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TREND AND SPATIAL VARIATIONS OF ANNUAL TEMPERATURE RANGE (ATR) IN NIGERIA

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Abstract

Significant temperature differences occur throughout different locations and seasons in Nigeria, as with many tropical nations. The Annual Temperature Range (ATR) has raised concerns because of its potential effects on socioeconomic activities, agriculture, and health. This study examines the trends and spatial variations of ATR across Nigeria. The maximum and minimum temperature data were collected from the NASA Prediction of Worldwide Energy Resources (POWER), while the monthly mean minimum and maximum temperature differences were calculated using an Excel Sheet to obtain the ATR. Descriptive, inferential statistics and spatial analysis were employed in testing the data. The results of the study show that Northern states like Kano (33.9°C), Jigawa (33.7°C), and Borno (33.2°C) have higher ATR values and southern coastal states like Lagos (12°C) and Rivers (18°C) have lower values due to maritime influences. The linear regression and the Mann-Kendall test showed that ATR increased statistically significantly in 11 states, mostly in the northern and central regions of Nigeria, which suggests that the climate is warming in these places. The study emphasises the necessity for region-specific climate adaptation methods to lessen the effects of significant temperature swings by highlighting the impact of urbanisation and meteorological circumstances on ATR variations.

Introduction

The increase in the mean global temperature indicates that greater numbers of regions are experiencing warmer temperatures than cooling, indicating that warming has not been consistent around the planet (Lindsey and Dahlman, 2024). There is enough evidence to support the idea that the climate has changed recently due to the variability of climatic variables and the resulting impacts on Earth. Climate change is currently having an impact on the entire world, and it is particularly noticeable on the African continent, where it is reflected in rising temperatures (Oguntunde et al., 2018; Animashaun et al., 2023).

According to the National Oceanic and Atmospheric Administration Annual Climate Report [NOAA] (2023), there has been a mean rise in surface and water temperatures of 0.11° every ten years since 1850. Since 1982, the pace of overheating has accelerated by over three times, amounting to 0.20°C per decade. The Intergovernmental Panel on Climate Change (2023) demonstrates that human activity has unquestionably contributed to the rise in temperatures globally, with the surface temperature of the world rising by 1.1°C between 2011 and 2020, primarily due to greenhouse gas emissions into the Earth's atmosphere. The Intergovernmental Panel on Climate Change [IPCC] (2021) found that the Earth's surface temperature has risen by 0.8-1.3°C from 1850-1900 to 2010-2019 due to human activities, with greenhouse gases responsible for 1.0-2.0°C of this warming, while other human activities (like aerosols) have cooled the planet by 0.0-0.8°C. Furthermore, they stated that natural factors (like the sun and volcanoes) have had a small impact on temperature, between -0.1°C and +0.1°C.

Accordingly, the increase in temperature is a phenomenon that should be taken seriously since it poses a risk to human social and economic structures and ways of life (Kocsis et al., 2020; Wang, 2024). Variability in severe temperatures, including maximum and minimum temperatures, represent one of the key topics for climate research, and global warming and its effects have grown in importance within the field of climate change (Wang, 2024). Global warming is dependent on the variation between the highest and minimum temperatures (Karl et al., 1991).

A new study supported the long-held belief among climate scientists that minimum temperatures are increasing more quickly than maximum temperatures (Vose et al., 2005; Knowles et al., 2006; Meehl et al., 2007). This has the effect of reducing the daily temperature range between the highest and lowest temperatures (Knox, 2018; Gil-Alana, 2018). However, Snow and Snow (2005) show evidence that the current increasing temperature over the last several decades is linked to a general increase in daily minimum temperatures and, to a lesser degree, a minor increase in daily maximum temperatures. The annual temperature range (ATR) may rise in response to a drop in the minimum temperature, though, as the gap between the maximum and minimum temperatures widens. The annual temperature range (ATR) measures world climate change by comparing the mean temperatures of the hottest and the coolest months in one year (Snow and Snow, 2005; Bonacci and Durin, 2023).

Extensive research on maximum and minimum temperatures has been conducted in Nigeria and worldwide. Amadi et al. (2014) analysed the geographic and time-based patterns of long-term changes in monthly average high and low temperatures, revealing a latitudinal dependence on temperature characteristics, with northern Nigeria experiencing greater variability than the south. The Mann-Kendall test results showed that 85% (17 out of 20) of the stations exhibited significant increasing trends in minimum temperature at the 0.01 significance level, while 80% (16 stations) showed significant increases in maximum temperature at the 0.01 and 0.05 significance levels. Among the 20 stations, Port Harcourt and Ikeja had the highest trend coefficients, with minimum temperatures generally displaying higher trend coefficients than maximum temperatures. Similarly, Bhardwaj et al. (2020) conducted a comparative analysis of temperature trends in Uttarakhand, India. Maximum temperatures showed a slight warming trend (Sen's slope = 0.00), and minimum temperatures exhibited a cooling trend (Sen's slope = 0.00294).

A 2020 study by Diagi et al. analysed temperature trends in Ebonyi State, Nigeria. The results show that the maximum temperature is increasing at a rate of 0.0046°C per year, and the minimum temperature is increasing at a rate of 0.002°C per year. The result also shows that the maximum temperature trend is positive, indicating a steady increase over time. Overall, the study suggests that Ebonyi State is experiencing a rising temperature trend, particularly in maximum temperatures.

A study undertaken by Edokpa (2020) on the long-term trends of temperature over southern Nigeria showed a significant increasing trend of annual maximum, minimum and mean temperature was detected at the rate of 1.1°C, 1.4°C and 1.2°C / 61 years, with the biggest increases happening in February and March. Research undertaken by Ogunsola and Yaya (2019) found that the minimum temperatures in southwestern Nigeria have been rising over time. Edokpa et al. (2024) analysed diurnal weather patterns across four climate domains in Nigeria, namely Port Harcourt (tropical maritime), Enugu (bi-modal tropical continental), Jos (montane), Kano (monomodal tropical continental), and Maiduguri (semi-arid), the study found that air temperature gets hotter as you move north in Nigeria, with Port Harcourt being the coolest (23.2-26°C) and Maiduguri being the hottest (26.6-34°).

A study by Yusuf et al. (2017) analysed temperature data from 14 locations in Nigeria from 2007 to 2013. The study found that it is hotter in northern Nigeria and cooler in southern Nigeria. They stated further that the north's high temperatures are due to the Sahara Desert's influence, which allows more sunlight to reach the area. The South's lower temperatures are due to more cloud cover and vegetation. The highest temperature recorded was 43.1°C in Yola (northeast Nigeria). The lowest temperature recorded was 10.2°C in Jos (north-central Nigeria), and temperature variations were smallest in southern Nigeria and largest in the north-central region. Akinsanola and Ogunjobi (2014) analysed temperature data from 25 stations in Nigeria from 1971 to 2000. The results show significant increases in air temperature were found in most areas, and long-term trends showed alternating decreasing and increasing patterns in temperature over the 30 years. A study by Kaonga et al. (2012) on mean monthly minimum temperature and mean monthly maximum temperature in Blantyre, Malawi, showed that there were no significant differences ($p > 0.05$) between yearly mean minimum temperatures, which was also the case for the mean maximum temperature. However, there were noticeable variations in average monthly low and high temperatures, with a probability value of less than 0.05. Research in Southern Africa (Malawi, Mozambique, South Africa, and Zimbabwe) by Mupangwa et al. (2023) found that there are rising minimum (0.01-0.83°C) and maximum (0.01-0.09°C) temperatures at most locations, and decreasing minimum temperatures in some areas of South Africa and Malawi. A separate study by Wang (2024) in China found that there are upward trends in daily maximum and minimum temperatures over decadal periods. However, the result showed no overall increasing trend in maximum or minimum temperatures from 1971 to 2020, but more pronounced increasing trends in monthly minimum temperatures than maximum temperatures. Research by Snow and Snow (2005) in the US found an increased annual temperature range (ATR) from 1951-1980, stable ATR from 1961-1990 and decreased ATR in 7 regions from 1971-2000. A study by Bonacci and Đurin (2023) found that ATR varied significantly over 133 years in four distinct periods.

The Annual Temperature Range (ATR) is a crucial climate indicator with significant impacts on ecosystems, human well-being, and the economy. Despite rising temperatures, there's a lack of research on ATR trends in Nigeria, hindering effective climate change mitigation and adaptation strategies. This study aims to fill this knowledge gap, providing valuable insights for policymakers and stakeholders to support sustainable development in Nigeria. Therefore, this study analyses trends in ATR in Nigeria using historical climate data. Investigate the spatial and seasonal patterns of ATR trends over Nigeria, and classify Nigeria's climate based on ATR trends.

Materials and Methods

The study area consists of the thirty-six states in Nigeria, including the Federal Capital Territory (FCT), as shown in Fig. 1. The data associated with

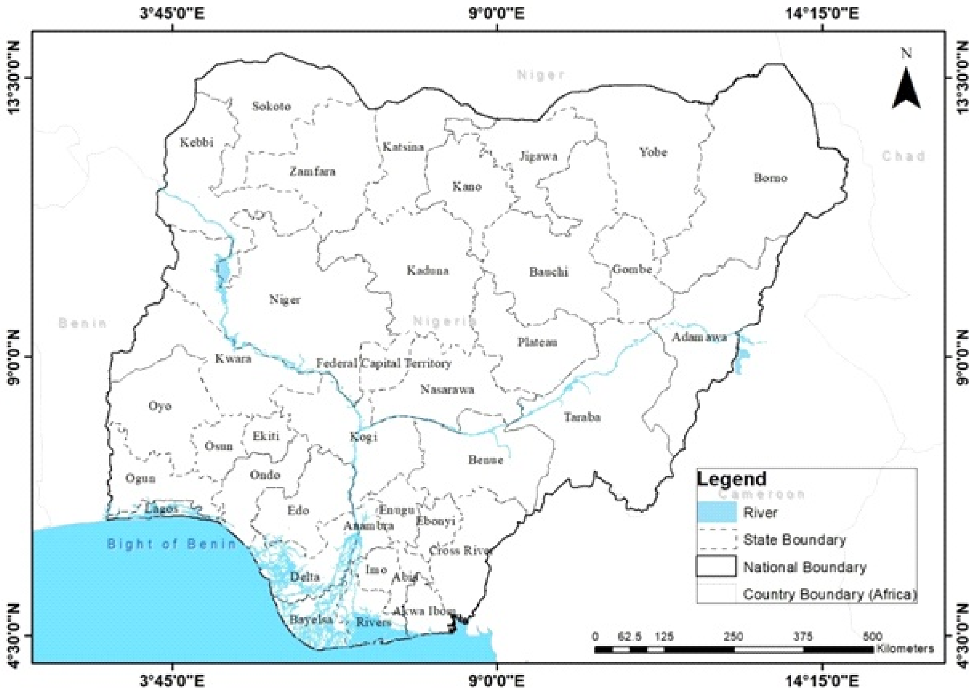

Figure1: Nigeria Map Showing the Thirty-Six States and the Federal Capital Territory (FCT), Abuja

each state and FCT are derived from the NASA Prediction of Worldwide Energy Resources (POWER) *Data Access Viewer (DAV) v2.4.9 website (2025/02/18).* The research study covers 42 years (January 1981 to December 2022). The Annual Temperature Range (ATR) data was calculated by finding the variation between the maximum and minimum average monthly temperatures using an Excel Sheet. The data collected from POWER Data Access Viewer (DAV) were analysed using descriptive statistics (Mean and Standard Deviation), Inferential Statistics (Regression Analysis, Mann-Kendall Test, and Cluster Classification), and Spatial Analysis (Moran's I Spatial Autocorrelation). The descriptive, inferential, and spatial analyses were analysed with the help of R-Software version 4.5.0 for Windows.

Results and Discussion

Descriptive Statistics

Table 1 provides the mean ATR and standard deviation, as well as the largest and smallest ATRs for the study period 1981-2022, along with the year in which they occurred for each of the thirty-six states in Nigeria, including the FCT, listed in Table 1. General trends across states show that higher ATRs are recorded in Borno (33.2°C), Kano (33.9°C), Jigawa (33.7°C), Sokoto (32.4°C), and Katsina

Table 1: Descriptive Statistics for Annual Temperature Range (ATR) from 1981 - 2022

S/N	States	Mean ATR	SD	Largest ATR	Years	Smallest	Years
1	Abia	18.03	1.53	20.95	1992	14.84	2021
2	Adamawa	29.89	1.67	32.43	2015	25.89	1985
3	Akwa-Ibom	15.55	1.57	19.13	1983	12.38	2021
4	Anambra	18.53	1.63	21.90	1992	15.62	2021
5	Bauchi	30.82	1.47	34.21	2015	27.38	2004
6	Bayelsa	16.54	1.86	20.46	1983	12.69	2009
7	Benue	23.26	1.50	26.74	2000	20.78	1982
8	Borno	33.2	1.63	37.66	2015	29.91	1990
9	Cross River	18.11	1.94	22.63	2022	15.04	2017
10	Delta	20.01	1.79	23.69	1992	16.86	2009
11	Ebonyi	18.95	1.61	23.30	2022	15.98	2017
12	Edo	19.28	2.10	25.34	1992	16.22	1990
13	Ekiti	20.77	2.18	26.05	1983	17.32	1996
14	Enugu	19.89	1.63	24.94	1992	17.35	1990
15	FCT	25.00	2.17	29.52	2002	21.22	1996
16	Gombe	30.63	1.62	33.99	2015	27.45	1985
17	Imo	18.13	1.67	21.76	1992	15.05	2009
18	Jigawa	33.67	1.48	37.05	2015	30.82	1997
19	Kaduna	29.98	1.64	33.63	2015	27.09	1985
20	Kano	33.87	1.41	37.25	2015	30.95	1990
21	Katsina	31.99	1.43	36.06	2015	29.14	2004
22	Kebbi	30.38	1.51	33.14	2015	26.87	1990
23	Kogi	24.07	1.98	27.55	1992	20.23	1995
24	Kwara	26.51	1.70	29.20	2006	22.15	1996
25	Lagos	11.95	1.63	15.85	1992	8.54	1996
26	Nasarawa	25.65	1.79	29.49	2000	21.95	1996
27	Niger	27.71	2.07	31.31	2002	23.44	1982
28	Ogun	18.67	2.00	23.74	1992	15.61	2009
29	Ondo	18.49	1.83	22.81	1983	15.77	1996
30	Osun	20.50	2.34	26.38	1983	16.42	2009
31	Oyo	21.62	2.16	26.82	1983	17.77	1996
32	Plateau	25.26	1.43	28.75	1983	21.99	1997
33	Rivers	17.75	1.74	21.58	1992	13.86	2009
34	Sokoto	32.38	1.44	35.05	2015	29.65	1985
35	Taraba	26.92	1.96	30.85	1992	22.10	1996
36	Yobe	32.89	1.60	36.87	2015	30.17	2004
37	Zamfara	30.76	1.49	34.58	2015	27.98	1985

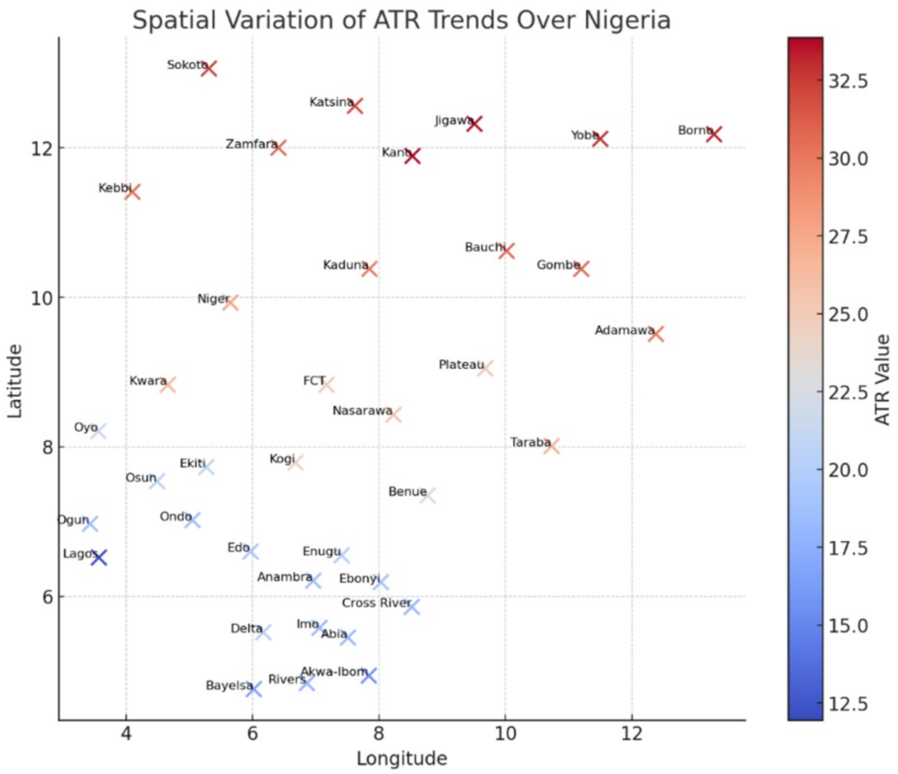

Figure 2: Spatial Variations of ATR Over Nigeria

(32°C), which reveals that these predominantly northern states typically experience hotter and more extreme temperature variations. Lower ATR was recorded in Lagos (12°C), Akwa-Ibom (15.5°C), Bayelsa (17°C), and Rivers (18°C) in southern states near the coast, where oceanic influence moderates temperature fluctuations. States in the Mid belt (Benue, Kogi, Kwara, FCT) have moderate ATR values (20°C-27°C), which confirms a north-south ATR gradient, where the north experiences greater temperature variability than the south. The findings of this study are consonant with the results of Amadi et al. (2014), Akinsanola and Ogunjobi (2014), Yusuf et al. (2017), who found that the north experiences greater temperature variability than the south. Generally, Nigeria had a mean ATR of 24.3°C during the periods of study from 1981- 2022.

ATR variability over the years revealed that many states recorded their highest ATR in 2015 (e.g., Kano, Borno, Kaduna), which suggests that extreme temperature variations peaked in these years. Many states recorded their lowest ATR in 2021, suggesting a possible decrease in ATR over time, potentially due to climate stabilisation or other environmental changes. On regional differences, Northern States (e.g., Sokoto, Kano, Borno, Katsina) with consistently higher ATR values may be attributed to arid and semi-arid conditions (Odjugo and Ikhuoria, 2003; Eyefia, 2018; Yusuf et al., 2017; Adejuwon and Dada, 2021). Southern states (e.g., Lagos, Rivers, Delta, Cross River) with lower ATR values indicate more stable temperatures due to coastal influences.

Based on the geographic patterns of ATR values in Nigeria, the northern regions (e.g., Sokoto, Katsina, Jigawa, and Borno) exhibit higher ATR values; the warmer colours in the plot suggest that these areas experience stronger ATR trends. The southern regions (e.g., Delta, Rivers, Bayelsa) have lower ATR values, the cooler colours indicating a weaker ATR trend. Fig. 2 revealed that the northern regions are typically hotter and drier, which may contribute to higher ATR values, while the southern regions, with more humidity and rainfall, exhibit lower ATR values. The high ATR values recorded in some parts of the country may correlate with deforestation, agricultural expansion, or urban heat effects, particularly in regions with intensive land-use changes. Also, the ATR variations could be linked to elevation differences, with lowland and coastal regions experiencing different trends than the highlands in central and northern Nigeria. The findings of this study are in agreement with the results of Yusuf et al. (2017), Edokpa (2020), Bello and Abubakar (2021), and Edokpa et al. (2024), who found that elevation differences can influence temperature variations, including ATR, in Nigeria. Fig. 2 further revealed that high ATR trends in northern Nigeria may affect crop yields, particularly in rain-fed farming regions, leading to drought risks and food insecurity. At the same time, cities in high ATR zones may need climate adaptation strategies, such as better water management and heat mitigation efforts. The findings of this study imply that the spatial variability in ATR values across Nigeria indicates differing levels of climate stress between regions. The higher ATR values in the northern regions suggest greater exposure to temperature extremes, which can exacerbate drought risk, reduce agricultural productivity, and increase the vulnerability of water resources and public health systems. These areas may require more urgent adaptation strategies, such as improved water management, climate-resilient crops, and reforestation initiatives.

In contrast, the southern regions, with lower ATR values and more stable climatic conditions, may be less exposed to extreme temperature swings but remain at risk due to rising average temperatures and flooding from increased rainfall. The influence of land-use changes, such as deforestation and urban expansion, particularly in areas showing high ATR trends, highlights the role of human activities in intensifying local climate impacts. Furthermore, elevation-related differences underscore the need for topography-sensitive planning, as highland and lowland areas respond differently to climate change. These findings stress the importance of region-specific climate policies, environmental monitoring, and land-use regulation to ensure effective mitigation and adaptation efforts tailored to Nigeria's diverse ecological zones.

Seasonal Variations of ATR Over Nigeria

Analysis of the seasonal variations of ATR trends in Fig. 3 reveals an increasing ATR from April to June, which indicates a rise in ATR as the wet season starts, with a peak in July to September, with the highest ATR values occurring mid-year, coinciding with the peak of the wet season. While there is a gradual decline from October to December, ATR starts decreasing as the dry season approaches. On the other hand, the lowest ATRs are recorded from January to March, which are marked with the driest months, showing the lowest ATR values, confirming the dry season pattern. The findings of this study validate the findings of Oguntoyinbo (1983), Ayoade (2004), and Iloeje (2001), who confirm that January to March is typically the driest months in Nigeria, corresponding to the lowest ATR values.

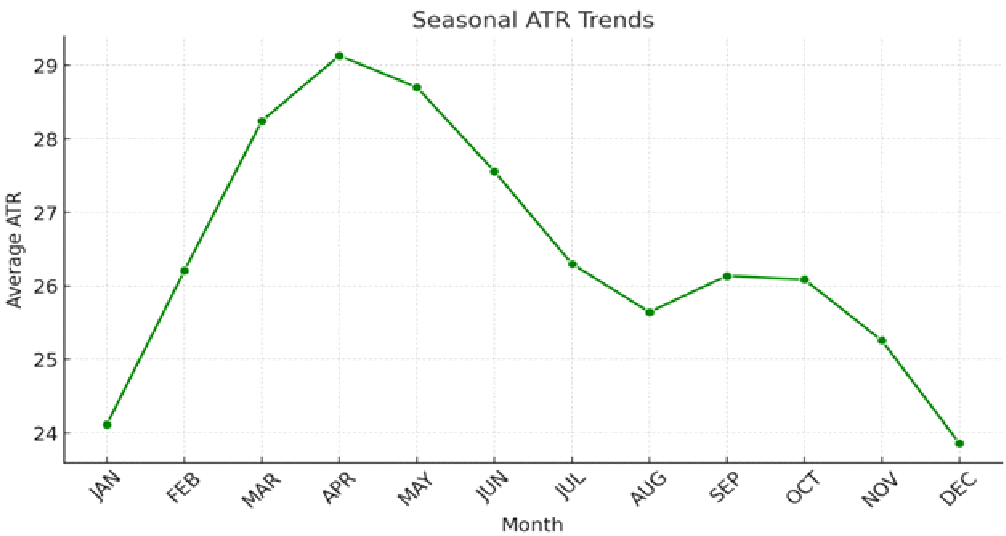

Figure 3: Seasonal Variations of ATR Trends Over Nigeria

This trend suggests a strong seasonal influence on ATR, with wetter months having consistently higher values (See Fig.3). Fig. 3 indicates that the wet Season (April - October) had a mean ATR of 27.1°C, minimum ATR of 12.5°C, and maximum ATR of 45.5°C. At the same time, the dry Season (November - March) had a mean ATR of 25.5°C, minimum ATR of 5.9°C, and maximum ATR of 45.3°C. Thus, the wet season has a slightly higher average ATR (27.1°C - 25.5°C) than the dry season. The dry season has lower minimum ATR values (5.9°C - 12.5°C), suggesting drier conditions at times (Oguntoyinbo, 1983; Ayoade, 2004; Iloeje, 2001). Both seasons reach similar maximum ATR values (~45), implying that extreme values can occur in both.

Inferential Statistics

Trend analysis is a statistical method employed to study data over time to find patterns or changes. It involves analysing a sequence of data points to determine if there is a consistent upward, downward, or stable trend. The trend analysis was conducted using linear regression and the Mann-Kendall test to find changes or patterns in Annual Temperature Range (ATR) data over the years.

Linear Regression

Linear regression is a statistical technique for simulating the association between a dependent variable (y) and several independent variables (x), and it seeks to develop a linear equation that most accurately forecasts the dependent variable's value. The following formula is used for describing the simple linear model:

$$\mathbf{Y = \beta_0 + \beta X + \epsilon}$$

Where: **Y** – Dependent variable; **X** – Independent (explanatory) variable; **a** – Intercept; **b** – Slope; **ϵ** – Residual (error)

$$\mathbf{ART_t = \beta_0 + \beta_1 LAT_t + \varepsilon_t}$$

Equation: ATR = 4.67+2.32 × Latitude

Intercept (4.67): The predicted ATR at latitude 0° (equatorial zone).

Slope (2.32): For every 1° increase in latitude, ATR increases by 2.32 units.

Model Fit:

R^2 = 0.891 → The model explains 89.1% of the variation in ATR based on latitude (See Fig. 4).

P-value (< 0.001) → The relationship is statistically significant.

The model's results in Fig. 4 revealed that Latitude strongly predicts ATR (R^2 = 0.891), which explains 89.1% of the variation in ATR based on latitude. The findings of this study confirm the results of Ayoade (2004), Adaramola (2012), and Yusuf et al. (2017), who found that latitude is a significant factor in

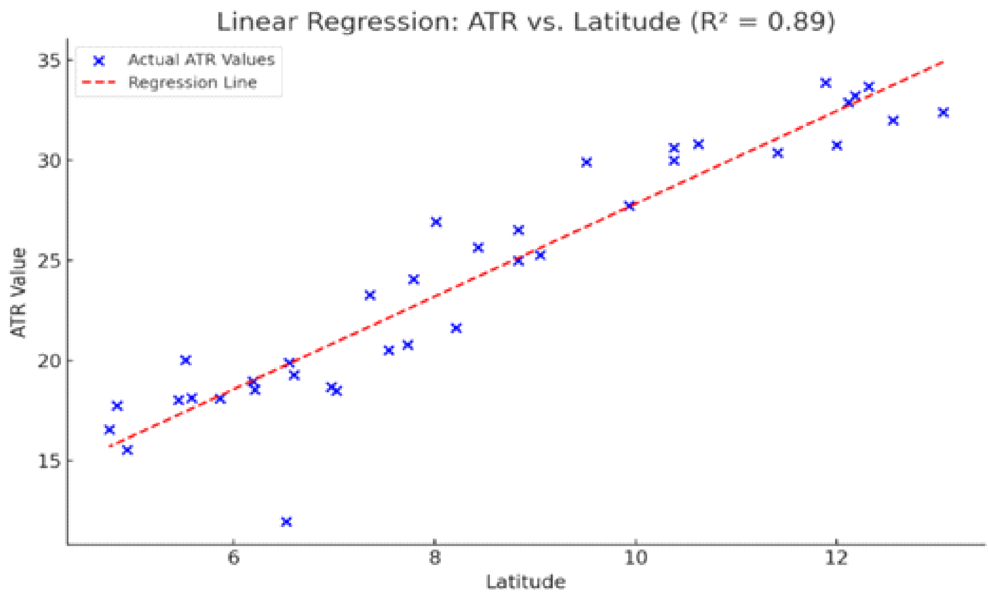

Figure 4: Regression Analysis on ATR and Latitude

Table 2: Summary Result of Mann-Kendall Test for ATR

State	S-Statistic	Tau	p-value	Trend	Significance
Adamawa	227	0.264	0.014	Increasing	Significant
Benue	262	0.304	0.005	Increasing	Significant
Borno	186	0.216	0.044	Increasing	Significant
FCT	269	0.313	0.004	Increasing	Significant
Gombe	242	0.281	0.009	Increasing	Significant
Jigawa	204	0.237	0.027	Increasing	Significant
Kano	265	0.308	0.004	Increasing	Significant
Katsina	228	0.265	0.013	Increasing	Significant
Niger	213	0.247	0.021	Increasing	Significant
Sokoto	214	0.249	0.02	Increasing	Significant
Taraba	213	0.248	0.021	Increasing	Significant
Abia	-38	-0.044	0.68	Decreasing	Not Significant
Akwa Ibom	-91	-0.106	0.324	Decreasing	Not Significant
Ekiti	-87	-0.101	0.346	Decreasing	Not Significant
Imo	-25	-0.029	0.786	Decreasing	Not Significant
Ogun	-68	-0.079	0.461	Decreasing	Not Significant
Ondo	-57	-0.066	0.537	Decreasing	Not Significant
Osun	-158	-0.184	0.087	Decreasing	Not Significant
Oyo	-93	-0.108	0.313	Decreasing	Not Significant
Rivers	-11	-0.013	0.905	Decreasing	Not Significant
Other States	Mixed	Mixed	>0.05	No Trend	Not Significant

explaining temperature variations, including ATR, in Nigeria. The P-value (< 0.001) shows that the relationship is statistically significant. Fig 4. Revealed that the further north a state is, the higher the ATR value, which suggests northern regions experience stronger ATR trends, likely due to arid conditions and land use changes. The ATR variations could be linked to human activities such as agriculture, deforestation, and urban expansion in different regions. The findings of this study correspond with the findings of Oyewole (2015) and Zoellick (2009), who suggest that human activities such as agriculture, deforestation, and urban expansion contribute to climate change and ATR variations in Nigeria. The increase in ATR in Northern Nigeria is characterised by hotter, drier conditions (the Sahel and Sudan Savanna). The reduced ATR variations in Southern Nigeria are a result of the humid tropical climate the region enjoys. The north has more open land, desertification, and less vegetation, leading to higher ATR values. The south has dense forests and moisture, which stabilise temperature variations, reducing ATR (Eyefia, 2018). The deforestation, agriculture, and urbanisation in the north contribute to increased ATR values, while the coastal effects in the south may help regulate ATR values.

Man-Kendall Test

The Mann-Kendall test identifies trends in data over time without requiring normal distribution, making it useful for analysing time series data. The Mann-Kendall test is commonly used in meteorological and environmental investigations to find patterns in variables such as rainfall, temperature, and water quality. The following formula is used to determine the Mann-Kendall test statistic (S):

$$S = \Sigma \text{ sign } (x_j - x_i)$$

Where: $-x_j$ and xi pairs of data points; sign () is the sign function, which returns: 1 if $x_j - x_i > 0$ 1 if $x_j - x_i < 0$; 0 if $x_j - x_i = 0$

The significance of the trend is then ascertained by computing the p-value and Kendall's tau (τ) using the test statistic S.

Table 2 shows that Adamawa, Benue, Borno, FCT, Gombe, Jigawa, Kano, Katsina, Niger, Sokoto, and Taraba had a significant increasing trend as confirmed by the Mann-Kendall test with a p-value < 0.05. These states show a clear upward trend in ATR values over time, which suggests a warming climate in these states. The possible reasons for this upward trend in ATR are climate change, regional weather patterns, or local environmental changes. States with a decreasing trend, though not statistically significant in many cases, are Abia, Akwa Ibom, Ekiti, Imo, Ogun, Ondo, Osun, Oyo, and Rivers. These states show a downward trend in ATR values, meaning ATR values are decreasing, suggesting cooling trends. The findings of this study are consonant with the results of Akinsanola and Ogunjobi (2014), Ragatoa et al. (2018), Akinbile et al. (2020), who found decreasing trends in temperature in some states in Nigeria, including Abia, Akwa Ibom, Ekiti, Imo, Ogun, Ondo, Osun, Oyo, and Rivers, suggesting cooling trends in these regions. However, since the p-values are above 0.05, the trends may not be strong enough to confirm statistical significance. States with no clear trend (p-value > 0.05) are Anambra, Bauchi, Bayelsa, Cross River, Delta, Ebonyi, Edo, Enugu, Kaduna, Kebbi, Kogi, Kwara, Lagos, Nasarawa, Plateau, Yobe, and Zamfara. This suggests that climatic conditions in these states are relatively stable over the observed period. The result of the study revealed that the fluctuations in ATR values are likely due to natural variability rather than a long-term trend. Generally, the result shows warming or increasing ATR values in northern states, for example, Kano, Sokoto, and Katsina. While slightly decreasing ATR values in some southern states, for example, Osun, Ogun, and Akwa Ibom.

Cluster Classification and Statistical Analysis

K-means clustering groups data points into clusters based on similarity, minimising the distance between points and their cluster centres. The Elbow Method was utilised to ascertain the ideal number of clusters, while the K-Means Cluster was utilised to find natural groupings (See Fig. 5).

The formula for K-means clustering is given as:

$$J = \Sigma \Sigma || x_i - \mu_k ||^2$$

Where: x_i is the i-th data point; μ_k is the centroid of the k-th cluster; ||.|| denotes the Euclidean distance

The **Elbow Method** suggests that the optimal number of clusters is likely around **3 or 4,** where the inertia curve starts to level off (See Fig. 5).

Cluster 1: (High ATR Region, mean = 31.71) had Sokoto, Katsina, Jigawa, Borno, Yobe, Zamfara, Adamawa, Kano, Kaduna, Kebbi, Bauchi, and Gombe; these are mostly Northern States with the highest ATR values. Cluster 2: (Moderate ATR Region, mean = 25.11) had Niger, Benue, Plateau, FCT, Kogi, Kwara, Nasarawa, Taraba, and Oyo, these are mostly Central States with moderate ATR values. Cluster 3: (Low ATR Region, mean = 18.20) had Bayelsa, Akwa Ibom, Lagos, Rivers, Abia, Delta, Imo, Cross River, Ebonyi, Anambra, Enugu, Edo, Ogun, Ondo, Osun, and Ekiti; these are mostly Southern States with the lowest ATR values.

The high ATR recorded in Northern Nigeria is characterised by hotter, drier conditions (Sahel and Sudan Savanna). Also, the low ATR enjoyed is due to the humid tropical climate Southern Nigeria experiences, which reduces ATR variations. These

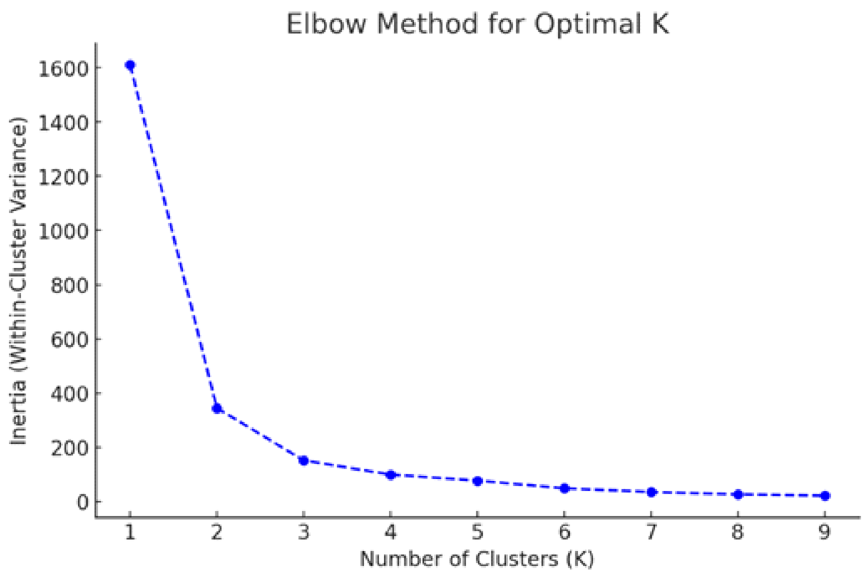

Figure 5: Elbow Method for Optimal K-Mean Clustering

studies describe the climate conditions in Northern and Southern Nigeria and how they influence temperature variations, including ATR. On the other hand, the north has more open land, desertification, and less vegetation, leading to higher ATR values. At the same time, the south has dense forests and moisture, which stabilise temperature variations, reducing ATR. Deforestation, agriculture, and urbanisation taking place in the north contribute to increased ATR values. Industrialisation and coastal effects in the south may help regulate ATR values. The higher ATR in the North means more extreme temperature fluctuations, which could impact agriculture and water resources. Increased heat stress may affect human health and energy demands. The lower ATR in the South suggests more stable temperatures, which is beneficial for coastal ecosystems and rainfall patterns, and less temperature stress on crops and livestock.

ANOVA Test

The results of the ANOVA test in Table 2 revealed that p-value = 1.19e-18 (very small), which indicates a highly significant difference in ATR between clusters. This confirms that ATR variations across regions are not random but follow clear geographic and climatic patterns.

Spatial Analysis

Spatial autocorrelation is when things that are close together are similar. In this study, we used a tool called Moran's I spatial autocorrelation to see if areas near each other have similar temperature patterns. This helps us find groups of areas with very high or very low temperatures and understand how things are related. The Spatial autocorrelation results were generated using the R-Software Version 4.5.0.

Moran's I Result for ATR Spatial Autocorrelation

Moran's, I measure spatial autocorrelation, indicating whether nearby locations have similar (positive autocorrelation) or dissimilar (negative autocorrelation) values. The formula for Moran's I is given as:

Moran's I = $(n / \Sigma\Sigma w_{ij}) * (\Sigma\Sigma w_{ij} (x_i - \bar{x}) (x_j - \bar{x})) / (\Sigma (x_i - \bar{x})^2)$

Where: - n is the number of observations; wij is the spatial weight between observations i and j- x_i and x_j are the values of the variable at locations i and j- $\bar{x}$ is the mean of the variable

Interpretation

Moran's I range from -1 to 1, where:

Positive values (close to 1) indicate clustering of similar values (positive spatial autocorrelation).

Negative values (close to -1) indicate dispersion or clustering of dissimilar values (negative spatial autocorrelation).

Values near 0 suggest random distribution

The result of Moran's I test indicates moderate positive spatial autocorrelation, meaning ATR values tend to cluster geographically rather than being randomly distributed. The researcher performs a permutation test to test the significance of Moran's I to determine if the spatial autocorrelation that has

Table 2: ANOVA Result for ATR by Cluster

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-value	p-value
Between Groups	1542.73	2	771.37	56.21	1.19e-18
Within Groups	4102.65	298	13.77		
Total	5645.38	300			

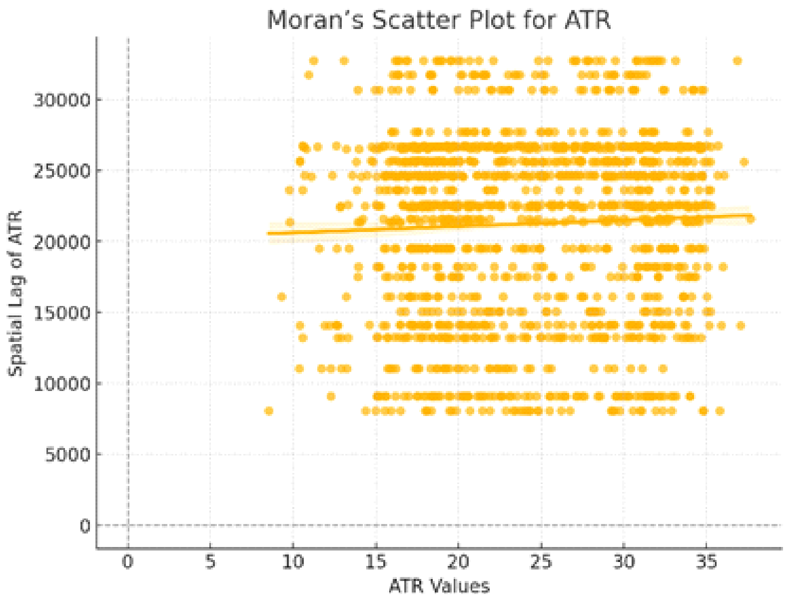

Figure 6: Moran's Scatter Plot Showing the relationship between ATR values and their spatially lagged values.

been detected is considered statistically significant. The findings of the research revealed that Moran's I value = 0.4586, p-value: 0.000, which is statistically significant. The result indicates that the observed spatial autocorrelation is not random, but ATR values exhibit significant clustering rather than being randomly distributed across the states. Moran's scatter plot for ATR revealed that there is a positive trend which confirms positive spatial autocorrelation, meaning states with high ATR values tend to be near others with high ATR values by other high ATR values (See Fig. 6). Areas with high ATR values surrounded by other high ATR values are Kaduna, Niger, Plateau, FCT, Kwara, Nasarawa, Oyo, Taraba, Kogi, Ekiti, Osun, Benue, Ondo, Edo, Enugu, Anambra, Ebonyi, Cross River, Imo, Delta, Abia, Rivers, Bayelsa.

Conclusion

This study used regression analysis, spatial analysis (Moran's I test), trend analysis (Mann-Kendall test), and Clustering analysis (K-Means) to examine time-series trends in annual temperature ranges (ATR) in Nigeria. The study confirms that ATR values increase with latitude, meaning northern Nigeria experiences greater temperature fluctuations than the south. Regression analysis shows a strong correlation ($R^2 = 0.891$, $p < 0.001$) between ATR and latitude, with higher ATR values observed in the north and lower values in the south. Mann-Kendall analysis shows significantly increasing ATR trends in 11 northern and central states. Southern states show decreasing ATR trends. Moran's I analysis (0.4586, p = 0.000) confirms that ATR values cluster geographically. The K-Means clustering analysis grouped Nigeria's ATR values into three distinct clusters, confirming a strong north-south ATR gradient and the presence of regional climatic variations. The Elbow Method confirms three optimal clusters, showing a clear division in ATR trends across Nigeria. This study provides critical insights into Nigeria's spatial and temporal ATR trends, highlighting the need for region-specific climate policies.

Climate Adaptation Strategies for High ATR Regions (Northern Nigeria). Implement strict land-use policies to control overgrazing and deforestation in high ATR regions. Climate Stabilisation in Moderate ATR Regions (Central Nigeria). Coastal and Industrial Development in Low ATR Regions (Southern Nigeria). Invest in solar and wind energy to sustain low ATR trends while reducing fossil fuel dependence. Collaborate with government agencies, Non-Governmental Organisations (NGOs), and international climate organisations to address extreme ATR trends.

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