the employer. The study revealed that solid waste collectors in Port Harcourt were exposed to ergonomic hazards and the hazard minimization strategies were ineffective. Arising from the finding of this study, the study recommends the provision of adequate training, first aid kits and personal protective equipment.

Key words: Ergonomic, Risk, Solid Waste, Minimization

1.0 Introduction

Waste materials are by-products of industrial and domestic human activities which cause environmental damage and affect human health. The generation of waste products has continued to increase due to industrialization and urbanization (Kaza *et al*., 2018).

Solid waste collectors are saddled with the responsibility of collecting and disposing municipal waste materials. However, poor waste disposal systems and methods in addition to insufficient facilities presents solid waste collectors with several ergonomic hazards (Thakur *et al*., 2018).

Ergonomic hazards are prevalent among solid waste collectors because they usually gather waste manually, lift heavy loads and work under unfavourable conditions and uncomfortable posture (Lopez-Arquillos *et al*., 2019).

The health impacts associated with ergonomic risks of solid waste collection is enormous. Solid waste collectors suffer musculoskeletal disorders, cuts and lacerations, sprain and fractures (Ramos *et al*., 2017). Worse still, it is estimated that over 2.3 million deaths per annum is attributed to work related diseases connected to solid waste collection (Lissah *et al*., 2022).

In Port Harcourt metropolis, the gory sites of refuse dumps adorn the city. The inadequate waste disposal system can be attributed to the rise in commercial activities and population surge (Miwano *et al.*, 2018).

However, despite the variety of ergonomic risks and associated health impacts solid waste collectors are exposed to, majority of them within the city metropolis do not wear personal protective equipment (PPE) and are not provided with the adequate tools to minimize risks while undertaking their jobs with ease (Alozie *et al.*, 2020).

In addition, literature on occupational risks of solid waste collection within the city metropolis concentrated on the biological, chemical and psychosocial risks. Scholarly article on ergonomic hazards of solid waste collection is scanty. This study is therefore imperative to assess the ergonomic hazards and risk minimization strategies of solid waste collectors in Port Harcourt metropolis.

2.0 Materials and Methods

The study was undertaken in Port Harcourt metropolis located between latitude 04^0 43' and 04^0 57' North of the Equator and between 06^0 53' and 07^0 08' East of the Greenwich Meridian (Figure 1).

The study design adopted for this study was a survey research design. A sample size of 250 was adopted for the study which is representative of the population of study. The cluster sampling technique was adopted to select 25 refuse collection centers in Port Harcourt Metropolis. To distribute the questionnaires to the solid waste collectors, the purposive sampling technique was adopted to select solid waste collectors from each of the 25 refuse collection centers.

The face and content validity of the questionnaire were tested through the help of research professionals who are knowledgeable in the field of enquiry. The test-retest method was used to determine the reliability of the research instrument. The Cronbach Alpha reliability coefficient of 0.7 implies that the questionnaire is reliable.

Data was collected for a period of four (4) weeks from 2nd June 2024 to 30th June, 2024. Descriptive statistics such as frequency distributions and percentages were used to present the data.

3.0 Result

3.1 Socio-economic characteristics of respondents

Table 1 shows the socio-demographic characteristics of respondents. The distribution of sampled respondents from the questionnaires analyzed shows that 51.2% were within the ages of 18-28, 36.8% were within the ages of 29-39, 10.0% were within the ages of 40-50 and 2.0% were within the ages of 50 and above. Furthermore, questionnaire analysis revealed that 100.0% of the respondents were males and 0.0% of the respondents were females. In the analysis of the marital status of respondents, it was revealed that 61.6% of the respondents were single and 29.2% were married. The percentages of divorced/separated and widowed respondents were 7.2% and 2.0% respectively. It was also revealed that 77.2% of the respondents were Christians, 13.0% were Muslims and others accounted for 4.8% of the respondents. From the

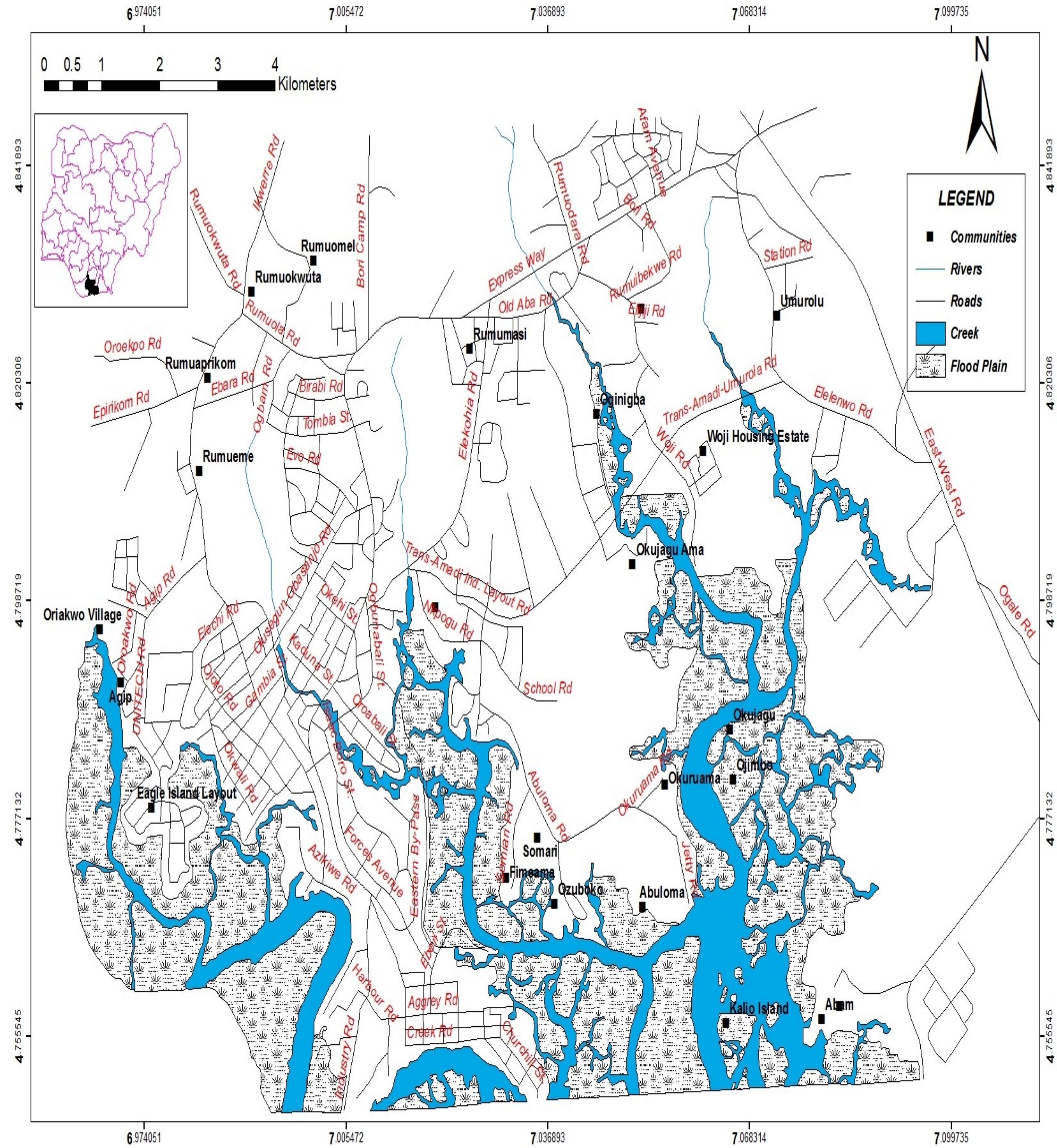

Fig. 1**:** Map of Port Harcourt Metropolis

Source: *Cartography/GIS Laboratory, Department of Geography and Environmental Management, University of Port Harcourt, Choba.*

questionnaire analyzed, it shows that 22.4% of the respondents had no formal education, 48.0% had primary school education, 29.6% had secondary education while 0.0% had tertiary education. The questionnaire analysis also revealed that 60.0% of the respondents earned N25,000-35,000 monthly, 37.2% earned N36,000-50,000 and 2.8% of the respondents earned above N50,000.

Table 1: Socio-demographic characteristics of respondents

Variables	Frequency(n=250)	Percent (%)
Age(years)		
18-28	128	51.2
29-39	92	36.8
40-50	25	10.0
>50	5	2.0
Gender		
Male	250	100.0
Female	0	0.0
Marital Status		
Single	154	61.6
Married	73	29.2
Divorced/Separated	18	7.2
Widow/Widower	5	2.0
Religion		
Christianity	193	77.2
Islamic	45	18.0
Others	12	4.8
Level of education		
None	56	22.4
Primary	120	48.0
Secondary	74	29.6
Tertiary	0	0.0
Monthly Income		
N25,000-35,000	150	60.0
N36,000-50,000	93	37.2
> N50,000	7	2.8

Source: Researchers' Analysis (2024)

3.2 Ergonomic hazards among solid waste collectors

Table 2 shows the ergonomic hazards among the solid waste collectors. 81.2% of the respondents work in uncomfortable positions/ posture, 16.0% of the respondents did not and 2.8% were undecided. In the same vein, 78.0% of the respondents stood for long hours in moving vehicles, 20.0% of the respondents did not and 2.0% of the respondents were undecided. Similarly, 79.2% of the respondents frequently lifted heavy objects, 17.2% of the respondents did not and 3.6% of the respondents were undecided. Moreso, 90.0% of the respondents were exposed to slippery surfaces, 6.0% of the respondents were not and 4.0% were undecided. Furthermore, 60.4% of the respondents worked in extreme temperatures of heat and cold, 35.6% of the respondents did not work in extreme temperatures of heat and cold and 4.0% of the respondents were undecided.

Table 2: Ergonomic hazards among solid waste collectors

Ergonomics Hazards	Frequency (n=250)	Percent (%)
Uncomfortable work positions		
Yes	203	81.2
No	40	16.0
I don't know	7	2.8
Stood long hours in moving vehicles		
Yes	195	78.0
No	50	20.0
I don't know	5	2.0
Frequently lifted heavy objects		
Yes	198	79.2
No	43	17.2
I don't know	9	3.6
Exposure to slippery surfaces		
Yes	225	90.0
No	15	6.0
I don't know	10	4.0
Working in extreme temperature of heat and cold		
Yes	151	60.4
No	89	35.6
I don't know	10	4.0

Source: Researchers' Analysis (2024)

3.3 Human health implications of ergonomic hazards associated with waste collectors.

Fig 1 reveals the human health implications of ergonomic hazards associated with waste collectors in the study area. Questionnaire analysis revealed that 30.2% of the total respondents suffered carpal tunnel syndrome, 28.5% suffered fatigue and reduced energy levels, 18.6% suffered back and neck pain, 13.2% suffered shoulder, wrist and elbow injuries and 9.5% of the total respondents suffered stress and mental health issues.

3.4 Risk minimization practices among solid waste collectors

Table 3 shows the risk minimization practices among solid waste collectors. 68.0% of the respondents do not wear protective clothing while working and 32.0% of the respondents wear protective clothing while working. Further analysis revealed that 63.8% of solid waste collectors who wear protective clothing wear them sometimes while only 36.2% always wear their protective clothing. This implies poor safety practice among the solid waste collectors. 43.0% of solid waste collectors who do not wear protective clothing opined that they do not wear protective clothing because it is not provided by the management, 34.1% of the waste collectors opined that they do not wear protective clothing because the one provided is torn and worn out and 22.9% opined that they do not wear personal protective clothing because it is discomforting while working. In the same vein, 75.2% of the respondents do not wear safety shoes while working and 24.8% of the respondents wear safety boots while working. Similarly, 66.8% of the respondents do not wear nose

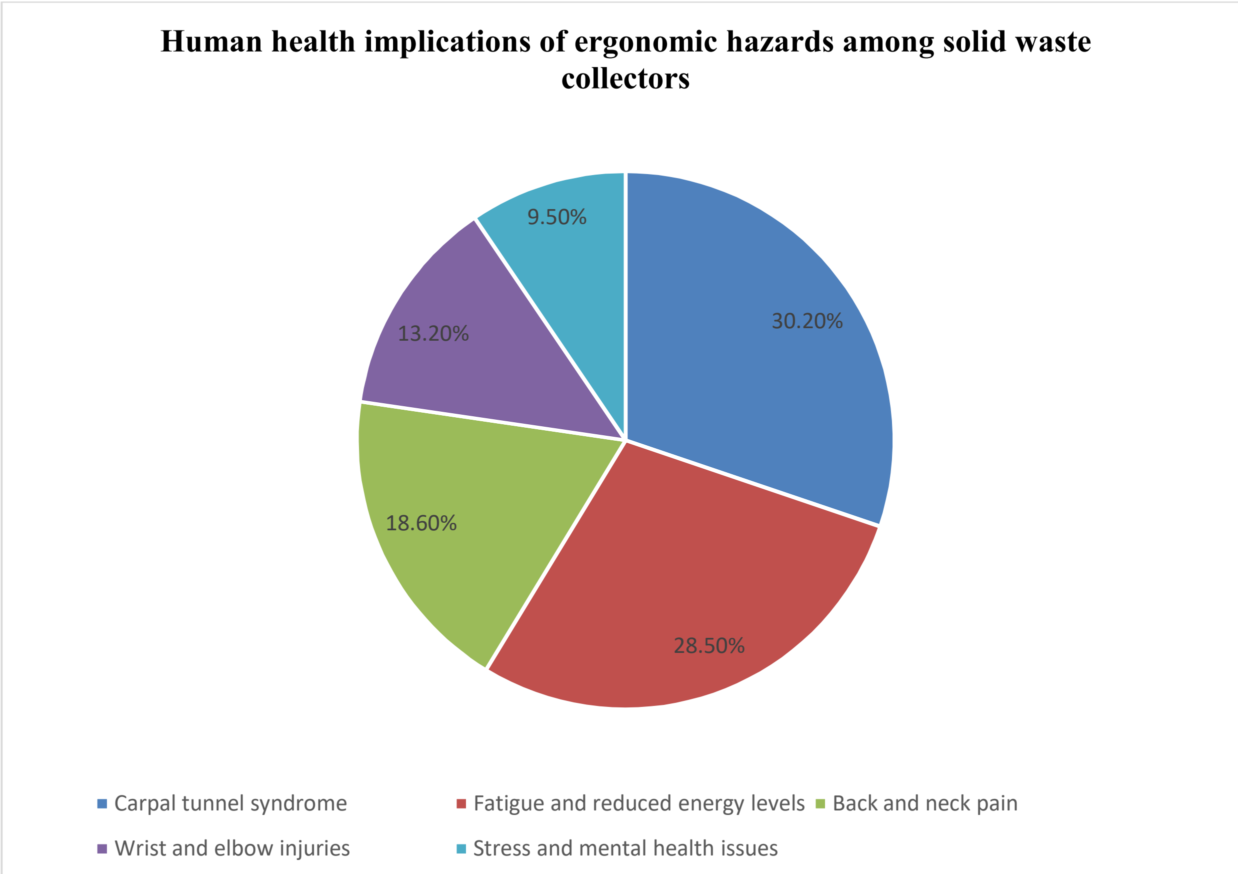

Figure 1: Human health implications of ergonomic hazards associated with waste collectors

masks while working and 33.2% of the respondents wear nose masks while working. Furthermore, 70.4% of the respondents use lights while working at nights and 29.6% of the respondents have no access to light while working at nights. In addition, 74.8% of the respondents wear reflective vest while working at nights and 25.2% of the respondents do not wear reflective vests while working at nights. Further analysis revealed that 51.5% of the solid waste collectors do not wear reflective vests because it was not provided by the management, 27.5% of the waste collectors opined that they do not wear reflective vests because theirs were torn and worn out and 21.0% of the solid waste collectors were of the opinion that they do not wear reflective vests because it was discomforting to put them on while working.

3.5 Organizational strategy for risk minimization

Table 5 shows the organizational strategy for risk minimization among solid waste collectors. Results revealed that 74.8% of the respondents opined that the waste management companies did not provide adequate working tools and 25.2% of the respondents were of the opinion that the waste management companies provided adequate working tools. Results also revealed that 84.8% of the respondents opined that the waste management companies did not equip them with training on occupational hazard and prevention strategies in the last one year and 15.2% of the respondents were of the opinion that the waste management companies have equipped them with training on occupational hazard and prevention strategies in the last one year. Questionnaire analysis revealed that 94.4% of the respondents noted that the waste management companies did not provide them with first aid kits while working and 5.6% of the respondents noted that first aid kits were provided by the waste management authorities.

Table 3: Risk minimization practices among solid waste collectors

Variables	Frequency (n=250)	Percent (%)
Wear protective cloths while working		
Yes	80	32.0
No	170	68.0
If yes, often wear (80)		
Sometimes	51	63.8
Always	29	36.2
If no, why don't you wear it (170)		
It is discomforting while working	39	22.9
Mine is torn and worn out	58	34.1
Is not provided by the management	73	43.0
Put on safety shoes before going out for work		
Yes	62	24.8
No	188	75.2
Wear any nose mask while on the field		
Yes	83	33.2
No	167	66.8
Use safety goggles while working		
Yes	15	6.0
No	235	94.0
Use lights while working at nights		
Yes	74	29.6
No	176	70.4
Wear reflective jackets		
Yes	63	25.2
No	187	74.8
If yes, how often (63)		
Sometimes	40	63.5
Always	23	36.5
If no, why don't you wear reflective jackets (167)		
Mine is torn and worn out	46	27.5
It is very discomforting while working	35	21.0
Not provided by employer	86	51.5

Source: Researchers' Analysis (2024)

Table 5: Organizational strategy for risk minimization

Variables	Frequency (n=250)	Percent (%)
Provision of adequate working tools		
Yes	63	25.2
No	187	74.8
Received any training on occupational hazard and prevention strategies		
Yes	38	15.2
No	212	84.8
Provision of first aid kits to solid waste collectors		
Yes	14	5.6
No	236	94.4

Source: Researchers' Analysis (2024)

4.0 Discussion

The finding of this study revealed that solid waste collectors were exposed to ergonomic risks which include working in uncomfortable positions, standing for long hours, exposure to slippery surfaces, working in extreme temperatures of heat and cold. The finding of this study agrees with the findings of Lopez-Arquillos *et al*. (2019) who noted in their study that solid waste collectors were exposed to various ergonomic hazards.

The finding of the study revealed that the risk minimization practices among the solid waste collectors were not implemented. A vast majority of the solid waste collectors did not wear personal protective equipment. The study also revealed poor safety practices among the solid waste collectors who do not wear safety shoes and reflective vest while working. This is attributed to the lack of provision by the waste management authorities. The finding of this study is in tandem to the findings of Miwano *et al*. (2018) who revealed in their study that waste collectors in Port Harcourt metropolis did not wear personal protective equipment and reflective vest in the course of their jobs.

Furthermore, it was revealed by the study that the waste management authorities did not provide adequate working tools and first aid kits for the solid waste collectors. Similarly, the solid waste collectors had not undergone any training on occupational hazards and prevention strategies. The finding of this research is synonymous with the finding of Alozie *et al*. (2020) who in their separate study revealed that solid waste collectors were not adequately equipped with personal protective clothing and other safety gadgets. This could be attributed to inadequate budgetary allocations to solid waste collection, disposal and management and the lack of a safety culture.

The finding of this study reveals human health implications of ergonomic hazards associated with waste collectors in the study area. It was noted that the carpal tunnel syndrome, back pain, fatigue and mental health issues were among the health impacts of ergonomic hazards associated with solid waste collection. The study is synonymous with the finding of Gowda *et al*. (2023) who noted in their study that musculoskeletal disorders is the main health risk associated with ergonomic hazards among solid waste collectors which is caused by excessive lifting of waste bags, repetitive work and awkward posture.

The study is also synonymous with the finding of Ziaei *et al*. (2018) who noted that frequent jumping up and down on waste trucks and lifting heavy waste bags predisposes them to back pain and sprains.

5.0 Conclusion and Recommendation

This study clearly shows that solid waste collection in Port Harcourt metropolis is bedeviled with myriads of ergonomic risks leading to human health issues. Moreso, the waste management authorities have been deficit in providing adequate training and personal protective equipment for solid waste collectors. Arising from these, the study recommends the provision of adequate training, first aid kits and personal protective equipment to solid waste collectors by the waste management authorities.

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Development of a Foot Operated Grease Dispenser

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Abstract

When two or many metal surfaces join in moving contact with each other friction is generated between them. Lubrication is use to eliminate or reduce this friction. In other means, it minimize the wear and tear which friction may cause. Lubrication also does the function of removing corrosion by providing a protective film on the robbing surfaces. In the early years of industrial revolution lubrication of machinery was done systematically. Lubricants were used when friction began to wear out machinery rather than to prevent it from happening. But as sophisticated machinery was continually developed. Grease was applied with finger to bearings on machine and equipment and this method of grease application at many times the grease cannot get to hidden parts of the machine/equipment. It is also time wasting, burden, and injured the finger. Also, by using finger for applying grease this lead to the contamination of the grease and as well condemn and lead to waste of resources. However, foot grease dispenser was developed for applying grease instead of finger, this will control wastage of grease and will not be contaminated. It helped to grease either under or upper side of a machine/equipment in a planned period. Is to apply lubricant through an aperture to a rolling and robbing part, through a nipple of the part into the housing and circulate to the necessary point. The aperture is adjustable type that can be fits closely with any type of mechanical devices. Foot operated grease dispenser developed was high pressure movable grease devices for fast, effortless operation in everyday lubrication, such as lubricating of all earth moving equipment, agricultural equipment, Automobile, generators, trolley etc. operating using foot lever, which greatly reduces effort, high efficiency and comfortable.

Keywords: Grease, Foot lever, Nozzle, Tank and Aperture

1.1 Introduction

When two or many metal surfaces are join in moving contact with each other friction is mostly generated between them. Lubrication is used to reduce this friction. In the process, they also reduce the wear and tear which the friction causes. Ito *et al.* (2019). Lubrication also counters corrosion by providing a protective film on the concerned surface. Lubrication of machinery by Lubricants was used when friction began to wear out machinery to prevent it from damage. Suganth *et al* (2017)**.**

Traditionally, grease is applied with finger to machine moving parts but the major problem of this method of grease application is that the grease cannot get to hidden parts of the machine (Groz and Rev, 2019). In order to solve this problem a grease dispenser is constructed and incorporated lever for foot operation. It was with the aim to construct grease dispenser with the method of foot operating for quick and easy lubrication to;

ii reduce stress and longer greasing time of machine and equipment
ii. increase the lifespan of machineries.
iii. allow machine robing parts to slide smoothly

In many industry grease dispenser is one of the most important equipment use to lubricate their machine/equipment. The principle of the dispenser is that, pump is used to force grease out through nozzle to the appropriate location, scope of this development is to source for available local materials, affordable, and make a comprehensive research on fabrication of the dispenser (Grade, 2017). Greases are applied only to mechanisms that can be lubricated infrequently and where a lubricant would not stay in position. They act as sealants to prevent ingress of water and other incompressible materials. When bearings are lubricated it provides greater frictional characteristics because of their high viscosity (Surya *et al.*, 2017). When the foot lever is pulled back, then the cap opened while grease filled in the chamber, as the cap is refitted the piston will set for dispensing forced through the grease nozzle to the appropriate machine point (Sparham, 2014).

2. Description of the Foot Operated Grease Dispenser

This section gives the overall description of the developed foot operated grease dispenser.

2.1 Technology of Grease Dispenser

Hand greasing (HG) of a machine parts is an act that, at least on the surface, shows to be really physical. One grabs the grease gun, pumps it with full of grease or using a cartridge, goes to the machine, attaches the gun aperture to the grease nipple and continuing pumping the lever to deliver grease right in the needed point (Smith *et al*., 1997)

2.2 Dispenser Mechanism

The mechanisms of this foot operated grease dispenser is foot-lever, grease tank, hose, aperture, and pump. Grease dispenser is one of the most important tool in an industry used for lubrication. Grease gun is usually used to induce lubricant to a specific point, usually on grease nipple whereby grease is lead to the necessary point (Waghmare *et al*, 2015). The aperture fits closely with the receiving nipple on any mechanical devices and ensures that grease is applied only where it is needed (Maadhav, 2016)

2.3 Operational Principle of the Grease Dispenser

It mainly consists of grease gun, grease cylinder, lever, aperture and hose. The cylinder is mounted on the base frame of the machine. The piston rod of the cylinder is coupled with the lever of the pump (Maadhav Kumar, 2016). The pump is used for pumping of the grease from the tank. The output of the grease tank is split into a provided nipple outlet. When the lever is press the valve will be actuated and when the lever is release the valve rest (Surendran, 2017).

According to Mbajiorgu (2019), Foot operation is easy and one single adult with a body weight from 50 kg can operate the freely. By leg-pressing the lever effort is added to the inner pump which creates vacuum in the tank thereby causing the inner to open and grease enters into the pump chamber. When the foot lever is turned again, the pump at the inlet (tank) closes; then the nozzle valve at the outlet opens to allow the grease at the pump chamber to move out at positive pressure created by the couple pump. This action continues thereby sucking and discharging while the dispenser operates.

3. Fabrication process of the Foot Operated Grease Dispenser

The foot operated grease dispenser was fabricated according to the steps in the following subsections.

3.1 Materials Selection

The selection of the materials used, was based on specifications and requirements for the development of the foot operated grease dispenser and presented in Table 1. However, it was also depends on the suitable available local materials in our environment, cost-effectiveness was also considered to maintain the feasibility of the dispenser. For the concept selection design functionality was considered from a combination of the engineering and risk analysis, development process, and marketing survey. This gave us data on what others would like to appreciate from our development.

3.2 Working Operation

The pump has a spring-loaded wave action mechanism installed at the bottom of the container. Pressing the foot lever makes the cylinder to move forward leaving empty space behind it. The grease due to its weight fills this empty space. On releasing the foot lever, the cylinder returns to its original position pushing the accumulated grease into a hollow piston that throws the grease from the pump outlet into delivery hose

3.3 Method of Fabrication

The method involved in this development was done one after the other these are, cutting, folding, welding, and mechanical joining and coupling of the grease dispenser presented in the flow chart below based on a consistent drawing analysis as shown in Figures 1 and 2 respectively.

4.1 Overview

i. Grease application using the foot operated dispenser will greatly reduces effort and allows high pressure greasing with highest comfort.
ii. Can be operated by foot and also by hand when under low machinery.
iii. Can be operated by a single person and it is economical.

Table 1. Basic Components of the Grease Dispenser and their Specifications

S/N	Items	Specification	Qnts/	Size
i	Hydraulic Pressure hose	10°c/50°f	2 m	¼inc
ii	Pump coupling	Cast iron	1	
iii	Tyre	Carbide Robber	2	
iv	Lock pin	Cast iron	6	
v	Tank	Mild Steel	1½	2 mm
vi	Extension spring	Mild Steel	2	3 mm
vii	Rods	Stainless Steel	1	16 mm
viii	Nozzle	Cast iron	1	
ix	Pressure pad	Rubber	1	5 mm
x	Platform	Mild Steel	¼ Plate	5 mm
xi	Pedal	Mild Steel	1	5 mm

Development Process
⇩
Measuring and Marking out
⇩
Cutting and folding of sheet metals
⇩
Welding and Mechanical Joining
⇩
Filling and smoothing
⇩
Finishing

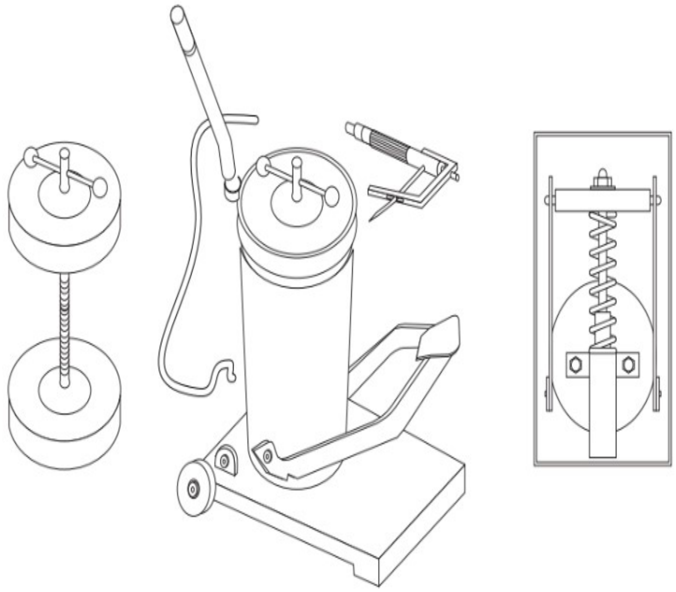

Fig. 1. AutoCad drawing of the foot grease dispenser

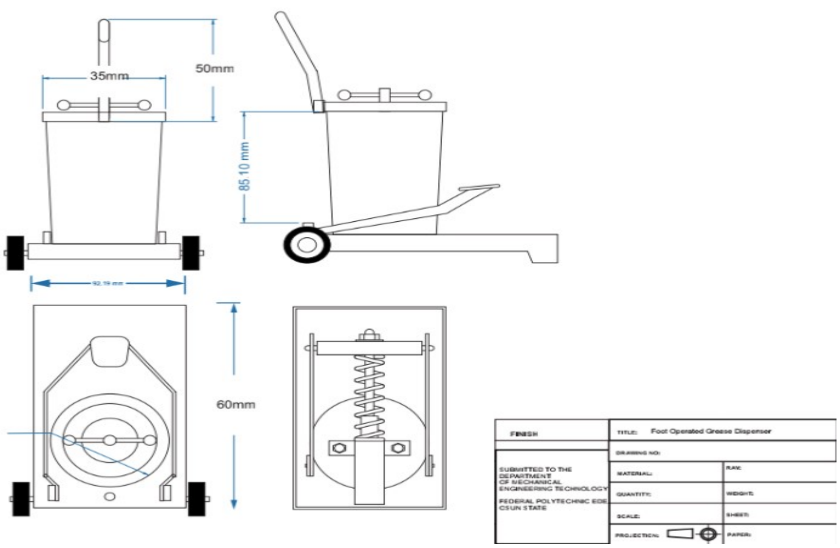

Fig. 2. Complete drawing of the foot operated grease dispenser

4.1.1 Result

Experiment replication was carried out on difference machine and equipment each experiment were conducted at a speculated period and the duration were recorded and presented in Table 2. Hand greasing (HG) and foot operated greasing (FOG) were compared on different machine and tractor plough bearing and the duration was 300 s and 120 s respectively. Engineering analysis was performed on two design concepts to show how well they met design specifications. The decision-making process compared design options of important functionality and weight them to determine the best result. The risk analysis detailed risks of the chosen design concept. Various views of the foot operated grease dispenser is as presented in Fig.3

Table 2. Computation of result carried out

S/N	Vehicles/Equipment	Part tested	FOG (s)	HG (s)
I	Toyota RAV 4 (07)	Propeller bearing	25	60
Ii	Honda CRV 1999	Shaft Inner cup	11	32
Iii	Toyota RAV 4 (07)	Wheel hub	15	45
Iv	Excavator Machine	Roller bearing	5	20
V	Bulldozer	External drive	120	250
Vi	Tractor	Plough machine	120	250
Vii	Mining/Lathe Machine	Saddle/Carriage	30	70

4.2 Discussion

Foot operated grease dispenser is safer than greasing by hand, since a worker does not have to climb and stay over the machinery to lubricate the bearings, it improved housekeeping

Table 3. Dimension and the Technical Data of the Machine

S/N	Unit	Dimension
1	Capacity	18 kg
2	Weight	10 kg
3	Size (H x D)	300 x 120 mm
4	Tank thickness	2 mm
5	Platform thickness	5 mm

and assures that all bearings will be lubricated and that each will receive its proper proportion of lubricant. Foot operated grease dispenser permits more frequent application of lubricant and, thereby, gives better lubrication and longer equipment life time.

Also, foot operated grease dispenser reduces down-time of operating equipment since the machine may be lubricated while it is at work in case of emergency, it takes less time than hand-lubrication methods.

5.1 Conclusion

Foot operated grease dispenser method is developed in order to reduce cost as well manual power require for the lubrication of various grease points can be drastically reduce. The loss of grease during lubrication reduces when compared with the hand grease method. The method provides safety to the lubricating component and the person in charge of operation. This system enables the greasing to the points which are not reachable to operator and also reduces down time

Figure 3. Various views of the developed grease dispenser

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Analysis of Perceived Environmental Impacts and Trend of Building Collapse in Port Harcourt Metropolis

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Abstract

The study undertook an assessment of the environmental impacts of building collapse in Port Harcourt metropolis. Data for this work was retrieved from both primary and secondary sources. The primary data was obtained from the field specifically from a well-structured questionnaire which was distributed to the 395 respondents generated for this study. Results revealed that 30.7%, 25.2%, 17.1%, 11.3%, 9.8% and 6.2% of the respondents opined that building collapse was as a result of poor materials and workmanship, design errors, unethical practices of professionals, inadequate legislation against building failure, lack of on-site training and inadequate soil investigation respectively. The study revealed that the perceived environmental effects of building collapse were increased emission of air pollutants (38.1%), soil degradation (21.7%), water contamination (19%), loss of environmental aesthetic values (15.5%) and habitat loss/ ecosystem disruption (5.7%). Analysis of the trend of building collapse in Port Harcourt metropolis revealed a rising trend. The study recommends that geotechnical investigations in addition to land surveys should be carried out before the commencement of construction projects.

Key words: Trend, Perceived, Environmental, Impacts, Building collapse

1.0 Introduction

Building collapse refers to the inability of a building to perform its primary functions of safety, comfort and stability caused by the partial or complete failure of some components of the building (Windapo & Rotimi, 2012).

Previous studies have indicated that the incidence of building collapse in Nigeria is generally on the increase particularly in southern Nigeria which poses very critical questions about the reasons for the rising trend (Ede, 2013; Okwulehie *et al*., 2024).

Building collapse may be attributed to natural disasters such as earthquakes, hurricanes, flood and man-made factors (human errors). These human errors include poor building design, inadequate soil investigation, the use of poorly skilled workmen and lack of quality materials (Odeyemi *et al*., 2019).

It is believed that buildings and the provision of safe and affordable homes are cardinal points of sustainable development and pivotal aspects of the environment. Therefore, the collapse of buildings unavoidably has severe impacts on the environment. These impacts include water pollution, soil erosion, air pollution etc (Obodoh *et al*., 2021).

The socioeconomic impacts of building collapse are enormous. Building collapse results to loss of income and source of livelihood, loss of manpower and in many cases, have resulted to the death of site workers or inhabitants of the collapsed building (Obodoh *et al*., 2019).

Despite the socioeconomic and environmental consequences of building collapse in Nigeria, the incidence of building collapse has continued to rise. Obviously, the issue of building collapse has not received the attention that it deserves from relevant stakeholders. Furthermore, there is paucity of literature on the environmental impact of building collapse in Port Harcourt metropolis. This study is necessary to fill the literature lacuna.

2.0 Materials and Methods

The study area, Port Harcourt metropolis is located between latitude 04^0 43' and 04^0 57' North of the Equator and between 06^0 53' and 07^0 08' East of the Greenwich Meridian as shown in Figure 1 below.

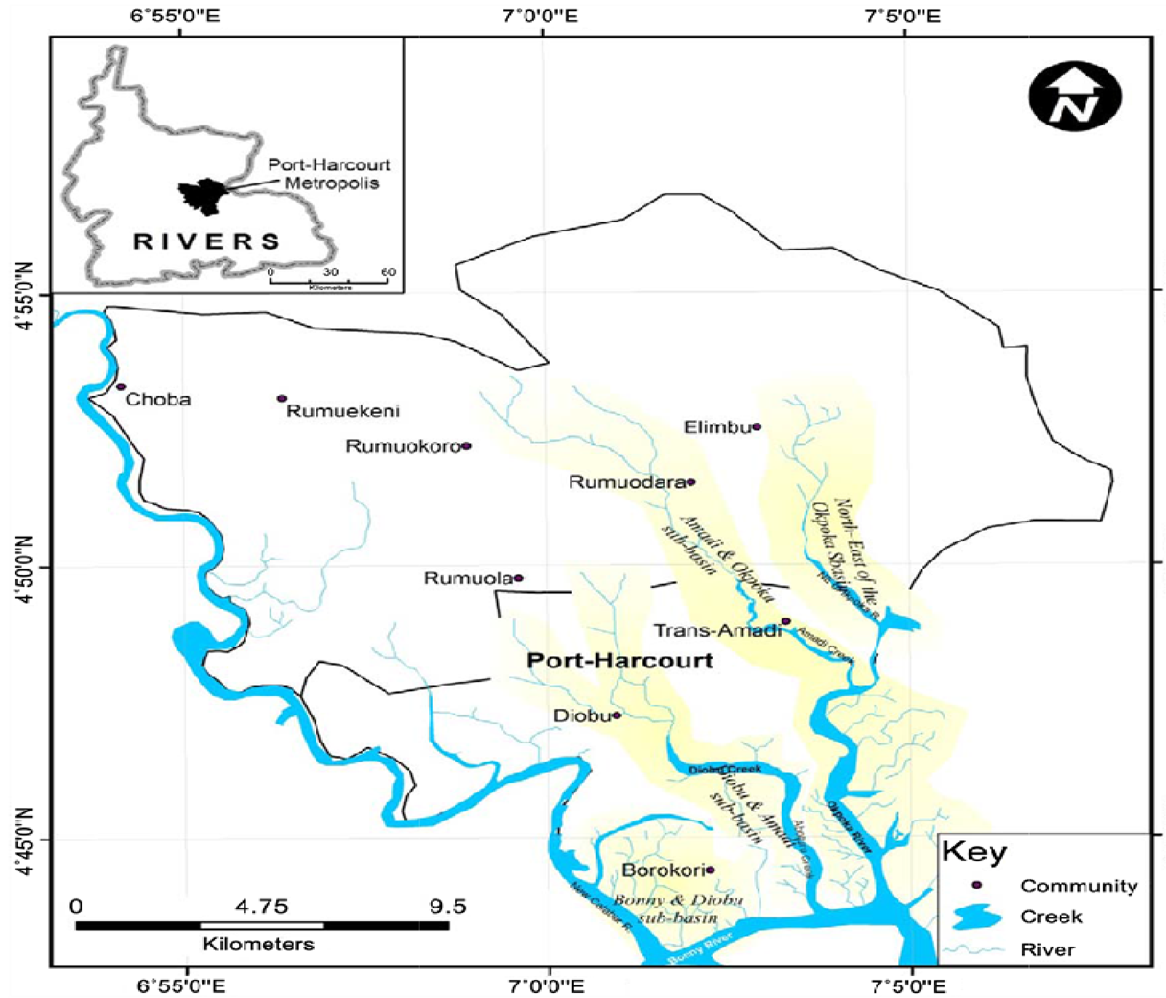

Figure 1: Map of Port Harcourt Metropolis

In this study the survey research design was used in planning and executing the research. The study population consist of professionals, clients and users within the city metropolis. The Taro Yamane formular was used to arrive at a sample size of 396 respondents. Data for this work was retrieved from both primary and secondary sources. The primary data was obtained from the field specifically from structured questionnaire. The face and content validity of the instrument was established with the assistance of two (2) professionals in the relevant field. Data for this study was presented in tables and analyzed using descriptive statistics.

3.0 Results and Discussion

3.1 Socio-economic characteristics of respondents

Table 1 shows the socio-demographic characteristics of respondents. The distribution of sampled respondents from the questionnaires analyzed shows that 16.7% were within the ages of 30-40 years, 39.1%

were within the ages of 41-50, 28.3% were within the ages of 51-60 and 15.9% were within the ages of 60 and above. Furthermore, questionnaire analysis revealed that 58.3% of the respondents were males while 41.7% of the respondents were females. From the questionnaire analyzed, it shows that 54.5% of the respondents had HND/BSc, 35.6% had an MSc and 9.8% of the respondents had a PhD. The distribution of sampled respondents from the questionnaires analyzed shows that 10.1% had working experience less than 10 years, 26.5% of the respondents had 10-19 years working experience, 40.9% of the respondents had 20-29 years working experience and 22.5% of the respondents had working experience above 30 years. Moreso, questionnaire analysis revealed that 21.5% of the respondents were architects, 8.8 of the respondents were electrical engineers, 17.9% of the respondents were builders, 14.1% of the respondents were mechanical engineers, 25.8% of the respondents were civil engineers and 11.9% of the respondents were quantity surveyors.

Table 1: Socio-demographic characteristics of respondents

Variables	Frequency(n=396)	Percent (%)
Age(years)		
30-40	66	16.7
41-50	155	39.1
51-60	112	28.3
>60	63	15.9
Gender		
Male	231	58.3
Female	165	41.7
Educational Status		
HND/BSc	216	54.5
MSc	141	35.6
Ph.D	39	9.8
Work Experience		
< 10 years	40	10.1
10-19 years	105	26.5
20- 29 years	162	40.9
> 30 years	89	22.5
Profession		
Architect	85	21.5
Electrical engineer	35	8.8
Builders	71	17.9
Mechanical engineer	56	14.1
Civil engineer	102	25.8
Quantity surveyor	47	11.9

Source: Researcher's analysis (2024)

3.2 Causes of Building Collapse

Fig 2 shows the causes of Building Collapse in Port Harcourt. The questionnaire responses revealed that 30.7% of the respondents opined that building collapse was as a result of poor materials and workmanship, 25.2% of the respondents opined that building collapse was as a result of design errors 17.1% of the respondents opined that building collapse was as a result of inadequate soil investigation, 11.3% of the respondents opined that building collapse was as a result of unethical practices of professionals, 9.8% of the respondents opined that building collapse was as a result of lack of on-site training while 6.2% of the respondents opined that building collapse was as a result of inadequate legislation against building failure. The finding of this research agrees with the finding of Odeyemi *et al.* (2019) who in their study revealed that building collapse was as a result of the use of substandard material and patronizing quacks.

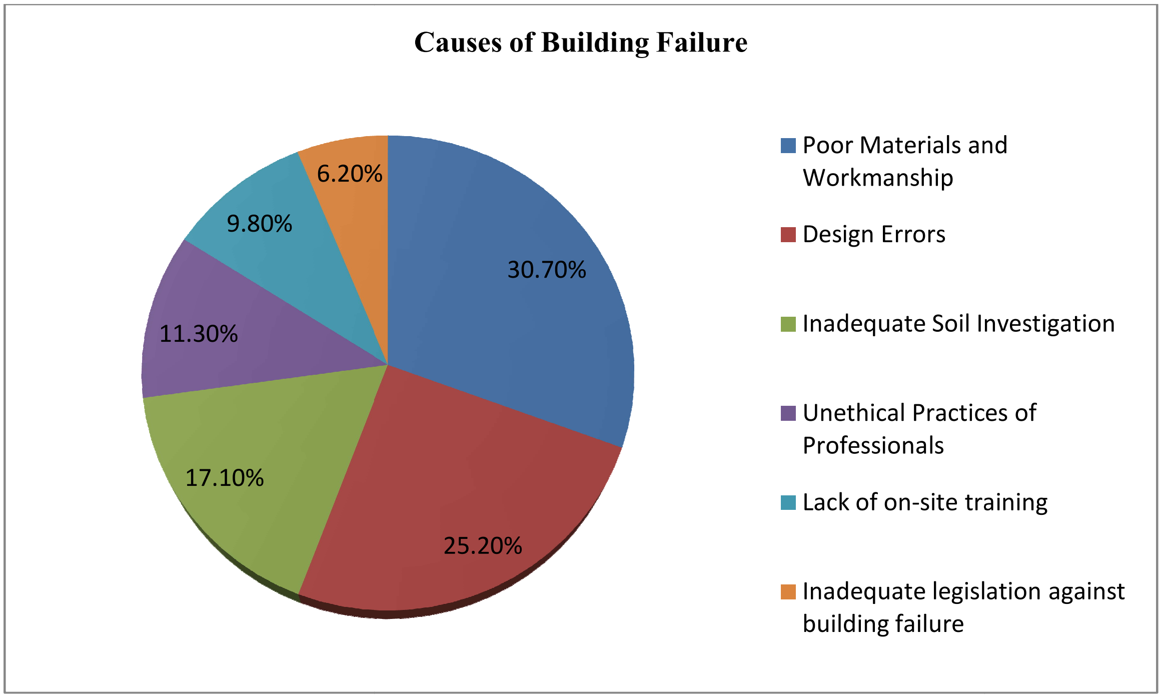

Figure 2: Causes of Building Collapse

3.3 Incidence and Trend of Building Collapse

Analysis of questionnaire responses revealed that 96.1% of the respondents were in agreement that the incidence of building collapse was on the increase annually while 3.9% of the respondents were not in agreement. This is represented in Figure 3 below. The finding of this research is in agreement to the findings of Emekoma *et al.* (2023) who revealed rising trends of building collapse in Southern Nigeria.

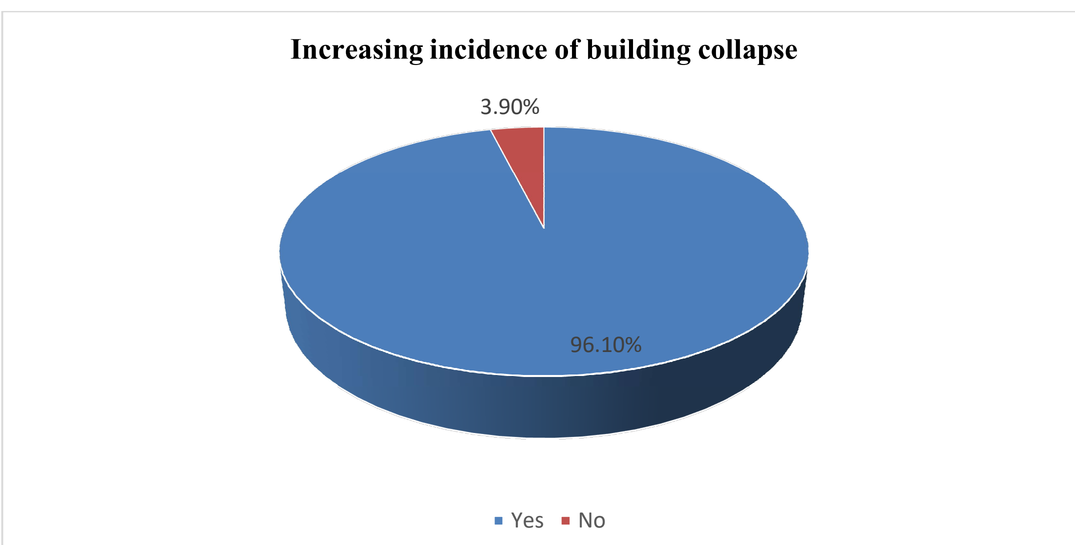

Figure 3: Increasing incidence of Building Collapse

3.4 Perceived impact of Building Collapse on the Environment

Fig 3 shows the impact of building collapse on the environment. The questionnaire responses revealed that the perceived environmental effects of building collapse were increased emission of air pollutants (38.1%), soil degradation (21.7%), water contamination (19%), loss of environmental aesthetic values (15.5%) and habitat loss/ ecosystem disruption (5.7%). The finding of this research is in tandem to the finding of Obodoh *et al.* (2021) who in their study noted that the environmental impacts of building collapse are water pollution, soil erosion, air pollution.

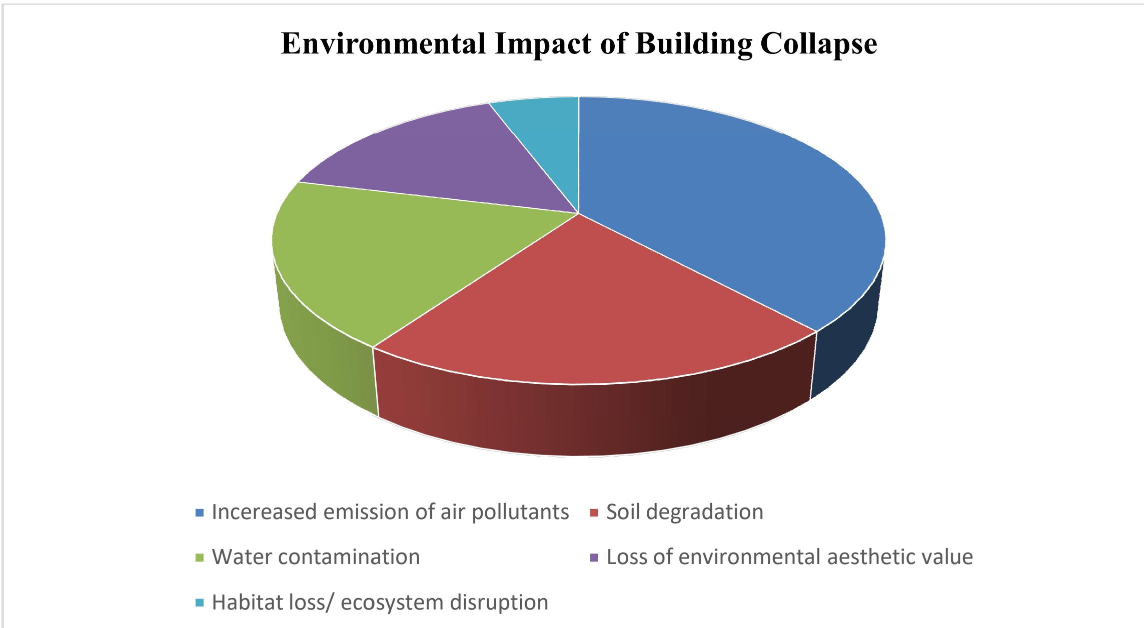

Figure 4: Perceived impact of Building Collapse on the Environment

4.0 Conclusion and Recommendation

Building collapse has had attendant environmental consequences in Port Harcourt. The incidence of building collapse has continued to rise over the years despite technological innovations in the construction industry. This could be attributed to the use of sub-standard materials, adding load that differ from the original design and non-compliance on the professional ethics these and many more lead to destruction of lives in several forms and degrees of injuries, and also properties. Moreso, environmental impacts include soil degradation, water contamination, air pollution and erosion. The study recommends that geotechnical investigations in addition to land surveys should be carried out before the commencement of construction projects.

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INDIRECT TENSILE STRENGTH AND PERMEABILITY PROPERTIES OF ASPHALTIC CONCRETE REINFORCED WITH CERAMIC TILES WASTE

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Abstract

This study explores the feasibility of enhancing asphaltic concrete sustainability through the incorporation of ceramic tiles waste (CTW) as a reinforcing additive. The research focuses on evaluating two critical properties, namely, indirect tensile strength (IDT) and permeability, to assess the performance of CTW-modified asphaltic concrete. Experimental procedures involved gradation analysis of aggregates, determination of physical and mechanical properties, and assessment of IDT and permeability. Results indicated a decrease in IDT with increasing CTW content due to its stiffening effect, while permeability showed a linear increase with higher CTW percentages. However, the CTW-modified asphaltic concrete remained within acceptable limits for pavement applications, suggesting its suitability for medium to heavy traffic loads thereby ensuring sustainable cities and community. Furthermore, multivariate analysis provided insights into predicting permeability based on IDT and stability tests thereby fostering innovation and sustainable industrialization.

Keywords: Asphalt; Ceramic Tiles Waste (CTW); Indirect Tensile Strength (IDT); Permeability; Sustainability, Traffic.

1.0 Introduction

In Nigeria, asphalt concrete pavement is integral to the transportation infrastructure, facilitating the movement of goods and services. Enhancing the properties of asphalt mixtures has been a subject of considerable research interest, with a focus on incorporating additives to improve performance. Asphalt concrete, comprised of coarse and fine aggregates with bitumen as the binder, relies on the properties of its constituents for overall performance (Liu *et al.*, 2019).

Hot Mix Asphalt (HMA), a dominant material in road construction globally, faces challenges due to the increasing costs of production, primarily attributed to diminishing petroleum resources and high-quality aggregate (Çagdas and Murat, 2017). Bitumen, derived from petroleum, serves as the binder in asphaltic concrete, and its behavior depends on various factors including material composition and environmental conditions (Mallick and El-Korchi, 2009; Hu *et al.*, 2014).

Concerns over the environmental impact of natural aggregate extraction in Nigeria have prompted exploration into alternative materials. Crushed ceramic wastes sourced from the ceramics industry or construction and demolition activities, presents a viable alternative due to its abundance and availability (Juan *et al.*, 2010; Silva *et al.*, 2010). Furthermore, its reuse offers environmental benefits, conserving natural resources and reducing energy consumption (Silva *et al.*, 2010).

Previous research has shown the feasibility of utilizing crushed ceramic waste as a substitute for conventional aggregate in concrete and road pavement construction (Ikponmwosa and Ehikhuenmen, 2017; Olawale and Tijani, 2018). However, there is a scarcity of literature regarding its use in asphalt mixtures. Thus, this study aims to investigate the practicality of incorporating crushed ceramic tile waste as a partial substitute for aggregate in asphalt mixtures.

2.0 Materials

2.1 *Coarse Aggregate*

Crushed granite samples were obtained from a local quarry in Osogbo, Osun State, and examined for physical and micro-mechanical properties. Prior to gradation, the samples were dried for 24 hours. Crushed ceramic stone was derived from disintegrating quarry rock, boulders, or sizable gravel. Tests conducted included moisture content, sieve analysis, relative density, rate of water absorption, aggregate abrasion, crushing, and impact values. Granite samples passing sieve apertures of 31.5mm and 0.075mm were used, while those retained on sieves ranging from 5mm to 19mm were prepared for the Hot Mix Asphalt (HMA) mix.

2.2 *Fine Aggregate*

Fine aggregates, including natural sand or crushed stone not exceeding 5mm, were sourced from deposits along the Iwo-Osogbo road. Samples underwent washing, drying for 24 hours, and grading. Tests conducted included sieve analysis, moisture content, specific gravity, rate of water absorption, aggregate abrasion, crushing, and impact values.

2.2 *Ceramic Tiles Waste*

Ceramic tiles waste was obtained from environment, construction, and demolition waste in Osogbo. Samples were crushed for required physical and mechanical tests, including sieve analysis, moisture content, relative density, rate of water absorption, aggregate abrasion, crushing, and impact values. The chosen sizes ranged between 5mm to 19mm and were prepared for the HMA mix.

2.3 *Bitumen*

Grade 60/70 bitumen was used in the asphaltic mixtures, sourced from the Ogun State bitumen plant. Bitumen underwent tests including penetration, flash point, ductility, and softening point tests, adhering to specified procedures for each.

These materials underwent rigorous testing procedures to ensure their suitability and compliance with asphaltic mixture requirements, as detailed in the subsequent sections.

3.0 Methods

3.1 *Aggregate Gradation*

Aggregate gradation was conducted using mechanical sieves in accordance with BS 812: Part 103.1: 1985 and ASTM C 136-92 standards. Materials were weighed and sieved to ascertain particle size distribution, ranging from 0-5mm for sand and 5-19mm for granite and crushed tile waste. The cumulative percentage passing through each sieve was recorded, and the results were plotted on a semi-log graph to determine uniformity coefficients (Cu) and coefficients of curvature (Cc).

3.2 *Moisture Content*

Moisture content evaluation utilized the oven-drying method as per BS 812: Part 109: 1990. Aggregate samples were dehydrated, and the mass of water was divided by the mass of solids to calculate water content (w). The method ensured accurate determination of total water present in the sample.

3.3 *Specific Gravity*

Specific gravity of aggregate specimens was determined following BS 1377: 1990 and ASTM C 127-93 standards. Samples weighing 400g underwent a process to ensure suitability for testing, and specific gravity (Gs) was calculated, providing precise values to the nearest 0.01g.

3.4 *Indirect Tensile Strength*

The modified asphalt mixtures incorporating crushed ceramic tile waste underwent evaluation for strength using resilient modulus and indirect tensile (IDT) tests, as per ASTM D4123 (ASTM 1995) specifications. Vertical loads were applied to cylindrical specimens, and IDT strength (St) was calculated, considering maximum load (P), specimen height (t), and diameter (D). This method facilitated the assessment of asphalt concrete strength, providing essential data for performance evaluation.

4.0 Result

4.1 *Gradation of Aggregates*

The particle size gradation results for the constituent aggregates (fine, coarse, and CTW) used in the CTW modified asphalt mixture are illustrated in Figure 4.1. This logarithmic plot depicts the % finer of aggregate calculated from sieve analysis against sieve diameter. Comparing the percentage passing with the approved gradation from the ministry of works revealed that the fine aggregates, coarse aggregates, and CTW used were well graded and met the recommended sizes for medium to heavy trafficked roads. The Cu and Cc values for all three materials indicated compliance with ASTM specifications ($Cu \leq 6$ and $1 < Cc < 3$).

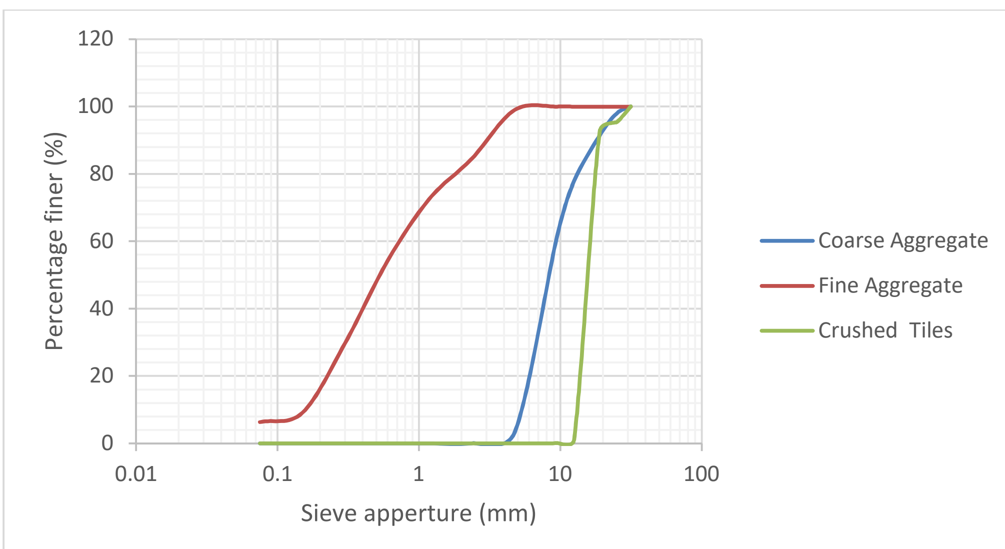

Figure 4.1: Gradation Plot of All Aggregates Used

Analyzing Figure 4.1, the following insights were deduced:

(i) The diameter at which 60% by weight of aggregate (D60) is distributed: 0.75 mm for sand, 9.0 mm for granite, and 8.5 mm for CTW.

(ii) The diameter at which 30% by weight of aggregate (D30) is distributed: 0.35 mm for sand, 7.5 mm for granite, and 6.2 mm for CTW.

(iii) The diameter at which 10% by weight of aggregate (D10) is distributed: 0.17 mm for sand, 5.5 mm for granite, and 4.1 mm for CTW.

4.2 *Physical and Mechanical Properties of Aggregates*

The specific gravity values obtained for granite, CTW, and sand in Table 4.1 fell within specified ranges, confirming similarity to materials used by previous researchers and adherence to standard specifications. The Los Angeles abrasion values slightly exceeded FMWH (2016) requirements but remained within acceptable ranges set by the Asphalt Institute and other standards. Moisture content and water absorption values also met standard specifications. Aggregate impact and crushing values, while slightly above FMWH (2016) requirements for CTW, fell within acceptable limits specified by ASTM and other standards, making them suitable for CTW modified asphalt.

4.3 *Indirect Tensile Strength and Permeability of CTW Modified Asphalt*

The results obtained for the indirect tensile strength and permeability of CTW modified asphalt samples are presented in Table 4.2. Notably, as the percentage of CTW in the mixture increased, there was a corresponding decrease in the indirect tensile strength. Specimen A, which had 0% CTW, exhibited the highest tensile strength at 8.59 kPa, while specimen E, with 100% CTW replacement, showed the lowest tensile strength at 3.41 kPa. This reduction in tensile strength with increasing CTW content can be attributed to the stiffening and brittleness effect of CTW. It's worth noting that the indirect tensile strength of asphaltic concrete correlates with its resistance to fatigue and thermal cracking, implying that a mixture with lower tensile strength may have a shorter fatigue life.

Table 4.1: Properties of Materials

Material	Specific gravity	Moisture content (%)	Water absorption	LAAV (%)	AIV (%)	ACV (%)
Granite	2.89	0.52	0.33	31.58	26.50	35.11
CTW	2.499	1.01	6.77	32.46	37.27	35.31
Sand	2.811	1.03	0.47			
FMWH 2016 Specification	3 max	3 max	3 max	30% max.	35% max.	35% max.
Asphalt Institute Specification	3 max	3 max	3 max	40% max.	40% max.	40% max.

Table 4.2: Indirect Tensile and Permeability of CTW Modified Asphalt

Samples	Indirect Tensile Strength(kPa)	Coefficient of Permeability (mm/s)
A	8.59	0.0622
B	6.84	0.0667
C	6.22	0.0669
D	4.29	0.0675
E	3.41	0.0732

Additionally, the permeability coefficient increased with higher percentages of CTW replacement thereby indicating higher permeability in specimens with greater CTW content. This increase in permeability could be linked to the water absorption properties of CTW, as indicated in Table 4.2. Despite the increase in permeability, the maximum coefficient of permeability obtained (0.0732 mm/s for sample E) remained below the recommended maximum value of 0.093 mm/s for asphaltic concrete, as suggested by Chen *et al.* (2019). This suggests that even with the highest CTW content, the permeability of the asphaltic concrete remains within acceptable limits for asphalt pavement, particularly for medium to heavy traffic conditions. Furthermore, analyzing the trend of permeability coefficient with varying CTW replacement percentages, it was observed that the coefficient initially increased linearly up to 20% replacement, then remained relatively constant up to 80% replacement with a slight gradient change of less than 5%. However, beyond 80% replacement, the coefficient decreased sharply by more than 90%, attributed to the total absence of granite content in the mixture.

In summary, the CTW modified asphaltic concrete demonstrated suitable characteristics for asphalt pavement applications, particularly for medium to heavy traffic conditions, as evidenced by its indirect tensile strength and permeability results.

4.4 *Correlation and Goodness of Fit Statistics*

The correlation statistics presented in Table 4.3 reveal the relationships between IDT, Stability, and CoP. A correlation coefficient close to 1 indicates a strong positive correlation, while a coefficient close to -1 indicates a strong negative correlation. The correlation between Stability and IDT is notably strong and positive (+0.945), suggesting that these two variables may be effectively used to predict each other. Additionally, the correlation between CoP, IDT, and Stability is also strong but negative (-0.868 to -0.899), indicating an inverse relationship between CoP and the other two variables.

Table 4.3: Correlation statistics

	IDT	CoP
IDT	**1**	-0.868
Stability	0.945	-0.899
COP	-0.868	**1**

Moving to the goodness of fit statistics in Table 4.4, the R^2 value (0.811) indicates that 81.1% of the supplied data of IDT and Stability results were utilized in generating the equation for predicting the CoP variable. A higher R^2 value suggests a better fit of the model to the data. The adjusted R^2 (0.433) considers the number of predictors in the model and penalizes for over-fitting. Mean Squared Error (MSE) and Root Mean Squared Error (RMSE) provides measures of the model's accuracy, with lower values indicating better performance. Mean Absolute Percentage Error (MAPE) quantifies the accuracy of the model's predictions, with 0% indicating perfect predictions.

Table 4.4: Goodness of fit statistics

Statistic	Training set	Validation set
Observations	4	1
Sum of weights	4	1
DF	1	-2
R^2	0.811	
Adjusted R^2	0.433	
MSE	0.000	
RMSE	0.002	
MAPE	1.162	0.000

.5 *Equation for Predicting Coefficient of Permeability (CoP)*

The linear regression equation (Equation 4.1) provides a predictive model for estimating the CoP based on the results of IDT and Stability tests. Once the values of these tests are determined in the laboratory, the CoP can be calculated using this equation. The coefficients in the equation represent the weights of each predictor variable in predicting the outcome variable (CoP).

$$COP = 8.33044538693214 \times 10^{-2} - 2.4438719797331 \times 10^{-4} \times IDT - 1.44858536253948 \times 10^{-3} \times Stability \quad (4.1)$$

4.6 *Analysis of Variance (ANOVA)*

The ANOVA table (Table 4.5) assessed the significance of the variables in predicting the CoP. The model's performance is evaluated based on the F-statistic and its associated p-value. A low p-value (typically < 0.05) indicates that the model's explanatory variables significantly contribute to predicting the outcome variable. In this case, the p-value for the model (0.435) suggested that the information provided by the explanatory variables (IDT and Stability) was not significantly different from what a basic mean would provide. This implies that either the variables do not contribute significantly to the model or that some important covariates are missing, warranting further investigation or refinement of the model.

Overall, multivariate analysis provided valuable insights into the relationships between variables and aided in predicting the CoP of CTW modified asphalt concrete based on laboratory test results.

Table 4.5: Analysis of variance (COP)

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	2	0.000	0.000	2.147	0.435
Error	1	0.000	0.000		
Corrected Total	3	0.000			

5.0 Conclusion

In conclusion, this study investigated the sustainable reinforcement of asphaltic concrete using ceramic tiles waste (CTW) as an additive. The evaluation focused on two critical properties: indirect tensile strength (IDT) and permeability. Results revealed a decrease in IDT with increasing CTW content, attributed to its stiffening effect. Additionally, permeability increased with higher CTW percentages due to its water absorption properties. Despite these variations, the CTW modified asphaltic concrete remained within acceptable limits for asphalt pavement, suggesting its suitability for medium to heavy traffic applications. Furthermore, multivariate analysis provided insights into predicting the coefficient of permeability based on IDT and stability tests, enhancing the understanding of CTW's impact on asphaltic concrete performance. Overall, this study contributes valuable knowledge to the field of sustainable construction materials, highlighting the potential of incorporating ceramic tiles waste to enhance asphaltic concrete properties while promoting environmental sustainability.

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THE USE OF PALM OIL FUEL ASH AS A PARTIAL REPLACEMENT OF CEMENT IN CONCRETE PRODUCTION

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ABSTRACT

Cement is the most widely used binding material in all construction works. Due to its high cost and heat liberation property, attempts have been made to replace cement in concrete using agricultural or industrial waste. This study involves partial replacement of cement in concrete production using Palm Oil Fuel Ash (POFA) which is an agro-waste generated in palm oil industry. POFA is a pozzolanic material which has economical and technical advantage when used in concrete production. In this research compressive strength test was conducted on hardened concrete after replacing cement with 5%, 10%, 15% and 20% of POFA and compared the results with control mix (0%POFA). The grade of concrete adopted was MI5. It has been observed that concrete with 5% replacement of POFA gave the highest strength.

Keywords: Cement, Palm Oil Fuel Ash (POFA), Compressive strength, Concrete.

1. Introduction

Due to advancements in material technology, innovation shows concrete up to 10OMpa are utilized, generally these high strength concrete requires high amount of cement which leads to increase in the heat of hydration leading to formation of cracks. This higher usage of cement leading to increase in heat of hydration can be tackled by reducing the amount of cement with some other cementing agents, and one such among is PALM OIL FUEL ASH. This palm oil fuel ash is the agro-waste product from the manufacturing process of palm oil. In many developing nations, waste management poses a great challenges and threat to survival of both fauna and flora and also cause environmental degradation. A good solution to these problems is by recycling agro-industrial residues by burning them in a controlled environment and use the ashes (waste) generated for more noble means (Ghavami K., Toledo R. D. and Barbosa N. P. 2001). Utilization of such wastes as cement replacement materials may reduce the cost of concrete production and also minimize the negative environmental effects with disposal of these wastes (Abdulkadir, T. S., Oyejobi, D. O. and Lawal, A. A., 2014).

According to Sirirat and Supaporn (2010), the calcium hydroxide (unfavorable product from the cement hydration) release during the hydration of ordinary portland cement (OPC) reacts with silica present in the pozzolans and water to form additional calcium silicate hydrate which is responsible for the compressive strength in concrete. A pozzolan is a siliceous and aluminous materials which has litle or no cementitious values but in finely divided form and in presence of moisture chemically react with calcium hydroxide liberated during the hydration of Portland cement to produce stable, insoluble cementitious compounds which contributes to its strength and impermeability (Karim, M. R. Zain, ME.M. Jamil, M. and Islam, M. N., 2011). As a usual practice, ashes (POFA) generated are simply disposed off without any commercial return and constitutes environmental nuisance as they form refuse heaps. However, it has been identified that POFA has good pozzolanic properties that can be used as a cement substitute in mortar and concrete mixes (Abdul and Nguong, 2010).

Aim:

The aim of this research is to investigate the potential of producing high strength concrete by partial replacement of cement with palm oil fuel ash.

The objectives include:

i. To design a concrete mix with a targeted 28-day strength of 15MPa which will have the properties of high Strength Concrete.

ii. To investigate the compressive strength of concrete containing POFA produced.

iii. To compare the tests result from Concrete containing POFA as a partial replacement for cement, with that of conventional concrete with Ordinary Portland Cement (OPC).

2. Literature Review

Pozzolans:

Pozzolans are usually defined as fine grained siliceous materials that chemically react with calcium hydroxide (lime) and alkalis to form cementations compounds. Pozzolans are also Alumino-siliceous materials which are highly vitreous (Oyejobi, et al. 2014). They independently have fewer cementatious properties but with the presence of the compound named above, they show better cementatious property towards the latter day strength (>28 days).

A pozzolanic reaction may be slower than the rest of reactions that occur during cement hydration, and thus the strength of concrete made with p0zzolans may not be as high as concrete made with purely cementations materials. On the other hand. highly reactive pozzolans such as silica fume and high reactivity metakaolin can produce "much early strength" concrete that increase the rate at which concrete gains strength. (Sata, V., Jaturapitakkul C. and Kiatikomol K., 2007).

Fly Ash

Fly ash is a by-product of coal burning plants. In the past, fly ash was sent to landfills. Recently it has been found that fly ash could be used as a supplement to cement without affecting the strength. Fly ash is the most commonly used supplementary cementatious material. They mostly consist of silicon di oxide (SiO2), Aluminium Oxide (A1203) and Iron Oxide (Fe203) and are hence a suitable source of Aluminium and silicon geopolymers. When processed to the correct Surface area (Particle size), they can be pozzolanic in nature and react with calcium hydroxide and alkali to form calcium silicate hydrates (cementatious compounds). (T. Subramani, P. Sakthivel, 2016).

Properties of Palm Oil Fuel Ash

Physically, palm oil fuel ash is grayish in color and becomes dark with increasing proportions of unburned carbon. This material is finer than ordinary Portland cement (OPC) (A. A. Awal and M. W. Hussin, 2011l). In overall. POFA satisfies the chemical and physical properties of pozzolanic material and can be classified under class F pozzolans (J. H. Tay and KY. Show, 2009). This by -product is moderately rich in silica content, meanwhile lime content is very low as compared to OPC as presented in the table below. It's also added that POFA is confirmed to be good pozzolanic material when the test conducted in the laboratory revealed that the strength activity index is 115 which is higher than the minimum requirement of 75, as specified in ASTM C 618 - 92 (10). In general, the POFA chemical composition can be different due to operating system in the palm oil mill. (A. A. Awal and M. W. Hussin, 2011).

It has been discovered that inclusion of POFA in cement paste retards the setting time; the higher the amount of ash, the more the retarding time as presented in the table below (A. A. Awal and M. W. Hussein, 2011). Actually, the advantage of this particular property in construction works whereby the slight retarding effect with higher amount of ash is beneficial to concreting in hot weather conditions.

Chemical Composition of OPC and POFA.

CHEMICAL COMPOSITION	OPC%	POFA%
Silicon Dioxide ($Si0_2$)	20.2	43.60
Aluminium oxide (Al_2O_3)	5.70	14.0
Ferric oxide (Fe_2O_3)	3.00	4.70
Calcium oxide (CaO)	62.50	8.40
Magnesium oxide (Mg)	2.60	4.80
Sodium oxide (Na_2O)	0.16	0.39
Potassium oxide (K_2O)	.87	3.5
Sulphur oxide (SO_3)	1.87	2.80
Loss of Ignition (LOI)	2.7	18.00

3. **Methods**

Materials

Materials used for this study includes: ordinary Portland cement of grade 53, fine aggregate, coarse aggregate, palm oil fuel ash (POFA), water.

Cement

There are many types of Portland cement but for the purpose of this research, the type used is known as ORDINARY PORTLAND CEMENT (OPC) which is obtained from DANGOTE GROUP under the brand name of DANGOTE PORTLAND CEMENT and was stored in an air tight container and in a cool dry place and free fromn damp in order to maintain the quality of the cement.

Fine Aggregates

Particles that passes through 4.75mm sieve are called fine aggregates. Natural sand is generally used as fine aggregate.

Palm Oil Fuel Ash (POFA)

Palm oil fuel ash (POFA) Was obtained as a result of the combustion of coal when burning the palm oil husk and fibers, For the purpose of this research the palm oil husk and fibers were obtained from a palm oil processing mill located at OBAAGUN town along Ikirun - Ila road, Osun State. The ash was produced as a result of burning both the palm oil husk and fibers together to arrive at residue regarded as ash. Thus, the ash obtained was collected (especially the ones that are grayish in color) sorted out and dried in order to remove moisture in it Thus, the dried ashes were sieved through 75um in order to remove bigger sizes of ash particles and impurities. Only the fine ashes passing through 75um sieve were collected and used to replace Ordinary Portland Cement (OPC) in varying percentage to produce the desired concrete.

Method of Design

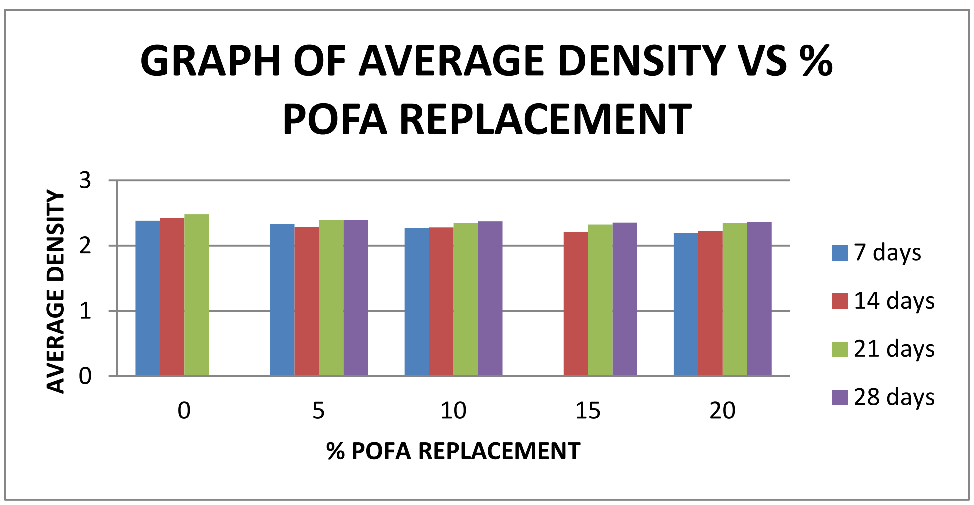
This section implies the process and the method by which design of mixes are done. Concerning this research, whereby palm oil fuel ash (POFA) was used as part of the binder, the method of the design involved using percentages of POFA and OPC to have a whole ratio of binder While the aggregate and water ratio remains constant. The table I below shows the estimate of the quantity of materials required for the production of concrete cubes for different POFA replacement levels and mix proportion of the constituents. The percentage of cement replaced by POFA in this project are:- 0%,5%, 10%, 15%,20% by weight.

TABLE 1: Estimate of the quantity of materials required for the production of concrete cubes.

% POFA replaced (%)	Ash (kg)	Cement (kg)	Find Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)	Quantity of cubes (unit)	W/C Ratio
0	0	3.84	7.68	15.36	1.92	12	0.5
5	0.19	3.65	7.68	15.36	1.92	12	0.5
10	0.38	3.46	7.68	15.36	1.92	12	0.5
15	0.58	3.26	7.68	15.36	1.92	12	0.5
20	0.77	3.07	7.68	15.36	1.92	12	0.5

4. Results And Analysis

% POFA Replaced (%)	7 days average density (g/cm^3)	14days average density (g/cm^3)	21 days average density (g/cm^3)	28 days average density (g/cm^3)
0	2.38	2.42	2.48	2.50
5	2.33	2.29	2.39	2.39
10	2.27	2.28	2.34	2.37
15	2.20	2.21	2.32	2.35
20	2.19	2.22	2.34	2.36



The graph above showed that the concrete cubes produced can be classified as lightweight concrete because their density is below the range of the density for heavy concrete which is between 3360kg/m³ and 3840kg/mn³. Lightweight concretes can be produced with an over-dry density range of approximately 300 to a maximum of 2000 kg/m³, with corresponding cube strengths from approximately 1 to over 60 MPa (Newman and Seng, 2003). However, the density is a little bit larger than the specified density for light weight concrete but it is far lesser than the specification for heavy weight concrete, so it can be classified as light weight concrete. Also, as the percentage replacement of OPC with POFA is increasing, the weights of the concrete cubes were reducing leading to a reduction in their densities.

Results of Compressive Strength on Hardened Concrete.

Compressive strength is the most important property of concrete. It is the maximum compressive strength that, under a gradually applied load, a given solid material can sustain without fracture. Test was conducted using cubes of size 100mmX100mm. Curing period adopted was 7,14,21 and 28 days. Average of the compressive strength obtained for the curing days are shown in table below. Similarly results are also represented in graphical form.

Results of Density of Hardened Concrete

Cube No.	Age at Testing	Crushing Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^3)
0%	7 Days	186.91	18.69	18.76
		181.11	18.11	
		194.80	19.48	
	14 Days	209.84	20.98	21.42
		219.25	21.93	
		213.47	21.35	
	21 Days	240.13	24.01	24.82
		271.28	27.13	
		233.21	23.32	
	28 Days	263.84	26.38	26.00
		254.55	25.46	
		261.69	26.17	
Cube No.	**Age at Testing**	**Crushing Load (KN)**	**Compressive Strength (N/mm^2)**	**Average Compressive Strength (N/mm^3)**
5%	7 Days	172.43	17.24	17.26
		178.66	17.87	
		166.82	16.68	
	14 Days	198.36	19.84	20.10
		204.43	20.44	
		200.12	20.01	
	21 Days	239.53	23.95	23.67
		242.60	24.26	
		228.05	22.81	
	28 Days	250.31	25.03	24.72
		247.17	24.72	
		244.20	24.42	

Cube No.	Age at Testing	Crushing Load (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength (N/mm^3)
10%		142.96	14.30	

	7 Days	157.30	15.73	14.95
		148.17	14.82	
	14 Days	165.28	16.53	16.26
		153.76	15.38	
		168.84	16.88	
	21 Days	170.58	17.06	17.90
		187.02	18.70	
		179.27	17.93	
	28 Days	197.00	19.70	19.32
		192.84	19.28	
		189.65	18.97	

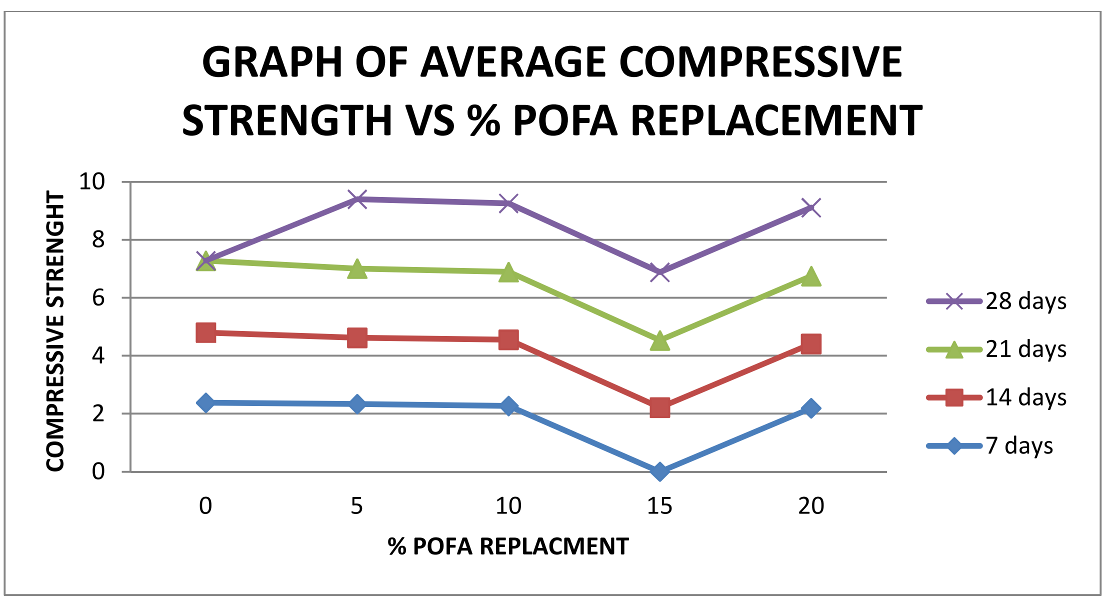
Cube No.	Age at Testing	Crushing Load (KN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm³)
15%	7 Days	68.94	6.89	7.25
		71.71	7.17	
		76.85	7.69	
	14 Days	93.10	9.31	9.51
		102.79	10.28	
		89.28	8.93	
	21 Days	126.34	12.63	12.37
		120.19	12.02	
		124.60	12.46	
	28 Days	142.91	14.29	14.03
		138.03	13.80	
		140.00	14.00	

Cube No.	Age at Testing	Crushing Load (KN)	Compressive Strength (N/mm²)	Average Compressive Strength (N/mm³)
20%	7 Days	62.28	6.23	7.02
		60.33	6.03	

		88.10	8.81	
	14 Days	114.15	11.42	8.61
		73.60	7.36	
		70.42	7.04	
	21 Days	121.53	12.15	11.53
		108.46	10.85	
		115.81	11.58	
	28 Days	133.46	13.35	12.42
		113.97	11.40	
		125.18	12.52	

The above tables are therefore summarized below;

% POFA Replaced (%)	7 days average Compressive Strength (N/mm²)	14days average Compressive Strength (N/mm²)	21 days average Compressive Strength (N/mm²)	28 days average Compressive Strength (N/mm²)
0	18.76	21.42	24.82	26.00
5	17.26	20.10	23.67	24.72
10	14.95	16.26	17.90	19.32
15	7.25	9.51	12.37	14.03
20	7.02	8.61	11.53	12.42



The graph above showed variation of compressive strength for different percentage of POFA replacement. It also showed that the compressive strengths of the concrete are increasing as the curing age increases. Consequently, compressive strengths of the concrete are reducing as the percentage of POFA replacements are increasing. The compressive strength of 5%. 10%, 15% and 20% replacement are 5.18%. 34.58%. 85.32% and 109.34% reduction compare to that of the control at 28th day of curing respectively. According to BS 8110:1 (1997) specification for different concrete class as shown in the below, specifies that the minimum strengths for plain concrete as 7N/mm2, 15N/mm2 for reinforced concrete with lightweight aggregate, 20N/mm2 for reinforced concrete with normal aggregate, 30N/mm2 for post-tensioned concrete and 40N/mm2 for pre-tensioned concrete, The POFA-concrete produced with 5% replacement can therefore be used for reinforced concrete with normal aggregate while that of 10% replacement is useful for reinforced concrete with lightweight aggregate.

Characteristics Compressive strength for structural Concept [Bs 811 (1997)].

GRADE	CHARACTERISTICS STRENGHT (N/mm^2)	CONCRETE CLASS
7 10	7 10	Plain concrete
15	15	Reinforced concrete with lightweight aggregate
20 25	20 25	Reinforced concrete with dense aggregate
30	30	Concrete with post tensioned tendons
40 50 60	40 50 60	Concrete with pre-tensioned tendons

5. Conclusion and Recommendations

Conclusion

Extensive experimentation was carried out on control concrete with POFA replacement from 0 -20%. Cement replacement were prepared with constant water -binder ratio of 0.5. For all mixes, compressive strength was determined at 7, 14, 21 and 28 days of curing. From the analysis, it can be concluded that;

(i) The compressive strength and density of the concrete cubes was increasing with increase in the curing age but decreases as the POFA content increases.

(ii) Compressive strengths of 5%, 10%, 15% and 20% POFA are 24.72N/mm2, 19.32N/mm, 14.03N/mm² and 12.42N/mm² respectively. They all satisfied the minimum strength required for plain concrete and they can be used for this type of concrete. For 10% replacement of cement with POFA, the compressive strength was 19.32N/mm2 and this can be used for reinforced concrete with lightweight aggregates.

(iii) The percentage reduction of compressive strength for 5%, 10%, 15% and 20% replacement of cement with POFA after 28 days curing period compared with the control samples were 5.18%, 34.58%, 85.32% and 109.34% respectively.

(iv) The results showed that the ultimate compressive strength of concrete could be improved by using up to 10% of POFA to replace Ordinary Portland Cement in the concrete mix as increase in the POFA replacement beyond that limit will cause decrease in the strength properties and failure.

(v) POFA is a pozzolanic material that has the potential to be used as partial cement replacement material and can contribute to the sustainability of the construction materials.

Therefore the following recommendations wre made:

From the results of the experiment carried out in this research work, the following can be recommended;

(i) The burning of Palm Oil Fuel Ash (POFA) should be done in a closed container to avoid its fineness being blown away by air or breeze.

(ii) Cultivation of more palm trees should be encouraged because the materials such as POFA derived from it are good pozzolanic materials.

(iii) The palm oil husk and fibers should be kept dry for adequate and proper burning to normal or fine aggregate.

(iv) It is recommended for use as partial replacement for cement in producing reinforced concrete with light weight aggregate at a percentage up to 10% using a mixing ratio of 1:2:4. There will be an appreciable fall in the compressive strength value for percentage beyond this level.

(v) For environmental sustainability, POFA can be utilized for the production of lightweight, durable and cheap concrete because of its availability in significant quantities across the country considering the fact that every household in Nigeria consumes palm oil and its products.

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SUSTAINABLE REMOVAL OF Cu AND Pb FROM A GALVANIZED INDUSTRIAL EFFLUENT USING SUGARCANE BAGASSE

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Abstract

A major factor in sustainable development and environmental protection is the conservation of natural resources. The likelihood of water being reused and the protection of natural resources will save fresh and natural water, and these can only be attained by removing poisonous and hazardous elements from industrial wastewater to achieve Sustainable Development Goals (SDG). This research was conducted to study the occurrence and adsorption treatment of Cu^{2+} and Pb^{2+} in a galvanizing industry effluent using Sugarcane bagasse (SCB). The removal efficiency of activated SCB in adsorbing Cu^{2+} and Pb^{2+} from effluent and the adsorption study with the effects of adsorbent dosage (0.2 g–1.0 g), contact time (20 min–100 min), and agitation speed (50 rpm–200 rpm) on the adsorption process during the wastewater treatment were determined. The results showed that activated carbon (AC) produced from Sugarcane Bagasse Ash (SCBA) using H_2SO4 activation is an efficient adsorbent for Cu^{2+} and Pb^{2+} with removal efficiencies of 97.7% and 100%, respectively, at a pH of 5.5, 0.2 g of SCBA, a contact time of 60 minutes, and a rotating speed of 150 rpm. As the dosage of SCBA increases, the adsorptive capacity also increases. It was deduced that AC produced from sugarcane bagasse activated by 0.1 M H_2SO4 activation is an efficient adsorbent for Cu^{2+} and Pb^{2+}.

Keywords: Heavy metal, Adsorption, Sugarcane bagasse, Pollution.

1.0 Introduction

Water is the main natural resource component, and is critical for the survival of all living species, including human, economic development and food production. Many towns around the world today are confronted by an acute water shortage (Awofadeju & Akanni, 2014; Akanni *et al.,* 2019; Mustafa *et al.,* 2023). The regional and seasonal accessibility of water and the quality of surface and groundwater all have a major influence on the climate, economic growth and development. Water quality is influenced by human activities and decreases because of rapid population growth, increased urbanization high level of industrialization, poor waste management and climate change (Awofadeju & Akanni, 2014, Joshi, Sharma & Singh, 2017; Hoang *et al.*, 2019;). Other sources of water pollution in Nigeria include dumping industrial waste into our water, oil spillage, waste drains, crop littering, sewage transportation into our waters, heavy metal, combustion, power facility for mineral processing, mining, pesticides, fertilizers, herbicides etc. industrial effluents transport in the environment particularly aquatic system multiple kinds of contaminants like; metals, organic and inorganic material, Polycyclic Aromatic Hydrocarbons (PAHs), and microorganisms (Maaroof & Dursun, 2018) The use of heavy metals in particular industries has grown over the previous century and has led to the flow of metallic materials to the aquatic ecosystem (Gupta, Gupta & Kharat, 2018; Dai *et al.*, 2019).

Industrial waste contains heavy metals such as copper, chromium, nickel, lead etc. (Ogbiye *et al.*, 2018; Joshi, Sharma & Singh, 2017). Copper is a persistent, bio accumulative, toxic heavy metal that does not break down in the environment. The various potential sources of copper pollution include metallurgical and metal finishing, corrosion inhibitors in cooling and boiling systems, fungicides, corrosion of copper piping, copper plating and primer paints (Rana *et al.,* 2014). The existence of copper in water bodies can cause health problems, such as transient gastrointestinal distress, and abdominal discomfort due to ingestion; the destruction of red blood cells and anaemia in humans (Rana *et al.,* 2014). Lead is non-biodegradable and tends to accumulate in the organism through food chain. It is an incredibly poisonous heavy metal that interferes with different physiological procedures of plants and has no biological tasks, as opposed to other metals such as zinc, carbon and manganese (Xiong *et al*., 2019; Abbas *et al.,* 2014). WHO, 2009, Joshi, Sharma & Singh, (2017) and Rana *et al.,* (2014) revealed that Lead has led to comprehensive pollution and health issues such as damage of fetal brains, kidney disease, circulatory & nervous system disorder. While excessive ingestion of copper can intoxicate the liver leading to renal failure and destruction of red blood cell; Wilson disease and insomnia (Joshi et al., 2017).

In Nigeria, there is a shortage in purified water resources due to decline in economic status and expensive purification (Akanni *et al.,* 2019; Ogbiye *et al.,* 2018). This is why ideal viable techniques of treatment at low cost are needed. There is need to provide an alternative (low - cost and efficient) method of treating industrial wastewater (effluent) containing heavy metal. Various treatment technologies for the removal of heavy metals such as Lead and Copper include ion exchange, chemical precipitation, ultrafiltration, nanofiltration, reverse osmosis, coagulation, chemical oxidation, adsorption and electrodialysis (Dai *et al*., 2019; Hoang *et al*., 2019; Abbas *et al.,* 2014). Among all these technologies adsorption is considered to be the most reliable and efficient method because of its low cost, high efficiency, minimization of chemical or biological sludge, regeneration of biosorbent and possibility of metal recovery especially with the use of agricultural waste product like peanut shells, peach stones and sugarcane bagasse which are cost prohibitive and eco-friendly. (Marciniak *et al*., 2019; Varshney *et al*., 2019; Hoang *et al.,* 2019; Abbas *et al*., 2014). Other technologies have inherent limitations such as large amount of sludge, low efficiency, costly disposal and sensitive operating conditions.

The sugarcane industry provides a large supply of Sugarcane (*Saccharum officinarum*) Bagasse (SCB). It is the fibrous material remaining behind after cane stem is crushed and sugarcane juice extracted. The extraction of Sugarcane Bagasse arises from the external rind and the internal rind needs a minimum effort. It can be utilized at a low cost both in the natural form (SCB) and in a modified form (MSB) (Renu & Singh, 2017; Gupta, Gupta & Kharat, 2018). This lignocellulose material is characterized by large specific surface area, porous structure, abundant surface functional groups and mineral components which makes it a good adsorbent (Dai *et al.,* 2019; Renu & Singh, 2017). SCB's chemical components include polyoses (27 %), lignin (23 %), and cellulose (50 %) (Esfandiar, Nasernejad, & Ebadi, 2014; Wang et al., 2017).

Its biological element polymerizes SCB and its group can be changed to increase its absorption potential by chemical modifications of phenolic and hydroxylic components (Renu & Singh, 2017; Varshney *et al*., 2019). SCB also increases its mechanical characteristics through a chemical alteration. This includes flexural strength, hardness, tensile capacity, bending modulus, impact strength (Loh *et al.,* 2013). Sugarcane bagasse modified chemicals include succinic anhydride; sulfuric acid; pyromellic anhydrides; citric acid; potassium bicarbonate and ethylene diamines, which act as a useful activating agent. SCB polymerized to increase the amount of chelating sites and pore areas (porosity) that remove heavy water from wastewater (Xiong *et al.,* 2019; Renu & Singh, 2017). The aim of this research is to conduct an intensive study of the occurrence and treatment of copper and lead in an industrial effluent using Sugarcane bagasse.

2.0 Materials and Methods

2.1 *Industrial Effluents Sample Collection*

The preliminary experimental study was conducted on the wastewater samples collected from a galvanizing industry at Abeokuta, Ogun State, Nigeria. The sample was carefully bottled in a plastic container and transported to the laboratory for Atomic Absorption Spectrophotometry (AAS) analysis.

2.2 *Material and Adsorbent Preparation*

Sugarcane stem was collected from *Papalanto* town in Ogun State, Nigeria where sugarcane farming is dominant. It was peeled with knife to remove the hard bark of the sugarcane. The soft edible fiber of the stem was cut into 5mm sizes and crushed inside mortar with pestle. The crushed sugarcane stem was filtered with a clean towel handkerchief to remove the juice from the bagasse. After the removal of juice, the Sugarcane Bagasse (SCB) was rinsed with distilled water to completely remove ligneous, cellulose and trapped impurities in the bagasse. The filtration process was repeated and the final clean bagasse was dried at $40^{o}C$ for 24hrs after which it was ground and sieved to get particle size 125μm and the fines passing through the sieve were stored in airtight 0.75L PET bottles (Ojoawo *et al.,* 2016). The efficiency of adsorbents relies to a large extent on the pollutant type and condition of the experiment. Chemical surface modification significantly increases the removal effectiveness with favorable kinetics and adsorption mechanisms (Hoang *et al.,* 2019; Ojoawo *et al.,* 2016).

2.3 *Carbonization and Activation of Adsorbent*

The carbonization and activation procedures followed were adopted from the report of (Salihi, Kutty & Isa, 2017). The SCB powder obtained earlier was placed in a muffled furnace/oven; heated to $500^{0}C$ at $10^{0}C$ / min heating rates. The oven temperature was maintained at $500^{o}C$ for three hours to obtain a carbon like material. The resulting carbonized substance was allowed to cool in a desiccator, washed in distilled water and subsequently soaked in 0.1 M Sulphuric acid for 24hours. It was washed again with distilled water and dried in the oven at $105^{o}C$ for 1hour, it was then allowed to cool in a desiccator and stored in a closed container. Fig. 1 shows oven dried sugarcane bagasse.

Fig. 1. Oven dried sugarcane bagasse

2.4 *Characterization of Samples*

Characterization of the SCBA and wastewater was determined using Scanning Electron Microscope (SEM), Fourier Transform Infrared Spectroscopy (FTIR) analysis, digestion of effluent samples and Atomic Absorption Spectrophotometry (AAS) analysis at Central Laboratory, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso. The digestion of the effluent samples from a galvanizing industry was carried out with the aim of breaking down the complexity of the samples before the AAS analysis. Atomic absorption spectrophotometry (AAS) analysis was carried out to determine the concentration of the untreated wastewater and the final concentration after the treatment using AAS model number PG6990.

The batch experiments with One Factor at a Time (OFAT) was conducted on the effluent samples varying the factors of adsorbent dosage, contact time and rotating speed of rotary incubator.

These are the factors that influence the biosorption process of heavy metals from wastewater. Others include; temperature, initial heavy metal concentration and co-ions (Xiong *et al.,* 2019; Salihi, Kutty & Isa, 2017).

(a) Adsorption study:
50ml of effluent sample was poured into 250ml conical flask and 0.2g of prepared SCBA adsorbent was added, a rotary shaker at room temperature was agitated at 150 revolutions per minute (rpm) for 60mins. The suspension was filtered with Dr. Watt's filter paper and the filtrate subjected to AAS analysis.

(b) Effect of adsorbent dosage:
This was studied with the varying dosages of 0.2-1.0g/L into 50ml of the effluent sample in a conical flask respectively and agitated at 150 rpm for 60minutes, the suspension was filtered with Dr. Watt's filter paper, and the filtrate was subjected to AAS analysis.

(c) Effect of rotating speed:
0.2g of the adsorbent was measured into 50ml of effluent sample into different conical flasks and subjected to various agitation from 50 to 200rpm at 50 rpm intervals. The filtrate from each batch was then subjected to AAS analysis.

(d) Effect of the contact time:
0.2g of adsorbent was added to the 50 ml samples of effluent, placed on a rotating shaker and agitated at 150 rpm for each contact time selected in 20, 40, 60, 80 and 100 minutes. The adsorbent was separated with Dr. Watt's filter paper, and subjected to AAS analysis. Leandro, Rossimiriam and Laurent (2008); Rana *et al.,* (2014); Kumar *et al.* (2012) have shown that adsorption of Cu^{2+} and Pb^{2+} is optimum at a pH range of 5 to 6. A pH of 5.5 was however maintained for all the adsorption studies.

(e) Percentage removal of adsorbate/biosorption:
The percentage biosorption of heavy metal for the experiment were obtained according to (Rana *et al.*, 2014).

Calculation: $$\% \text{ Biosorption} = \frac{Icm - Ifm}{Icm} \times 100\% \quad (1)$$

I_{cm} = Initial concentration of metal (mg/L)

I_{fm} = Final concentration of metal (mg/L)

Fourier Transform Infrared analysis was performed on SCB using Infrared Spectrophotometer model: BUCK M530 series to determine its functional group in other to evaluate its rate of absorption (Somyanonthanakun *et al.*, 2023). 1g of SCB sample was taken to LAUTECH Central Energy Laboratory, Ogbomoso for FTIR analysis using pressed disc of KBr power. The Scanning Electron Microscope (SEM) was used to examine the surface morphology of adsorbents. The sample was prepared by drying to eliminate any remaining moisture, then grinding and sieving to get a uniform particle size. The SEM sample was placed on a carbon template-coated SEM sample holder. The sample was then sprayed with a sample spray coat in order to attach the entire grain particle from the sample and prevent cross contamination of sample in the sample holder compartment of the instrument (Olorundare *et. al.,* 2014). Magnifications of 500X and 1000X were used for imaging. The secondary electron mode was employed to record the topography of the surface.

3.0 Results and Discussion

3.1 *Concentration of Heavy Metals in the Sample before Treatment*

The heavy metal concentration of the galvanized industrial effluent sample is shown in Table 1. Eight metals were analysed which include Manganese (Mn), Lead (Pb), Zinc (Zn), Iron (Fe), Cadmium (Cd), Chromium (CR), Cobalt (Co) and Copper (Cu). The table shows that the industrial effluent was not adequately treated before it was discharged into the river during the period of the research. The effluent samples showed that Co, 0.158, Pb 0.0457, Mn 0.248, Cd 0.123mg/L have concentrations higher than the Maximum Permissible Level (MPL) of Nigeria Standard (National Environmental Standard and Regulations Enforcement Agency - NESREA Limits) and same also for WHO standard. While, Fe, Zn and Cu have concentration below

NESREA Limits. The initial waste water classification bar graph in Fig. 2 shows that Pb has 5%, Zn has 12%, Cu has 24%, Cr has 13%, Co and Mn have 16% and 26% and respectively, while Fe has 1%.

Table 1: Pre-treatment concentration of heavy metals in the wastewater sample compared to quality guidelines and standards

Metals	WHO Standards MPL[a] (mg/L)	Nigeria standard MPL (mg/L)	Present Study (mg/L)
Lead (Pb)	0.01	0.01	0.0457
Cobalt (Co)	-	0.05	0.158
Cadmium (Cd)	0.003	0.003	0.0007
Chromium (Cr)	0.05	0.05	0.123
Zinc (Zn)	3.00	3.00	0.119
Copper (Cu)	2.00	1.00	0.263
Manganese (Mn)	0.40	0.20	0.248
Iron (Fe)	0.30	0.30	0.0108

*MPL = Maximum Permissible/Permitted Levels

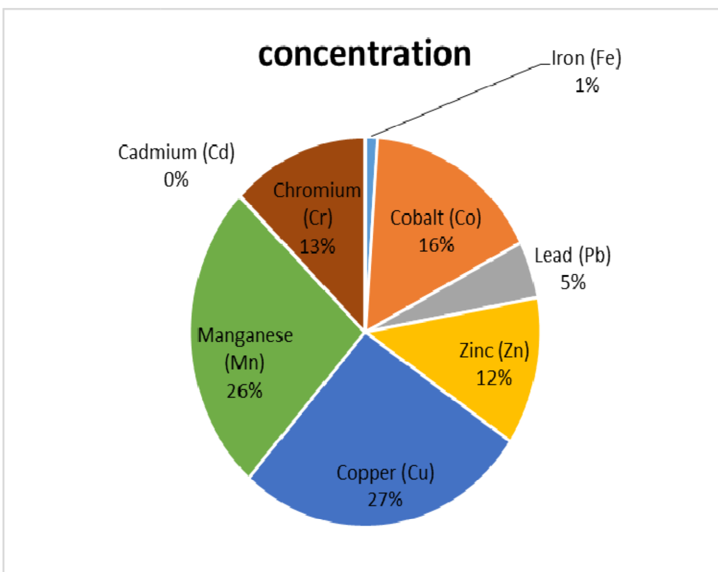

Fig. 2. Percentage composition of heavy metal present in the wastewater prior to treatment

3.2 *Adsorption Studies*

The following are the results of the batch experiment with One Factor at a Time (OFAT) conducted on the wastewater sample.

.2.1 *Effect of adsorbent dosages*

The result of the AAS assessment for the adsorbent dosages (0.2–1.0 g) on the removal efficiency of Cu^{2+} and Pb^{2+} is presented in Fig. 3. At a pH of 5.5 and a rotating speed of 150 rpm, the result shows that Pb^{2+} was completely removed at all adsorbent dosages. The removal efficiency of Cu^{2+} with SCBA increases with an increase in adsorbent dosage because of an increase in the available adsorption sites. Aliyuda *et al.*, (2023) reported that the optimum operating condition for Cadmium adsorption were found to be at adsorbent dosage of 1.0 g. At optimum conditions, the value obtained shows that SCBA is a good adsorbent. Pb^{2+} is most sensitive to the adsorbent, irrespective of any quantity added; the percentage removal of Pb^{2+} is approximately 100%. This is a result of the low concentration of Pb^{2+} when compared to that of Cu^{2+} in the wastewater sample. Feng *et al.* (2011) reported in their work that at low concentrations of Pb^{2+}, the removal efficiency is high and decreases as the concentration increases. However, when considering $Cu^{2+,}$ the efficiency of the adsorbent removal increases with an increase in the adsorbent dosage.

3.2.2 *Effect of rotating speed*

The impact of spinning velocity on metal adsorption is demonstrated in Fig. 4. The adsorption ability increases with a rise in the rotating speed from 50 rpm to 150 rpm for both Cu^{2+} and $Pb^{2+.}$ While there was no noticeable change in the removal efficiency at 200 rpm for both Cu^{2+} and Pb^{2+}, the percentage of removal efficiency remained constant.

3.2.3 *Effect of contact time*

The effect of contact time on the removal efficiency of Cu^{2+} and Pb^{2+} in the adsorption batch experiment of heavy metals in industrial effluent is shown in Fig. 5. The absorption of Cu2+ and Pb^{2+} increased with contact time. At 20 minutes, the removal efficiency of Cu^{2+} and Pb^{2+} is 88.6% and 99.1%, respectively. The adsorbent, however, offered optimum removal at a contact time of 60 minutes, with 96.2% and 100% for Cu^{2+} and Pb^{2+}, respectively. The removal efficiency declined as the contact duration rose in the removal of Cu^{2+} (Carpanedo de Morais Nepel *et al.,* 2020). This may be as a result of saturation of the adsorption sites on the SCBA surface. The pH also has a significant influence on the surface charge of the adsorbent as well as the degree of ionization and adsorbate species (Leandro, Rossimiriam and Laurent, 2008; Kumar *et al.,* 2012). In the report of Zdravković *et al.*, (2018), it was stated that the efficiency of Cu and Pb removal decreases with an increase in pH. Feng *et al.* (2011) also revealed that the biosorption of Pb (II) increases with increasing pH up to pH of 5.5.

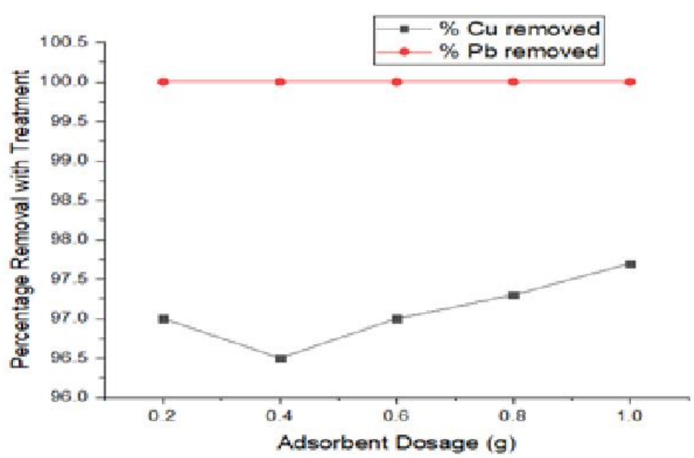

Figure 3: Percentage removal with adsorbent concentration

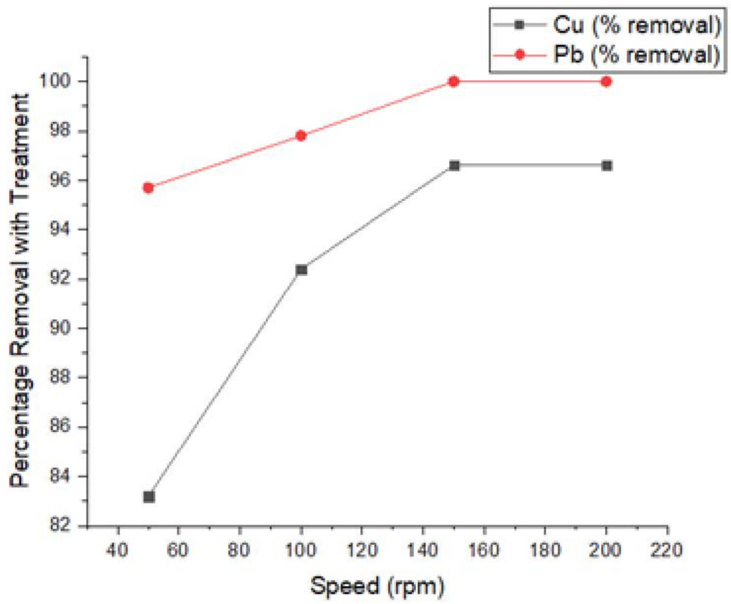

Figure 4: Percentage removal with rotating speed of rotary incubator (rpm)

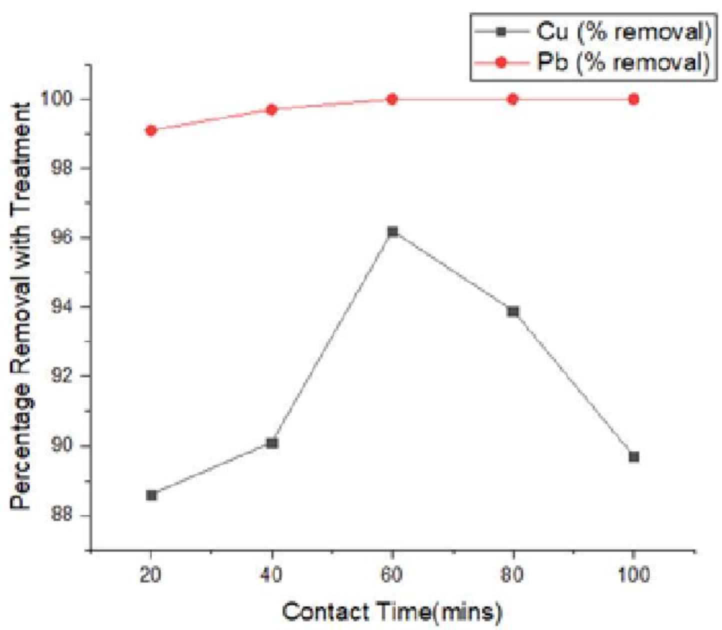

Figure 5: Percentage removal with contact time of the adsorbed

3.3 ***Fourier transform infrared spectroscopy (FTIR) spectrum interpretation.***

Fourier transform infrared spectroscopy FTIR determined the surface functional groups of sugarcane bagasse. An infrared spectrum is usually presented as a plot of the percentage of radiation of each wavelength transmitted through the sample (0% transmission corresponds to total absorption by the sample).

The functional group present in the molecules of the sample before treatment is as shown in Fig. 6. Include (3949.7–3593.7) free or non-associated hydroxyl (-OH), (3498.6–3234.9) hydrogen-bonded hydroxyl (-OH) stretching vibration, (2975.8–2706.3) C-H of aldehyde stretching vibration, and (1757.6–1631.8) carbonyl (C = O) stretching vibration.

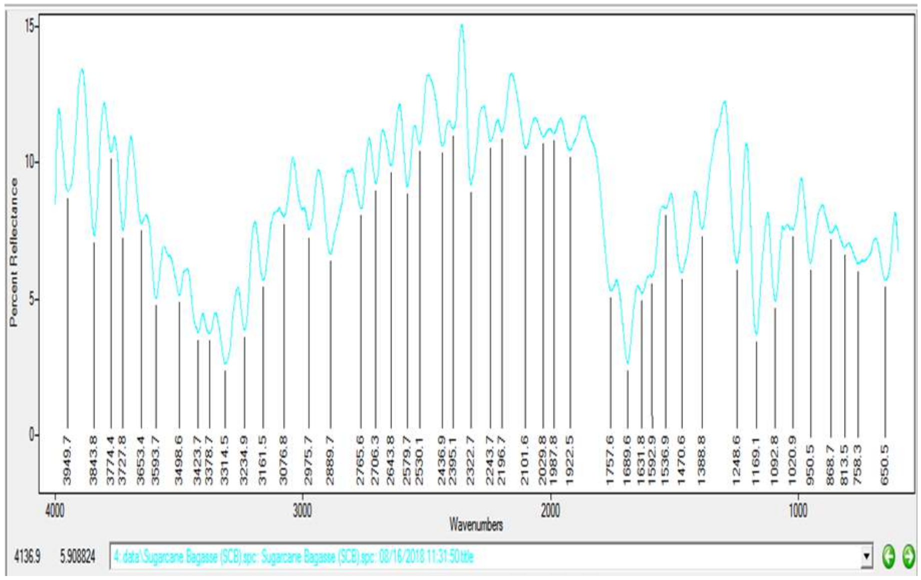

Figure 6: FTIR spectrum for SCB powder sample before treatment

(a) (b)

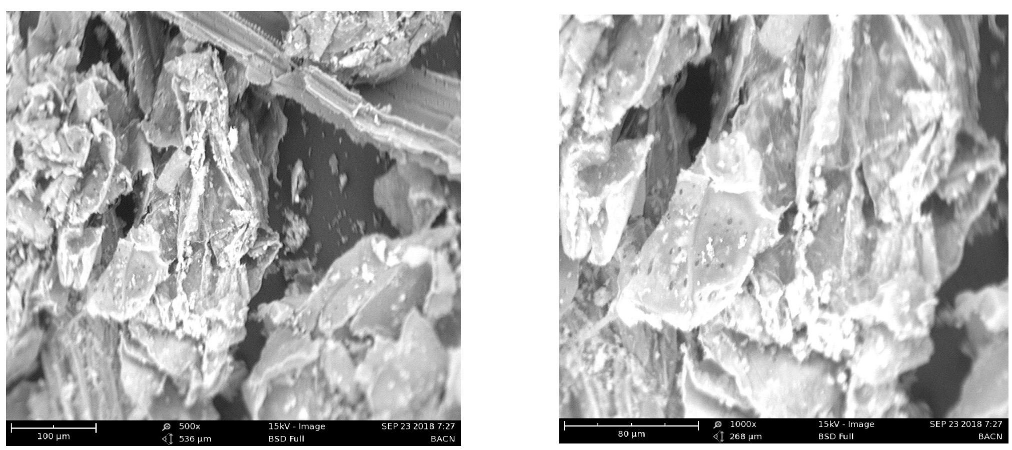

Figure 7a-b: SEM images of SCB sample before treatment at (a) 500x, (b) 1000x,

In Figure 7a-b, Scanning Electron Microscope (SEM) images of pure adsorbent before treatment were displayed at two distinct magnifications of 500x and 1000x. SEM was used to investigate the surface texture and morphology of the adsorbent. It can be proven or asserted that the raw adsorbent has a heterogeneous, well-developed framework. According to the SEM assessment, the adsorbed heavy metal particles are spread evenly on the surface and interior pores of the SCB adsorbent and are distinguished by a smoother compact and consistent framework in line with studies carried out by Kołodyn'ska *et al.,* (2017).

4.0 Conclusions

This study demonstrates that sugarcane bagasse is abundantly accessible and can be used to remove Cu^{2+} and Pb^{2+} ions in a galvanized industrial wastewater as an efficient biosorbent. The method of adsorption depends on pH, contact time, rotating speed and the dose. With activated sugarcane bagasse adsorbent, the highest removal efficiency of Cu^{2+} ions from the wastewater is 97.7% While that of lead (Pb^{2+}) is 100% both at 0.2g dosage of SCBA, pH of 5.5, rotating speed of 150rmp and contact time of 60min. As dosage increases, the removal efficiency of Cu^{2+} and Pb^{2+} ions also increases until they reach equilibrium. It further revealed that contact time, pH, rotating speed and adsorbent dosage are parameters affecting heavy metal absorption capability of SCBA.

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Harnessing Artificial Intelligence Potentials for Sustainable Landscape and Public Health Outcomes

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Abstract

Research on the application of artificial intelligence (AI) has primarily focused on areas such as disease diagnosis and management, public health surveillance, and healthcare as a whole. However, the interrelated domains of landscape and well-being have received comparatively little attention, despite their significant reciprocal relationship. The intersection between AI, landscape, and public health is a burgeoning research area, particularly in developing countries like Nigeria. This review aims to explore the potential applications of AI in promoting sustainable landscape and wellbeing planning and management in Nigeria, as well as the challenges and opportunities associated with its adoption. A comprehensive literature review reveals that AI can enhance landscape planning, environmental monitoring, and health impact assessments, ultimately contributing to improved public health outcomes. To harness the full capacity of AI, it is essential to address deterrents such as knowledge gaps, inadequate infrastructure, and the existing disparity in access to and benefits from this digital technology. This review highlights the need for collaborative efforts between researchers, policymakers, and practitioners to develop context-specific AI solutions that prioritise Nigerian needs and contexts. By doing so, AI can be adequately harnessed to create sustainable, healthy, and resilient landscapes that support the well-being of its citizens.

Keywords: Artificial intelligence, Landscape, Wellbeing, Public Health, Nigeria, Sustainable Development.

Introduction

1.1 Background of Study

Globally, the level of revolution artificial intelligence (AI) has brought into different sectors of human endeavours including healthcare and landscape cannot be overemphasized. In healthcare, AI has improved disease diagnosis and management (Esteva *et al*., 2019), public health surveillance (Nsoesie *et al*., 2019), and healthcare generally (Rajkomar *et al*., 2019). The algorithm generated by AI has become of great use in analysing medical images, predicting patient outcomes, and enhancing personalized medicine (Esteva *et al*., 2019). In the same vein, AI has enhanced environmental monitoring (Kattenborn *et al*., 2019), land cover classification (Li *et al*., 2020), and urban planning (Bibri, 2019) in terms of landscape. AI-powered geographic information systems (GIS) can analyze satellite images, detect land use changes, and optimize urban development (Kattenborn *et al*., 2019). Despite these advancements, the intersection of AI, landscape, and public health remains understudied, particularly in developing countries like Nigeria (Aigbavboa *et al*., 2018; Oke *et al*., 2017). The existing gap in research is noteworthy, as the oversight of landscape and well-being in AI studies may impede the achievement of good health and well-being, as well as the establishment of sustainable cities and communities (United Nations, 2015). Scholars have argued that the integration of AI in landscape and public health research has the potential to bring about creative approaches to address environmental and health-related problems (Kattenborn *et al*., 2019; Li *et al*., 2020). However, the scarcity of research along this line, especially in Nigeria, may be attributed to the limited availability of data, infrastructure, and expertise (Oyewole *et al*., 2017).

This current effort is to examine the potential application of artificial intelligence in promoting sustainable landscape and wellbeing in Nigeria. The study seeks to investigate how AI can be leveraged to enhance landscape planning, environmental monitoring, and health impact assessments, ultimately contributing to improved well-being and public health outcomes in Nigeria (Kattenborn *et al*., 2019; Li *et al*., 2020). Previously, the efficacy of AI to analyse satellite images, detecting land use changes, and optimising urban development was demonstrated by Bibri (2019) and Esteva *et al.* (2019). By focusing the opportunities and challenges associated with AI adoption in Nigeria, this study hopes to contribute to the development of context-specific AI solutions that prioritise Nigerian needs and contexts. This is in line with the call by scholars for more research on the application of AI in developing countries, where the potential benefits are enormous (Nsoesie *et al.*, 2019; Rajkomar *et al.*, 2019).

Literature Review

2.1 Overview of the Applications of Artificial Intelligence

2.1.1 Disease Diagnosis and Management

Leveraging Artificial Intelligence (AI) in disease diagnosis and management has garnered significant attention in Nigeria, with numerous studies exploring its potential. Adeoye *et al.* (2020) demonstrated AI's accuracy in diagnosing malaria. They discovered that AI-powered diagnostic systems achieved an accuracy rate of 95.6% in diagnosing malaria, outperforming human clinicians. Additionally, they identified data quality and availability as significant challenges. Ojo *et al.* (2020) showcased potentials of artificial intelligence in tuberculosis diagnosis. They found that AI-assisted tuberculosis diagnosis reduced diagnostic time by 75% and improved diagnostic accuracy by 20%. They also highlighted the need for increased AI adoption in resource-constrained settings. Furthermore, Akinade *et al.* (2022) highlighted AI's role in cancer diagnosis, emphasizing its ability to enhance diagnostic accuracy. They demonstrated that AI-powered cancer diagnosis achieved an accuracy rate of 92.1%, surpassing human pathologists. They emphasized the potential of AI in enhancing diagnostic accuracy and reducing false positives.

In disease management, Ogunjobi *et al.* (2021) explored AI's application in diabetes management, and discovered that AI-powered diabetes management systems improved blood glucose control by 25% and reduced hospitalization rates by 30%. They also identified patient engagement and education as crucial factors. Adeyinka *et al.* (2022) discussed its potential in hypertension management, and found that AI-assisted hypertension management reduced blood pressure levels by 15% and improved medication adherence by 25%. They highlighted the potential of AI in enhancing patient outcomes and reducing healthcare costs. These studies underscore AI's capacity to improve patient outcomes and enhance healthcare delivery. However, challenges persist, including limited data quality (Laoye *et al.*, 2022), inadequate infrastructure (Adeoye *et al.*, 2020), and insufficient expertise (Ojo *et al.*, 2020). Overcoming the downsides to this technology is essential to fully harness its potential in Nigerian healthcare.

2.1.2 Public Health Surveillance

The integration of this digital intelligence to public wellness initiatives surveillance has gained substantial interest in Nigeria, with various studies exploring its potential. Ojo *et al.* (2020) demonstrated the effectiveness of AI-powered surveillance systems in detecting and tracking infectious diseases, such as Ebola and Lassa fever. They highlighted the capacity of AI to augment early warning systems, facilitating rapid response strategies. Building upon this research, Adeoye *et al.* (2020) explored the use of machine learning algorithms for the prediction of epidemics, achieving an accuracy rate of 85.6%. They emphasized the need for high-quality data and collaborative efforts. Laoye *et al.* (2022) discussed the application of natural language processing in analyzing social media data for disease surveillance, highlighting its potential in detecting early warnings and monitoring public health trends. However, challenges persist, including data quality and availability (Ojo *et al.*, 2020), inadequate infrastructure (Adeoye *et al.*, 2020), and limited expertise (Laoye *et al.*, 2022).

2.1.3 Healthcare Generally

The capacity of artificial intelligence to improve healthcare outcomes, streamline clinical workflows, and enhance patient experiences has garnered considerable global interest, including Nigeria, owing to its functional capabilities. The discovery of AI's potential in healthcare is evident in various studies. Globally, AI has been shown to be effective in medical imaging analysis (Rajpurkar *et al*., 2020), disease diagnosis (Esteva *et al*., 2019), and personalized medicine (Chen *et al*., 2019). In Nigeria, research has demonstrated AI's potential in healthcare management (Oyedotun *et al*., 2020), disease surveillance (Adewole *et al*., 2020), and telemedicine (Adebayo *et al*., 2020). Specifically, Adewole *et al*. (2020) identified AI's potential in enhancing disease surveillance, while Adebayo *et al*. (2020) found that AI-powered telemedicine can improve healthcare access and outcomes. Chen *et al*. (2019) demonstrated AI's potential in reducing healthcare disparities through personalized medicine. However, limitations exist in AI adoption in healthcare. Data quality and availability (Adewole *et al*., 2020; Oyedotun *et al*., 2020), infrastructure limitations and regulatory frameworks (Adebayo *et al*., 2020), and the need for diverse and representative datasets (Chen *et al*., 2019) are significant challenges. Additionally, legal and ethical considerations, including data privacy and bias (Rajpurkar *et al*., 2020), must be addressed. To address these, Adewole *et al*. (2020) and Oyedotun *et al*. (2020) recommended improved data quality and availability, while Adebayo et al. (2020) opined that increased investment in healthcare infrastructure and policy development will be of immense help. In the same way, Chen *et al*. (2019) in their study concluded that addressing bias in AI decision-making is a necessity. Esteva *et al*. (2019) also recommended ensuring responsible AI adoption through regulatory and ethical considerations in order to address the limitations existing in AI adoption in healthcare. Furthermore, increased transparency and accountability in AI decision-making (Rajpurkar *et al*., 2020) are crucial for successful AI adoption in healthcare.

2.1.4 Intersection of AI, Landscape, and Public Health

Research has increasingly explored the intersection between Artificial Intelligence (AI), landscape, and wellbeing/public health. A study by Sullivan et al. (2020) demonstrated how AI-powered landscape analysis can inform urban planning decisions to promote physical activity and reduce obesity. Another study by Kardan *et al*. (2019) found that AI-driven landscape design can improve mental health outcomes by incorporating natural elements. Moreover, AI has been utilised in analysing the influence of environmental landscape on public health. Li *et al*. (2020) employed machine learning algorithms to examine the relationship between landscape features and cardiovascular disease. In a similarly vein, a study by Yang *et al*. (2019) used AI to investigate the effect of landscape on air quality and respiratory health. Nevertheless, apprehension regarding the potential negative impacts of AI on landscape and wellbeing exist in connection with the society. These impacts are multifaceted and far-reaching. Globally, AI-driven urbanization can lead to decreased green spaces, increased stress levels, and reduced wellbeing (Zhang *et al*., 2020). Furthermore, AI-powered resource extraction and processing can exacerbate environmental degradation, negatively impacting landscape and wellbeing (Esteva *et al*., 2019). Additionally, AI-driven automation can displace jobs, leading to increased stress, anxiety, and decreased wellbeing (Forsyth et al., 2020).

In Nigeria, the negative impacts of AI on landscape and wellbeing are equally concerning. AI-driven urbanization can lead to the destruction of cultural heritage sites, negatively impacting landscape and wellbeing (Akingbola *et al*., 2020). Moreover, AI-powered industrialization can increase environmental pollution, negatively impacting landscape and wellbeing (Ogundipe *et al*., 2020). Furthermore, AI-driven resource allocation can exacerbate existing inequalities, limiting access to resources and negatively impacting wellbeing (Adeyinka *et al*., 2020).

2.2 Potential of Artificial Intelligence

2.2.1 Landscape Planning

Artificial Intelligence (AI) has revolutionized various fields, and its potential in landscape planning is vast and promising. Research conducted worldwide has illustrated the capabilities of artificial intelligence in analyzing and simulating landscape designs, forecasting environmental impacts, and optimizing planning decisions (Li et al., 2022). For instance, a study in China employed machine learning algorithms to design urban parks, considering factors like user preferences, climate, and vegetation (Wang *et al.*, 2020). In Nigeria as well, AI can address pressing landscape planning challenges, such as rapid urbanization and environmental degradation (Adeyemi *et al.*, 2020). Researchers have applied GIS and machine learning to identify suitable areas for green infrastructure development in Lagos (Oke *et al.*, 2022). Additionally, AI-powered participatory mapping and virtual reality can enhance community engagement in landscape planning (Mbachu *et al.*, 2020).

The potential of artificial intelligence in landscape planning is further demonstrated by its capacity to analyze extensive datasets, discern patterns, and forecast future trends (Aljoumani *et al.*, 2020). This can inform evidence-based planning decisions, ensuring sustainable and resilient landscapes. It can also optimize landscape planning by considering multiple objectives, such as environmental, social, and economic factors (Zhang *et al.*, 2022). These are indications that AI has the potential to transform landscape planning by enhancing design, planning, and management processes. Its applications in analyzing data, simulating scenarios, and engaging communities can lead to more sustainable and resilient landscapes.

2.2.2 Environmental Monitoring

Artificial Intelligence (AI) has transformed environmental monitoring through the improvement of data collection, analytical processes, and predictive capabilities. Globally, studies have demonstrated AI's potential in monitoring air and water quality (Kumar *et al.*, 2020), detecting deforestation and land degradation (Dobos *et al.*, 2020), and predicting climate patterns (Chen *et al.*, 2022). For instance in Asia, machine learning algorithms was been employed to monitor water quality, achieving high accuracy in predicting pollutant levels (Li *et al.*, 2019). The Nigeria experiences have proven that AI can address pressing environmental challenges, such as oil spill detection and monitoring (Isebor *et al.*, 2020). Researchers have utilized satellite image analysis and machine learning techniques to detect regions impacted by oil spills in the Niger Delta (Okeke *et al.*, 2022). Furthermore, AI-enabled sensors are capable of monitoring air quality in urban environments, delivering real-time data to facilitate informed decision-making (Adeyemi *et al.*, 2022).

2.2.3 Health Impact Assessments

Artificial Intelligence (AI) possesses the potential to transform Health Impact Assessments (HIAs) by improving the accuracy, efficiency, and comprehensiveness of the process of assessment. Globally, studies have demonstrated AI's capabilities in predicting health outcomes, identifying risk factors, and evaluating the effectiveness of interventions (Srivastava *et al.*, 2020). Li et al. (2019) utilized machine learning algorithms to forecast the health effects of air pollution, attaining a high level of accuracy in predicting mortality rates in the United States. In the same vein, Adeyemi *et al.* (2020) assert that artificial intelligence has the potential to tackle critical health issues, including infectious disease outbreaks and maternal mortality in Nigeria. Researchers have similarly substantiated this claim by employing AI-driven predictive models to pinpoint high-risk regions for malaria outbreaks, thereby facilitating targeted interventions (Okeke *et al.*, 2022). Additionally, Eze *et al.* (2022) demonstrated that artificial intelligence can analyze extensive datasets to identify risk factors associated with maternal mortality, thereby informing evidence-based policy decisions.

The impact of artificial intelligence in HIAs is further enhanced by its capacity to integrate various data sources, including electronic health records, environmental data, and social determinants of health (Kumar *et al.*, 2020). This integration can yield a comprehensive understanding of the intricate relationships among environmental factors, health outcomes, and social determinants. Moreover, AI can promote community engagement and participation in HIAs through the use of AI-driven tools and platforms (Mbachu *et al.*, 2020). These potentials could be achieved by enhancing predictive capabilities, identifying risk factors, and evaluating interventions. Its applications in predicting health outcomes, identifying high-risk areas, and analyzing diverse data sources can lead to more effective and targeted health interventions.

Methodology

3.1 Comprehensive Literature Review Approach

This approach refers to a methodical and thorough process of identifying, evaluating, and synthesizing existing research studies and literature on a specific research topic or question. The study investigated the potential applications of AI in advancing sustainable landscapes and public health in Nigeria. It also analyses the intersection of AI, landscape, and public health, emphasizing the opportunities and challenges related to the adoption of AI in the Nigerian context. This review covered various aspects, including disease diagnosis and management, public health surveillance, healthcare generally, the intersection of AI, landscape, and wellbeing/public health, and the potential of AI in landscape planning, environmental monitoring, and health impact assessments. The study highlights challenges including data scarcity, inadequate infrastructure, and the digital divide, which must be addressed in order to fully harness the potential of artificial intelligence. The need for collaborative efforts between researchers, policymakers, and practitioners to develop context-specific AI solutions that prioritize Nigerian needs and contexts has also been emphasised through the study. This review provides a solid foundation for understanding the potential of AI in promoting sustainable landscape and wellbeing in Nigeria. It underscores the necessity for additional research and collaboration to capitalize on the advantages of artificial intelligence and to tackle the challenges related to its implementation.

3.2 Data Sources and Strategy

The information used in this study was drawn mainly from secondary data sources. The information included published works on the subjects related to disease diagnosis and management, public health/wellbeing, landscape planning, environmental monitoring, and health impact assessments. These published papers were sourced from various online databases, including academic platforms such as Google Scholar, PubMed, Scopus, and Web of Science. They were also obtained from online libraries and repositories, such as Research Gate, as well as government and organizational websites, including the World Health Organization, the United Nations, and the National Institutes of Health. Furthermore, online journals and publications, such as Science Direct, were also utilized.

Results of Findings

4.1 Summary of Research Findings

4.1.1 Landscape Planning

Artificial intelligence has the capacity to transform landscape planning by improving the analysis and simulation of landscape designs, forecasting environmental impacts, and optimizing planning decisions. AI-powered GIS and machine learning algorithms can identify suitable areas for green infrastructure development, leading to more sustainable and resilient landscapes. Furthermore, AI can optimize landscape planning by considering multiple objectives, such as environmental, social, and economic factors, to create holistic and integrated plans.

4.1.2 Environmental Monitoring

AI can significantly enhance environmental monitoring by analyzing large datasets, identifying patterns, and predicting future trends. AI-powered sensors and satellite image analysis can effectively monitor air and water quality, detect deforestation and land degradation, and predict climate patterns, enabling proactive measures to mitigate environmental degradation. Additionally, AI can integrate data from various sources, providing a comprehensive understanding of environmental systems and informing evidence-based decision-making.

4.1.3 *Health Impact Assessments*

Artificial intelligence can enhance health impact assessments by forecasting health outcomes, identifying risk factors, and assessing the effectiveness of interventions. It can equally analyze a variety of data sources, including electronic health records, environmental data, and social determinants of health, thereby offering a comprehensive understanding of the intricate relationships among environmental factors, health outcomes, and social determinants. Moreover, AI can facilitate community engagement and participation in health impact assessments through AI-powered tools and platforms, ensuring that assessments are inclusive and effective.

4.1.4 *Overall Potential*

AI has the potential to transform landscape planning, environmental monitoring, and health impact assessments by enhancing data collection, analysis, and prediction capabilities. By identifying areas for improvement, optimizing resource allocation, and predicting future trends, AI can promote sustainable landscape and wellbeing. Nevertheless, challenges such as lack of information, inadequate infrastructure, and the digital inequality must be addressed in order to fully capitalize on the potential of artificial intelligence and to ensure that its benefits are distributed equitably.

4.2 *Challenges and Opportunities Associated with AI Adoption in Nigeria*

4.2.1 *Challenges of AI Adoption*

The adoption of Artificial Intelligence (AI) in Nigeria faces several challenges, including data scarcity and limited access to quality data, which hinders the development and training of AI models. Additionally, limited infrastructure, including inadequate computing power and internet connectivity, constrains the deployment and utilization of AI solutions. Furthermore, the digital divide and lack of AI expertise and skills in Nigeria pose significant barriers to AI adoption. Furthermore, issues related to data privacy, security, and ethical considerations must also be addressed to facilitate the responsible adoption of artificial intelligence.

4.2.2 *Opportunities of AI Adoption*

Despite the challenges, AI adoption in Nigeria presents numerous opportunities for sustainable development. AI can enhance landscape planning, environmental monitoring, and health impact assessments, leading to improved wellbeing and public health outcomes. Additionally, AI can optimize resource allocation, predict future trends, and identify areas for improvement, enabling proactive measures to address development challenges. Moreover, AI can facilitate community engagement and participation in development initiatives, ensuring that solutions are inclusive and effective. By leveraging AI, Nigeria can leapfrog traditional development pathways and achieve sustainable development goals.

Discussion of Findings

5.1 *Implications of Artificial Intelligence*

5.1.1 *Landscape Planning*

The adoption of AI in landscape planning has significant implications for creating sustainable and resilient landscapes. AI can optimize landscape design, predict environmental impacts, and identify areas for improvement, leading to enhanced biodiversity, ecosystem services, and human wellbeing. Moreover, AI can facilitate community engagement and participation in landscape planning, ensuring that plans are inclusive and effective. However, AI also raises concerns about the potential for biased or unfair planning decisions, highlighting the need for transparent and accountable AI systems.

5.1.2 Environmental Monitoring

AI has far-reaching implications for environmental monitoring, enabling real-time tracking of environmental changes, predicting future trends, and identifying areas for conservation. AI-powered sensors and satellite image analysis can monitor air and water quality, detect deforestation and land degradation, and predict climate patterns, enabling proactive measures to mitigate environmental degradation. However, artificial intelligence also raises concerns regarding data privacy, security, and the potential for environmental surveillance, underscoring the necessity for responsible adoption of AI technologies.

5.1.3 Health Impact Assessments

The integration of artificial intelligence into health impact evaluations significantly influences the prediction of health outcomes, the identification of risk factors, and the assessment of intervention efficacy. In this context, AI is adept at analyzing a diverse array of data sources, including social determinants of health, environmental data, and electronic health records, thereby providing a comprehensive understanding of the complex interrelationships among social determinants, environmental factors, and health outcomes. However, the use of AI also raises concerns regarding data security, privacy, and the potential for inequitable or biased health outcomes, highlighting the necessity for transparent and responsible AI systems.

5.2 Addressing the Challenges Poised Towards Artificial Intelligence

5.2.1 Data Scarcity

To address data scarcity, efforts should be made to collect and share data across various sectors and stakeholders. Governments and organizations can establish data repositories and platforms for data sharing, while also ensuring data privacy and security. Additionally, initiatives can be launched to collect new data, such as surveys, sensors, and crowd-sourcing. Utilizing various data sources, such as social media data and satellite imagery, can also mitigate issues related to data scarcity.

5.2.2 Limited Infrastructure

The challenges posed by limited infrastructure can be mitigated through investments in the development of digital infrastructure, including high-speed internet, data centers, and cloud computing technologies. Governments and private sector organizations can collaborate to establish infrastructure development initiatives, while also promoting public-private partnerships. Moreover, alternative infrastructure solutions, such as edge computing and offline data processing, can be explored to overcome infrastructure limitations.

5.2.3 Digital Divide

The digital divide can be addressed by promoting digital literacy and skills development programs, targeting marginalized communities and underserved populations. Initiatives can be launched to provide access to digital technologies, such as computers, smartphones, and internet connectivity, while also ensuring affordability and accessibility. Moreover, inclusive design principles can be applied to develop AI solutions that are accessible and usable by diverse populations, reducing the risk of exacerbating existing inequalities.

5.3 Collaborative Efforts between Researchers, Policymakers, and Practitioners

The successful adoption of AI in promoting sustainable landscape and wellbeing in Nigeria requires collaborative efforts between researchers, policymakers, and practitioners. Researchers can provide expertise in AI development and application, while policymakers can facilitate the integration of AI into policy and decision-making processes. Practitioners, including community leaders and stakeholders, can ensure that AI solutions are context-specific, effective, and equitable. Collaboration can facilitate the co-creation of AI solutions, ensuring that they address local needs and priorities. Moreover, collaborative efforts can leverage resources, expertise, and funding, accelerating the development and deployment of AI solutions. Through collaboration, researchers, policymakers, and practitioners can tackle the challenges related to the adoption of artificial intelligence and ensure that AI effectively contributes to sustainable development and well-being in Nigeria.

Conclusion

6.1 AI's Potential in Promoting Sustainable Landscape and Wellbeing in Nigeria

Artificial Intelligence (AI) has vast potential in promoting sustainable landscape, public health and wellbeing in Nigeria by enhancing landscape planning, environmental monitoring, and health impact assessments. AI can optimize landscape design, predict environmental impacts, and identify areas for improvement, leading to enhanced biodiversity, ecosystem services, and human wellbeing. Additionally, AI can facilitate real-time environmental monitoring, predict future trends, and detect early warnings of environmental degradation. AI can also analyze complex relationships between environmental factors, health outcomes, and social determinants, enabling proactive measures to mitigate health risks. By leveraging AI, Nigeria can achieve sustainable development goals, ensure environmental sustainability, and promote wellbeing for present and future generations. Overall, AI can serve as a powerful tool in promoting sustainable landscape and wellbeing in Nigeria, but its potential can only be fully realized through collaborative efforts and responsible adoption.

6.2 Call for Context-Specific AI Solutions Prioritizing Nigerian Needs and Contexts

There is a pressing need for context-specific AI solutions that prioritize Nigerian needs and contexts, addressing the unique challenges and opportunities in the country. AI solutions must be tailored to Nigeria's specific social, economic, and environmental realities, rather than relying on generic or imported solutions. This requires collaborative efforts between researchers, policymakers, and practitioners to develop AI solutions that are grounded in local knowledge, needs, and priorities. Context-specific AI solutions can ensure that AI adoption is inclusive, equitable, and effective, addressing the needs of diverse populations and promoting sustainable development. Moreover, prioritizing Nigerian needs and contexts can foster innovation, entrepreneurship, and job creation, contributing to the country's economic growth and development. By developing context-specific AI solutions, Nigeria can benefit from the full capacity of the technology in driving sustainable landscape and wellbeing, while avoiding the risks of AI exacerbating existing inequalities or environmental degradation.

6.3 Future Research Directions

The development and evaluation of context-specific artificial intelligence solutions that consider Nigeria's unique opportunities and challenges should be the primary focus of future research. To identify areas where artificial intelligence can exert the greatest influence, researchers should explore its applications across various domains, including healthcare, education, and environmental management. Research should also examine the ethical and societal implications of artificial intelligence adoption in Nigeria, including issues related to bias, security, and data privacy. Furthermore, studies should examine the effectiveness of AI in promoting sustainable landscape and wellbeing, including its impact on biodiversity, ecosystem services, and human health. Research should also explore innovative AI technologies, such as edge AI, transfer learning, and explainable AI, to enhance AI adoption and effectiveness in Nigeria. Finally, future research should prioritize interdisciplinary collaboration, involving researchers, policymakers, and practitioners to ensure that AI solutions are evidence-based, context-specific, and effective in promoting sustainable development and wellbeing in Nigeria.

Recommendations

7.1 Policy and Practice Implications

Policymakers should develop and implement policies that support the development and adoption of AI solutions in Nigeria, including investments in digital infrastructure, data privacy and security, and AI research and development. Additionally, policies should prioritize the use of AI in promoting sustainable landscape and wellbeing, including environmental monitoring, health impact assessments, and landscape planning. Practitioners should prioritize the development of context-specific AI solutions that address local needs and priorities, involving communities and stakeholders in the design and deployment of AI solutions. Furthermore, practitioners should ensure that AI solutions are inclusive, equitable, and effective, addressing the needs of diverse populations and promoting sustainable development. Moreover, policymakers and practitioners should collaborate to establish AI governance frameworks that ensure transparency, accountability, and ethical considerations in AI adoption and deployment. Finally, continuous monitoring and evaluation of AI adoption and impact should be prioritized to inform policy and practice decisions.

7.2 Research Agenda for Future Studies

Future studies should investigate the impact of AI on sustainable landscape and wellbeing in Nigeria, exploring the effects of AI on biodiversity, ecosystem services, and human health. Research should investigate the potential role of artificial intelligence in assisting Nigeria in addressing environmental challenges such as land degradation, deforestation, and climate change. Additionally, studies should investigate the use of AI in health impact assessments, exploring its potential to predict health outcomes, identify risk factors, and evaluate interventions. The role of AI in landscape planning and design should also be examined, including its potential to optimize landscape functionality, promote sustainable urban planning, and enhance community engagement. Research should also examine the ethical and societal implications of artificial intelligence adoption in Nigeria, particularly regarding issues of bias, security, and data privacy. Furthermore, to enhance the adoption and effectiveness of AI in Nigeria, investigations should focus on advanced AI technologies such as explainable AI, edge AI, and transfer learning.

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Analysis of Duty Cycle Variations in the UHF Bands in Osun State University, Osogbo, Nigeria

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Abstract

The duty cycle of the Ultra-High Frequency (UHF) bands has been recognised as a pivotal element influencing the performance and reliability of wireless communication systems especially in the developing or growing societies, towns and cities. This study explores the variations in duty cycle within the UHF bands in Osun State University, Osogbo, Nigeria. The field measurements were conducted using an Agilent N9342C Handheld Spectrum Analyser, focussing on the duty cycle across six distinct locations within the Osun State University main campus in Osogbo. The findings reveal a significant variability in duty cycle values across all study locations, influenced by frequency bands ranging from 470 MHz to 870 MHz, as well as by peak and off-peak usage periods. The duty cycle values exhibited comparably higher results in location 4 (with a value of 23.1%) during the morning and late evening rush hours because of its proximity to a local TV broadcasting station while location 2 recorded the lowest values of 11.9%. An average duty cycle of 17.9% was recorded for the studied bands in all the locations. The research study presents considerable implications for comprehending the utilisation of UHF band and the management of spectrum in Osun State. The results could assist policymakers in making informed decisions and guiding the appropriate utilisation of wireless communication systems.

Keywords: Duty cycle, UHF, spectrum analyser, frequency band, wireless communications.

Introduction

There has been a significant increase in the adoption of wireless communication technologies due to the growing demand for radio frequency (RF) spectrum licenses. Users have exerted pressure on wireless communication services, leading to the increased utilisation of Ultra High Frequency (UHF) bands. The UHF is a portion which falls between 300 MHz and 3 GHz on the electromagnetic spectrum (Mustapha *et al*., 2015).

Spectrum can be licensed or unlicensed. The licensed band requires a charge to ensure exclusivity and reduce interference from other wireless users. The local regulatory authority manages the radio spectrum and collects licensed band auction earnings. Due to their limited quantity and rising user competition for access to open spectrum bands, unlicensed channels are prone to interference (Coll, 2012). Unlicensed bands like Bluetooth and Wi-Fi are used for communication. The FCC allocates spectrum for licensed and unlicensed use based to their vital tasks. Cognitive radio technology was approved by the FCC in 2004 for unlicensed wireless devices to use unoccupied television channel frequencies. If unregulated, unlicensed wireless devices may interfere with broadcast television systems (Marcus, 2013).

In Nigeria, the present television broadcasting services generally run on analogue broadcast in the VHF range spanning from 174MHz – 230MHz and UHF range spanning from 470MHz – 860MHz band excluding the television stations that changed to digital propagation platform (Adediran *et al*., 2014). The UHF bands of 470 MHz – 870 MHz have developed considerably, becoming a vital spectrum for numerous applications. Therefore, the efficient utilization of these UHF bands is essential to guarantee the provision of effective wireless communication services.

In recent years, Nigeria has seen consistent progress in the development of wireless communication infrastructure, driven by an increasing interest in the integration of voice and data via mobile broadband. This is particularly evident in the case of Osun State, which has recently experienced a rapid urbanisation process and represents a significant portion of the rapidly expanding population, thereby exerting considerable pressure on the wireless communication networks.

Duty cycle is a critical factor that influences the effectiveness and reliability of wireless communication systems. The duty cycle analysis is useful for determining how much time the band is utilised in a certain period (ITU-R, 2016). The utilisation of all bands can be determined by averaging their occupancies, thus revealing the bands accessible for CR or other innovative technologies. Modifications in the duty cycle significantly influence the quality of signal transmission, network load, and interference. Nevertheless, given its importance, limited empirical research has been conducted to investigate fluttering variations related to duty cycles in UHF bands within Osun State. The performance of wireless communication can be significantly affected by changes in the duty cycle across different locations, frequencies, and time intervals.

Extensive analysis has been conducted on duty cycle variations in wireless communication systems. The study by Babalola *et al.* (2015) examined the temporal fluctuations of the duty cycle within the television band in Kwara State, Nigeria. Outdoor spectrum occupancy measurements revealed no consistent pattern, with TV band 3 exhibiting the highest occupancy rates in both rural and urban regions. The research suggests the application of software-defined radio to improve spectrum utilisation efficiency.

Faruk *et al.* (2017) examined the spatial variation of duty cycle within the GSM spectrum at specified rural and urban locations in Ilorin, Kwara State, Nigeria. The findings indicate that the duty cycle differs by location, with average occupancy rates of 1.67% in rural areas, 17.76% in urban areas, and an overall average of 10.55% across all sites. The duty cycle metric, which assesses the intensity of received signals, may not consistently indicate the signal's quality.

Ishola *et al.* (2019) analyses a temporal variation of duty cycle in the GSM bands. The author performed a long-term measurement of spectrum occupancy in GSM bands at a designated site within the Faculty of Communication and Information Sciences, University of Ilorin, Nigeria. Data measurements were collected continuously over a 4-week period, encompassing 24 hours each day. The collected data were utilized to analyze the temporal variation of duty cycle across all bands. The average spectrum occupancy for GSM 900 and GSM 1800 is 10% and 9%, respectively. The findings indicated temporal variation influenced by differing activity levels during days and nights, as well as weekdays and weekends. This effort aims to establish a spectrum usage repository for big data analytics research. This would assist researchers and policymakers in comprehending the activities occurring within spectrum bands, enabling them to develop intelligent spectrum models for effective utilization.

The research conducted by Faruk *et al.* (2019) examines the spatial diversity of duty cycle in the GSM 900 and 1800 MHz frequency bands in Kwara State, Nigeria. The data indicate disparate occupancy levels, with rural areas exhibiting elevated occupancy rates. The study emphasises the favourable association between rural and urban 900/1800 MHz frequencies, whereas unfavourable correlations are observed between urban 900 and rural 1800 frequencies, as well as between rural 1800 frequencies. The results indicate that regulatory commissions should use adaptable spectrum reuse solutions to improve the efficiency of constrained radio resources in licensed bands.

Isa *et al.* (2020) investigated the duty cycle radio spectrum characteristics for cellular bands, specifically analysing GSM 900 MHz, GSM 1800 MHz, and 3G. The Advantest U3741 spectrum analyser and the ITU's noise floor value were utilised. The research revealed duty cycles of 35.31%, 9.59%, and 28.08%, signifying considerable spectrum underutilisation. Other investigations into the spectrum occupancy of UHF bands are as well carried out by researchers, academia and Engineers. Lasisi et al. (2022) performed spectrum occupancy measurements of UHF TV channels ranging from 470 MHz to 870 MHz. Oki (2019) analysed the TV spectrum occupancy in South Africa, Selflek & Yaldiz (2017) measured the spectrum occupancy in university campus in Turkey, Babalola *et al.* (2015) in Kwara State, Nigeria, Xue *et al.* (2013) in Beijing, Van de Beek *et al.* (2011) in Europe, among others.

This study presents a detailed examination of duty cycle variations in UHF bands within Osun State University main campus Osogbo.

The research aims to analyse the spatial variations in duty cycle across different locations in Osogbo campus and to assess the influence of frequency bands (470 MHz - 870 MHz) on duty cycle.

2. Materials and Methods

2.1. Measurement sites

To get a broad view of spectrum occupancy, measurements were taken at six locations in Osun State University, Osogbo Campus namely; Engineering Complex, Health Sciences, Library, Auditorium, Administrative, and URP building. Table 1 depicts the measurement Sites with their respective coordinates.

Table 1. Measurement Sites

Location	Coordinate	Identifier
Engineering Complex	4° 36' 13" E, 7° 45' 40" N	Loc. 1
Health Sciences	4° 36' 16" E, 7° 45' 27" N	Loc. 2
Library	4° 36' 09" E, 7° 45' 31" N	Loc. 3
Administrative Building	4° 36' 04" E, 7° 45' 42" N	Loc. 4
Auditorium	4° 35' 52" E, 7° 45' 26" N	Loc. 5
URP Building	4° 35' 55" E, 7° 45' 22" N	Loc. 6

2.2. Measurement setup

Fig. 1 illustrates the set up of the measurement equipment at the designated locations. The measurement setup primarily comprises an Agilent N9342C Handheld Spectrum Analyzer (HSA), a RH799 wideband antenna, and a data storage unit. Agilent N9342C HSA can measure frequencies ranging from 100 kHz to 7 GHz by employing energy detection to directly measure the received signal strength in dBm. This energy detector is equipped with an integrated Global Positioning System (GPS) for location functionalities, as well as an external GPS connection to enhance position precision. The RH799 broad band antenna is a telescopic whip antenna capable of detecting signals from 70 MHz – 1 GHz, with 180 degrees' tilt angle adjustable.

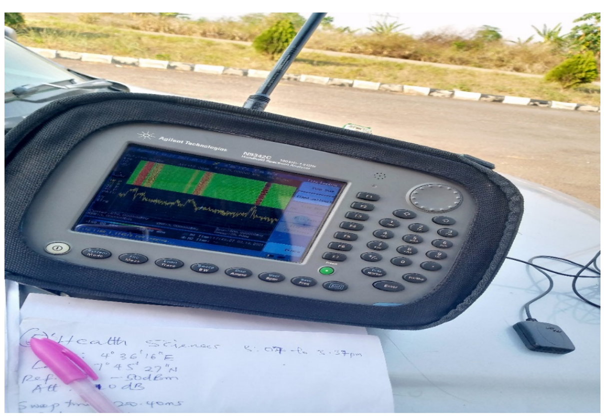

Fig. 1. Measurement equipment setup at the designated location

It can convey faster data rates as well as magnifying distant things. A 16GB Universal Serial Bus (USB) flash drive was utilized as the data storage medium for the preservation of log files produced by the spectrum analyser in real-time.

The precision of the measurement result is intricately linked to the settings of the measurement parameters; thus, the spectrum analyser was setup as detailed in Table 2.

Table 2. Spectrum Analyser Configuration

Parameter	Value
Resolution Bandwidth (RBW)	3 MHz (Automatically set by the SA)
Video Bandwidth (VBW)	3 MHz (Automatically set by the SA)
Sweep Time	20.40ms (Automatically set by the SA)
Sweep Type	Continuous
Reference Level	-50 dBm
Preamplifier	ON
Impedance	50Ω

2.3. Data collection, processing and analysis

The measured signal strengths were generated in comma-separated value (csv) file format and saved in the 16GB USB flash drive. A total of 1500 frames were received into the analyser per band per location, with 461 number of time slots (N) measured per received frame. The signals received from the spectrum analyser were processed in a laptop using Microsoft excel.

Assessing the occupancy statistics requires that the received signal from the analyser, being a raw data be inputted and processed, establish the threshold, and calculate the average duty cycle for each channel. The noise floor is a crucial measure of signal utilization, averaging the instantaneous power of each location to eliminate noise and accurately quantify utilization. The decision threshold determines if a channel is occupied, using the M-dB criteria to ensure reliable estimation. To reduce the occurrence of false alarms, a threshold set at 5 dB (ITU-R, 2016) above the noise floor was implemented for the purpose of this study.

The duty cycle, defined as the average occupancy of a frequency band or channel within a specified duration, quantifies the frequency at which a signal is detected during a designated sampling interval. It is expressed mathematically as shown in equation (1):

$$Duty\ Cycle = \frac{Signal\ Occupation\ period\ (n)}{Total\ Observation\ period\ (m)} \times 100\ \% \tag{1}$$

More so, the duty cycle can be computed from a time series, t, of channel power measurements as expressed in equation (2):

$$\boldsymbol{Duty\ Cycle = \frac{n}{m}\, t\ \times 100\ \%} \tag{2}$$

where n represent the signal duration and m denote the period of the observed measurement.

The duty cycle analysis is useful for determining how much time the band is utilized in a certain period.

3. Results and Discussion

Duty cycle measurement provides useful information on spectrum utilization by frequency band, time, and location. Table 3 provides the duty cycle across the bands in all the measurement locations. In Table 3, a duty cycle of 16.6% was obtained for location 1, while a significant decreased value of 11.9% was observed in loc. 2. Loc. 3 had duty cycle of 18.7%, a value slightly higher than location 1.

Table 3. Duty Cycle Results for all Locations

Location	Duty Cycle (%)	Average Duty Cycle (%)
Location 1	16.6	
Location 2	11.9	
Location 3	18.7	17.9
Location 4	23.1	
Location 5	17.7	
Location 6	19.4	

A duty cycle of 23.1% was obtained for location 4, while location 5 recorded 17.7%, a value far lower than what was obtained in location 4. A slight decreased value of 19.4%, when compared with location 4, was however observed in location 6. Overall occupancy of 17.9% was recorded for the studied bands in all the locations.

From the findings, typical percentage occupancy of the UHF TV spectrum varies from 11.9% to 23.1% with location 2 highly underutilized while location 4 is slightly utilized. Thus, the spatial variation of duty cycle in the UHF TV spectrum measured revealed that the spectrum is not uniformly utilized in all the locations. The duty cycle variations by frequency band were also examined. Fig. 2 to Fig. 7 present the duty cycle across the frequency bands at each location.

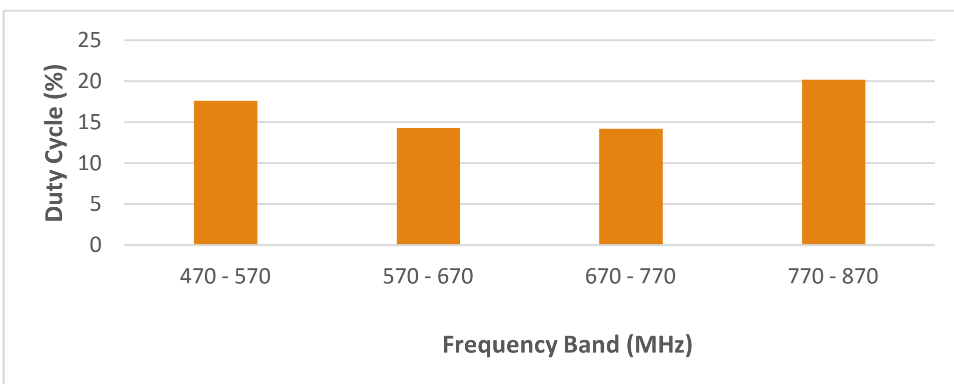

Fig. 2: Duty cycle variation by frequency bands at Loc. 1

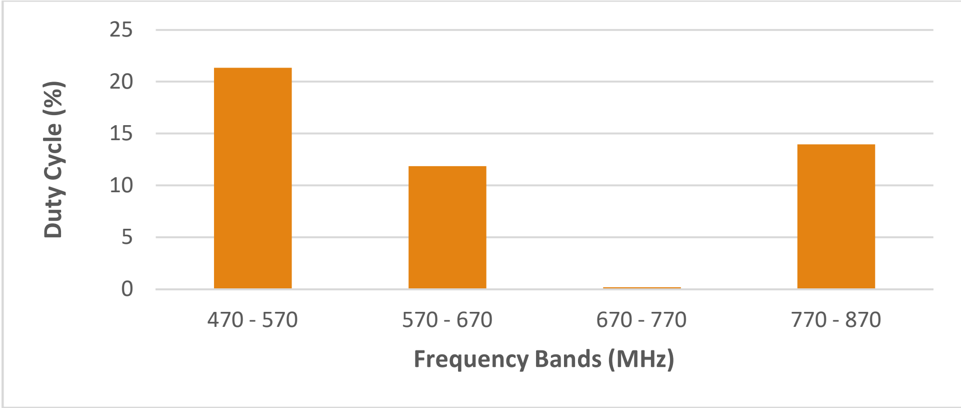

Fig. 3: Duty cycle variation by frequency bands at Loc. 2

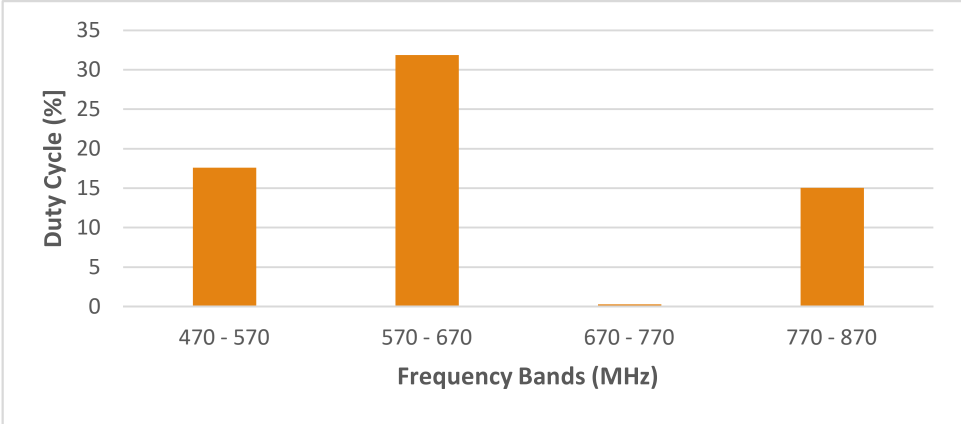

Fig. 4: Duty cycle variation by frequency bands at Loc. 3

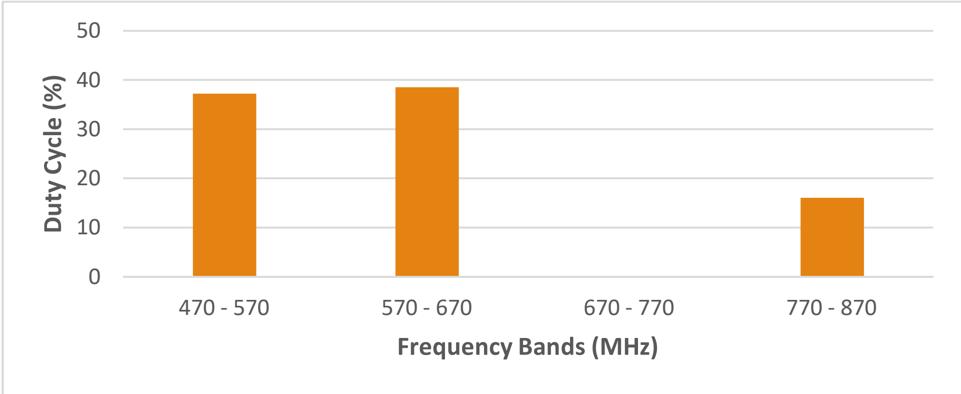

Fig. 5: Duty cycle variation by frequency bands at Loc. 4

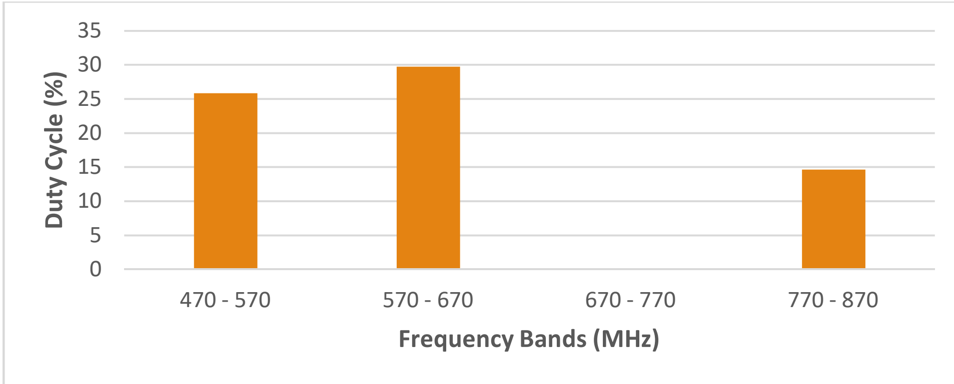

Fig. 6: Duty cycle variation by frequency bands at Loc. 5

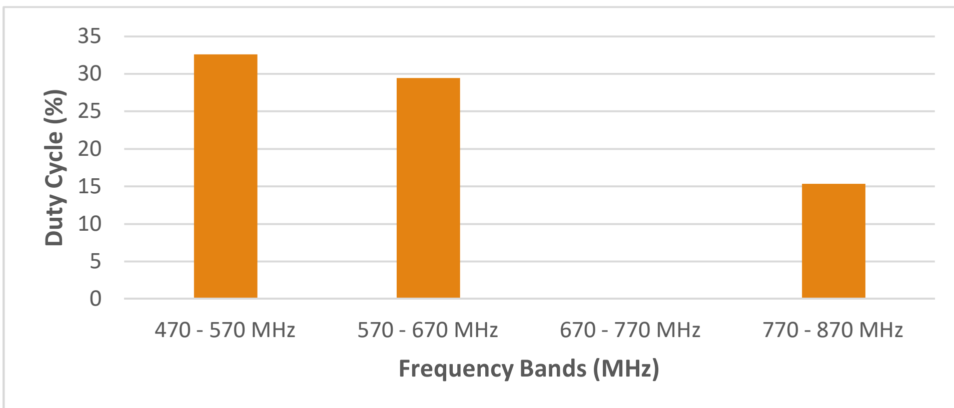

Fig. 7. Duty cycle variation by frequency bands at Loc. 6

Fig. 2 depicts that all frequency band examined were received at the Engineering Complex Building designated as Loc. 1 with frequency bands 770 – 870 MHz having a higher duty cycle of 20% while bands 570 – 670MHz and 670 – 770 MHz are having the least and almost the same duty cycle. On the other hand, Loc. 2 experienced a 0.2% duty cycle at band 670 – 770 MHz, an indication that the band is highly underutilised as at the time of the research. Frequency band 470 – 570 MHz however has the highest duty cycle of 21% at this location as illustrated by Fig. 3.

In fig. 4, frequency bands 570 – 670 MHz experienced highest duty cycle of 32% than the other bands while a very minute duty cycle was obtained at bands 670 – 770 MHz just like that of Loc. 2 of fig. 3. Evidently from Figs. 5 to 7, a 0% duty cycle was recorded at frequency bands 670 – 770 MHz of locations 4, 5 and 6. However, frequency bands 470 – 570 MHz and 570 – 670 MHz were well received at about 37% and 39% duty cycle respectively. This is an indication that the bands were duly utilised as at the time of the study. In addition, bands 570 – 670 MHz recorded the highest duty cycle in loc. 5 while bands 470 – 570 MHz had the highest duty cycle in loc. 6.

4. Conclusions

In this paper, duty cycle variations in the UHF bands were investigated based on energy detection measurement technique. Measurements, spanning from frequency band 470 MHz to 870 MHz, were conducted at six different locations in Osun State University main campus, Osogbo at the busiest hours of the day.

Based on spatial measurement, it was revealed from the results that:

(iii) Location 4 exhibits highest occupancy level of 23.1 % duty cycle, while other locations had occupancy rate lesser than 20%, with location 2 having the lowest value of 11.9%. The reason for this spatial variation is that location 4 (Administrative Building) is the central to the university and has direct line of sight to a TV broadcasting station.

(iv) The duty cycle varies based on frequency bands, locations and time and therefore the results demonstrate notable spatial discrepancies in duty cycle throughout Osun State.

These significantly implies that, the efficiency of UHF band usage must be enhanced and policies regarding spectrum management be informed. Conclusively, this research enhances the comprehension of duty cycle fluctuations in UHF bands. The findings offer significant insights for stakeholders in wireless communications and aids in the advancement of intelligent spectrum models for efficient resource allocation.

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Construction activities affecting water bodies in Lagos Metropolis, Nigeria

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Abstract

Human activities continue to deplete the environment and construction industry is not let out from this trend. The activities involved in the delivery of construction works affect environment including life below water. Limited research works exist that examine activities in construction processes, which affect water bodies, hence this study. This paper examines construction activities that affect life below water with a view to achieving a sustainable aquatic habitat. Through the use of copies of questionnaire, a quantitative research approach was employed to purposively collect data from 60 contracting organizations represented by 14 architects, 16 builders, 23 quantity surveyors and 7 engineers. Data collected were analyzed using frequency distribution, mean score and analysis of variance. Although the views of individual construction professionals surveyed were examined, their overall perspectives revealed that deposition of metallic chemicals (M=3.83), the by product from the sawing process (M=3.78), industrial garbage (M=3.75), chemical usage (M=3.70), minor coastal construction (M=3.70) and muddy water onsite (M=3.70) were ranked high as construction activities affecting the waters bodies. The study concludes that industrial activities and their products affect water bodies and survival of life below water. The paper recommends a construction procurement policy that safeguard water bodies and treatment of industrial waste for a sustainable life below water.

Keywords: Construction Activities, Water Bodies, Below Water, Nigeria

INTRODUCRION

Sustainability has recently been acknowledged as a crucial issue in infrastructure projects. Developing a model to evaluate project sustainability according to sustainability indicators plays a major role in promoting the sustainable development of water environment treatment public-private partnership (PPP) projects (Li et al., 2019). The concept of "sustainable development has gradually been accepted by organizations and governments worldwide. The concept of sustainable design is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Therefore, when considering sustainability, water environment needs to be put into consideration (Li et al., 2019).
Since people enjoy living near water bodies and these water bodies combine with other water bodies within the nation, therefore, construction activities will surely take place near water bodies most especially in urban areas experiencing large development. This large development causes a great deal of water pollution. Rivers are also a major source of surface water for drinking, domestic, irrigation, and industrial purposes which are of tremendous benefits to humans that's why monitoring of water quality of rivers regularly is quite necessary for the assessment of water quality for beneficial purposes (Giri, 2021).

Pollution to water bodies by activities of the construction industry is a major issue that the construction industry cannot ignore. Construction activities impact the environment throughout the life cycle of development. These impacts occur from initial work on-site through the construction period, operational period, and to the final demolition when a building comes to an end of its life (Jalaei et al., 2021). Construction sites are one of the largest contributors of sediment loading to most water bodies within the nation United State Environmental Protection Agency (USEPA, 2005) in the same report, erosion from construction sites ranges from 7.2 to 500 tons ac^{-1} $year^{-1}$. Pollution to water bodies happens when toxic chemicals end up in water bodies such as rivers, lakes and oceans. Construction activities often involve the use of toxic chemicals and pollutants that can end up in the water table if not managed well.

The increase in construction activities due to urbanization in Lagos State has increased the growth of both water consumption and wastewater discharge, which in turn results in the growth of effluent charges which are disposed into water bodies. Sediments eroded from construction sites that are eroded into water bodies also cloud the water surface, therefore, restricting the penetration of sunlight, and limiting the processes that depend on light and choke out aquatic life. These particles could also eventually become major water pollutants. Construction activities can also be said to be a major cause of detriment to water bodies within the nation. Runoff from construction sites that eventually gets eroded into water bodies is also classified as anon-point source.

According to Cooke et al. (2016), 39% of rivers were classified as impaired, meaning "partially or not supporting one or more uses" such as aquatic life support, fish consumption, primary or secondary contact recreation, drinking water supply, and agricultural uses. The pollutants identified as causing impairment include pathogens, sediment, habitat alterations, oxygen-depleting substances, and nutrients while the leading sources of this pollution were identified as agriculture, hydrologic modification, habitat modification, and urban runoff/storm sewers (Cooke et al., 2016).

The Nigerian Construction Industry

The Nigerian construction industry is a major contributor to the country's Gross Domestic Profit (GDP). This is because it contributes a huge quota to the employment and infrastructure of the country (Olanrewaju et al.,2018). The International monetary fund also predicts that the Nigerian economy will grow in 2008 at an impressive rate of 9.1% (International Monetary Fund (IMF, 2008)). This is not only due to the rise in the price of oil, which generates more revenue, but also due to the increase in investments and the glorious reforms seen in other sectors of the economy such as telecommunications, manufacturing, and Banking. According to the Nigerian Bureau of Statistics, the non-oil sector of the economy grew at a rate of 8.6% in 2005, (NBS, 2006), and continues to grow at impressive rates since then, reaching 9.6% in2007 (Ogbonna, 2018).

The construction industry is broad and multi-disciplinary, it caters for housing and civil engineering infrastructural facilities that are needed by the inhabitants of a state, it is described as the driver of economic growth (Balaji et al., 2022). It encompasses various professionals such as architects, engineers, urban and regional planners, quantity surveyors, builders, and artisans such as carpenters, plumbers, masons, and many others (Fortune et al., 2019). The Construction industry is majorly divided into three which are building, civil engineering and the industrial engineering component, but the Nigeria Institute of Quantity Surveying recognizes 2 aspect of construction which are Building works and Engineering works where it further divided the Engineering aspect into Civil and Heavy engineering works (BESMM 4). The building component caters to man's basic need for shelter. It involves the construction of residential buildings, recreational buildings, sports facilities, educational buildings, and soon. Civil engineering infrastructure comprises works such as airport construction, roads, bridges, railways, side drains, culverts, and others.

Hung, (2019) stated that the construction industry's significance is also because it sets a strong linkage with other sectors of the economy. World Bank Report (2009) also suggested the need for developing countries to concentrate efforts in diversifying their economies from mono-product and natural resources-based, towards more sustainable human resources that can also create jobs for the fast population. To achieve this, human and infrastructure developments must be enhanced for the growth and development of small-scale industries and internal microeconomic development. Building and construction sector is one of the top five sectors used in measuring the National Gross Capital Formation (NGCF) and the GDP of any country and its effect on every other sector, makes it a significant front for sustainable development (Ali, 2021).

Construction Activities that affect Water Bodies

The construction activities around water bodies include construction of residential buildings, recreational and industrial buildings this is now very large around the coastal areas but with effective controls lacking, it should come as no surprise that the quality of coastal infrastructure is unsatisfactory in many areas (Vinogradova et al., 2021). Throughout the region, there has been a trend of shifting away from traditional architectural practices to more vulnerable forms of construction, such as the squatter settlements that proliferate in many urban areas. These settlements are generally characterized by substandard infrastructure, and are particularly vulnerable to extreme weather events and SLR, as they are the least equipped to withstand high wind speeds and flooding. As coastal urbanization and uncontrolled development continue to increase in the Caribbean, so too will the number of highly vulnerable squatter settlements (Mycoo, 2022).

Research by Akhtar et al. (2021) shows that the process construction there is usually a high deposit of solid waste is usually deposited into the river basin during construction process he also states that construction has no significant effect on the surface water nutrient during their study they also discovered increased calcium concentrations were observed during construction but no negative biological impacts were associated with the increase. More so, residential building permits issued in Dane County increased 15 percent in a single year, from 1,489 in 1997 to 1,709 in 1998 (Owens et al., 2000). Some of the various forms of construction waste that are generated during construction activities and affects water bodies are highlighted below;

Construction of canals and waterways as identified by Steyne & Crowe, (2022) comprises construction of culverts on waterbodies (Purcell et al., 2012), construction of residential apartments because people love living close to water bodies (Prosun, 2011). Construction of coastal infrastructures for public use for eastern Caribbean regions, construction of factories for operation around water bodies and islands (Liu, 2018) Construction of paved roads, curbs, and gutters are also some of the major construction activities that affect water bodies and construction of railway lines (Huihua, Hujun, Yige, & Baoquan, 2020).

Construction activities that affect water bodies as outlined by literature have been explained above, while from practice some other construction activities that affect water bodies that are not stated in the literature include: the construction of bridges which is a major significant activity that also affects water bodies, the deposition of hydrocarbon substance into the bodies of water, also another construction activity that affects water body is the construction of cofferdam it which during the cause of construction there is usually high level of displacement of water which will lead to flooding of other areas. Also, the disposition of by-products from sawing process by the sawmill which is sawdust do mostly settle down on water bodies which in turn after some time eventually blocks off waterways, and affects the aquatic life present within that water body.

Another major construction activity that affects water bodies is the cleaning of the roofs, during the process of roof cleaning most especially flat roofs, there is usually deposition of waste materials such as chemicals used in the cleaning or even hard waste indirectly into water bodies which do in turn affect the bodies of water that is being deposited into.

METHOD

This paper examines Construction activities affecting water bodies in Lagos state**, t**he whole study employed a quantitative research method in data collection and analysis. The study was conducted on Lagos State construction companies which are Registered contracting firms. These firms were selected for this study because of high level of construction works going on around water bodies as the urbanization process is ongoing at a very rapid rate. There are among the construction companies that are consulting and consortium. However, only contracting firms who had practical experiences were requested to respond to questionnaire survey. Therefore, construction companies within Lagos State were the population for the study, that is registered contracting firms present in Lagos state. The method used for data collection for this research is a questionnaire. The questionnaire survey was structured into two (2) sections. Section A explored the General Information of the Responding firms and this include the respondents' gender, professional designation, highest academic qualification, professional qualification, years of work experience, and year of establishment, section B explored the Construction activities affecting water bodies. Data were obtained through well-structured questionnaires. A total of one hundred and five (105) questionnaires were administered to construction professionals in contracting firms in Lagos State, Nigeria.

To develop the data collection instrument, a review of the literature was carried out to find studies on Construction activities that affect water bodies. A list of background information about the respondent was generated from the literature which was categorized into gender, professional designation, highest academic qualification, professional qualification and years of work experience.

A second list, made up of variables in construction activities affecting water, was also constructed from the literature. These formed the research constructs. The variables in the constructs were made up of 21 variables on construction activities that affect water. The research instrument (survey) was structured into two sections: Section A requested background information on each firm and its responding officer. Section B focused on Construction activities that affect water bodies.

Data Analysis and Discussion

The data collected in the study were presented and analyzed under the following sub-headings:

Background Profile of the respondents

This section sought to know the background information about the companies and the responding officer. An evaluation of the gender of the respondents revealed that the highest percentage of respondents were males (73.3%) and the least percentage were females (26.7%). The highest percentage of respondents were Quantity Surveyors (38.3%), followed by Builders (26.7%), Architects (23.3%), Others (8.3%) and the least percentage were Engineers (3.3%). Respondents based on the highest academic qualification with the highest percentage were B.Sc. holders (58.3%), followed by M.Sc. (23.3%), Ph.D. (8.3%), OND/HND (6.7%), and Others (3.3%) with the least percentage.

Respondents based on professional qualification with the highest were MNIQS (41.7%), followed by Others (28.3%), MNIA (16.7%), and probationer members (13.3%) with the least percentage. Respondents with years of work experience between 5-10 years had the highest percentage (36.7%). Others were 0-5 years (26.7%), 10-15 years (25%), 25 years and above (8.3%), and 15-20 years (3.3%). Respondents' firms with an age range between 5-10 years had the highest percentage (36.7%). Others include 25 years and above (23.3%), 0-5 years (13.3%), 10-15 years (13.3%) and 15-20 years (13.3%).

Table 1: General Information of Respondents

	Frequency (f)	Percent
Gender of the respondent		
Male	44	73.3
Female	16	26.7
Total	**60**	**100.0**
Position of the Respondent in the Organization		
Builders	16	26.7
Architects	14	23.3
Quantity surveyors	23	38.3
Engineers	2	3.3
Others	5	8.3
Total	**60**	**100.0**
Highest Academic Qualification		
OND/HND	4	6.7
B.Sc.	35	58.3
M.Sc.	14	23.3
PhD	5	8.3
Others	2	3.3
Total	**60**	**100.0**
Professional Membership		

Probationer member	8	13.3
MNIQS	25	41.7
MNIA	10	16.7
Others	17	28.3
Total	**60**	**100.0**
Years of Work experience		
0-5 years	16	26.7
5-10 years	22	36.7
10-15 years	15	25.0
15-20 years	2	3.3
25 years and above	5	8.3
Total	**60**	**100.0**
Age of Firm		
0-5 years	8	13.3
5-10 years	22	36.7
10-15 years	8	13.3
15-20 years	8	13.3
25 years and above	14	23.3
Total	**60**	**100.0**

Construction Activities Affecting Water bodies

Table 2 outlines the results of the objective of this study identifies and examines the construction activities that affect water bodies in Lagos metropolis, Nigeria. A list of 21 construction activities were identified from the literature. These variables were examined based on the respondents' level of agreement on a rating scale of 1 (very low) to 5 (very high). The retrieved data were analyzed based on the position of the respondents in the organization. The construction activities that builders rated on ranging on the scale of 1 (Very low) to 5 (very high) mean score is as follows having very high and high ranking: crushed concrete reagent usage (M= 4.38), industrial garbage (M= 4.33), roof cleaning (M= 4.31),unmapped pipe network (M= 4.19), deposition of hydrocarbon substance (M= 4.13), deposition of metallic chemicals (M= 4.13), dirty runoff from a construction site, (M= 4.00).

Table 2: Construction activities that affect Water bodies

No	Construction activities	Overall Mean	Overall Rank	Builder Mean	Builder Rank	Architect Mean	Architect Rank	Quantity Surveyor Mean	Quantity Surveyor Rank	Engineers Mean	Engineers Rank	Others Mean	Others Rank	ANOVA f	ANOVA Sig
1	Deposition of solid waste	3.38	21	3.50	19	3.00	21	3.26	16	4.50	1	4.20	1	1.534	.205
2	Deposition of hydrocarbon substance	3.55	17	4.13	5	3.50	13	3.09	21	3.50	12	4.00	3	4.125	**.005**
3	Displacement of water	3.67	10	3.81	13	3.79	4	3.70	3	3.00	18	3.00	20	.667	.618
4	The byproduct from the sawing process	3.78	2	3.94	8	3.57	12	3.74	2	4.50	1	3.80	5	.572	.684
5	Roof cleaning	3.63	13	4.31	3	3.21	18	3.39	13	3.50	12	3.80	5	2.667	**.042**
6	Chemical usage	3.70	4	3.81	13	3.21	18	3.91	1	4.50	1	3.40	15	2.516	.052
7	Sewage discharge by workers	3.62	14	3.50	19	3.64	10	3.70	3	4.00	7	3.40	15	.184	.946
8	Discharge by construction machinery	3.62	14	3.94	8	3.29	17	3.61	6	3.50	12	3.60	12	.749	.563
9	Vehicle washing wastewater	3.48	19	3.81	13	3.43	14	3.17	19	4.00	7	3.80	5	1.045	.393
10	Industrial garbage	3.75	3	4.33	2	3.71	7	3.43	12	3.00	18	3.80	5	2.111	.092
11	Minor coastal construction	3.70	4	3.88	11	3.64	10	3.61	6	3.50	12	3.80	5	.270	.896
12	Muddy water onsite	3.70	4	3.38	21	4.07	1	3.57	8	4.50	1	4.00	3	1.304	.280
13	Sediment deposition on site	3.53	18	3.69	17	3.79	4	3.13	20	3.50	12	4.20	1	2.000	.107
14	Dirty runoff from the construction site	3.68	7	4.00	7	3.93	3	3.26	16	4.00	7	3.80	5	1.299	.282
15	Oil Spillage from pipe works	3.57	16	3.81	13	3.71	7	3.26	16	4.00	7	3.60	12	.717	.584
16	Unmapped pipe network	3.68	7	4.19	4	3.43	14	3.52	10	4.50	1	3.20	17	2.099	.093
17	Washing of concreting plants and tools	3.65	11	3.69	17	3.71	7	3.70	3	3.50	12	3.20	17	.279	.890
18	Lime stabilization works	3.42	20	3.94	8	3.14	20	3.30	15	3.00	18	3.20	17	1.859	.131
19	Crushed concrete reagent usage	3.65	11	4.38	1	3.36	16	3.57	8	2.50	21	3.00	20	3.380	**.015**
20	Asbestos materials in walls, ceiling, etc	3.68	7	3.88	11	3.79	4	3.39	13	4.50	1	3.80	5	1.065	.382
21	Deposition of metallic chemicals	3.83	1	4.13	5	4.07	1	3.52	10	4.00	7	3.60	12	1.256	.298

The construction activities that the architect ranked and rated from 1 (very low) to 5 (very high) are as follows muddy water onsite (M= 4.07), deposition of metallic chemicals (M= 4.07), dirty runoff from the construction site (M= 3.93), displacement of water (M= 3.79), sediment deposition on-site (M= 3.79), asbestos materials in walls, ceiling, etc. (M= 3.79), industrial garbage (M= 3.71).

The construction activities that quantity surveyors ranked and rated from 1 (very low) to 5 (very high) on were chemical usage (M= 3.91), a byproduct from sawing process (M= 3.74), displacement of water (M= 3.70), sewage discharge by workers (M= 3.70), washing of concreting plants and tools (M= 3.70), discharge by construction machinery (M= 3.61), minor coastal construction (M= 3.61). The construction activities that engineer ranked and rated from 1 (very low) to 5 (very high) on were deposition of solid waste (M= 4.50), a byproduct from sawing process (M= 4.50), chemical usage (M= 4.50), muddy water onsite (M= 4.50), unmapped pipe network (M= 4.50), asbestos materials in walls, ceiling, etc. (M= 4.50) and vehicle washing wastewater (M= 4.00).

The construction activities that others ranked and rated from 1 (very low) to 5 (very high) on was the deposition of solid waste (M= 4.20), sediment deposition on-site (M= 4.20), deposition of hydrocarbon substance (M= 4.00), muddy water onsite (M= 4.00), vehicle washing wastewater (M= 3.80), industrial garbage (M= 3.80), minor coastal construction (M= 3.80).The construction activities that were overall ranked and rated from 1 (very low) to 5 (very high) based on the findings of this research includes deposition of metallic chemicals (M= 3.83), a byproduct from sawing process (M= 3.78), industrial garbage (M= 3.75), minor coastal construction (M= 3.70), muddy water onsite (M= 3.70), chemical usage (M= 3.70), and dirty runoff from the construction site (M= 3.68).

It can be noted from the results of the survey carried out that the results are in adherence to the results of past literature which discussed the following construction activities that affect water bodies which are the deposition of metallic chemicals (Akhtar et al., 2021) which has the highest rating, then byproduct from sawing process which was found out during research work being done, then industrial garbage (Huihua, Hujun, Yige, & Baoquan, 2020), minor coastal construction (Liu, 2018), and the dirty runoff from construction site which was outlined in the study (Huihua, Hujun, Yige, & Baoquan, 2020).

Inferential statistics were carried out to test the level of rating and ranking of respondents on the construction activities that affect water bodies based on the position of the respondent in the organization using ANOVA. The resulted presented in Table 2 indicated that three of the twenty-one construction activities had P-value< 0.05; Deposition of hydrocarbon substance (sig = 0.05); Roof cleaning (sig = 0.042); Crushed concrete reagent usage (sig = 0.015). This implies that there is a significant difference in the agreement of respondents on these construction activities based on the position of the respondent in the organization.

Discussion of Findings

The process of construction usually involves a high deposit of solid waste that is usually deposited into the river basin during the construction process. This activity is however the least ranked in the findings which portrays that it is not so much practiced in the study area of Lagos metropolis, Nigeria. Other activities that are in agreement with previous studies from findings include industrial garbage, minor coastal construction, dirty runoff from the construction sites and muddy water onsite are among the highly ranked activities.

CONCLUSIONS

This paper examine the construction activities that affect water bodies in Lagos state, Nigeria. The whole study employed a quantitative research method in data collection and analysis. The study was conducted on Lagos State construction companies that are registered. Data collected from the quantitative strand were analyzed using descriptive and inferential statistical methods. Examples of descriptive statistical tools in this study include charts, frequency distributions, means scores, and standard deviation, whereas inferential statistical tools include analysis of variance (ANOVA) and factor analysis. The construction activities were measured and the result revealed that respondent's opinion of the activities varies across different designations. Therefore, the study recommends the need to encourage public awareness and environmental education to curb the adverse ignorance on the part of all parties to the construction process and various levels, most especially laborer on these project sites, teaching them on personal hygiene, health and safety practices that extends to the harmony and cleanliness of the site and its surrounding water bodies.

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REVIEW ON BIOGAS PRODUCTION FROM THE ASPECT OF DIFFERENT PRODUCTION CONDITIONS

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Abstract

This review focused on biogas production from organic wastes, including fruit, vegetables, and animal dung. Due to the availability of methane, the usage of biogas can decrease the dependence on fossil fuel and thus decrease pollution of the environment. The review detailed the four main biochemical stages in biogas formation: acid formation, which involves hydrolysis, acidogenesis as well as acetogenesis, and methane production, methanogenesis, which ultimately produces biogas from organic material. Dropping or waste of fruits and vegetables containing principally simple sugars yielded considerable energy when decomposed anaerobically while animal dung improved microbial action indispensable in the generation of biogas. The review also discussed some of the ways to enhance biogas production including; mechanical, chemical and biological treatment and identified co-digestion as a good way to do it. This paper assessed optimum parameters including operating temperature, pH, carbon-to nitrogen ratio and hydraulic retention time with regards to their impacts on biogas production. Accepting feedstock variability and contamination issues, and digester instability, the review recommended enhanced waste pretreatment and changes in digester technology. In conclusion, the study kept on noting that biogas from organic waste is a sustainable waste management solution which requires more studies to increase its effectiveness.

Keywords: Biogas production, Organic waste, Anaerobic digestion, Methane yield, Renewable energy

Introduction

The global energy structure is changing as more countries acquire cost-effective renewable electricity for global climate change and sustainable development planning. Renewable energy is a classification of energy that originates from solar, wind, hydro and biomass sources and is derived from natural sounding processes that are replenished at a faster rate than consumed. According Park, Lee, and Won (2024), the total renewable energy was approximately 2.799 GW, of which biomass was a fraction of 10/100 At the same time, far from being only an environmental problem, it has primarily turned into energy security and economic stability (Rossi, Pasciucco, Iannelli, & Pecorini, 2022).

Among all the renewable energy technologies mentioned above, biogas is one of the most successful in achieving the mentioned goal. Biogas technology employs the use of microorganisms to break down organic feedstocks, mainly composed of livestock manure, crop residues, debarked wood and other perishable crops, and wet organic wastes from the food processing industries. This process also reduces waste and minimizes the emission of greenhouse gases while generating energy. It is, therefore, evident that biogas has a valuable contribution to providing sustainable energy for direct use in cooking and electricity to under-equipped developing countries. Specifically, Haider, Völker, Kramm, Landfester, and Wurm (2019) noted that utilizing biogas may improve the likelihood of meeting the energy requirement of the next generation and address environmental issues that transpire (Azeez et al., 2021). As such, biogas represents a dual opportunity: through proper use of renewable power, it provides power while preventing the effects of waste products.

This study highlights the current state of affairs of biogas derivation from waste fruits, vegetables, and animal dung, as well as the technology utilized and the approaches implemented. This means that prior works have established that adding different organic waste feeds can significantly increase biogas production. Co-digested materials such as printed paper and sugarcane waste cited real-life examples of a particular proportion of co-digested materials that produce a high biogas production rate, according to the evidence supported by Khalid, Ratnam, Chuah, Ali, and Choong (2008). The study discusses the consequences of the environment and the economy of utility biogas in the context of post-sustainable development. The potential for biogas production from agricultural waste is substantial; for example, the average biogas yield from cow dung can reach up to 0.5 m^3 per kilogram of volatile solids, as reported in a study on anaerobic digestion (Azevedo, Sequeira, Santos, & Mendes, 2019)

For the current review, the items will include all the literature produced from 2019 to the present for data, new technologies, and policies on biogas production. The review will be done based on categories of organic waste suitable for biogas production, the types of Anaerobic Digestion technologies, their productivity and biogas social and economic factors. For instance, one of the most recent studies shows that the maximum value obtained for the C/N ratio is 20-25, contributing to anaerobic digestion. From the observations of this present review, ideas from the various studies were explored to assist in presenting an integrated outlook on the application of sustainable energy sources and biogas, especially regarding wastes and RE systems (Bhuiya et al., 2016; Cândido & Silva, 2017).

The quest to discover biogas out of fruits, vegetables, and animal dung also appears to have been researched to a similar extent since the increase in global concern about climate change and energy vulnerability. This study aims to contribute to the public's understanding of RE sources, and the information available about them will help formulate and inform policies, technologies, and community practices that embrace RE solutions. Attention must be given to the actual use of biogas and its need; this is due to the fact that the forward-looking research done in this study aims to reveal the opportunity of biogas as a player in the energy revolution (Bhuiya et al., 2016; Cândido & Silva, 2017).

This review is based on current best practices in biogas production concerning the aerobic digestion process, with particular emphasis on the anaerobic digestion pathway as the most transformative one in converting organic waste to energy. The period of interest for the review is from 2019 to the present year, and only the methods, resources, and practices that enhance biogas production are discussed in this study. The feedstock required for biogas generation is agricultural residue, food waste, fruits and vegetables, and animal manure. A strategy of the systematic review proved helpful in compiling data from different kinds of studies conducted in the last five years. This process included networking with academic databases, such as Science Direct, Google Scholar, and IEEE Xplore, to source literature. The primary focus was experimental research, case studies, and pilot investigations of various types of feedstock sources, treatment technologies, and operating parameters affecting the efficient production of biogas. With this systematic approach, it is possible to detect trends and issues and optimize approaches to biogas production.

Biogas Study Design

Biogas Production Process

Data collection included identifying methods and parameters for improving biogas production, such as mechanical, chemical, biochemical, and co-digestion techniques. These were feedstock categories, biogas production, efficiency, and environmental effects under temperature, pH, C/N ratio, and HRT (Elkelawy, El Shenawy, Bastawissi, & El Shennawy, 2022).

Mechanical treatment

This enters converting organic waste through milling, shredding, or chopping to enhance the surface area for microbial action was considered. Physical and mechanical methods were intended to raise the value of the flow of available surfaces for hydrolysis, which is the first stage of anaerobic digestion Biogas production through anaerobic digestion involves the breakdown of organic matter by microorganisms in the absence of oxygen, resulting in the production of biogas, a mixture of methane and carbon dioxide. As reported by

Altalhi, Mohamed, Morsy, Abou Kana, and Negm (2021), mechanical treatment of organic waste is a crucial step in enhancing biogas production, as it increases the surface area, reduces particle size, and breaks down complex organic molecules, making them more accessible to microorganisms. Mechanical treatment techniques, such as grinding, milling, shredding, and chopping, can be applied to various organic waste materials, including agricultural residues, food waste, and sewage sludge. By reducing the particle size and increasing the surface area, mechanical treatment enhances the contact between microorganisms and organic matter, leading to faster degradation rates and increased biogas production. Additionally, mechanical treatment can also help to break down lignin, a complex organic compound that can inhibit microbial activity, further enhancing biogas production. Overall, mechanical treatment is a simple yet effective method to optimize biogas production and improve the efficiency of anaerobic digestion systems (Enwereuzoh, Harding, & Low, 2020).

Chemical treatments

This included a literature review on acid and alkali pretreatments which solubilize solubilize lignocellulosic structures: sulfuric and hydrochloric acids for acid hydrolysis, sodium or calcium hydroxide for alkaline hydrolysis. Information was collected as to the impact of these treatments applied on the feedstock and biogas production. Authors such as Arif et al. (2020) and Azeez et al. (2021) reported that biogas production through anaerobic digestion can be significantly enhanced through chemical treatment of organic waste, which involves the use of chemicals to break down complex organic molecules and increase their bioavailability. Chemical treatment methods, such as alkaline pretreatment, acid hydrolysis, and oxidative treatment, can be applied to various organic waste materials, including agricultural residues, food waste, and sewage sludge. Alkaline pretreatment, for example, involves the use of bases such as sodium hydroxide to break down lignin and other complex organic compounds, making them more accessible to microorganisms. Acid hydrolysis, on the other hand, involves the use of acids such as sulfuric acid to break down cellulose and hemicellulose, releasing simple sugars that can be easily consumed by microorganisms. Chemical treatment can increase biogas production by up to 50% by enhancing the degradation rate of organic matter, reducing the retention time of anaerobic digestion, and improving the quality of the biogas produced. Thus, chemical treatment is a powerful tool to optimize biogas production and improve the efficiency of anaerobic digestion systems (Elkelawy et al., 2022; Enwereuzoh et al., 2020).

Biological methods

Studies on the methodology of introducing various microbial species, including Methanosarcina and Methanosaeta, to promote methanogenesis were examined. Moreover, the evaluation of the contribution of EM cultures to the acceleration of decomposition of organic matter and methane production was included (Elkelawy et al., 2022; Enwereuzoh et al., 2020). Biogas production through anaerobic digestion relies heavily on biological treatment, which involves the use of microorganisms to break down organic matter and produce biogas. Biological treatment is a complex process that involves the coordinated effort of multiple microorganisms, including bacteria, archaea, and protozoa. These microorganisms work together to hydrolyze, acidify, and methanize organic compounds, ultimately producing biogas, a mixture of methane and carbon dioxide. Biological treatment can be optimized through various strategies, including the addition of microorganisms, manipulation of operating conditions such as temperature, pH, and retention time, and the use of bioaugmentation and biostimulation techniques. For example, the addition of methanogenic microorganisms can enhance methane production, while the optimization of operating conditions can improve the overall efficiency of the anaerobic digestion process. By understanding and manipulating the complex microbial processes involved in biological treatment, biogas producers can optimize biogas production, improve process stability, and reduce the environmental impact of anaerobic digestion systems (Hazrat et al., 2021; Karthikeyan, Periyasamy, & Prathima, 2020).

Co-Digestion strategies

Literature was also assessed based on feedstock synergism to improve biomethane generation from the digesters. The examples involved a good mix of food waste with cow dung and other agricultural residues to realize the best microbial action during digestion and the proper nutrient ratios (Elkelawy et al., 2022; Enwereuzoh et al., 2020). Biogas production through anaerobic digestion can be significantly enhanced through co-digestion strategies, which involve the simultaneous digestion of multiple organic substrates. Co-digestion allows for the optimization of nutrient balance, pH, and carbon-to-nitrogen ratio, leading to improved microbial activity, increased biogas production, and enhanced process stability. By combining substrates with complementary characteristics, such as energy-rich food waste and nitrogen-rich manure, co-digestion can increase biogas yields by up to 50% compared to mono-digestion. Additionally, co-digestion can help to mitigate potential issues associated with mono-digestion, such as ammonia inhibition, foam formation, and process instability. Effective co-digestion strategies involve careful selection of substrate combinations, optimization of feedstock ratios, and monitoring of process parameters to ensure optimal conditions for microbial growth and biogas production. Therefore, co-digestion strategies, biogas producers can improve the efficiency and sustainability of anaerobic digestion systems, while also reducing greenhouse gas emissions and promoting a circular economy (Hazrat et al., 2021; Karthikeyan et al., 2020).

Analytical Parameters and Experimental Setup

The effectiveness of the methods used for biogas production was examined based on the following biogas production parameters: temperature, pH, C/N, and HRT, which were investigated using data from the presented works (Ewunie, Morken, Lekang, & Yigezu, 2021).

Temperature

Investigations focused on the mesophilic (30- 40 °C) and thermophilic (above 50 °C) temperatures to assess the temperature regime of anaerobic digestion. According to the study, the mesophilic conditions derive from a fairly stable microbial environment, while the thermophilic conditions promote a faster rate of digestion but must be controlled carefully to prevent microbial washout (Hasan & Rahman, 2017). Analytical parameters such as pH, temperature, total solids, volatile solids, and nutrient content are crucial in monitoring and optimizing the anaerobic digestion process. Temperature is a critical parameter, as it affects microbial growth, metabolism, and biogas production. The experimental setup for biogas production typically involves a bioreactor or digester, where organic substrates are fed and microorganisms break down the biomass to produce biogas. According to Narowska, Kułażyński, and Łukaszewicz (2020), the temperature of the bioreactor is controlled and maintained within an optimal range, typically between 30-40°C for mesophilic digestion and 50-60°C for thermophilic digestion. The temperature is monitored using thermocouples or temperature sensors, and adjustments are made as necessary to maintain optimal conditions. Other analytical parameters, such as pH and nutrient content, are also monitored regularly to ensure optimal conditions for microbial growth and biogas production. By controlling temperature and other analytical parameters, biogas producers can optimize the anaerobic digestion process, increase biogas yields, and reduce the environmental impact of biogas production (Ewunie et al., 2021).

pH Level

This work reveals a suitable pH of 6.8-7.4 for preserving methanogenic activity. Another aspect examined involved the effect of pH compensation using buffer agents on the further stabilization of the anaerobic digestion process (Hasan & Rahman, 2017). In biogas production, pH is a critical analytical parameter that plays a significant role in maintaining optimal conditions for microbial growth and biogas production. The pH of the bioreactor or digester is monitored regularly to ensure that it remains within the optimal range of 6.5-8.0, which is suitable for most anaerobic microorganisms. A pH outside this range can inhibit microbial activity, reduce biogas production, and even lead to process failure. The experimental setup for biogas production typically involves a pH meter or pH probe to monitor the pH of the bioreactor. pH adjustments are made as necessary using acid or base solutions to maintain optimal conditions. Other analytical parameters, such as temperature, total solids, volatile solids, and nutrient content, are also monitored regularly to ensure optimal conditions for microbial growth and biogas production. Controlling pH and other analytical parameters ensure that biogas producers can optimize the anaerobic digestion process, increase biogas yields, and reduce the environmental impact of biogas production (Ewunie et al., 2021; Hasan & Rahman, 2017).

C/N Ratio

Optimal C/N ratios of between 20/1 and 30/1 were established to be effective for bacterial growth and highest biogas production. Literature was sourced on how increasing the C/N ratio using high-carbon feedstocks, fruits and vegetable wastes, and high-nitrogen sources, such as animal manure, affected total biogas production (Hasan & Rahman, 2017). The carbon-to-nitrogen (C/N) ratio is a critical analytical parameter that plays a significant role in maintaining optimal conditions for microbial growth and biogas production. The C/N ratio represents the balance between carbon-rich organic matter and nitrogen-rich nutrients, which is essential for microbial growth and biogas production. An optimal C/N ratio of 20-30 is typically recommended for biogas production, as it ensures that microorganisms have access to sufficient carbon for energy production and nitrogen for growth. The experimental setup for biogas production typically involves monitoring the C/N ratio of the feedstock and adjusting it as necessary by adding carbon-rich or nitrogen-rich materials. For example, adding straw or sawdust can increase the carbon content, while adding manure or blood meal can increase the nitrogen content. By maintaining an optimal C/N ratio, biogas producers can optimize microbial growth, increase biogas yields, and reduce the environmental impact of biogas production. Regular monitoring of the C/N ratio, along with other analytical parameters such as pH, temperature, and nutrient content, is essential for ensuring optimal biogas production (Hasan & Rahman, 2017).

Hydraulic Retention Time

Another essential variable was HRT, which is the time organic matter stays in a digester. Therefore, duration HRTs with 15 to 30 days seemed to produce greater methane yields, particularly for the more complex feed types that may take longer to break down (Hazrat et al., 2021; Hoang et al., 2021). Hydraulic Retention Time (HRT) is a critical analytical parameter that plays a significant role in maintaining optimal conditions for microbial growth and biogas production. HRT refers to the average time that wastewater or organic substrate remains in the bioreactor or digester, and it is typically measured in days. The optimal HRT for biogas production varies depending on factors such as temperature, pH, and substrate composition, but it is typically in the range of 10-30 days. A longer HRT allows for more complete degradation of organic matter, resulting in higher biogas yields, while a shorter HRT can lead to process instability and reduced biogas production. The experimental setup for biogas production typically involves monitoring the HRT and adjusting it as necessary by controlling the flow rate of the influent and effluent streams. By maintaining an optimal HRT, biogas producers can optimize microbial growth, increase biogas yields, and reduce the environmental impact of biogas production. Regular monitoring of HRT, along with other analytical parameters such as pH, temperature, and nutrient content, is essential for ensuring optimal biogas production (Hazrat et al., 2021; Hoang et al., 2021).

Statistical Analysis

The data obtained from synthesizing the reviewed articles was then quantitatively analyzed using statistical tools to establish the relationship between various treatments and biogas production. Meta-analysis techniques were used to provide quantitative measurements of the efficiency of each treatment method and the best combination for the highest biogas generation to compare the effects of all the treatment methods for enhancing biogas production. Clear indicators were employed to assess the effectiveness of various techniques, including the per cent increase in methane yield as a result of certain treatments and the rate of time decrease (Ewunie et al., 2021). Statistical analysis plays a crucial role in understanding the relationships between various analytical parameters, such as pH, temperature, hydraulic retention time, and nutrient content, and their impact on biogas yields. Statistical analysis involves the use of mathematical techniques to analyze and interpret data, identify patterns and trends, and make predictions about future outcomes. In the context of biogas production, statistical analysis can be used to optimize operating conditions, predict biogas yields, and identify potential process bottlenecks (Oyewo et al., 2024a). Common statistical techniques used in biogas production include regression analysis, analysis of variance (ANOVA), and principal component analysis (PCA). For example, regression analysis can be used to model the relationship between temperature and biogas yield, while ANOVA can be used to compare the effects of different operating conditions on biogas production. By applying statistical analysis to biogas production data, researchers and practitioners can gain valuable insights into the complex interactions between analytical parameters and biogas yields, ultimately leading to more efficient and productive biogas production systems (Oyewo, 2024b).

According to Griffiths et al. (2022), the experimental setup for biogas production typically involves designing and conducting experiments to collect data on various analytical parameters and biogas yields. Statistical analysis is then applied to the collected data to identify significant relationships and trends. For example, a researcher may design an experiment to investigate the effect of temperature on biogas yield, collecting data on temperature, pH, and biogas yield over a period of several weeks. Statistical analysis would then be applied to the collected data to identify the relationship between temperature and biogas yield, and to determine the optimal temperature for biogas production. By combining experimental design with statistical analysis, researchers and practitioners can develop a deeper understanding of the complex interactions between analytical parameters and biogas yields, ultimately leading to more efficient and productive biogas production systems (Oyewo, 2024).

Limitations

In biogas production, analytical parameters and experimental setup are crucial in understanding the complex interactions between microorganisms, substrates, and operating conditions. However, there are several limitations associated with analytical parameters and experimental setup that can impact the accuracy and reliability of biogas production data. One major limitation is the complexity of anaerobic digestion processes, which can make it difficult to identify and quantify the relationships between analytical parameters and biogas yields. Additionally, the heterogeneity of organic substrates and the variability of microbial communities can introduce significant uncertainty into biogas production experiments. Furthermore, the scalability of laboratory-scale experiments to industrial-scale biogas production systems can be limited by factors such as differences in reactor design, operating conditions, and substrate composition. Another limitation is the lack of standardized methods for analyzing biogas production data, which can make it difficult to compare results across different studies and experiments (Oyewo, 2024).

Moreover, experimental setup limitations, such as the use of batch reactors or Continuous Stirred-tank Reactors (CSTRs), can restrict the range of operating conditions that can be explored and may not accurately represent the complex dynamics of industrial-scale biogas production systems. Additionally, the measurement of analytical parameters, such as pH, temperature, and nutrient content, can be subject to errors and uncertainties, which can propagate through the experimental results and limit their accuracy. To overcome these limitations, researchers and practitioners are developing new experimental techniques, such as the use of pilot-scale reactors and advanced sensors, and applying statistical analysis and modeling approaches to improve the accuracy and reliability of biogas production data. By acknowledging and addressing these limitations, the biogas production community can continue to advance our understanding of anaerobic digestion processes and develop more efficient and productive biogas production systems (Hazrat et al., 2021).

Formula involves in obtain biogas production

The biochemical transformation steps used in biogas production through anaerobic digestion draw their origin from a series of microbial occurrences accomplishing the reduction of the organic matter into methane CH_4 and Carbon dioxide CO_2. It is important to note that the theoretical part of this work focuses mainly on the critical quantitative parameters determined by the biochemical conversion processes and regulating biogas production, including substrate composition, degradation kinetics, and thermodynamic yield.

Stoichiometry of biogas production

The biochemical process of decomposition in an anaerobic system involves essential chemical reactions of carbohydrates, proteins and lipids concerning the anaerobic system. A typical stoichiometric reaction for carbohydrate breakdown, as an example, is represented as follows in equation 1 (Mistry, Ganta, Chakrabarty, & Dutta, 2019):

$$C_6H_{12}0_6 \longrightarrow 3C0_2 + 3CH_4 \quad (1)$$

This reaction shows that, under the most favorable conditions, 1 mole of glucose ($C_6H_{12}O_6$) yields three moles of methane and three moles of carbon dioxide. The stoichiometric analysis is required to determine the quantities of biogas produced by the given substrate based on its carbon, nitrogen, and hydrogen content.

The yield of biogas depends on the biochemical constitution of the materials used for different substrates. It has been reported that methane yield is high in substrates containing more carbon, such as agricultural and food waste. On the other hand, animal manure furnishes a good C/N ratio favourable for microbial activities (Löfgren, Forsberg, & Ståhlman, 2016; Mehariya, Goswami, Verma, Lavecchia, & Zuorro, 2021).

Energy yield calculations

The energy content of biogas depends on the concentration of methane since this component of the biogas has a more calorific value than carbon monoxide. The thermal value of the pure methane is about 55.5 MJ/m^3. The overall energy yield (E) from biogas can be calculated using the following equation 2 (Löfgren et al., 2016; Mehariya et al., 2021):

$$E = V_{CH4} \text{ x } 55.5 \text{ MJ/m}^3 \quad (2)$$

VCH_4V/VCH_4 is the methane produced per unit volume of the substrate. This equation assists in comparing the energy potential of biogas from the several kinds of organic waste substrates.

Kinetics of Anaerobic Digestion

The anaerobic digestion process can be represented by the first order of Monod kinetics, relating the substrate consumption rate with microbial growth rate and substrate concentration as presented in equation 3.

$$R = k. S \quad (3)$$

For the process where, RRR is rate of biogas production, kkk is the reaction rate constant and SSS is the concentration of the substrate. Alternatively, the Monod equation, which accounts for substrate limitations, is given in equation 4 (Mistry et al., 2019):

$$R = R_{max}.S/(K_s + S) \quad (4)$$

where R_{max} is the maximum reaction rate and K_8 is the half-saturation constant. These kinetic models provide theoretical frameworks for estimating biogas yields under varying concentrations of organic material.

C/N Ratio Calculation

The carbon-to-nitrogen (C/N) ratio plays a critical role in maintaining microbial balance and preventing ammonia toxicity in the digester. The C/N ratio for optimal anaerobic digestion is calculated with the aid of equation 5 (Mistry et al., 2019):

$$C/N\ Ratio = \frac{Total\ Carbon\ Content\ of\ Substrate}{Total\ Nitrogen\ Content\ of\ Substrate} \quad (5)$$

A balanced C/N ratio, typically between 20:1 and 30:1, supports efficient microbial growth, maximizing methane yield while minimizing inhibitory effects.

Hydraulic Retention Time and Methane Production Rate

The hydraulic retention time (HRT) impacts the residence time of the substrate in the digester. The relationship between HRT and methane yield (Q) is expressed as equation 6 (Mofijur et al., 2021):

$$Q = \frac{V}{HRT} \quad (6)$$

where VVV is the volume of the digester. In terms of the net HRTs, it is found that digesting efficiency increases if the HRTs are longer, even though the per-volume yields may reduce. Based on the substrate type, calculating the HRT is easy and useful to obtain the best balance between the retention time and economic biogas.

Temperature and pH Effects

Temperatures of the process affect microbial growth with mesophilic (30 to 40°C) and thermophilic (50 to 60°C) requiring varied anaerobic microorganisms. The Arrhenius equation can predict the impact of temperature changes on reaction rates as presented in equation 7 (Mofijur et al., 2021):

$$K(T) = k_0 .\ \boldsymbol{e^{-Ea/RT}} \quad (7)$$

Where k(T) is the rate constant at temperature T, k_0 is the frequency factor, Ea is the activation energy, and RRR is the gas constant. This relationship offers the theoretical frame for changing the temperature of the digester to control microbial activity and, thereby, biogas yield.

Profiling Phase

This study, particularly the profiling phase, looked at different organic waste types that would work as substrates for biogas and their biochemical characteristics, energy potential, and compatibility with anaerobic digestion. Screening of each substrate included assessing the organic fraction, the C/N ratio, and estimated YIM. These are essential determinants of the rate of digestion, volume and quality of biogas produced, and solubilization of the feedstock in the digester. The substrates studied encompassed fruit and vegetable waste, cow dung, and agriculture residues. These organic wastes were selected because they are primarily available locally, rich in nutrients, and have been reported to enhance biogas production (Narowska et al., 2020; Navaneeth, Suraj, Mehta, & Anand, 2021). The detailed profiling results are enumerated in Table 1.

Table 1: Substrate Profiles and Biogas Production Potential (Narowska et al., 2020; Navaneeth et al., 2021)

Substrate Type	**Organic Content**	**Carbon-to-Nitrogen (C/N) Ratio**	**Average Biogas Yield (m^3/kg VS)**	**Methane Content (%)**
Fruit Waste	High carbohydrates	20-25	0.5	60-65
Vegetable Waste	Moderate carbohydrates	15-20	0.4	58-62
Animal Dung (Cow)	High organic matter	25-30	0.6	65-70
Agricultural Residue	High lignocellulosic	30-35	0.3	55-60
Fruit Waste	High carbohydrates	20-25	0.5	60-65
Vegetable Waste	Moderate carbohydrates	15-20	0.4	58-62
Animal Dung (Cow)	High organic matter	25-30	0.6	65-70
Agricultural Residue	High lignocellulosic	30-35	0.3	55-60

As presented in Table 1, each substrate possesses its own characteristic feature. To get a clearer picture of the studied substrate's aptitude to be treated through anaerobic digestion, the following parameters were assessed: the C/N ratio and biogas productivity. This table also displays methane content, an essential measure of energy quality in biogas production. An increased proportion of methane indicates a greater efficiency of biogas production and increased energy capacity, which is essential in a resource of renewable energy.

Biogas Production

Biogas Yield and Methane Content

Among all feedstocks, cow dung had the highest and the most stable average biogas yield at 0.6m^3/kg VS and 65-70% methane content. Animal dung is rich in nutrients with a better C/N ratio, which stimulates microbial growth and production of high-yield methane (Rossi et al., 2022). Similarly, fruit waste had a reasonable biogas production (0.5 m^3/kg VS) and 60-65% methane percentage due to high carbohydrate fraction (Rossi et al., 2022). Carbohydrates are relatively rapidly degradable, and since methanogens require carbon and energy sources for biogas synthesis, carbohydrates contribute significantly to efficient biogas synthesis (Patel & Sankhavara, 2017; Randhir, Laird, Maker, Trengove, & Moheimani, 2020).

Crops containing high lignocellulosic matter and agricultural residues displayed the least biogas and methane production of 0.3 m^3/kg VS and 55-60%, respectively. Because of their fibrous structures, lignocellulosic materials limit microbes' ability to attack and degrade the materials present. Hence, these might require other pretreatments, for instance, mechanical or chemical, to enhance the biodegradation of such substrates (Patel & Sankhavara, 2017; Randhir et al., 2020).

Optimization of Anaerobic Digestion Parameters

Temperature

The profiling also analyzed the best temperature environment part. The highest methane yield was also identified under mesophilic conditions ranging between 35-37°C across the substrates, especially the cow dung and fruit wastes. These conditions encourage steady microbial growth that is easy to maintain and does not require intense operational manipulation, thus making them ideal for commercial biogas plants (Saravanan, Mathimani, Deviram, Rajendran, & Pugazhendhi, 2018).

Influence of Carbon-to-Nitrogen Ratio

In maintaining nutrient availability for the microbial communities, the C/N ratio is deemed to be of paramount importance. Besides, it guarantees that adequate nitrogen is available to feed the microorganisms, and the absence of oxygen brought about by this process discourages the formation of ammonia, which hinders the process. Among animal dung, cow dung was found to have the best C/N of 25 – 30, which is ideal for stable methane production. This range is well understood to boost microbial assimilation, emphasizing methanogens **that fuel methane formation. On the other hand, the C/N ratio of the agricultural residues was relatively higher, 30-35, signifying low nitrogen content. Despite a high carbon content, these residues are often nitrogen-deficient and likely to require nitrogen addition or co-digestion with nitrogen-containing substrates (Oliveira et al., 2021).**

pH

The subjects firmly established that the appropriate pH intervals for methanogen activity vary between 6.8 and 7.4. This pH range allows microbial communities, especially methanogens, to achieve a high level of function, hence eliminating inhibition of the process. Any variation to this pH range on either side, low or high, reduced the biogas yield as the microbial action was affected (Saravanan et al., 2018).

Substrate Composition on Biogas Production

High carbohydrate stock feed such as fruit and vegetable waste offer convenient energy and facilitates high biogas. Carbohydrate feeds have high VFA production and can be easily converted into methane through the action of methanogens. Animal dung can be used through anaerobic digestion because it contains microbes that facilitate the decomposition of the nutritive compounds in organic materials in animal dung. Further, loading high organic matter and appropriate C/N ratio of animal dung helps enhance continuous methane generation. The structure poses a barricade to microbial utilization for agricultural residues, specifically those with high lignocellulosic composition. This is true because pretreatment methods to increase biogas yield from the substrates are required before proceeding to the digesters (Rossi et al., 2022).

Conclusions

The profiling phase of this study clearly shows how substrate choice and the basic parameters of anaerobic digestion influence the output rate of biogas. Cow dung and fruit wastes, which have relatively nearly equal C/N ratios and better organic content, gave better methane yields than the others. However, other substances, like agricultural residues, might need pretreatment to optimize their biogas generation capacity.

Therefore, C/N ratios of the chosen substrates, temperature and pH levels, and co-digesting possibilities should be considered to achieve positive biogas results. These results can help identify the process of turning organic waste into a stable form of energy to service waste management and renewable energy initiatives. This paper aimed to establish factors influencing construction labour productivity, their relative importance, management policies and practises relating to labour productivity. This was carried out empirically, and based on the findings, it is concluded that they have identified five broad classifications of factors that impact labour productivity and supplementing management policies whereby organizations engage to enhance labour productivity include training and good welfare amenities.

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Harnessing Artificial Intelligence Potentials for Sustainable Landscape and Public Health Outcomes

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Abstract
Research on the application of artificial intelligence (AI) has primarily focused on areas such as disease diagnosis and management, public health surveillance, and healthcare as a whole. However, the interrelated domains of landscape and well-being have received comparatively little attention, despite their significant reciprocal relationship. The intersection between AI, landscape, and public health is a burgeoning research area, particularly in developing countries like Nigeria. This review aims to explore the potential applications of AI in promoting sustainable landscape and wellbeing planning and management in Nigeria, as well as the challenges and opportunities associated with its adoption. A comprehensive literature review reveals that AI can enhance landscape planning, environmental monitoring, and health impact assessments, ultimately contributing to improved public health outcomes. To harness the full capacity of AI, it is essential to address deterrents such as knowledge gaps, inadequate infrastructure, and the existing disparity in access to and benefits from this digital technology. This review highlights the need for collaborative efforts between researchers, policymakers, and practitioners to develop context-specific AI solutions that prioritise Nigerian needs and contexts. By doing so, AI can be adequately harnessed to create sustainable, healthy, and resilient landscapes that support the well-being of its citizens.

Keywords: Artificial intelligence, Landscape, Wellbeing, Public Health, Nigeria, Sustainable Development.

Introduction

1.1 Background of Study

Globally, the level of revolution artificial intelligence (AI) has brought into different sectors of human endeavours including healthcare and landscape cannot be overemphasized. In healthcare, AI has improved disease diagnosis and management (Esteva *et al*., 2019), public health surveillance (Nsoesie *et al*., 2019), and healthcare generally (Rajkomar *et al*., 2019). The algorithm generated by AI has become of great use in analysing medical images, predicting patient outcomes, and enhancing personalized medicine (Esteva *et al*., 2019). In the same vein, AI has enhanced environmental monitoring (Kattenborn *et al*., 2019), land cover classification (Li *et al*., 2020), and urban planning (Bibri, 2019) in terms of landscape. AI-powered geographic information systems (GIS) can analyze satellite images, detect land use changes, and optimize urban development (Kattenborn *et al*., 2019). Despite these advancements, the intersection of AI, landscape, and public health remains understudied, particularly in developing countries like Nigeria (Aigbavboa *et al*., 2018; Oke *et al*., 2017). The existing gap in research is noteworthy, as the oversight of landscape and well-being in AI studies may impede the achievement of good health and well-being, as well as the establishment of sustainable cities and communities (United Nations, 2015). Scholars have argued that the integration of AI in landscape and public health research has the potential to bring about creative approaches to address environmental and health-related problems (Kattenborn *et al*., 2019; Li *et al*., 2020). However, the scarcity of research along this line, especially in Nigeria, may be attributed to the limited availability of data, infrastructure, and expertise (Oyewole *et al*., 2017).

This current effort is to examine the potential application of artificial intelligence in promoting sustainable landscape and wellbeing in Nigeria. The study seeks to investigate how AI can be leveraged to enhance landscape planning, environmental monitoring, and health impact assessments, ultimately contributing to improved well-being and public health outcomes in Nigeria (Kattenborn *et al*., 2019; Li *et al*., 2020). Previously, the efficacy of AI to analyse satellite images, detecting land use changes, and optimising urban development was demonstrated by Bibri (2019) and Esteva *et al.* (2019). By focusing the opportunities and challenges associated with AI adoption in Nigeria, this study hopes to contribute to the development of context-specific AI solutions that prioritise Nigerian needs and contexts. This is in line with the call by scholars for more research on the application of AI in developing countries, where the potential benefits are enormous (Nsoesie *et al.*, 2019; Rajkomar *et al.*, 2019).

Literature Review

2.1 Overview of the Applications of Artificial Intelligence

2.1.1 Disease Diagnosis and Management

Leveraging Artificial Intelligence (AI) in disease diagnosis and management has garnered significant attention in Nigeria, with numerous studies exploring its potential. Adeoye *et al.* (2020) demonstrated AI's accuracy in diagnosing malaria. They discovered that AI-powered diagnostic systems achieved an accuracy rate of 95.6% in diagnosing malaria, outperforming human clinicians. Additionally, they identified data quality and availability as significant challenges. Ojo *et al.* (2020) showcased potentials of artificial intelligence in tuberculosis diagnosis. They found that AI-assisted tuberculosis diagnosis reduced diagnostic time by 75% and improved diagnostic accuracy by 20%. They also highlighted the need for increased AI adoption in resource-constrained settings. Furthermore, Akinade *et al.* (2022) highlighted AI's role in cancer diagnosis, emphasizing its ability to enhance diagnostic accuracy. They demonstrated that AI-powered cancer diagnosis achieved an accuracy rate of 92.1%, surpassing human pathologists. They emphasized the potential of AI in enhancing diagnostic accuracy and reducing false positives.

In disease management, Ogunjobi *et al.* (2021) explored AI's application in diabetes management, and discovered that AI-powered diabetes management systems improved blood glucose control by 25% and reduced hospitalization rates by 30%. They also identified patient engagement and education as crucial factors. Adeyinka *et al.* (2022) discussed its potential in hypertension management, and found that AI-assisted hypertension management reduced blood pressure levels by 15% and improved medication adherence by 25%. They highlighted the potential of AI in enhancing patient outcomes and reducing healthcare costs. These studies underscore AI's capacity to improve patient outcomes and enhance healthcare delivery. However, challenges persist, including limited data quality (Laoye *et al.*, 2022), inadequate infrastructure (Adeoye *et al.*, 2020), and insufficient expertise (Ojo *et al.*, 2020). Overcoming the downsides to this technology is essential to fully harness its potential in Nigerian healthcare.

2.1.2 Public Health Surveillance

The integration of this digital intelligence to public wellness initiatives surveillance has gained substantial interest in Nigeria, with various studies exploring its potential. Ojo *et al.* (2020) demonstrated the effectiveness of AI-powered surveillance systems in detecting and tracking infectious diseases, such as Ebola and Lassa fever. They highlighted the capacity of AI to augment early warning systems, facilitating rapid response strategies. Building upon this research, Adeoye *et al.* (2020) explored the use of machine learning algorithms for the prediction of epidemics, achieving an accuracy rate of 85.6%. They emphasized the need for high-quality data and collaborative efforts. Laoye *et al.* (2022) discussed the application of natural language processing in analyzing social media data for disease surveillance, highlighting its potential in detecting early warnings and monitoring public health trends. However, challenges persist, including data quality and availability (Ojo *et al.*, 2020), inadequate infrastructure (Adeoye *et al.*, 2020), and limited expertise (Laoye *et al.*, 2022).

2.1.3 Healthcare Generally

The capacity of artificial intelligence to improve healthcare outcomes, streamline clinical workflows, and enhance patient experiences has garnered considerable global interest, including Nigeria, owing to its functional capabilities. The discovery of AI's potential in healthcare is evident in various studies. Globally, AI has been shown to be effective in medical imaging analysis (Rajpurkar *et al*., 2020), disease diagnosis (Esteva *et al*., 2019), and personalized medicine (Chen *et al*., 2019). In Nigeria, research has demonstrated AI's potential in healthcare management (Oyedotun *et al*., 2020), disease surveillance (Adewole *et al*., 2020), and telemedicine (Adebayo *et al*., 2020). Specifically, Adewole *et al*. (2020) identified AI's potential in enhancing disease surveillance, while Adebayo *et al*. (2020) found that AI-powered telemedicine can improve healthcare access and outcomes. Chen *et al*. (2019) demonstrated AI's potential in reducing healthcare disparities through personalized medicine. However, limitations exist in AI adoption in healthcare. Data quality and availability (Adewole *et al*., 2020; Oyedotun *et al*., 2020), infrastructure limitations and regulatory frameworks (Adebayo *et al*., 2020), and the need for diverse and representative datasets (Chen *et al*., 2019) are significant challenges. Additionally, legal and ethical considerations, including data privacy and bias (Rajpurkar *et al*., 2020), must be addressed. To address these, Adewole *et al*. (2020) and Oyedotun *et al*. (2020) recommended improved data quality and availability, while Adebayo et al. (2020) opined that increased investment in healthcare infrastructure and policy development will be of immense help. In the same way, Chen *et al*. (2019) in their study concluded that addressing bias in AI decision-making is a necessity. Esteva *et al*. (2019) also recommended ensuring responsible AI adoption through regulatory and ethical considerations in order to address the limitations existing in AI adoption in healthcare. Furthermore, increased transparency and accountability in AI decision-making (Rajpurkar *et al*., 2020) are crucial for successful AI adoption in healthcare.

2.1.4 Intersection of AI, Landscape, and Public Health

Research has increasingly explored the intersection between Artificial Intelligence (AI), landscape, and wellbeing/public health. A study by Sullivan et al. (2020) demonstrated how AI-powered landscape analysis can inform urban planning decisions to promote physical activity and reduce obesity. Another study by Kardan *et al*. (2019) found that AI-driven landscape design can improve mental health outcomes by incorporating natural elements. Moreover, AI has been utilised in analysing the influence of environmental landscape on public health. Li *et al*. (2020) employed machine learning algorithms to examine the relationship between landscape features and cardiovascular disease. In a similarly vein, a study by Yang *et al*. (2019) used AI to investigate the effect of landscape on air quality and respiratory health. Nevertheless, apprehension regarding the potential negative impacts of AI on landscape and wellbeing exist in connection with the society. These impacts are multifaceted and far-reaching. Globally, AI-driven urbanization can lead to decreased green spaces, increased stress levels, and reduced wellbeing (Zhang *et al*., 2020). Furthermore, AI-powered resource extraction and processing can exacerbate environmental degradation, negatively impacting landscape and wellbeing (Esteva *et al*., 2019). Additionally, AI-driven automation can displace jobs, leading to increased stress, anxiety, and decreased wellbeing (Forsyth et al., 2020).

In Nigeria, the negative impacts of AI on landscape and wellbeing are equally concerning. AI-driven urbanization can lead to the destruction of cultural heritage sites, negatively impacting landscape and wellbeing (Akingbola *et al*., 2020). Moreover, AI-powered industrialization can increase environmental pollution, negatively impacting landscape and wellbeing (Ogundipe *et al*., 2020). Furthermore, AI-driven resource allocation can exacerbate existing inequalities, limiting access to resources and negatively impacting wellbeing (Adeyinka *et al*., 2020).

2.2 Potential of Artificial Intelligence

2.2.1 Landscape Planning

Artificial Intelligence (AI) has revolutionized various fields, and its potential in landscape planning is vast and promising. Research conducted worldwide has illustrated the capabilities of artificial intelligence in analyzing and simulating landscape designs, forecasting environmental impacts, and optimizing planning decisions (Li et al., 2022). For instance, a study in China employed machine learning algorithms to design urban parks, considering factors like user preferences, climate, and vegetation (Wang *et al*., 2020). In Nigeria as well, AI can address pressing landscape planning challenges, such as rapid urbanization and environmental degradation (Adeyemi *et al*., 2020). Researchers have applied GIS and machine learning to identify suitable areas for green infrastructure development in Lagos (Oke *et al*., 2022). Additionally, AI-powered participatory mapping and virtual reality can enhance community engagement in landscape planning (Mbachu *et al*., 2020).

The potential of artificial intelligence in landscape planning is further demonstrated by its capacity to analyze extensive datasets, discern patterns, and forecast future trends (Aljoumani *et al*., 2020). This can inform evidence-based planning decisions, ensuring sustainable and resilient landscapes. It can also optimize landscape planning by considering multiple objectives, such as environmental, social, and economic factors (Zhang *et al*., 2022). These are indications that AI has the potential to transform landscape planning by enhancing design, planning, and management processes. Its applications in analyzing data, simulating scenarios, and engaging communities can lead to more sustainable and resilient landscapes.

2.2.2 Environmental Monitoring

Artificial Intelligence (AI) has transformed environmental monitoring through the improvement of data collection, analytical processes, and predictive capabilities. Globally, studies have demonstrated AI's potential in monitoring air and water quality (Kumar *et al*., 2020), detecting deforestation and land degradation (Dobos *et al*., 2020), and predicting climate patterns (Chen *et al*., 2022). For instance in Asia, machine learning algorithms was been employed to monitor water quality, achieving high accuracy in predicting pollutant levels (Li *et al*., 2019). The Nigeria experiences have proven that AI can address pressing environmental challenges, such as oil spill detection and monitoring (Isebor *et al*., 2020). Researchers have utilized satellite image analysis and machine learning techniques to detect regions impacted by oil spills in the Niger Delta (Okeke *et al*., 2022). Furthermore, AI-enabled sensors are capable of monitoring air quality in urban environments, delivering real-time data to facilitate informed decision-making (Adeyemi *et al*., 2022).

2.2.3 Health Impact Assessments

Artificial Intelligence (AI) possesses the potential to transform Health Impact Assessments (HIAs) by improving the accuracy, efficiency, and comprehensiveness of the process of assessment. Globally, studies have demonstrated AI's capabilities in predicting health outcomes, identifying risk factors, and evaluating the effectiveness of interventions (Srivastava *et al*., 2020). Li et al. (2019) utilized machine learning algorithms to forecast the health effects of air pollution, attaining a high level of accuracy in predicting mortality rates in the United States. In the same vein, Adeyemi *et al.* (2020) assert that artificial intelligence has the potential to tackle critical health issues, including infectious disease outbreaks and maternal mortality in Nigeria. Researchers have similarly substantiated this claim by employing AI-driven predictive models to pinpoint high-risk regions for malaria outbreaks, thereby facilitating targeted interventions (Okeke *et al*., 2022). Additionally, Eze *et al.* (2022) demonstrated that artificial intelligence can analyze extensive datasets to identify risk factors associated with maternal mortality, thereby informing evidence-based policy decisions.

The impact of artificial intelligence in HIAs is further enhanced by its capacity to integrate various data sources, including electronic health records, environmental data, and social determinants of health (Kumar *et al*., 2020). This integration can yield a comprehensive understanding of the intricate relationships among environmental factors, health outcomes, and social determinants. Moreover, AI can promote community engagement and participation in HIAs through the use of AI-driven tools and platforms (Mbachu *et al*., 2020). These potentials could be achieved by enhancing predictive capabilities, identifying risk factors, and evaluating interventions. Its applications in predicting health outcomes, identifying high-risk areas, and analyzing diverse data sources can lead to more effective and targeted health interventions.

Methodology

3.1 Comprehensive Literature Review Approach

This approach refers to a methodical and thorough process of identifying, evaluating, and synthesizing existing research studies and literature on a specific research topic or question. The study investigated the potential applications of AI in advancing sustainable landscapes and public health in Nigeria. It also analyses the intersection of AI, landscape, and public health, emphasizing the opportunities and challenges related to the adoption of AI in the Nigerian context. This review covered various aspects, including disease diagnosis and management, public health surveillance, healthcare generally, the intersection of AI, landscape, and wellbeing/public health, and the potential of AI in landscape planning, environmental monitoring, and health impact assessments. The study highlights challenges including data scarcity, inadequate infrastructure, and the digital divide, which must be addressed in order to fully harness the potential of artificial intelligence. The need for collaborative efforts between researchers, policymakers, and practitioners to develop context-specific AI solutions that prioritize Nigerian needs and contexts has also been emphasised through the study. This review provides a solid foundation for understanding the potential of AI in promoting sustainable landscape and wellbeing in Nigeria. It underscores the necessity for additional research and collaboration to capitalize on the advantages of artificial intelligence and to tackle the challenges related to its implementation.

3.2 Data Sources and Strategy

The information used in this study was drawn mainly from secondary data sources. The information included published works on the subjects related to disease diagnosis and management, public health/wellbeing, landscape planning, environmental monitoring, and health impact assessments. These published papers were sourced from various online databases, including academic platforms such as Google Scholar, PubMed, Scopus, and Web of Science. They were also obtained from online libraries and repositories, such as Research Gate, as well as government and organizational websites, including the World Health Organization, the United Nations, and the National Institutes of Health. Furthermore, online journals and publications, such as Science Direct, were also utilized.

Results of Findings

4.1 Summary of Research Findings

4.1.1 Landscape Planning

Artificial intelligence has the capacity to transform landscape planning by improving the analysis and simulation of landscape designs, forecasting environmental impacts, and optimizing planning decisions. AI-powered GIS and machine learning algorithms can identify suitable areas for green infrastructure development, leading to more sustainable and resilient landscapes. Furthermore, AI can optimize landscape planning by considering multiple objectives, such as environmental, social, and economic factors, to create holistic and integrated plans.

4.1.2 Environmental Monitoring

AI can significantly enhance environmental monitoring by analyzing large datasets, identifying patterns, and predicting future trends. AI-powered sensors and satellite image analysis can effectively monitor air and water quality, detect deforestation and land degradation, and predict climate patterns, enabling proactive measures to mitigate environmental degradation. Additionally, AI can integrate data from various sources, providing a comprehensive understanding of environmental systems and informing evidence-based decision-making.

4.1.3 Health Impact Assessments

Artificial intelligence can enhance health impact assessments by forecasting health outcomes, identifying risk factors, and assessing the effectiveness of interventions. It can equally analyze a variety of data sources, including electronic health records, environmental data, and social determinants of health, thereby offering a comprehensive understanding of the intricate relationships among environmental factors, health outcomes, and social determinants. Moreover, AI can facilitate community engagement and participation in health impact assessments through AI-powered tools and platforms, ensuring that assessments are inclusive and effective.

4.1.4 Overall Potential

AI has the potential to transform landscape planning, environmental monitoring, and health impact assessments by enhancing data collection, analysis, and prediction capabilities. By identifying areas for improvement, optimizing resource allocation, and predicting future trends, AI can promote sustainable landscape and wellbeing. Nevertheless, challenges such as lack of information, inadequate infrastructure, and the digital inequality must be addressed in order to fully capitalize on the potential of artificial intelligence and to ensure that its benefits are distributed equitably.

4.2 Challenges and Opportunities Associated with AI Adoption in Nigeria

4.2.1 Challenges of AI Adoption

The adoption of Artificial Intelligence (AI) in Nigeria faces several challenges, including data scarcity and limited access to quality data, which hinders the development and training of AI models. Additionally, limited infrastructure, including inadequate computing power and internet connectivity, constrains the deployment and utilization of AI solutions. Furthermore, the digital divide and lack of AI expertise and skills in Nigeria pose significant barriers to AI adoption. Furthermore, issues related to data privacy, security, and ethical considerations must also be addressed to facilitate the responsible adoption of artificial intelligence.

4.2.2 Opportunities of AI Adoption

Despite the challenges, AI adoption in Nigeria presents numerous opportunities for sustainable development. AI can enhance landscape planning, environmental monitoring, and health impact assessments, leading to improved wellbeing and public health outcomes. Additionally, AI can optimize resource allocation, predict future trends, and identify areas for improvement, enabling proactive measures to address development challenges. Moreover, AI can facilitate community engagement and participation in development initiatives, ensuring that solutions are inclusive and effective. By leveraging AI, Nigeria can leapfrog traditional development pathways and achieve sustainable development goals.

Discussion of Findings

5.1 Implications of Artificial Intelligence

5.1.1 Landscape Planning

The adoption of AI in landscape planning has significant implications for creating sustainable and resilient landscapes. AI can optimize landscape design, predict environmental impacts, and identify areas for improvement, leading to enhanced biodiversity, ecosystem services, and human wellbeing. Moreover, AI can facilitate community engagement and participation in landscape planning, ensuring that plans are inclusive and effective. However, AI also raises concerns about the potential for biased or unfair planning decisions, highlighting the need for transparent and accountable AI systems.

5.1.2 Environmental Monitoring

AI has far-reaching implications for environmental monitoring, enabling real-time tracking of environmental changes, predicting future trends, and identifying areas for conservation. AI-powered sensors and satellite image analysis can monitor air and water quality, detect deforestation and land degradation, and predict climate patterns, enabling proactive measures to mitigate environmental degradation. However, artificial intelligence also raises concerns regarding data privacy, security, and the potential for environmental surveillance, underscoring the necessity for responsible adoption of AI technologies.

5.1.3 Health Impact Assessments

The integration of artificial intelligence into health impact evaluations significantly influences the prediction of health outcomes, the identification of risk factors, and the assessment of intervention efficacy. In this context, AI is adept at analyzing a diverse array of data sources, including social determinants of health, environmental data, and electronic health records, thereby providing a comprehensive understanding of the complex interrelationships among social determinants, environmental factors, and health outcomes. However, the use of AI also raises concerns regarding data security, privacy, and the potential for inequitable or biased health outcomes, highlighting the necessity for transparent and responsible AI systems.

5.2 Addressing the Challenges Poised Towards Artificial Intelligence

5.2.1 Data Scarcity

To address data scarcity, efforts should be made to collect and share data across various sectors and stakeholders. Governments and organizations can establish data repositories and platforms for data sharing, while also ensuring data privacy and security. Additionally, initiatives can be launched to collect new data, such as surveys, sensors, and crowd-sourcing. Utilizing various data sources, such as social media data and satellite imagery, can also mitigate issues related to data scarcity.

5.2.2 Limited Infrastructure

The challenges posed by limited infrastructure can be mitigated through investments in the development of digital infrastructure, including high-speed internet, data centers, and cloud computing technologies. Governments and private sector organizations can collaborate to establish infrastructure development initiatives, while also promoting public-private partnerships. Moreover, alternative infrastructure solutions, such as edge computing and offline data processing, can be explored to overcome infrastructure limitations.

5.2.3 Digital Divide

The digital divide can be addressed by promoting digital literacy and skills development programs, targeting marginalized communities and underserved populations. Initiatives can be launched to provide access to digital technologies, such as computers, smartphones, and internet connectivity, while also ensuring affordability and accessibility. Moreover, inclusive design principles can be applied to develop AI solutions that are accessible and usable by diverse populations, reducing the risk of exacerbating existing inequalities.

5.3 Collaborative Efforts between Researchers, Policymakers, and Practitioners

The successful adoption of AI in promoting sustainable landscape and wellbeing in Nigeria requires collaborative efforts between researchers, policymakers, and practitioners. Researchers can provide expertise in AI development and application, while policymakers can facilitate the integration of AI into policy and decision-making processes. Practitioners, including community leaders and stakeholders, can ensure that AI solutions are context-specific, effective, and equitable. Collaboration can facilitate the co-creation of AI solutions, ensuring that they address local needs and priorities. Moreover, collaborative efforts can leverage resources, expertise, and funding, accelerating the development and deployment of AI solutions. Through collaboration, researchers, policymakers, and practitioners can tackle the challenges related to the adoption of artificial intelligence and ensure that AI effectively contributes to sustainable development and well-being in Nigeria.

Conclusion

6.1 AI's Potential in Promoting Sustainable Landscape and Wellbeing in Nigeria

Artificial Intelligence (AI) has vast potential in promoting sustainable landscape, public health and wellbeing in Nigeria by enhancing landscape planning, environmental monitoring, and health impact assessments. AI can optimize landscape design, predict environmental impacts, and identify areas for improvement, leading to enhanced biodiversity, ecosystem services, and human wellbeing. Additionally, AI can facilitate real-time environmental monitoring, predict future trends, and detect early warnings of environmental degradation. AI can also analyze complex relationships between environmental factors, health outcomes, and social determinants, enabling proactive measures to mitigate health risks. By leveraging AI, Nigeria can achieve sustainable development goals, ensure environmental sustainability, and promote wellbeing for present and future generations. Overall, AI can serve as a powerful tool in promoting sustainable landscape and wellbeing in Nigeria, but its potential can only be fully realized through collaborative efforts and responsible adoption.

6.2 Call for Context-Specific AI Solutions Prioritizing Nigerian Needs and Contexts

There is a pressing need for context-specific AI solutions that prioritize Nigerian needs and contexts, addressing the unique challenges and opportunities in the country. AI solutions must be tailored to Nigeria's specific social, economic, and environmental realities, rather than relying on generic or imported solutions. This requires collaborative efforts between researchers, policymakers, and practitioners to develop AI solutions that are grounded in local knowledge, needs, and priorities. Context-specific AI solutions can ensure that AI adoption is inclusive, equitable, and effective, addressing the needs of diverse populations and promoting sustainable development. Moreover, prioritizing Nigerian needs and contexts can foster innovation, entrepreneurship, and job creation, contributing to the country's economic growth and development. By developing context-specific AI solutions, Nigeria can benefit from the full capacity of the technology in driving sustainable landscape and wellbeing, while avoiding the risks of AI exacerbating existing inequalities or environmental degradation.

6.3 Future Research Directions

The development and evaluation of context-specific artificial intelligence solutions that consider Nigeria's unique opportunities and challenges should be the primary focus of future research. To identify areas where artificial intelligence can exert the greatest influence, researchers should explore its applications across various domains, including healthcare, education, and environmental management. Research should also examine the ethical and societal implications of artificial intelligence adoption in Nigeria, including issues related to bias, security, and data privacy. Furthermore, studies should examine the effectiveness of AI in promoting sustainable landscape and wellbeing, including its impact on biodiversity, ecosystem services, and human health. Research should also explore innovative AI technologies, such as edge AI, transfer learning, and explainable AI, to enhance AI adoption and effectiveness in Nigeria. Finally, future research should prioritize interdisciplinary collaboration, involving researchers, policymakers, and practitioners to ensure that AI solutions are evidence-based, context-specific, and effective in promoting sustainable development and wellbeing in Nigeria.

Recommendations

7.1 Policy and Practice Implications

Policymakers should develop and implement policies that support the development and adoption of AI solutions in Nigeria, including investments in digital infrastructure, data privacy and security, and AI research and development. Additionally, policies should prioritize the use of AI in promoting sustainable landscape and wellbeing, including environmental monitoring, health impact assessments, and landscape planning. Practitioners should prioritize the development of context-specific AI solutions that address local needs and priorities, involving communities and stakeholders in the design and deployment of AI solutions. Furthermore, practitioners should ensure that AI solutions are inclusive, equitable, and effective, addressing the needs of diverse populations and promoting sustainable development. Moreover, policymakers and practitioners should collaborate to establish AI governance frameworks that ensure transparency, accountability, and ethical considerations in AI adoption and deployment. Finally, continuous monitoring and evaluation of AI adoption and impact should be prioritized to inform policy and practice decisions.

7.2 Research Agenda for Future Studies

Future studies should investigate the impact of AI on sustainable landscape and wellbeing in Nigeria, exploring the effects of AI on biodiversity, ecosystem services, and human health. Research should investigate the potential role of artificial intelligence in assisting Nigeria in addressing environmental challenges such as land degradation, deforestation, and climate change. Additionally, studies should investigate the use of AI in health impact assessments, exploring its potential to predict health outcomes, identify risk factors, and evaluate interventions. The role of AI in landscape planning and design should also be examined, including its potential to optimize landscape functionality, promote sustainable urban planning, and enhance community engagement. Research should also examine the ethical and societal implications of artificial intelligence adoption in Nigeria, particularly regarding issues of bias, security, and data privacy. Furthermore, to enhance the adoption and effectiveness of AI in Nigeria, investigations should focus on advanced AI technologies such as explainable AI, edge AI, and transfer learning.

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