DOI: 10.36108/ujees/4202.60.0171

UNIOSUN Journal of Engineering and Environmental Sciences. Vol. 6 No. 1. March. 2024

SELECTION OF SUITABLE LANDFILL SITE FOR WASTE DISPOSAL IN ILORIN METROPOLIS USING GEOGRAPHICAL INFORMATION SYSTEM

Abdulwaheed A. A., Agboola S. A., Moshood B. B, Adeniyi G., Abdulsalam M. A.

Abstract Rapid urbanization globally has aggravated and worsen the management of municipal solid waste (MSW) in cities, especially the developing countries. This article underscores the pressing need for effective waste management solutions from the unruly contamination of soil and groundwater, or improper waste disposal and focuses on the selection of suitable landfill sites using Geographic Information Systems (GIS) techniques. With a global increase in MSW generation, especially in Sub-Saharan Africa, the environmental and health consequences of open dumping is hazardous. The study employs Multi-Criteria Evaluation (MCE) and Analytical Hierarchy Process (AHP) within the GIS environment, considering criteria such as elevation, slope, aspect, soil properties, proximity to roads, water bodies, and settlements. The analysis integrates diverse data sources, including remote sensing and soil databases, offering a comprehensive evaluation of topographical factors, soil characteristics, and accessibility. Results indicated that approximately 29.73%, falls under the category of "Restricted Area," totaling 18,887.18 hectares. High Suitable areas cover 15.85% of the region, comprising 10,070.28 hectares, while "Very High Suitable" areas, though minimal in coverage at 0.02%, represent nearly perfect sites totaling approximately 12.35 hectares. The results offer valuable insights into landfill suitability, providing a foundation for informed decision-making and sustainable waste management strategies.

Keywords: Analytical Hierarchy Process (AHP), Geographic Information Systems (GIS), Landfill, Multi-criteria evaluation (MCE), Municipal Solid Waste (MSW).

I. Introduction

Municipal solid waste (MSW) is a major concern in many rapidly growing cities across the globe, owing to ineffective waste management, resource constraints, and improper planning [1]. These wastes are materials discarded for which municipalities are usually held responsible for collection, transportation, and final disposal. The challenge is more severe in the developing world as the collection, disposal, and dumping sites for MSW remain unsolved and complex to find solutions [2,3]. The annual municipal solid waste generated is estimated to be around 2.01 billion tones and this is expected to grow to about 3.40 billion tones by 2050, which double the estimated population growth around same period [4].

According to [4] the Sub-Saharan Africa waste generation is expected to be more than triple by 2050. Also, half of the waste generated in this region is currently openly dumped, and the trajectories of waste growth will have vast implications for the environment, health, and economic prosperity [4]. Hence, there is a need for special attention to waste management for a clean environment and better human health particularly in the cities of the developing world as they lack the necessary infrastructure for waste collection and disposal activities where wastes are either openly dumped or deposited in non-sanitary sites which generate toxic leachates

Abdulwaheed, A. A., Adeniyi, G., Abdulsalam M. A.
(Department of Surveying and Geo-informatics, University of Abuja, FCT, Nigeria)
Agboola, S. A.
(Department of Building and Quantity Surveying, University of Abuja, FCT, Nigeria)
Moshood, B. B.
(Department Estate Management and Urban and Regional Planning, University of Abuja, FCT, Nigeria)
Corresponding Author:
shamsudeen.agboola@uniabuja.edu.ng
Phone Number: +2348168915600

and greenhouse gas emissions as a result of poor management causing environmental degradation and global warming [5,6]. In order to avoid these adverse consequences of open dumping of MSW, it is important to manage the waste in a sustainable manner such as suitable landfill site selection which minimizes environmental degradation and public health hazards [6,7].

Landfills have been acknowledged as an appropriate method of organized solid waste disposal in urban areas. However, many countries are yet to adopt the strategy because of the technical expertise required in the design, operation, and monitoring process that will ensure compliance with environmental regulations [8,9,10,11]. Additionally, the increasing population densities and its resultant of less land availability for siting landfills coupled with environmental health concerns, are also difficulties to overcome. Thus, various international specialized studies are conducted in this present research in order to identify suitable areas for waste landfill location, using GIS techniques [12,13]. This method of siting landfills in this part of the world is still at the introductory level [2,6].

The method of siting landfill involves careful observation, and interpretation of different criteria at the minimum environmental, social, and economic cost [6,13,14]. Hence, the use of a multi-criteria evaluation (MCE) method seems inevitable.

The analytical hierarchy process (AHP) is an advanced techniques of multi-criteria decision analyses (MCDA) that logically integrate and segregate complex issues [15]. MCDA and AHP within the GIS is a state-of-art approach for spatial planning and management including landfill site selection and it has been extensively used for urban land suitability, construction risk management, suitability analysis for coastal land management, multifunctional forestry, agricultural forestry, and windfarm lands [16,17,18,19]. Therefore, this study tends to employ and analyzed the various criteria such as elevation, slope, aspect, soil texture, soil depth, settlement, road, and river in MCDA and AHP within the GIS environment for the landfill site selection in Ilorin metropolis, Kwara State, Nigeria.

II. Materials and Methods

The methodology integrates data from various sources, including remote sensing, geographic information systems (GIS), and soil databases. The study evaluates topographical factors, soil properties, and land accessibility, as criteria for the selection of landfill sites. The method ensures compliance with regulatory guidelines and environmental factors.

A. Topographical factors

Elevation data were analysed to identify areas with altitudes suitable for landfill construction. Slope data were used to evaluate terrain suitability, avoiding steep slopes. Aspect data considered the direction of prevailing winds, ensuring odour control.

B. Soil factors

Soil properties, including texture, were assessed to determine soil suitability for landfill construction. Effective Soil depth information was used to avoid areas with a high risk of groundwater contamination.

C. Land accessibility

The study assessed accessibility by road, considering proximity to existing road networks and considered to distance to settlement by following regulatory guidelines by avoiding landfill sites near urban or rural areas. It also considered distance to river where landfills were located at a safe distance from water bodies, adhering to legal requirements.

Table 1: Data and their source

S/no	Name	Format Scale or Resolution	Date	Source	Relevance
1	Map of Nigeria, Kwara State.	Digital	2019	Nigeria Shapefiles	For Demarcation of Study Area
2	Soil Map for Kwara State	Digital	2015	Harmonized World Soil Database and International Soil Reference and Information Centre.	For soil maps production.
3	DEM data	Digital	2014	Shuttle Radar Topographic Mission	For Elevation, Slope, and Slope Aspect of the Area
4.	Landsat 8 images	Digital	2020	USGS (United State Geological Surveys) explorer home	For land use and land cover of the area.

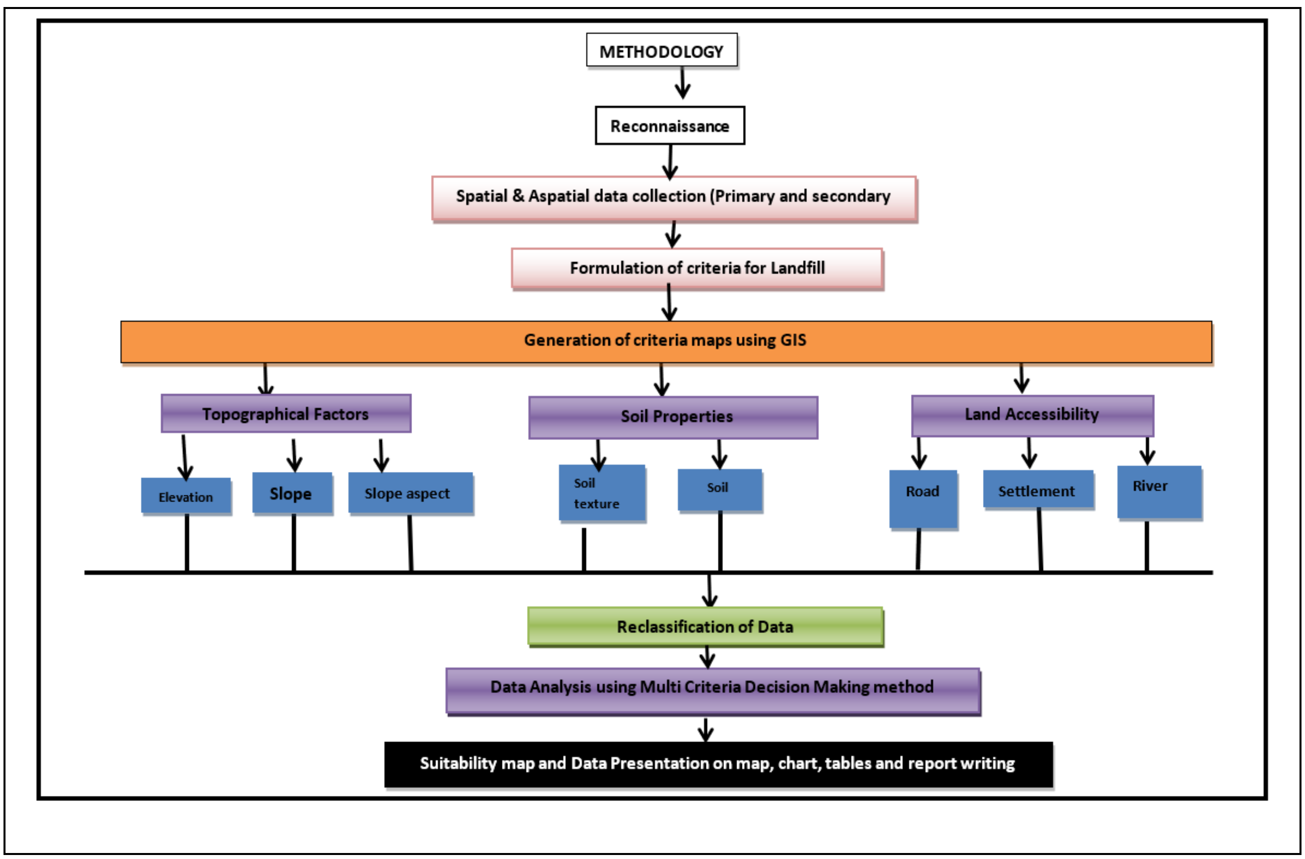

Figure 1: Research Methodology Flowchart

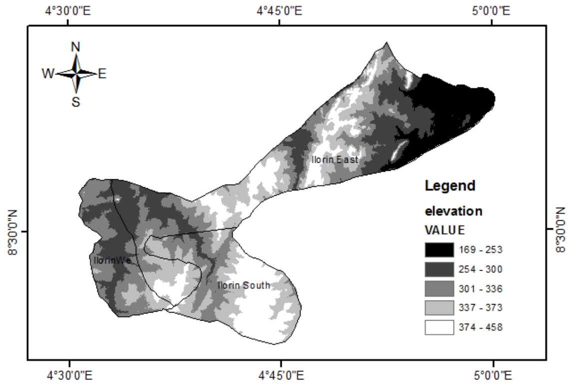

Figure 2: Digital Elevation Model of the Study Area

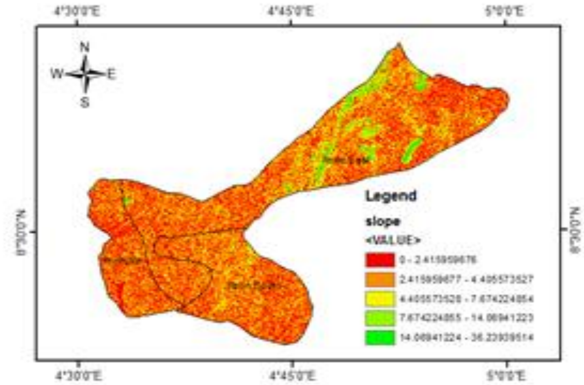

Figure 3: Slope of the Study Area

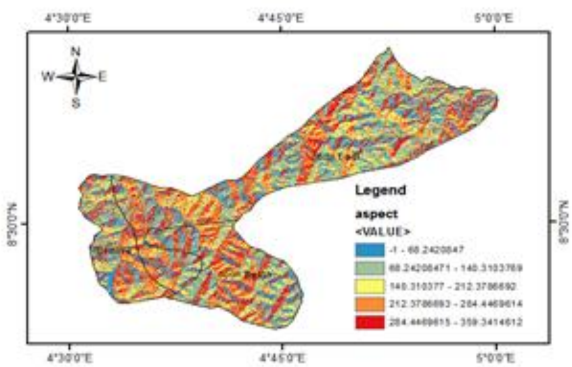

Figure 4: Aspect Map of the Study Area

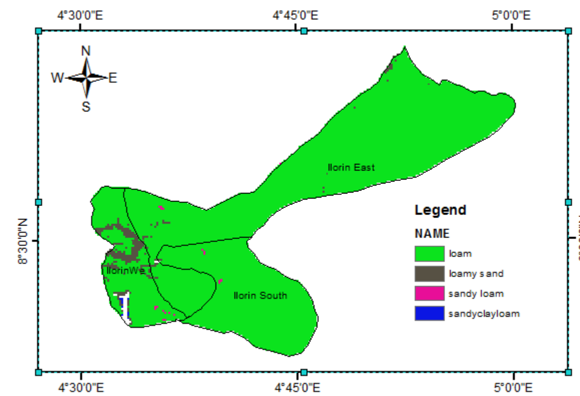

Figure 5: Soil Texture of the Study Area

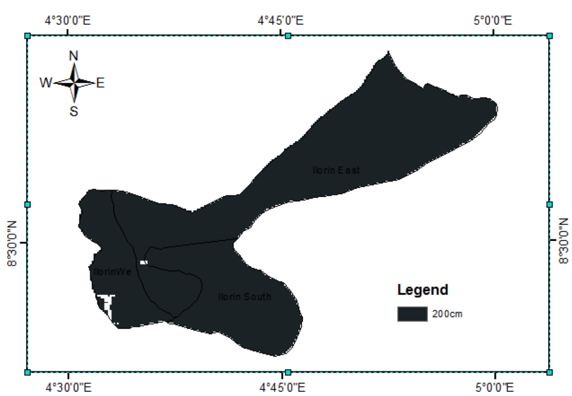

Figure 6: Soil Depth of the Study Area

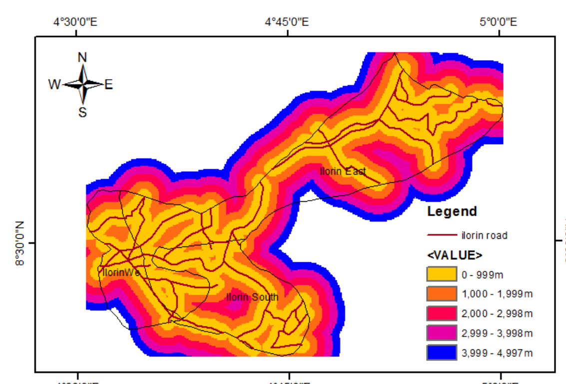

Figure 7: Buffer for Road Network

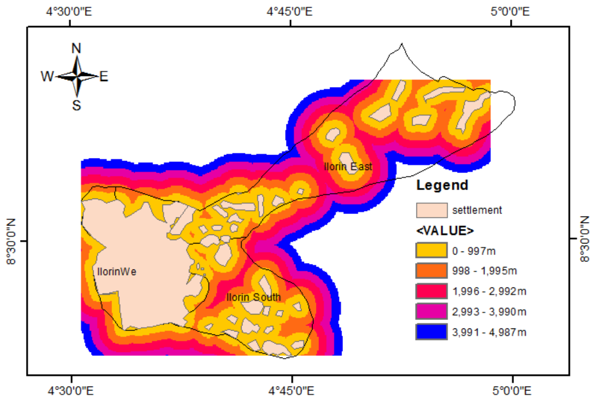

Figure 8: Buffer for Settlement of the Study Area

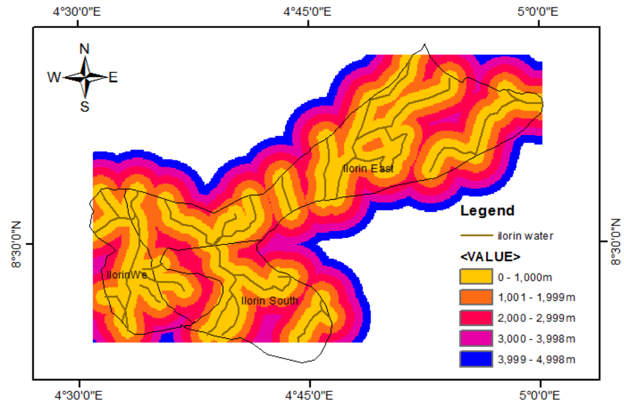

Figure 9: Buffer for River in the Study Area

D. Data analysis and suitability mapping

The data were processed and analysed in a GIS environment. Multi-criteria evaluation was performed by employing AHP for criteria weighting and suitability mapping. Also, to prevent bias through criteria weighting the Consistency Ratio was used. As a rule of thumb, a CR value of 10% (0.1) or less was considered. The final suitability classes were analysed using a Weighted Sum Overlay in the Arc GIS 10.7 environment by combining all raster layers to produce the final suitability map

III. Results and Discussion

The findings of this study are presented in maps and tables, for easy visualization of the results of the analysis that was conducted.

A. Land use classification

In this section, the results of the land use classification within the study area are presented in Table 2, showcasing the area covered by each land use category in square meters, as a percentage of the total area, and in hectares, which provides valuable insights into the composition of land cover.

The study identified approximately 6,657,490.582 square meters of water bodies within the region, constituting 0.96% of the total area. This category predominantly includes natural water features such as rivers, lakes, and reservoirs. The presence of water bodies is a significant aspect to consider in landfill site selection, as it affects the hydrological conditions. The analysis revealed that built-up areas covered a substantial portion of the study area, encompassing approximately 197,740,679.2 square meters, which accounts for 28.39% of the total area. These areas are characterized by the urban infrastructural development, including residential, commercial industrial and recreational properties. The prevalence of built-up areas is crucial in understanding the urbanization of the region and the demand for sustainable waste disposal solutions. Forested areas within the study region were determined to be approximately 141,479,537.3 square meters, constituting 20.32% of the total area. The presence of forests in the vicinity is ecologically significant, as they contribute to biodiversity, carbon sequestration, and environmental conservation efforts. Landfill site selection should take into account the preservation of these vital natural habitats.

Open grazing areas covered about 228,790,697.7 square meters, represents 32.85% of the total area, were identified in the land use classification. These areas play a role in maintaining ecological balance and may be suitable for specific types of land use, such as parks or recreational spaces.

The classification also uncovered approximately 121,730,809 square meters of barren land, accounting for 17.48% of the total area. Barren land areas are characterized by limited vegetation and sparse land cover. Understanding the distribution of barren land can be crucial in assessing its potential for landfill site suitability, especially factors like soil quality and groundwater.

Table 2: Land Use Classification

Land use	**Area (m^2)**	**Area in %**	**Area in hectares**
Water Bodies	6657490.582	1	665.7490582
Built-up Areas	197740679.2	28	19774.06792
Forest	141479537.3	20	14147.95373
Grass	228790697.7	33	22879.06977
Barren Land	121730809	18	12173.0809

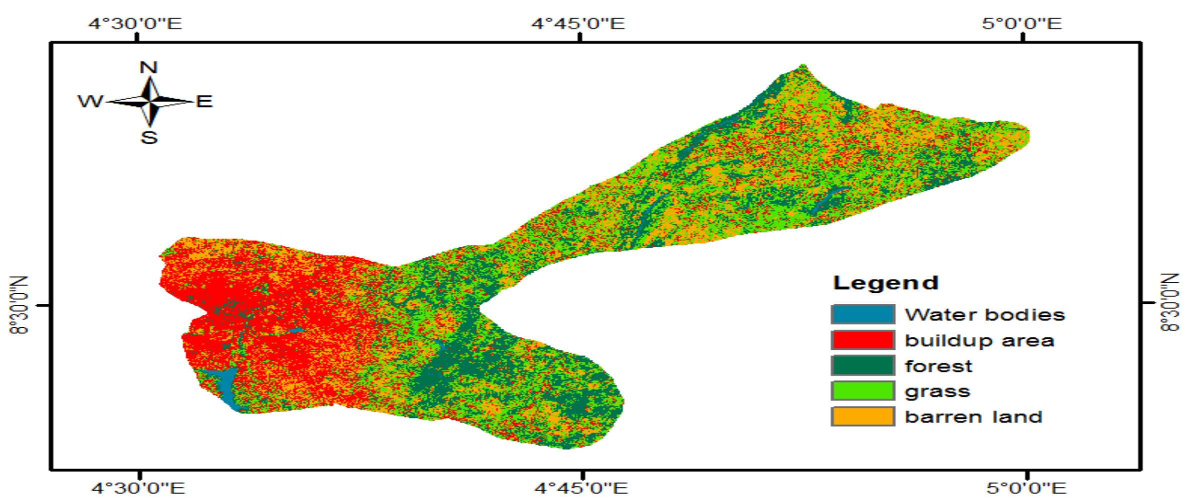

Figure 10: Land Use Classification in Ilorin Metropolis

B. Suitability criteria for landfill

The weighted factor was estimated by a pairwise comparison matrix based on land characteristics. After structuring the problem as a hierarchy using the Eigenvector. The criteria weight for parameters was performed together with the other factors like the slope and land uses. Geo-processing models were used to execute the sequence of commands to generate physical suitability maps which were developed in the AHP model for all the parameters or factors to generate the final suitability map. The analysis of suitability classes for landfill site selection in the study area reveals important considerations for making informed decisions about waste disposal. These suitability classes are categorized based on several criteria, including elevation, slope, aspect, soil texture, soil depth, distance to roads, and distance to water bodies and settlements.

Elevation classes provide insights into the suitability of different altitude ranges for landfill sites. Very low suitable areas with elevations between 374-458 meters cover 18.06% of the total area (12,574.37 hectares). Low suitable were within (337-373 meters) are 24.76% of the region (17,242.84 hectares). Moderately suitable which is within (301-336 meters) represent 26.40% (18,386.53 hectares). High-suitable areas (254-300 meters) account for 20.55% (14,313.29 hectares), while very high-suitable areas (169-253 meters) cover 10.23% (7,121.77 hectares).

In terms of slope suitability, areas with slopes under 0.01% are very low suitable, covering a minimal 0.01% of the area (4.64 hectares). Low suitable areas (0.01-0.16%) represent 0.16% (109.41 hectares). Moderately suitable areas (0.16-0.69%) occupy 0.69% (483.54 hectares). High suitable areas (4.22-15.20%) cover 4.22% (2,939.40 hectares), and very high suitable areas (0-15%) are the most extensive, representing 94.92% (66,101.81 hectares).

Aspects determine the direction a slope faces and this affect landfill suitability. Very low suitable aspects (N, -1-68 degrees) cover 20.04% of the total area (13,956.38 hectares). Low suitable aspects (S, 140-212 degrees) represent 18.10% (12,607.59 hectares). Moderately suitable aspects (W, SW, 212-284 degrees) occupy 18.99% (13,224.77 hectares). High suitable aspects (NW, 284-359 degrees) account for 19.59% (13,643.29 hectares), and very high suitable aspects (NE, E, SE, 68-140 degrees) cover 23.27% (16,206.76 hectares).

Soil texture suitability classes reveal that loam is of low suitability, covering 2.62% of the area (1,815.24 hectares). Loamy sand is moderately suitable (0.09% or 61.74 hectares). Sandy loam is highly suitable (97.11% or 67,318.36 hectares), and sandy clay loam is moderately suitable, occupying 0.19% (129.66 hectares). Areas with a soil depth of 200cm are very highly suitable for landfill construction, covering 100% of the region.

Proximity to roads in the range of 4,000 to 4,997 meters is classified as very low covering 11.28% of the area (13,491.38 hectares). Distance to roads from 3,000 to 3,999 meters is low suitable (13.67% or 16,355.99 hectares). Areas with distances between 2,000 and 2,999 meters to roads are moderately suitable, occupying 16.05% (19,198.12 hectares). Distance to roads from 1,000 to 1,999 meters is highly suitable (21.36% or 25,554.20 hectares), while proximity to roads within 1,000 meters is very highly suitable, covering 37.65% of the area (45,052.02 hectares).

Areas within 1,000 meters of water bodies are classified as very low suitable, covering 33.64%

Table 3: Suitability Classes for the landfill in the Study Area

		Area in %	Area in Hectares
	Elevation		
Very Low Suitable	374 – 458	18.06	12574.37
Low Suitable	337 – 373	24.76	17242.84
Moderate Suitable	301 – 336	26.40	18386.53
High Suitable	254 – 300	20.55	14313.29
Very High Suitable	169 -253	10.23	7121.77
		100.00	
	Slope	**Area in %**	**Area in Hectares**
Very Low Suitable	30 72%	0.01	4.64
Low Suitable	25 -30%	0.16	109.41
Moderate Suitable	20-25%	0.69	483.54
High Suitable	15-20%	4.22	2939.40
Very High Suitable	0-15%	94.92	66101.81
		100.00	
	Aspect	**Area in %**	**Area in Hectares**
Very Low Suitable	N(-1-68)	20.04	13956.38
Low Suitable	s(140-212)	18.10	12607.59
Moderate Suitable	W,SW(212-284)	18.99	13224.77
High Suitable	NW (284-359)	19.59	13643.29
Very High Suitable	NE,E,SE (68-140)	23.27	16206.76
		100.00	
	Soil Texture	**Area in %**	**Area in Hectares**
Very Low Suitable	CLAY		
Low Suitable	LOAM	2.62	1,815.24
Moderate Suitable	LOAMSAND	0.09	61.74
High Suitable	SANDYLOAM	97.11	67,318.36
Very High Suitable	SANDYCLAYLOAM	0.19	129.66
		100.00	69,325.01
	Soil Depth	**Area in %**	**Area in Hectares**
Very High Suitable	200cm	100	69324.57332
		100.00	
	Distance to road	**Area in %**	**Area in Hectares**
Very Low Suitable	4000-4997	11.28	13491.38
Low Suitable	3000-3999	13.67	16355.99
Moderate Suitable	2000-2999	16.05	19198.12
High Suitable	1000-1999	21.36	25554.20
Very High Suitable	0-999	37.65	45052.02
		100.00	
	Distance to water	**Area in %**	**Area in Hectares**
Very Low Suitable	0-1000	33.64	39417.11
Low Suitable	1001-1999	26.02	30485.61
Moderate Suitable	2000-2999	19.57	22928.35
High Suitable	3000-3998	12.15	14233.51
Very High Suitable	3999-4998	8.63	10114.80
		100.00	
	Distance to settlement	**Area in %**	**Area in Hectares**
Very Low Suitable	0-997	46.46	48786.83
Low Suitable	998-1995	18.54	19464.76
Moderate Suitable	1996-2992	14.13	14833.27
High Suitable	2993-3990	11.28	11844.66
Very High Suitable	3991-4987	9.59	10074.96
		100.00	

of the region (39,417.11 hectares). Distance to water bodies from 1,001 to 1,999 meters is considered low suitable (26.02% or 30,485.61 hectares). Areas with distances between 2,000 and 2,999 meters from water bodies are moderately suitable, occupying 19.57% of the total area (22,928.35 hectares). Distance to water bodies from 3,000 to 3,998 meters is classified as highly suitable (12.15% or 14,233.51 hectares), while proximity to water bodies within 1,000 meters is very highly suitable, representing 8.63% of the area (10,114.80 hectares).

Proximity to settlements within 997 meters is very low suitable, covering 46.46% of the region (48,786.83 hectares). Distance to settlements from 998 to 1,995 meters is low suitable (18.54% or 19,464.76 hectares). Areas with distances between 1,996 and 2,992 meters from settlements are moderately suitable, occupying 14.13% of the total area (14,833.27 hectares). Distance to settlements from 2,993 to 3,990 meters is classified as highly suitable (11.28% or 11,844.66 hectares), and proximity to settlements within 3,991 to 4,987 meters is very high suitable, covering 9.59% of the area (10,074.96 hectares). These suitability classes provide essential information for landfill site selection and highlight its need.

C. Reclassification of Criteria

The criteria underwent a reclassification process following the input of data into GIS. In alignment with established practices, expert knowledge, and existing literature, the suitability of these criteria was determined through linear standardization. This standardization process assigned scores on a scale from 1 to 5, with 5 indicating the highest suitability and 1 denoting the lowest suitability for a landfill site. The reclassification and evaluation of these criteria were executed utilizing the Reclassify tool within the ArcGIS 10.7 software package.

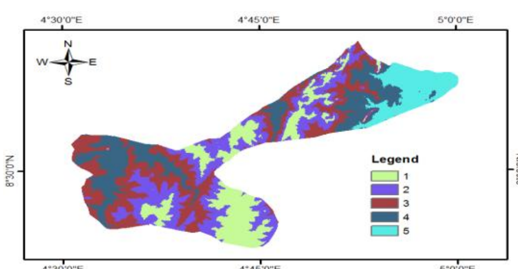

Figure 11: Elevation

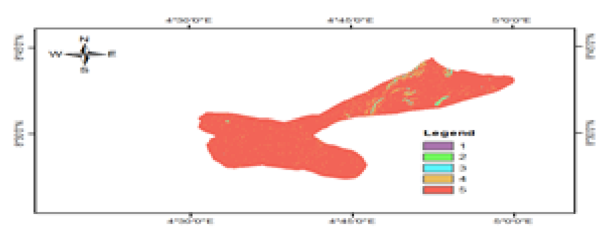

Figure 12: Slope

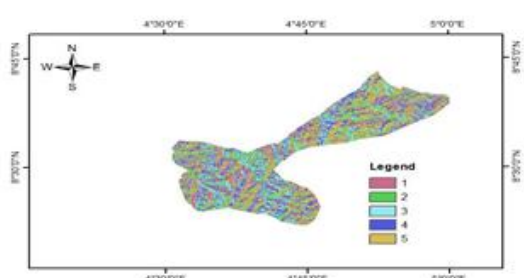

Figure 13: Aspect

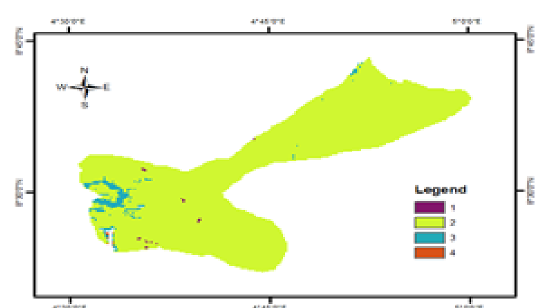

Figure 14: Soil Texture

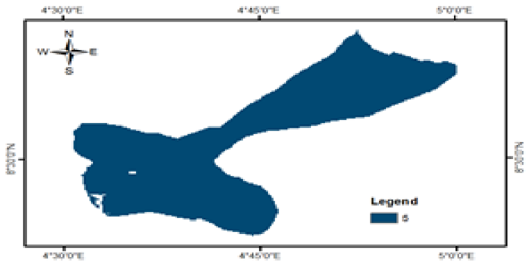

Figure 15: Soil Depth

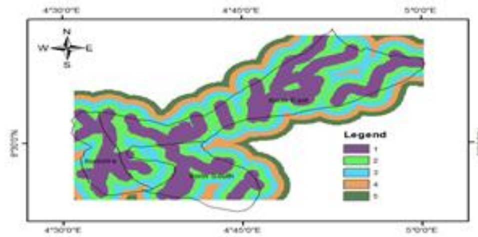

Figure 16: Distance to Roads

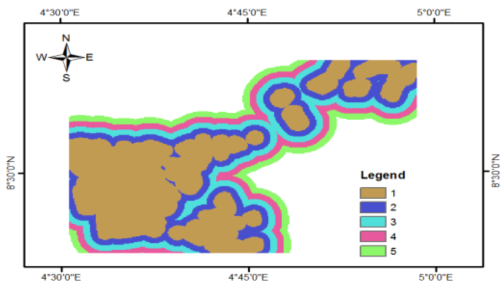

Figure 17: Distance to Settlements

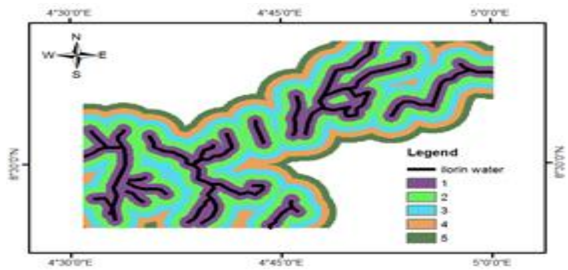

Figure 18: Distance to River

Table 4: Analytical Hierarchical Process (AHP) Analysis

	Elevation	Slope	Aspect	Soil depth	Soil Texture	Distance to settlement	Distance to road	Distance to river
Elevation	1	1	1	1	2	5	5	5
Slope	1	1	1	1	3	2	2	2
Aspect	1	1	1	2	5	1	1	3
Soil depth	1	1	0.5	1	5	2	2	2
Soil Texture	0.5	0.333333	0.2	0.2	1	1	1	2
Dist. To sett.	0.2	0.5	1	0.5	1	1	1	1
Dist. To road	0.2	0.5	1	0.5	1	1	1	1
Dist. To river	0.2	0.5	0.333333	0.5	0.5	1	1	1
Weight	0.22305	0.15641	0.179568	0.16139	0.066319	0.07701	0.07701	0.059244
	8.604967	0.061682						

Table 5: Criteria Ranks

Criteria	Rank	(+)	(-)
Elevation	22.3% (1)	9.6%	9.6%
Slope	15.6% (4)	3.0%	3.0%
Aspect	18.0% (2)	9.0%	9.0%
Soil depth	16.1% (3)	6.9%	6.9%
Soil Texture	6.6% (7)	3.0%	3.0%
Distance to settlement	7.7% (5)	3.8%	3.8%
Distance to road	7.7% (5)	3.8%	3.8%
Distance to river	5.9% (8)	1.6%	1.6%

CR = 6.2%

AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9-Extreme importance (2, 4, 6, 8 values in-between).

Resulting Priorities

Decision Matrix

Number of comparisons = 28

Consistency Ratio CR = 6.2%

Principal eigen value = 8.605

Eigenvector solution: 6 iterations, delta =2.0E-8

D. Combined Layers for Landfill Suitability

The "Final Landfill Suitability Index" table is a crucial outcome of the comprehensive landfill suitability analysis conducted in the study. This index is the culmination of a rigorous decision-making process that involves a detailed examination of eight distinct criterion, including elevation, slope, aspect, soil texture, soil depth, distance to roads, and proximity to water bodies and settlements. These criterions were individually weighted through pairwise comparisons, and the final suitability index was generated based on the Weighted Linear Combination (WLC) integrated into ArcGIS 10.7.

The results showcase a diverse distribution of suitability classes, each with its own implications for landfill site selection. The largest proportion of the area, 29.73%, falls under the category of "Restricted Area," encompassing 18,887.18 hectares. These areas are considered unsuitable for landfill construction due to factors such as the presence of water bodies or other unfavourable characteristics.

The "Low Suitable" category, which covers 18.36% of the region or 11,663.25 hectares, represents areas with some limitations but the potential for landfill development with careful planning and mitigation measures.

A significant portion of the region, 36.04%, is classified as "Moderate Suitable," indicating that 22,900.47 hectares offer moderately favorable conditions for landfill construction, making them attractive options for consideration.

The "High Suitable" category represents 15.85% of the area, approximately 10,070.28 hectares, suggesting areas with relatively favourable conditions for landfill sites.

In contrast, the "Very High Suitable" category, while the smallest in terms of area coverage, is a promising indicator, covering only 0.02% of the region, which equates to approximately 12.35

hectares. These areas are nearly perfect in terms of suitability for landfill development.

This classification into five distinct suitability classes provides a clear roadmap for decision-makers and urban planners, allowing them to prioritize areas for landfill construction while considering a range of environmental and land use constraints. The diversity in suitability classes enables a more strategic and informed approach to waste management, ensuring that landfill development is conducted in a manner that respects and optimizes the use of land resources.

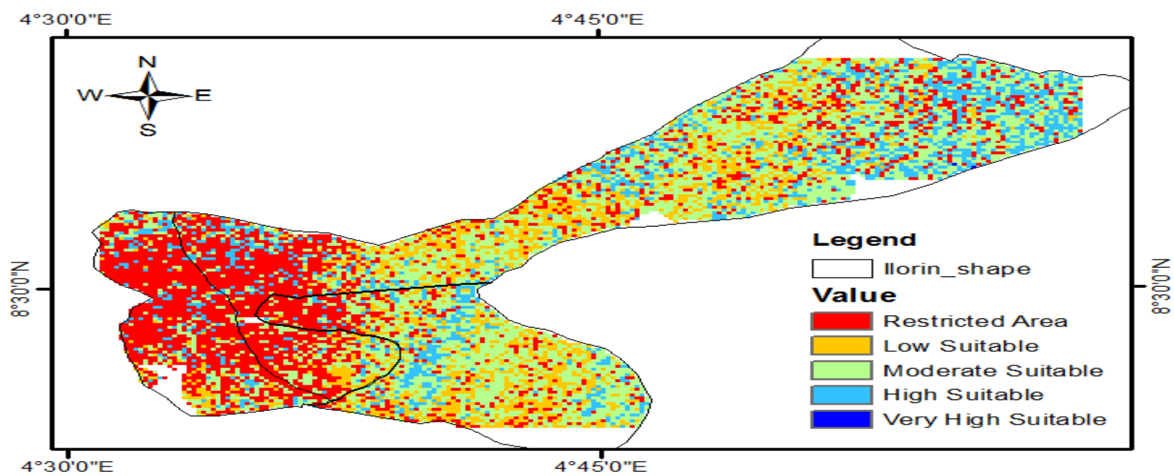

Figure 19: Suitability Potentials for Landfill Areas

Table 6: Final Landfill Suitability Index

	Area in %	Area in Hectares
Restricted Area	29.73	18887.18
Low Suitable	18.36	11663.25
Moderate Suitable	36.04	22900.47
High Suitable	15.85	10070.28
Very High Suitable	0.02	12.35
	100.00	

IV. Conclusion

In conclusion, the extensive analysis of landfill site selection in Ilorin Metropolis, Kwara State, reveals critical insights into waste management strategies, particularly highlighted in the "Final Landfill Suitability Index" (Table 6). Notably, approximately 29.73% of the region is designated as a "Restricted Area," representing 18,887.18 hectares unsuitable for landfill construction due to factors like the presence of water bodies. Conversely, the study identifies promising areas categorized as "High Suitable," covering 15.85% of the region, equivalent to 10,070.28 hectares, and "Very High Suitable," representing a minute yet nearly perfect 0.02% or approximately 12.35 hectares. These findings offer a nuanced perspective for decision-makers, emphasizing the need for strategic planning to optimize waste disposal, balancing environmental considerations and land use constraints. Thus, by incorporating the following recommendations, local authorities can improve waste management practices, reduce environmental risks, and enhance the overall quality of life in Ilorin Metropolis, Kwara State:

Local authorities and urban planners should consider the findings of this study when strategically sitting new landfills. Focus should be placed on areas categorized as "Moderate Suitable," "High Suitable," and "Very High Suitable" to minimize environmental impacts and maximize resource utilization. Prior to the establishment of new landfill sites, it is crucial to conduct detailed environmental impact assessments in accordance with regulatory guidelines. This should include studies on potential ecological, hydrological, and social impacts in the selected areas. Engaging with local communities and stakeholders is essential to address concerns and gather input regarding landfill construction. This engagement should be part of the decision-making process to ensure that the selected sites are acceptable to the affected communities. In addition to landfill site selection, the study underscores the importance of developing and implementing sustainable waste management strategies, including recycling and waste reduction, to reduce the overall reliance on landfilling. Once landfills are operational, regular monitoring and maintenance are essential to mitigate adverse environmental effects. Continuous evaluation and adjustment of landfill operations should be carried out to ensure long-term sustainability. Future studies could explore dynamic factors, including climate change impacts, to enhance the precision of suitability assessments.

References

[1] Ojo, J. S., Olorunfemi, M. O., Bayode, S., Akintorinwa, O. J., Omosuyi, G. O., & Akinluyi, F. O. Constraint Map for Landfill Site Selection in Akure Metropolis, Southwestern Nigeria. Ife Journal of Science, Vol.16, No. 2, 2014, pp. 405-416.

[2] Adewara, M. B., & Odeyemi, K. A. Searching for a Suitable Landfill Site. Ilaro Journal of Environmental Research and Development, Vol. 3, No. 1, 2019, pp. 183-195.

[3] Olayiwola, A. M., & Suleiman, U. A. (2022). Site Suitability Analysis for Landfill in an Industrial Area in Nigeria. Journal of Environmental Geography, Vol. 1, Nos 1-4, 2022, 1-10.

[4] The World Bank. "Trends in Solid Waste Management". Retrieved September 30, 2023, from http://datatopics.worldbank.org/what-a-waste/trends_in_solid_waste_management.ht

[5] Islam, A., Ali, S. M., Afzaal, M., and al., e. Landfill Sites Selection Through Analytical Hierarchy Process for Twin Cities of Islamabad and Rawalpindi, Pakistan. Environmental Earth Sciences, Vol 77, No. 2, 2018.

[6] Ali, I., Islam, A., Ali, S. M., and Adnan, S. Identification and Selection of Suitable Landfill Sites Using GIS-based Multi-Criteria Decision Analysis in the Peshawar District, Pakistan. Waste Management & Research, Vol. 41, No. 3, 2023, 608–619.

[7] Benezzine, G., Zouhri, A., & Koulali, Y. Use of GIS for Digital Mapping and Spatial Analysis of Landfills: Case of the Settat Province in Morocco. Ecological Engineering & Environmental Technology, Vol. 22, No. 3, 2021, pp. 1-10.

[8] Zadawa, A. N., Omran, A., & Robinson, G. M. Innovative Sustainable Solid Waste Management in Nigeria. In O. O. Schwarz-Herion, Strategies Towards the New Sustainability Paradigm (eds); Cham: Springer. 2015, pp. 157-169.

[9] Osei, E., Klutse, N. A., and Afrifa, C. Siting of an Engineered Sanitary Landfill in the Greater Accra Region of Ghana. International Journal of Science and Technology, Vol. 5, No. 2, 2016, 51-59.

[10] Jibril, B. A., Adewuyi, T., Muhammad, A. B., & Abdullahi, S. S. Identification of Suitable Landfill Sites for Kumo Urban Area Gombe State, Nigeria. FUTY Journal of the Environment, Vol. 11, No. 1, 2017, 1-16.

[11] Ezeudu, O. B. Urban Sanitation in Nigeria: The Past, Current and Future Status of Access, Policies and Institutions. Reviews on environmental health, Vol. 35, No. 2, 2020, 123-137. doi:10.1515/reveh-2019-0025

[12] Choududhury, E. S., & Das, E. S. GIS and Remote Sensing for Landfill Site Selection-A Case Study on Dharmanagar Nagar. IOSR Journal of Environmental Science, Toxicology and Food Technology., Vol. 1, No. 2, 2012, 36-43.

[13] Christian, H., & Macwan, J. E. Landfill Site Selection Through GIS Approach for Fast Growing Urban Area. International Journal of Civil Engineering and Technology (IJCIET), Vol. 8, No. 11, 2017, 10-23.

[14] Aziz, R. S., and Khodakarami, L. Application of GIS Models in Site Selection of Waste Disposal in an Urban Area. First International Symposium on Urban Development: Koya as a Case Study. 2013, pp. 27-35. Koya: WIT Press. doi:10.2495/ISUD130041

[15] Rahmat, Z. G., Niri, M. V., Alavi, N., & al., e. Landfill Site Selection Using GIS and AHP: A case study: Behbahan, Iran. KSCE Journal of Civil Engineering. Vol. 21, 2017, pp. 111–118.

[16] De Feo, G., & De Gisi, S. Using MCDA and GIS for Hazardouswaste Landfill Siting Considering Land Scarcity for Waste Disposal. Waste Management, Vol. 34, 2014, 2225–2238.

[17] Alkaradaghi, K., Ali, S. S., Al-Ansari, N., and al., e. Landfill Site Selection using MCDM Methods and GIS in the Sulaimaniyah Governorate, Iraq. Sustainability, Vol. 11, No. 17, 2019, 4530.

[18] Putri, Z., & Noram, I. R. Overview of Analytical Hierarchy Process Decision Making Method for Construction Risk Management. Pahang, Malaysia: Kuantan. 2019, pp. 1-110.

[19] Kang, Z., Wang, S., Xu, L., & al., e. Suitability assessment of urban land use in Dalian, China using PNN and GIS. Natural Hazards, Vol. 106, 2021, 913–936.