Spatiotemporal Variability and Trend Analysis of Rainfall and Temperature in Northern Nigeria

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Abstract

The consequential effects of global warming on the environment and economic sectors of every nation, particularly developing ones, have necessitated an urgent and continuous need to address the issue of climate change. This study aims to analyse the spatiotemporal variability and trends of rainfall and temperatures in Northern Nigeria. Data on rainfall and temperature for 19 meteorological stations spanning 40 years (1981-2020) were collected from the Nigeria Meteorological Agency (NiMET) for the study. For the variability assessment, descriptive statistics were employed, while linear regression, Mann-Kendall test, and Sen's Slope estimation were used for the trend analysis. The analysis was done at different spatial and temporal scales. The results showed a significant positive trend in rainfall across all the stations, with increases of about 5.1 mm/year in the Northwest zone and 5.0 mm/year in the Northeast zone. However, the North Central zone exhibits a moderate increase of 2.0 mm/year. Additionally, the results of temperature revealed a strong upward trend, with varying levels of significance for the annual maximum (Z = 3.62), minimum (Z = 4.45), and mean (Z = 4.30) temperatures. These suggest that heat stress may be intensified and water scarcity may be exacerbated in Northern Nigeria. These findings underscore the imperative need for adaptive, resilient infrastructure and farming strategies to mitigate the impacts of climate change. The variability in rainfall and the upward trend in temperatures highlight the importance of customised, proactive measures tailored to each region's specific climate conditions. There is a need to improve water management, promote drought-resistant crops, and establish early warning systems to enhance community resilience against the adverse effects of climate change.

Keywords: Climate change, rainfall, temperature, variability, Northern Nigeria.

1.0 Introduction

The issue of global warming is drastically growing critical, particularly in developing nations like sub-Saharan Africa, which has been a major victim of climate change [1]. In sub-Saharan Africa, Northern Nigeria is a prime example, where diverse climatic conditions intersect with socio-economic vulnerabilities. Northern Nigeria has experienced significant fluctuations in rainfall and temperature patterns, which have significantly impacted water availability, agricultural productivity, and the ecosystem [2]. It has become apparent from the threats associated with climate change that the design of roads, bridges, and irrigation systems must consider changing climate realities to ensure effectiveness [3].

Since both significantly impact living conditions and socio-economic stability, rainfall and temperature are key variables through which the effects of climate change are observed [2]. These factors impact Northern Nigeria's natural ecosystems; therefore, a thorough examination of their trends and variability is necessary. Rainfall patterns determine crop choices and the sustainability of subsistence farming, which supports over 70% of the Nigerian population [4]. Therefore, unpredictable weather can lead to lower crop yields, food insecurity, extreme hydrological events, and rising poverty levels [5]. Droughts have historically reduced agricultural productivity, leading to increased poverty and displacement [6]. The ongoing threat of flooding during peak rainfall periods endangers infrastructure and safety, emphasising the need for early warning systems based on reliable meteorological data.

Northern Nigeria has a well-defined climate characterised by a wet season that begins in April and lasts until October and a dry season that spans the remaining months (November to March). These distinctive dry and wet seasons have become disrupted in recent years, affecting the timing (early and late onset), duration, frequency, and intensity of rainfall events. These pose serious challenges to engineering structure, hence the need to incorporate recent climate data into climate resilience strategies. Re-evaluation based on the change in climate regime and its associated variability provides opportunities to identify trends that could worsen climate challenges in the region. Recent research has employed methods such as the Mann-Kendall test and linear regression to elucidate rainfall variability at both monthly and seasonal levels [7].

A shift in climate regime has also been noted in the temperature data [8]. Like rainfall, temperature is also a crucial factor that significantly influences ecosystems and agricultural production. The upward global temperature

trend from greenhouse gas emissions intensifies climate variability. At higher temperatures, crop evapotranspiration increases, further hampers agricultural productivity [9]. Consequently, analysing temperature variability alongside rainfall is paramount, as their interaction substantially impacts water resources and crop yields. Temperature data across Nigeria consistently reveal rising temperatures [10, 11]. The use of current climatic variables provides a better guide for developing robust engineering design standards that are likely to withstand recent and future climate conditions. It is worth mentioning that such an approach will not only help create an efficient infrastructure but also one that is capable of resisting extreme hydrological events. Assessing current trends in rainfall and temperature is vital for maintaining the integrity and sustainability of Northern Nigeria's water system, infrastructure, and agriculture. Furthermore, since the region relies heavily on agriculture, understanding rainfall patterns and temperature trends can help farmers adjust their practices to changing climate conditions. This knowledge is essential for improving food security, managing resources efficiently, and supporting livelihoods, ultimately building resilience in vulnerable communities affected by climate variability. This research aims to analyse the spatiotemporal variability and trend of rainfall and temperature in Northern Nigeria.

2.0 Materials and Methods
2.1 The Study Area

Northern Nigeria (NN) covers about three-quarters (75%) of the Nigeria's landmass, which totals 925,796 km² [12] (Figure 1). As earlier mentioned, the region has two defined seasons (dry and wet). The annual rainfall distribution of the region ranged between 400 to 1,500 mm depending on latitude and span over Nigeria's marginal, short and tall grass savanna agro-ecological zones [4]. NN is divided into three main zones (North Central, Northwest and Northeast). The North Central (NC) zone, characterised by a tropical savanna and humid climate, supports a diverse range of agriculture, including maize and yams. Moreover, the rainy season starts in April and ends in October, while November to March are the dry season period [13]. Arid conditions characterise the Northwest zone, which primarily cultivates cereals and groundnuts. Its climate is classified as a tropical savanna. The Northeast zone, covering about 279,203 km², features an arid to semi-arid climate with persistent drought [14].

2.2 Data and Analysis

The monthly rainfall and temperature data used in this study were collected from the Nigerian Meteorological Agency (NIMET), Nigeria. The dataset includes rainfall and both minimum and maximum temperatures. The data starts from January 1981 to December 2020 and covers 19 meteorological stations. This study used descriptive statistics to analyse variability, while linear regression and the Mann-Kendall (MK) test were employed to assess trends. The descriptive statistics include the mean, standard deviation, coefficients of skewness (Cs), kurtosis (Ck), and coefficient of variation (CV). The coefficient of skewness (Cs) is considered right-skewed if positive, left-skewed if negative, and a time series is regarded as normally distributed if it has coefficients of skewness and kurtosis equal to 0 and 3, respectively [2]. Conversely, the Mann-Kendall (MK) test and Sen's Slope estimator were used to determine the trend direction and magnitude. The GIS analyses were performed on the ArcGIS 10.5 platform using the Inverse Distance Weighting interpolation method.
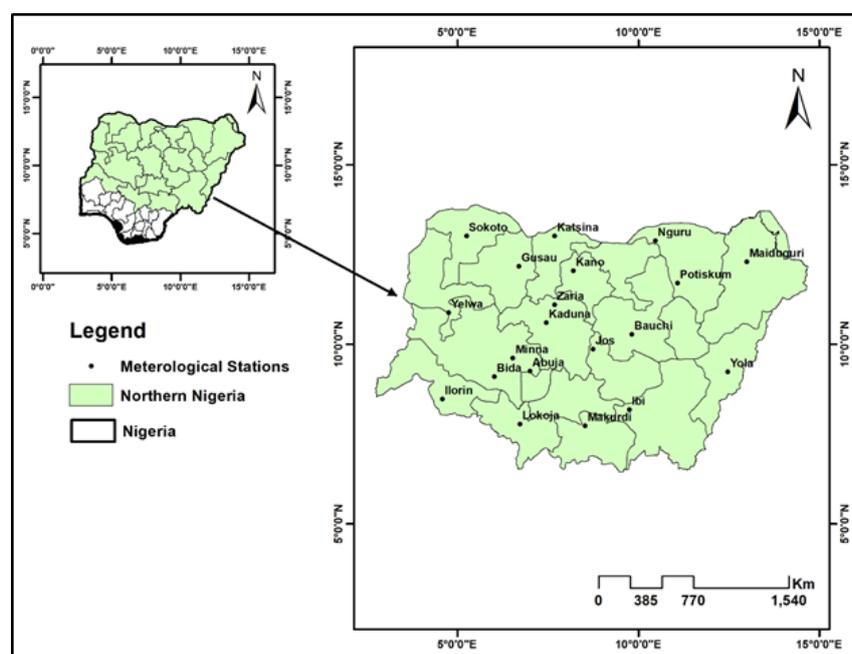

Figure 1: Map of the study area

2.2.1 Variability analysis

The coefficient of variation (CV) was calculated to assess rainfall and temperature variability. The degree of variability is a function of the indicator, implying that the higher the CV value, the greater the variability, and vice versa. The value of CV obtained is used to categorise the degree of variability of rainfall events as less (CV < 20), moderate (20 < CV < 30), and high (CV > 30) [15].

$$CV = (\sigma/\mu) \times 100 \tag{1}$$

Where σ is the standard deviation, and μ is the mean rainfall.

2.2.2 Mann-Kendall trend test

The Mann-Kendall (MK) trend test is effective at detecting the presence, direction (increasing or decreasing), and significance of changes in rainfall and temperature series. The MK test statistic is calculated using the equation below.

$$S = \sum_{i=1}^{n-1} \sum_{j=i=1}^{n} sign(Xj - Xi) \tag{2}$$

where xi and xj are the sequential data values, n is the data set record length, and

$$Sign = \begin{cases} +1 & \theta > 1 \\ 0 & if\ \theta = 0 \\ -1 & \theta < 0 \end{cases} \tag{3}$$

indicates positive differences, no differences, and negative differences, respectively, and S is computed as the sum of the integers. The expected value of S equals zero (E[S] = 0) for series without trend, and the variance is computed as below:

Expected value of S equals zero (E[S] = 0) for series without trend, and the variance is computed as below:

$$\sigma^2(s) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5) \right] \tag{4}$$

where q is the number of tied groups and tp is the number of data values in the pth group. The test statistic Z is then given as:

$$Z = \begin{cases} \frac{s-1}{\sqrt{\sigma 2(s)}} & S > 0 \\ 0 & if\ S = 0 \\ \frac{s+1}{\sqrt{\sigma 2(s)}} & S < 0 \end{cases} \tag{5}$$

The Z statistic is used to test the null hypothesis, H0, that the data are randomly ordered in time, with the alternate hypothesis, H1, indicating an increasing or decreasing monotonic trend.

2.2.3 Sen's slope estimator

Sen's Slope Estimator, used in conjunction with the MK test, quantifies the magnitude of the trend, providing insight into the rate of change in the time series data. Sen's slope estimation test calculates both the slope (i.e., change per unit time) and intercepts. A positive value of Z indicates an 'upward trend' (increasing values over time), whereas a negative value of Z signifies a 'downward trend'. Here, the slope (Q) of all data pairs was computed as presented below. The slope estimates of N pairs of data were initially calculated using (6) below:

$$Q = \frac{X_J - X_k}{J - K} \text{ for } i = 1\ldots\ldots\ldots N \tag{6}$$

where j > k.

Ranking of N values of Qi was done from the smallest value to the largest, and the Sen's estimator is given as:

$$Q = Q_{[(N+1)/2]} \quad \text{if N is odd} \tag{7}$$

$$Q = \frac{1}{2}(Q_{(N/2)} + Q_{[(N+1)/2]}) \text{ if N is even} \tag{8}$$

3.0 Result and Discussion

The descriptive statistics of rainfall in Northern Nigeria (NN) from 1981 to 2020 revealed notable trends and variations across dry and wet seasons, as well as annual totals (Table 1). The minimum recorded rainfall during the dry season is 8.7 mm, while the wet season has a minimum of 713.1 mm. The estimated annual minimum is 729.1 mm, indicating a distinct seasonal pattern. The same pattern was noted for the maximum rainfall. The average rainfall for the dry season is 23.5 mm, compared to a much higher mean of 944.9 mm for the wet season, resulting in an annual mean of 968.4 mm. This highlights the intense concentration of rainfall during the wet season. The standard deviation for the dry season is 7.7 mm, reflecting variability in conditions. In comparison, the standard deviation for the wet season is 86.4 mm, indicating a more consistent rainfall pattern compared to its respective mean value.

The positive skewness of 0.8 in dry season rainfall indicates a concentration at the lower end with some higher outliers, whereas the wet season's negative skewness of -0.5 suggests a symmetric distribution. The kurtosis values of 1.5 for the dry season and -0.3 for the wet season further demonstrate the distribution characteristics of the data.

Remarkably, 97.6% of total rainfall occurs during the wet season, underscoring its importance for agriculture and water resource management. This finding aligns with [16] claim that locations in the northern part of the country received over 90% of the total annual rainfall from April to October. The Z test values indicate significant upward trends in both wet and annual rainfall, while the dry season shows a slight decline. The Sen's slope analysis confirms a decreasing trend for dry season rainfall at -0.1, and increasing slopes of 3.8 for the wet season and 3.9 for annual totals, verifying a rise in wet-season rainfall over the study period. Similar findings have been reported by [17] Ogunrinde et al. (2019) for many locations in Nigeria.

Table 1: Weighted average rainfall trends in Northern Nigeria (1981–2020)

Statistic	Dry	Wet	Annual
Minimum	8.7	713.1	729.1
Maximum	48.8	1100.9	1118.3
Mean	23.5	944.9	968.4
Standard deviation	7.7	86.4	85.7
Variation coefficient	32.7	9.1	8.9
Skewness (Pearson)	0.8	-0.5	-0.5
Kurtosis (Pearson)	1.5	-0.3	-0.1
Contribution (%)	2.4	97.6	100.0
Test Z	-0.9	3.2	3.0
Sen slope	-0.1	3.8	3.9
Change nature	Decreasing	Increasing	Increasing

3.1 Rainfall Distribution Across the Zones

North Central (NC), Nigeria receives an average annual rainfall of about 1,272.2 mm, significantly more than the Northwest (NW). This illustrates the variation in rainfall patterns, which are crucial for local ecosystems and agriculture. During the rainy season, NC experiences an average of 1,221.1 mm of rain, indicating a strong tendency for wet season activity that benefits diverse agricultural practices. In contrast, NW and NE report significantly lower totals of 886.8 mm and 732.7 mm, respectively. During the dry season, rainfall drops sharply across all regions, with NC averaging 51.0 mm, while NW and NE record only 4.1 mm and 5.6 mm, respectively. These small amounts highlight the dry, arid conditions typical of the dry season, which are likely exacerbated by rising temperatures and potential droughts. The extreme dryness in the northwest and northeast underscores the urgent need for adaptive strategies, such as improved water management and planting drought-resistant crops. Areas with higher rainfall, like NC, can support diverse farming and more stable economies. Conversely, NW and NE could face challenges like rural poverty and migration. High rainfall value reported for NC in this study agrees with the finding of [4], which claimed that rainfall distribution, including latitudinal.
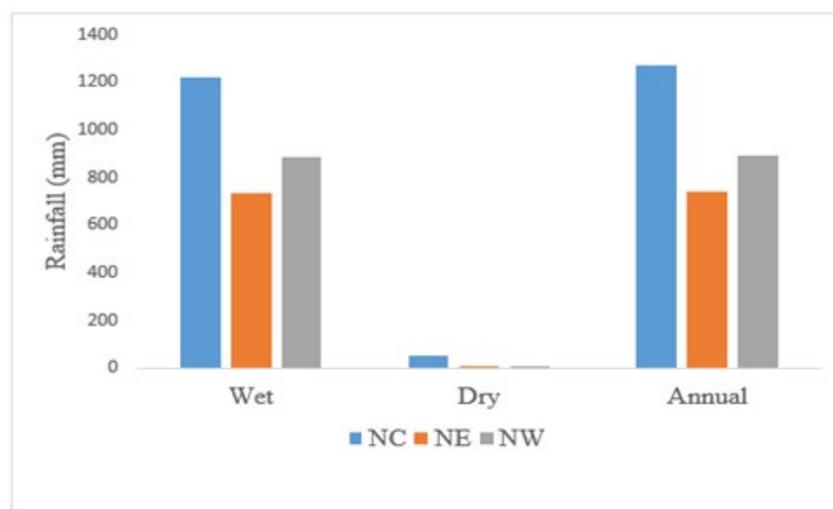

Figure 2: Linear trend analysis of rainfall in Northern Nigeria (1981-2020)

3.2 Linear Trend of Rainfall Across the Zone

The analysis of rainfall trends in NN from 1981 to 2020 reveals significant changes across the three zones (Figure 3). The NC zone exhibits a gradual increase in rainfall, with a slope of approximately 2.0 mm per year. In comparison, the NW zone has a steeper slope of 5.15, indicating an average annual increase of about 5.1 mm. The NE zone also experiences a notable upward trend with a slope of 4.96, suggesting an annual increase of around 5.0 mm. While all three regions exhibit rising rainfall trends, the NW and NE regions face substantially higher rates than NC, which may significantly impact agriculture, water resources, and drought management.
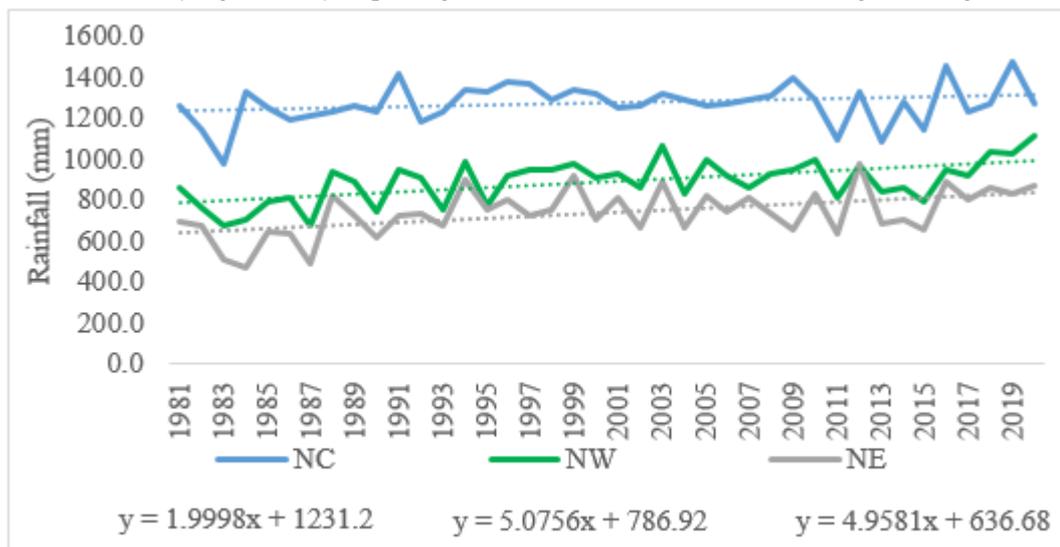

Figure 3: Time series and linear trend of rainfall across North Central (NC), North West (NW) and North East (NE) of Northern Nigeria

Year-to-year variability is notable, with NC peaking in 2016 and 2019 at 1459.2 mm and 1477.8 mm, respectively. The NW zone reached its highest in 2020 with 1116.6 mm, while NE peaked that same year at 871.5 mm. These fluctuations underline the regions' vulnerability to climatic anomalies, highlighting the need for enhanced monitoring and adaptive strategies. Despite consistently higher total rainfall recorded in NC, NW, and NE, these areas have demonstrated more significant increases, prompting questions about the current farming practices' adaptability. Increased precipitation could enhance agricultural productivity in the Northwest and Northeast if infrastructure and methods are improved. However, it also brings risks such as flooding and soil erosion, necessitating proactive measures.

3.3 Rainfall Variability Across the Weather Stations (1981 to 2020)

This analysis examines the spatial variability of annual rainfall across the stations using the coefficient of variation (CV) to assess the stability and predictability of precipitation, which is critical for agricultural practices and water resource management. The CV quantifies annual rainfall variability; lower values indicate stable patterns, while higher values reflect significant fluctuations. Notable differences were observed across monitoring stations, with Nguru (CV = 22.4%) and Potiskum (CV = 22.3%) showing the highest variability, signalling substantial annual fluctuations that could, though, be classified as moderate (Figure 4). Stations like Kano (CV = 18.4%), Sokoto (CV = 18.1%), Makurdi (CV = 6.8%), and Bauchi (CV = 9.0%) demonstrate low CV values, suggesting more consistent rainfall. Regions with higher CV values may require adaptive management practices, such as promoting drought-resistant crops and investing in irrigation systems. Conversely, areas with low variability can optimise crop rotation and maximise yields, guiding policymakers in resource allocation and strategic planning to enhance food security. High variability noted for Nguru aligned with the earlier studies, which asserted that variability increases with latitude [2], [4] and [17].
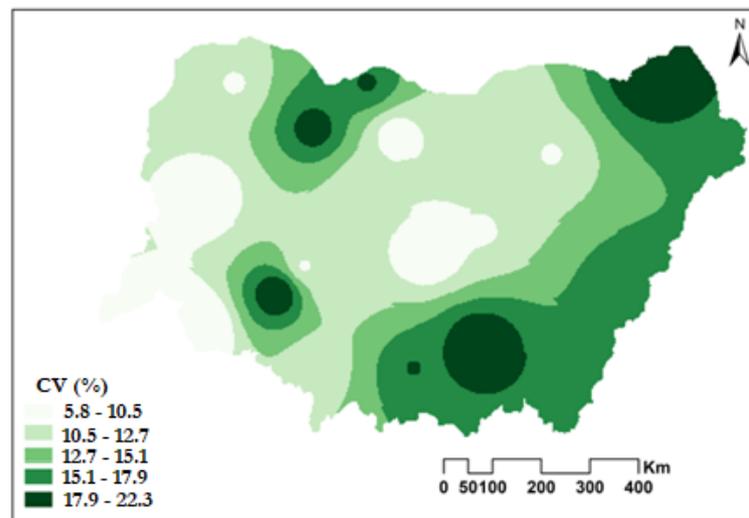
Figure 4: Rainfall variability

3.4 Spatial Analysis of Annual Rainfall Trends Across Northern Nigeria (1981-2020)

Variations in rainfall trends were noted across different stations, as indicated by Test Z values (Figure 5). Higher values reflect pronounced changes. In particular, stations like Kano (Z = 3.7), Katsina (Z = 3.9), Nguru (Z = 4.3), Potiskum (Z = 4.2), and Maiduguri (Z = 3.6) display significantly upward trends, suggesting substantial shifts in precipitation patterns that could impact agricultural viability and prompt enhanced water management strategies.

Additionally, stations like Abuja (Z = 1.3) and Bida (Z = 1.3) exhibit non-significant trends, indicating relative stability in rainfall patterns. These disparities emphasise the need for tailored adaptation strategies. Regions with strong positive trends may offer opportunities for agricultural expansion, but they could also face challenges such as increased humidity and flooding. Meanwhile, areas with stable or declining trends may struggle with water scarcity, necessitating the adoption of water conservation measures, improved irrigation practices, and drought-resistant crop varieties adapted to their specific conditions.
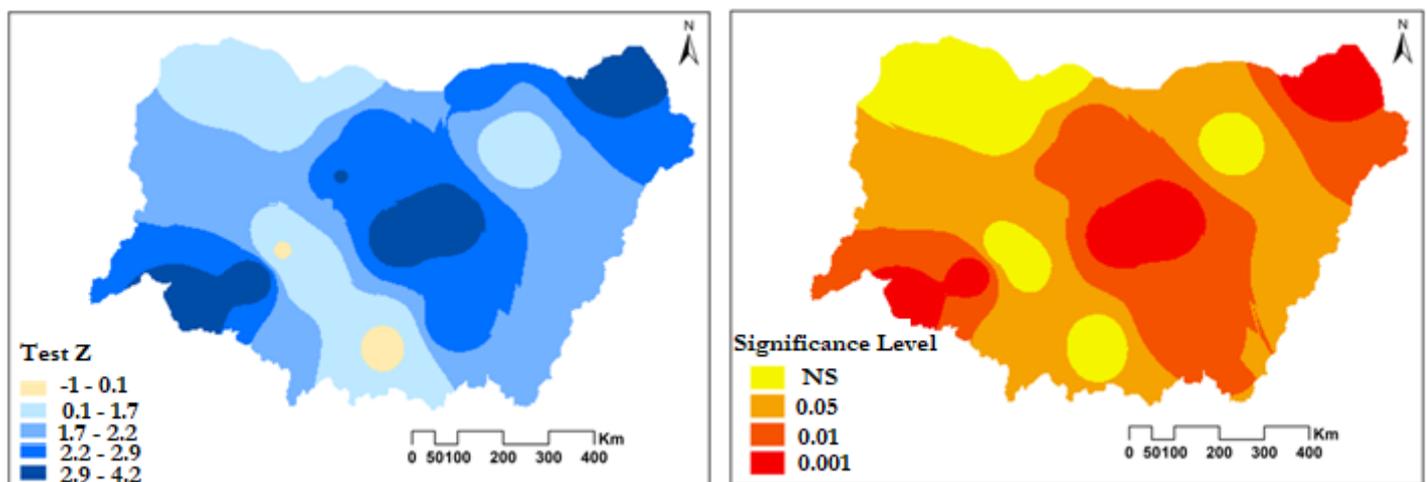

Figure 5: a) Magnitude of the rainfall trend   b) Significance level of the trend

3.5 Spatial Analysis of Monthly Rainfall Distribution Across Northern Nigeria (1981-2020)

The analysis of monthly rainfall distribution in NN from 1981 to 2020 reveals significant spatial variability among different monitoring stations, providing insights into regional precipitation patterns essential for agricultural development and water resource management.

April shows notable variability, with Abuja recording the highest rainfall at 57.9 mm and Katsina the lowest at 3.2 mm. This suggests that regions like Abuja and Yola experience an earlier onset of the rainy season, impacting agricultural planning and crop planting timings. The month of May marks a transition to increased precipitation, with Abuja receiving 143.4 mm while Kano records only 48.9 mm (Figure 6).

Peak rainfall typically occurs around July, with Jos reporting the highest amount at 261.0 mm, and other areas, such as Kaduna and Bauchi, exceeding 200 mm. This wet period is critical for agricultural systems, necessitating efficient rainwater management. As the rainy season winds down, September shows significant rainfall, especially

in Jos (277.4 mm), indicating a secondary peak. By October, rainfall decreases across all stations, affecting the availability of moisture for post-harvest activities. Conversely, continued rainfall in areas such as Lokoja and Makurdi, towards the South, supports a longer growing season compared to the upper north. The result shows a negative linear correlation between rainfall amount and latitude as rainfall increases with decreasing latitude [6] and [18].

This spatial variation is crucial for assessing water availability, selecting crops, and determining agricultural timing. Additionally, the uneven distribution of rainfall complicates yield predictions and water management strategies. Regions with consistently high rainfall can adopt intensive agricultural practices, while those with lower rainfall levels may need to use drought-resistant crop varieties.

These distinct rainfall patterns have broader climatic implications for food security, resource allocation, and environmental sustainability in Northern Nigeria. Incorporating these monthly rainfall distribution characteristics into policy frameworks is essential for aligning agricultural practices with prevailing climatic conditions.
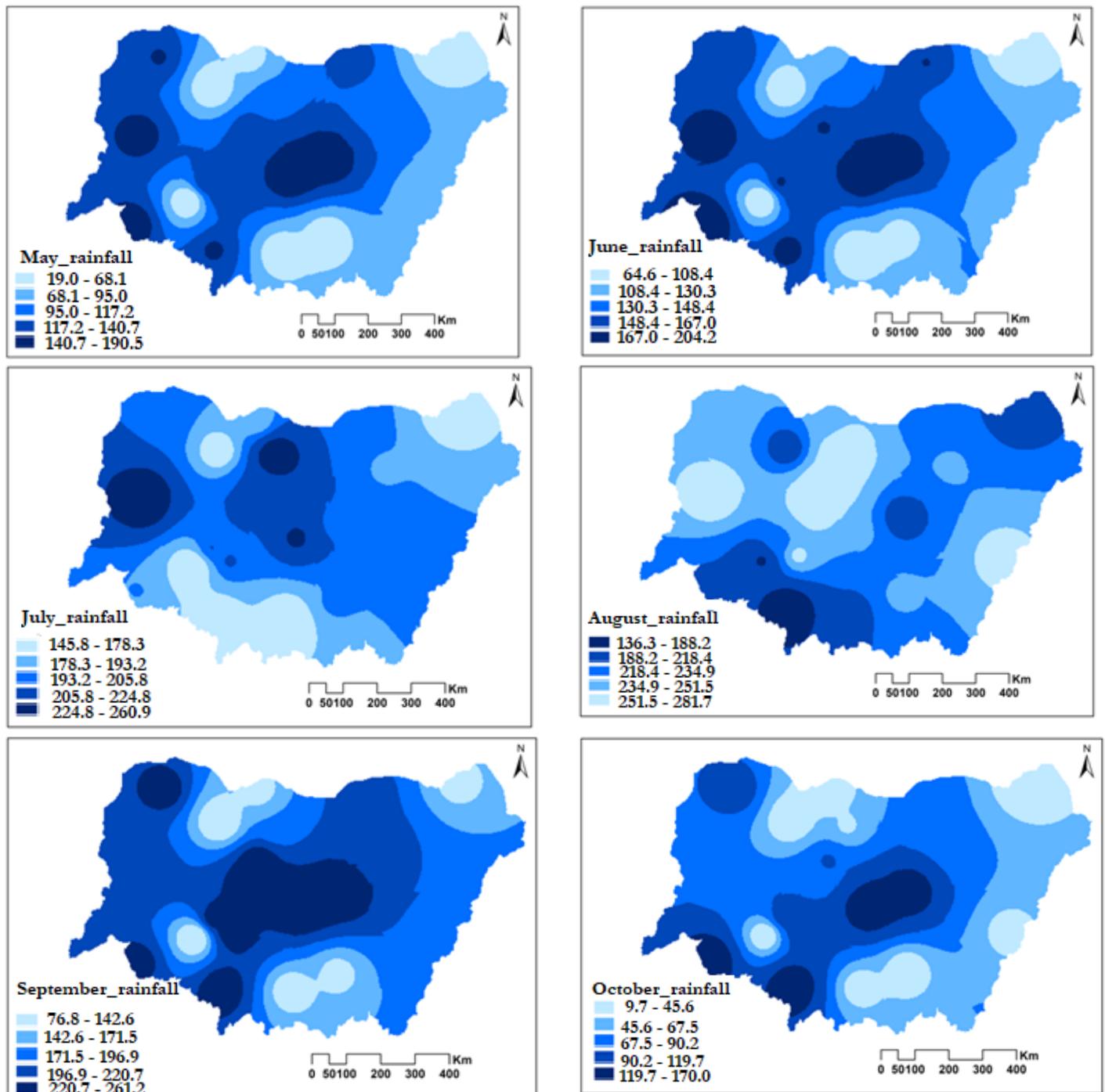
Figure 6: Monthly rainfall distribution across Northern Nigeria

3.6 Descriptive Statistics of Temperatures

The descriptive statistics of temperatures in NN from 1981 to 2020 provide essential insights into regional climatic trends. Analysing maximum temperature (TMAX), minimum temperature (TMIN), and mean temperature (TMEAN) reveals several key observations. January registers the lowest temperatures, with a TMAX of 32.3°C, TMIN of 16.7°C, and TMEAN of 24.5°C (Table 2). As the year progresses, temperatures gradually increase, peaking in March and April with TMAX reaching 37.0°C, reflecting the dry season pattern before the wet season. TMAX show significant variation, with high values in February (34.7°C) and March (36.8°C), while lower temperatures in July and August (30.4°C and 29.6°C, respectively) coincide with the wet season, when rainfall moderates temperatures. This aligned with the study of [19] that asserted that highest temperatures are known with month preceding the wet season.

Table 2: Descriptive statistics of temperatures over Northern Nigeria (1981–2020).

Statistic	TMAX			TMIN			TMEAN		
	Mean	SD	CV (%)	Mean	SD	CV	Mean	SD	CV
Jan	32.3	1.3	3.9	16.7	1.0	5.9	24.5	1.1	4.4
Feb	34.7	1.3	3.7	19.6	1.1	5.8	27.1	1.2	4.3
Mar	36.8	0.9	2.5	22.8	0.9	4.0	29.8	0.8	2.7
Apr	37.0	0.6	1.6	24.4	0.6	2.5	30.7	0.5	1.7
May	34.9	0.7	2.0	24.1	0.5	2.0	29.5	0.5	1.7
Jun	32.7	0.5	1.6	23.0	0.3	1.4	27.8	0.4	1.4
Jul	30.4	0.7	2.3	22.1	0.4	1.6	26.2	0.5	1.9
Aug	29.6	0.6	2.1	21.6	0.3	1.5	25.6	0.4	1.7
Sep	31.1	0.6	1.8	21.6	0.3	1.5	26.3	0.4	1.6
Oct	33.0	0.6	1.8	21.2	0.6	2.6	27.1	0.4	1.6
Nov	33.9	0.8	2.3	18.6	0.8	4.2	26.2	0.7	2.6
Dec	32.6	1.1	3.3	16.8	0.8	5.0	24.7	0.9	3.5
Annual	33.2	0.4	1.1	21.0	0.3	1.7	27.1	0.3	1.2
Wet	32.7	0.3	1.0	22.6	0.3	1.1	27.6	0.3	1.0
Dry	34.0	0.6	1.8	18.9	0.6	3.0	26.5	0.6	2.1

The standard deviation (SD) of TMAX is low, indicating minimal fluctuations, with the lowest SD observed in April (0.6), demonstrating consistent warmth during this month. The CV for TMAX also remains low, averaging 1.5% to 3.9%, which signifies minor temperature variations relative to the mean. TMIN values decline notably during the wet months, particularly from May to August, stabilising at around 21.6°C due to increased cloud cover and humidity. The annual mean TMAX is 33.2°C, indicating an overall hot climate, while a mean TMIN of 21.0°C suggests relatively mild night-time temperatures. The mean TMEAN of 27.1°C is typical for a tropical climate characterised by significant diurnal variations.

Comparing wet and dry seasonal averages reveals a stark contrast, with the dry season averaging a TMAX of 34.0°C, significantly higher than the wet season's average of 32.7°C, highlighting the cooling effects of precipitation during the rainy months.

The Mann-Kendall trend analysis for monthly, seasonal, and annual temperatures in NN reveals significant insights regarding temperature variation and trends within the region. The results presented in the Table 3 include test statistics (Z) and associated significance levels (Q), which facilitate a comprehensive understanding of temperature trends. In the analysis of TMAX, the months of March displays a statistically significant upward trend with a Z value of 3.62 ($p < 0.001$), indicating a strong positive trend during this period. November also show significant trend, with Z values of 2.26 ($p < 0.05$). For TMIN, February, March and October reveal significant upward trends at $p < 0.05$ while November and December with Z values of 3.11 and 2.96 were significant at $p < 0.01$. This suggests an increase in night-time temperatures during these months, while the other months do not show a significant trend. The mean TMEAN echo similar findings, with February (Z = 2.06, $p < 0.05$), March (Z = 3.54, $p < 0.001$), November (Z = 3.18, $p < 0.01$), and December (Z = 2.41, $p < 0.05$) indicating significant warming trends. Similar findings have been reported in Animashaun et al. (2023)

Table 3: Mann-Kendall statistics for monthly, seasonal, and annual temperatures over Northern Nigeria (1981–2020)

Time series	TMAX		TMIN		TMEAN	
	Test Z	Q	Test Z	Q	Test Z	Q
Jan	1.53	0.03	1.92	0.03	1.92	0.03
Feb	1.71	0.03	2.40*	0.04	2.06*	0.03
Mar	3.62***	0.04	2.07*	0.02	3.54***	0.03
Apr	1.51	0.01	1.25	0.01	1.55	0.01
May	1.70	0.02	1.21	0.01	1.53	0.01
Jun	1.28	0.01	1.57	0.00	1.10	0.01
Jul	1.90	0.02	1.91	0.01	2.04*	0.02
Aug	-0.80	-0.01	1.84	0.01	0.09	0.00
Sep	0.03	0.00	1.54	0.01	0.73	0.01
Oct	0.01	0.00	2.53*	0.02	1.36	0.01
Nov	2.26*	0.02	3.11**	0.03	3.18**	0.03
Dec	1.64	0.02	2.96**	0.03	2.41*	0.03
Annual	3.62***	0.02	4.45***	0.02	4.30***	0.02
Wet	1.22	0.01	3.02**	0.01	2.09*	0.01
Dry	4.21***	0.03	4.68***	0.03	4.65***	0.03

* denotes $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$

On a seasonal basis, annual temperatures present a compelling upward trend across all three metrics. Notably, TMAX (Z = 3.62), TMIN (Z = 4.45), and TMEAN (Z = 4.30) all exhibit strong significant trends with p-values indicating high levels of confidence ($p < 0.001$). This reflects a pronounced increase in temperatures over the entire year. The dry season exhibits particularly strong trends for TMAX (Z = 4.21), TMIN (Z = 4.68), and TMEAN (Z = 4.65), all with $p < 0.001$, indicating substantial temperature increases during these months. The wet season shows less pronounced trends, though the TMIN (Z = 3.02, $p < 0.01$) does indicate a significant increase. The findings from this trend analysis underscore a significant warming trend in NN across various temporal scales. The strong positive trends observed in maximum, minimum, and mean temperatures suggest a concerning climatic shift, which may have implications for agriculture, water resources, and overall environmental conditions in the region. The notable increase in temperatures during both the dry and wet seasons indicates that NN is experiencing a warming climate, which could exacerbate challenges related to heat stress, water scarcity, and affect agricultural productivity [20].

3.7 Linear Trend of Temperature Across the Zone
This analysis examines the trends in maximum temperature across the three regions. The derived linear equations provide a quantitative framework essential for future climate projections impacting agriculture, public health, and water resources. The NW region shows the greatest increase in TMAX, with a slope of 0. 0.021, indicating a faster rise compared to the moderate increases in NC (0. 014) and NE (0. 016). This trend is concerning, especially for agriculture and ecosystems sensitive to temperature changes (Figure 7).

Historical baselines reveal that the NE had the highest TMAX of 34. 2 ° C in 1981, compared to 32. 2 ° C in NC and 33. 4 ° C in NW. Understanding these baselines is important, as different starting temperatures can affect agricultural viability. The consistent rise in TMAX suggests long-term climate shifts that could worsen water scarcity and reduce agricultural yields, while the sharp increase in the NW poses serious food security risks due to its dependence on rain- fed agriculture [21].
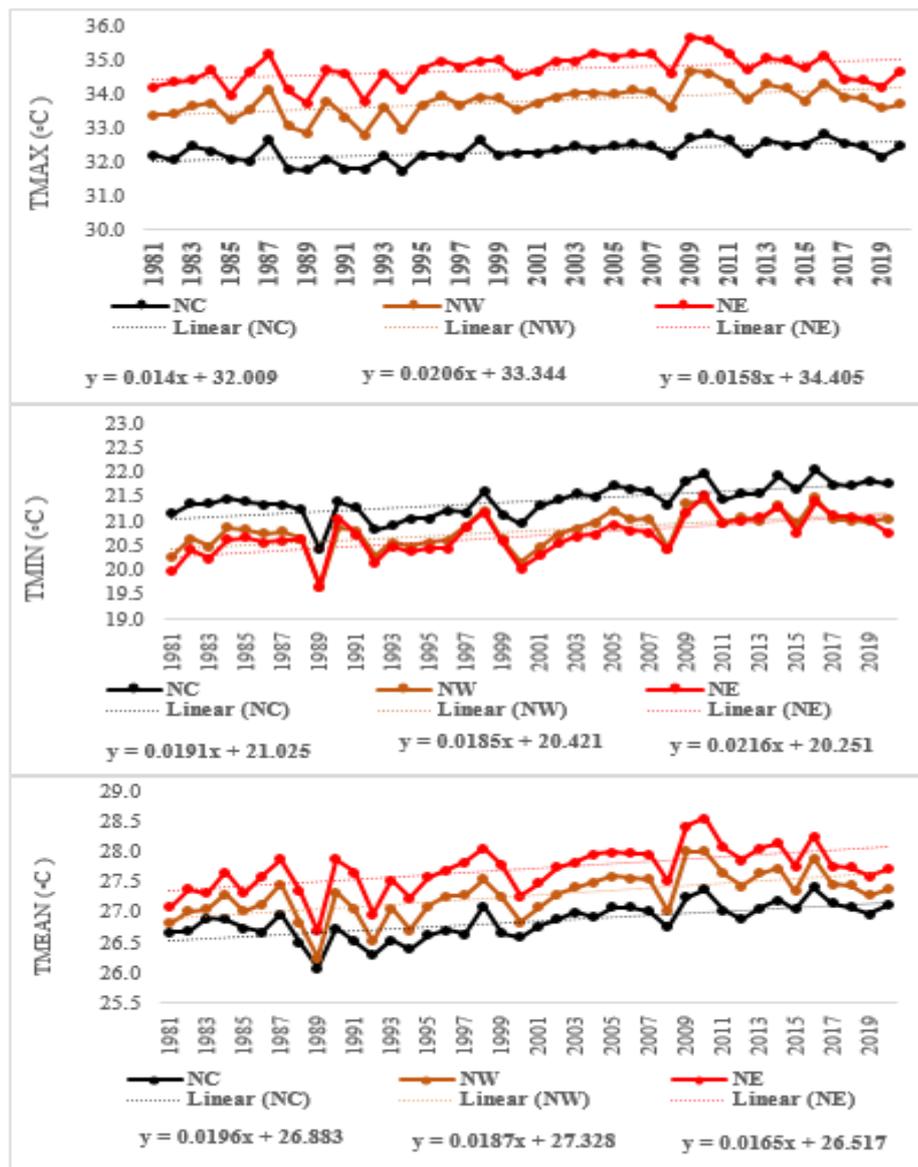
Figure 7: Time series and linear trend of the temperatures across the three zones

The NE region experienced the largest increase in TMIN, with a slope of 0. 022, indicating more rapid warming than NC (0. 0191) and NW (0. 0185). Understanding initial TMIN—21. 2 ° C in NC, 20. 3 ° C in NW, and 20. 0 ° C in NE—is essential for assessing thresholds for crops and animals. This rise in TMIN can negatively affect agriculture and public health by increasing energy demands for cooling and reducing cold weather extremes. Looking at mean temperatures, NC shows the highest rate of increase at 0. 0196 ° C per year, with NW at 0. 0187 ° C and NE at 0. 0165 ° C. Although the slower warming in NE suggests some resilience, it still faces significant impacts from climate change. The overall warming trends across these regions highlight the need for tailored adaptation strategies to address specific vulnerabilities related to climate change.

3.8 Trend of Temperatures of Various Locations Across Northern Nigeria (1981–2020)

The Mann-Kendall trend analysis for temperatures in NN from 1981 to 2020 reveals significant insights into temperature variations across the region. The average TMAX is 33.6°C, with a CV of 1.1%. A statistically significant upward trend (Test $Z = 3.6$, $p < 0.001$) indicates a marked increase in TMAX. For TMIN, the average is 21.0°C, accompanied by a CV of 1.7%, showing a significant upward trend (Test $Z = 4.4$, $p < 0.001$), suggesting warmer night-time conditions with potential implications for health and ecology.

Table 3:   Mann-Kendall statistics for temperatures of various locations across Northern Nigeria (1981–2020).

Stations	TMAX			TMIN			TMEAN		
	Mean	CV (%)	Test Z	Mean	CV (%)	Test Z	Mean	CV (%)	**Test Z**
Makurdi	32.6	0.7	4.0***	22.1	1.4	4.8***	27.3	0.9	4.7***
Lokoja	31.7	1.0	4.5***	21.6	1.6	3.7***	26.7	1.1	4.4***
Ibi	33.0	0.8	3.0**	22.0	1.5	5.4***	27.5	1.0	4.9***
Ilorin	32.2	1.1	4.1***	21.6	1.8	3.8***	26.9	1.3	4.3***
Bida	33.8	0.9	3.4***	22.8	1.5	4.2***	28.3	1.1	4.1***
Abuja	33.1	0.9	3.4***	22.1	1.5	4.3***	27.6	1.1	4.2***
Minna	33.1	1.0	2.7**	21.8	1.6	3.9***	27.5	1.1	3.8***
Jos	28.7	1.2	3.2**	17.4	2.1	4.8***	23.1	1.4	4.4***
Bauchi	32.3	1.3	3.0**	19.8	1.9	4.6***	26.0	1.4	3.9***
Kaduna	32.3	1.2	3.3**	20.4	1.8	4.1***	26.3	1.3	3.9***
Yelwa	35.0	1.0	3.8***	22.5	1.6	4.0***	28.8	1.1	4.2***
Zaria	32.2	1.2	3.4***	19.8	1.8	4.0***	26.0	1.4	3.9***
Kano	33.8	1.4	3.3***	19.9	2.0	3.7***	26.9	1.5	3.8***
Gusau	34.1	1.4	3.8***	20.4	1.8	3.9***	27.3	1.4	4.1***
Katsina	34.6	1.5	3.6***	20.9	1.8	3.0***	27.8	1.5	3.8***
Sokoto	35.7	1.3	4.0***	22.7	1.7	3.7***	29.2	1.3	4.3***
Yola	33.1	1.0	2.1*	20.2	1.9	5.2***	26.7	1.1	4.3***
Potiskum	34.5	1.5	2.6*	20.4	2.1	4.0***	27.5	1.5	3.5***
Maiduguri	35.8	1.4	2.3*	20.8	2.0	3.9***	28.3	1.4	3.5***
Nguru	35.5	1.4	2.9**	21.3	1.8	3.7***	28.4	1.5	3.5***
Average	33.6	1.1	3.6***	21.0	1.7	4.4***	27.3	1.2	4.3***

* denotes $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$

The TMEAN is recorded at 27.3°C with a CV of 1.2%, reflecting an increase supported by a statistically significant trend (Test Z = 4.3, p < 0.001). Noteworthy locations include Sokoto (TMAX = 35.7°C), Yelwa (35.0°C), and Maiduguri (35.8°C), all showing substantial upward trends (Z values of 4.0 and 2.3 for Sokoto and Maiduguri, respectively). In contrast, Jos has the lowest TMAX at 28.7°C, yet still shows a significant upward trend (Z = 3.2). Most locations, including Makurdi and Lokoja, exhibit consistent upward trends in TMAX and TMIN, with Z values exceeding 3.0. However, Yola and Potiskum show lower values (Z = 2.1 and 2.6), indicating less pronounced trends. As hitherto mentioned, the persistent rise in temperatures poses potential challenges for agriculture, water resources, and public health, emphasising the need for localised assessments and tailored strategies to address climate change impacts in Northern Nigeria. The strong positive trends noted for all the stations and greater warming trends observed for TMIN conform to the study of [22], who claim that night-time has the greatest warming trends over Nigeria.

4.0 Conclusion

This study analyses the variability and trends in rainfall and temperature in Northern Nigeria across different spatial and temporal scales. The results indicate a significant increase in rainfall, particularly in the Northwest and Northeast zones, coinciding with a substantial rise in temperature levels. The findings indicate a significantly positive annual trend (Z = 3.0) of rainfall over the entire region, which, when combined with heightened temperatures (Z = 4.30), represents a substantial threat to agricultural productivity and the resilience of local infrastructure. The implications of these high variability and positive trends are critical, as they may exacerbate existing socio-economic challenges, thereby jeopardising food security and livelihoods in the Northern Nigeria. It is paramount that policymakers fully recognise the urgency of these challenges and commit to investing in climate adaptation measures. To address these issues effectively, this study recommends enhancing water resource management through the development of improved irrigation systems, promoting the cultivation of drought-resistant and climate-resilient crop varieties, and constructing robust infrastructure that can withstand extreme hydrological events. Furthermore, establishing early warning systems for climate-related hazards is essential to safeguard communities against the adverse effects of flooding and drought. By implementing these strategic interventions, stakeholders can better equip Northern Nigeria to face the challenges of climate change, thus fostering greater regional resilience and stability.

Acknowledgements

References

[1] P.G. Oguntunde, G. Lischeid, B.J. Abiodun, "Impacts of climate variability and change on drought characteristics in the Niger River Basin, West Africa". *Stoch. Environ. Res. Risk Assess.* 32, 1017–1034, 2018 . https://doi.org/10.1007/s00477-017- 1484-y.

[2] I. M. Animashaun, P. G. Oguntunde, A. S. Akinwumiju, and O. O. Olubanjo, "Rainfall Analysis over Niger Central Hydrological Area, Nigeria: Variability, Trend and Change-point detection," *Scientific African*, vol. 2020, https://doi.org/10.1016/j.sciaf.2020.e00419

[3] W. H. Beitelmal, S. C. Nwokolo, E. L. Meyer, and C. C. Ahia, "Exploring Adaptation Strategies to Mitigate Climate Threats to Transportation Infrastructure in Nigeria: Lagos City, as a Case Study," *Climate*, vol. 12, no. 8, p. 117, 2024, https://doi.org/10.3390/cli12080117.

[4] P. G. Oguntunde, B. J. Abiodun, and G. Lischeid, "Rainfall trends in Nigeria, 1901–2000," *Journal of Hydrology*, vol. 411, no. 3-4, pp. 207–218, 2011, doi: 10.1016/j.jhydrol.2011.09.037

[5] I. M. Animashaun, P. G. Oguntunde, A. S. Akinwumiju, and O. O. Olubanjo, "Assessment of climate change impacts on the hydrological response of a watershed in the savanna region of sub-Saharan Africa," *Theoretical and Applied Climatology*, vol. 152, no. 23, 2023, https://doi.org/10.1007/s00704-023-04372-w.

[6] A. A. Akinsanola and K. O. Ogunjobi, "Analysis of rainfall and temperature variability over Nigeria," *Global Journal of Human-Social Science: B Geography, Geo-Sciences, Environmental Disaster Management*, vol. 14, no. 3, pp. 1–17, 2014.

[7] A. Asfaw, B. Simane, A. Hassen, and A. Bantider, "Variability and time series trend analysis of rainfall and temperature in north-central Ethiopia: A case study in Woleka sub-basin," *Weather and Climate Extremes*, vol. 19, pp. 29–41, 2018.

[8] R. I. Maidment, R. P. Allan, and E. Black, "Recent observed and simulated changes in precipitation over Africa," *Geophysical Research Letters*, vol. 42, pp. 8155–8164, 2015, doi: 10.1002/2015GL065765.

[9] S. Chattopadhyay and D. R. Edwards, "Long-Term trend analysis of precipitation and air temperature for Kentucky," *Climate*, vol. 4, no. 1, 2016, doi: 10.3390/cli4010010.

[10] A. O. Sojobi, I. I. Balogun, and A. W. Salami, "Climate change in Lagos state, Nigeria: what really changed?" *Environmental Monitoring and Assessment*, vol. 188, p. 556, 2016, doi: 10.1007/s10661-016-5549-z.

[11] A. A. Abatan, B. J. Abiodun, E. A. Adefisan, and W. J. Gutowski Jr., "Hot days and tropical nights in Nigeria: trends and associated large-scale features," *Theoretical and Applied Climatology*, vol. 137, no. 3-4, pp. 2077–2093, 2019, doi: 10.1007/s00704-018-2713-0

[12] A. T. Ogunrinde, I. Emmanuel, M. A. Enaboifo, T. A. Ajayi, and Q. B. Pham, "Spatio-temporal calibration of Hargreaves–Samani model in the Northern Region of Nigeria," *Theoretical and Applied Climatology*, 2021, doi: 10.1007/s00704-021-03897-2.

[13] M. Y. Otache, M. A. Tyabo, I. M. Animashaun, and L. P. Ezekiel, "Application of Parametric-Based Framework for Regionalisation of Flow Duration Curves," *Journal of Geoscience and Environment Protection*, vol. 4, pp. 89–99, 2016.

[14] D. Ishaku, E. T. Umaru, A. A. Adebayo, R. Löwner, and A. A. Okhimamhe, "Analysis of the Observed Trends in Rainfall and Temperature Patterns in North-Eastern Nigeria," *Climate*, vol. 12, p. 219, 2024, doi: 10.3390/cli12120219.

[15] A. Aminu, I. M. Animashaun, and M. Y. Otache, "Analysis of rainfall and temperature over a subbasin of Lake Chad, Nigeria," in *Utilizing the knowledge of Engineering, Science, and Technology for Sustainable Development*, International Conference, pp. 104–110, 2023.

[16] D. O. Adefolalu, "Rainfall trends in Nigeria," *Theoretical and Applied Climatology*, vol. 37, pp. 205–219, 1986.

[17] A. T. Ogunrinde, P. G. Oguntunde, A. S. Akinwumiju, and J. T. Fasinmirin, "Analysis of recent changes in rainfall and drought indices in Nigeria," *Hydrological Sciences Journal*, vol. 64, pp. 1981–2015, 2019, doi: 10.1080/02626667.2019.1673396.

[18] C. C. Nnaji, C. N. Mama, and O. Ukpabi, "Hierarchical analysis of rainfall variability across Nigeria," *Theoretical and Applied Climatology*, vol. 123, pp. 171–184, 2014, doi: 10.1007/s0 0704- 014- 1348 – z

[19] O. E. Adeyeri, P. Laux, A. E. Lawin, and J. Arnault, "Assessing the impact of human activities and precipitation variability on the river discharge of Komadugou-Yobe Basin, Lake Chad Area," *Environmental Earth Sciences*, vol. 79, p. 143, 2020, doi: 10.1007/s12665-020-8875-y.

[20] A. J. Oloruntade, T. A. Mohammad, A. H. Ghazali, and A. Wayayok, "Spatial and temporal trends in mean, maximum and minimum temperature in the Niger-South Basin, Nigeria," *Malaysian Journal of Civil Engineering*, vol. 28, no. 3, pp. 365–381, 2018, , doi: 10.11113/mjce.v28.15981

[21] O. E. Ogunsola and O. S. Yaya, "Maximum and minimum temperatures in South western Nigeria: time trends, seasonality and persistence," *Journal of Physics: Conference Series*, vol. 1299, 2019, doi: 10.1088/1742-6596/1299/1/012057

[22] A. A. Abatan, B. J. Abiodun, K. A. Lawal, and W. J. Gutowski Jr., "Trends in extreme temperature over Nigeria from percentile-based threshold indices," *International Journal of Climatology*, vol. 36, pp. 2527–2540, 2016, doi: 10.1002/joc.4510