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Research Article

Analysis of Trends and Variability of Rainfall and Temperature in Lapai LGA, Niger State, Nigeria

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ABSTRACT

Climate variability continues to impact the livelihoods of rural communities, especially families that rely on rainfed agriculture. This study examined the trends and variability of rainfall, minimum and maximum temperatures in Lapai, Niger State. Monthly rainfall, maximum and minimum temperature time series (January 1990–December 2025) were obtained from NASA Power covering 36 years. The study used the Coefficient of Variation (CV), Standardized Anomaly Index (SAI), Modified Mann-Kendall (MMK) trend test, Sen's slope estimator, Seasonal Mann-Kendall test, and Pettitt tests to analyze the data. The study revealed annual rainfall had moderate variability (CV=26.7%), while maximum and minimum temperatures had low variability with 6.13% and 10.8%, respectively. The MMK revealed a significantly declining trend in annual rainfall ($Z = -2.49$, $p < 0.05$) with a Sen's slope of −10.35 mm year^{-1}, while maximum and minimum temperatures revealed significantly increasing trends, increasing by 0.11°C and 0.05°C annually, respectively. The Seasonal MK also revealed significantly decreasing rainfall and an increase in maximum and minimum temperatures. The Pettitt's test revealed significant changepoints in rainfall in 1998, maximum temperature in 1997, and minimum temperature in 2002. Results of the SAI revealed an increased frequency of negative anomalies of annual rainfall, indicating intense drying in the area. The study concludes that the findings suggest emerging warming-drying spells in Lapai LGA, which can have negative implications for rain-fed agriculture, water resources, and climate adaptation planning.

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1 Introduction

Climate change and variability are among the most pressing global challenges of the 21st century, with profound implications for ecosystems, economies, and livelihoods, particularly in developing countries (IPCC, 2022). Across the world, climate change has been identified as a significant environmental challenge in the 21st century (Achite et al., 2023). This phenomenon is significantly increasing the frequency and intensity of extreme weather events (EWEs), including severe storms, catastrophic floods, prolonged heatwaves, and extended droughts (Ahmed et al., 2024; Huang et al., 2025). Several developing countries, including Nigeria, face heightened vulnerability due to their reliance on rainfed agriculture and limited adaptive capacity (Omokaro, 2025).

According to the IPCC (2023), global warming of 1.1°C above pre-industrial levels has been caused by over a century of burning fossil fuels and unequal, unsustainable energy and land use. With the increase in global temperature and changes in precipitation patterns, changes in aridity have been observed, with some areas getting drier and others getting wetter (Daramola et al., 2023). Additionally, the West African Monsoon (WAM) is a crucial component of the regional climate system, affecting agriculture, water resources, and livelihoods across West Africa (Datti et al., 2025). These interactions lead to higher spatial and temporal variability of temperature and rainfall, which can subsequently impact agricultural productivity and the availability of water for domestic and industrial use.

Nigeria, Africa's most populous country, has experienced notable shifts in its climate over recent decades. Studies have reported increasing trends in mean annual temperature and erratic rainfall patterns across many regions of the country (Ahmad et al., 2025; Bello et al., 2025). These changes severely affect the livelihoods of people who rely on rainfed agriculture in rural and peri-urban communities, specifically smallholder farmers in Northern Nigeria (Ideki et al., 2024; Sule et al., 2020). Rising temperatures and rainfall variability have been linked to crop failures, loss of livestock, food insecurity, and increased vulnerability to climatic extremes (Ariko et al., 2024; Haruna et al., 2025).

Despite the country's vulnerability to climate change, there is a paucity of literature that captures the peculiarities of Lapai LGA. Most studies focus on national, basin, or state level, which does not consider local dynamics and community specifics (Abubakar et al., 2025; Liman et al., 2021, 2024). Additionally, Lapai LGA is an agrarian town, known for planting millet, guinea corn, maize, wheat, rice, and beans. Thus, considering the reliance of the population on agriculture and natural resources, there is a need to conduct a robust assessment

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of rainfall and temperature, focusing on the variability and trends.

Therefore, this study examines the variability and trends of rainfall and temperature in Lapai LGA of Niger State. The study employed the Coefficient of Variation to examine the monthly and annual variability, while the Seasonal Mann-Kendall was used to examine the seasonal trends of rainfall and temperature. Lastly, the Modified Mann-Kendall was used to examine the monthly and annual trends of rainfall and temperature in Lapai LGA. The results of this study will add to the scientific understanding of climate behavior in Niger State and the North-central region of Nigeria. Additionally, the study will provide actionable information for local authorities, agricultural planners, and community stakeholders to develop resilient strategies in the face of climate variability and change.

2 Materials and Methods

2.1 Study Area

The study was conducted in Lapai Local Government Area of Niger State, Nigeria. The area lies between latitude 6.20 °E and longitude 8.20 °N. It is situated at 72km from Minna. It is bordered by Agaie Local Government Area to the west, Kogi State to the South, Federal Capital and Gurara Local Government to the North (Dawodu et al., 2024). The area has an estimated population of about 200,700 and occupies a total area of about 3,051 km² (Abdulkadir & Iyanda, 2016). Lapai LGA comprises eleven Districts and each of the districts is headed by a district head. The two major languages are Nupe and Dibbo. However, some minority tribes are found in different locations scattered throughout the area. Also, the Local Government has two distinctive seasons, namely the wet and dry seasons. The wet season commences from April to October, while the dry season commences from November to March. The annual rainfall distribution pattern shows a maximum of 1300mm rainfall and a minimum of 900-1000mm. Mean maximum temperature remains high throughout the year (Dangana et al., 2015). The average minimum temperature is about 21.1 °C. People in the region are mostly farmers, and the climate conditions in the area favor the cultivation of a variety of crops (Abdulkadir et al., 2024). The main crops cultivated in the area include rice, sorghum, maize, cassava, sesame, melon, and yams. The major means of transportation are the road transport system (Ibrahim et al., 2016).

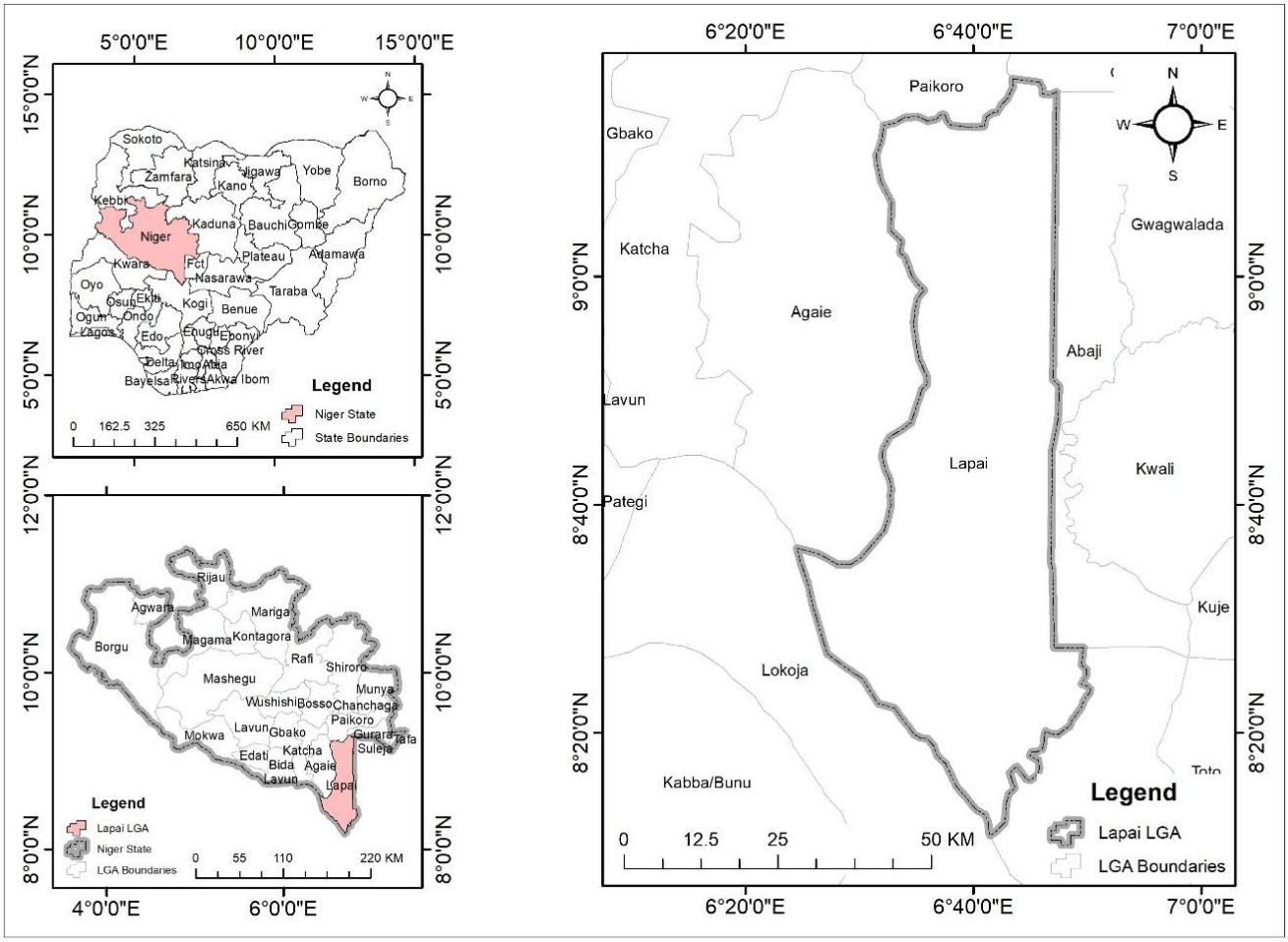


Figure 1: Location of Lapai in Niger state
Source: Modified from GRID3 - Nigeria, 2024

2.2 Data Sources

Monthly reanalysis time series of rainfall (mm), minimum temperature (Tmin), and maximum temperature (Tmax) from January 1990 to December 2025 were extracted for the grid point 8.7823°N, 6.6689°E (nearest to Lapai town centre) from NASA Power (17th January, 2026). The datasets consist of all the variables spanning 36 years (432 months), which is in line with the World Meteorological Organization (WMO) recommendation of a minimum of 30 for climatological analysis.

2.3 Data Analysis

2.3.1 Coefficient of Variation (CV)

This study employed the Coefficient of Variation to examine the interannual variability of rainfall and temperature in Lapai LGA, Niger State. This was computed using Equation (1):

$$CV = \frac{\sigma}{\bar{X}} * 100 \quad (1)$$

where σ represents the standard deviation and $\bar{X}$ denotes the average rainfall or temperature. Typically, CV values less than 20% are classified as low, values from 20% to 30% as moderate, values from 30% to 40% as high, and values exceeding 40% as very high (Asfaw et al., 2018; Haruna et al., 2025). The CV was computed using the hydroTSM package (v 0.7-0.1) in R Studio.

2.3.2 Modified Mann-Kendall (MMK) trend test

The modified MK provides improved accuracy for trend detection in time series data by adjusting the variance of the test statistic using an effective sample size (Hamed & Ramachandra Rao, 1998). The modified VAR(S) statistic is calculated using Equation (2):

$$VAR(S) = \left(\frac{n(n-1)(2n+5)}{18}\right).\left(\frac{n}{n_e^*}\right) \quad (2)$$

Here, the correction factor $\left(\frac{n}{n_e^*}\right)$ is adjusted to the autocorrelated data using Equation (3):

$$\left(\frac{n}{n_e^*}\right) = 1 + \left(\frac{2}{n^3 - 3n^2 + 2n}\right)\sum_{f=1}^{n-1}(n-f)(n-f-2)\rho_e(f) \quad (3)$$

where $\rho_e(f)$ represents the autocorrelation function between the ranks of the observations and can be estimated using Equation (4):

$$\rho(f) = 2sin\left(\frac{\pi}{6}\,\rho_e(f)\right) \quad (4)$$

2.3.3 Sen's slope

Sen's slope is a nonparametric approach that is frequently employed to identify slope trends in hydrometeorological datasets (Bekele et al., 2017; Gocic & Trajkovic, 2013). It was developed by Sen (1968) and calculated using Equation (5):

$$f(t) = Qt + B \quad (5)$$

In Equation (5), Qt represents the slope, whereas B represents a constant. To calculate the slope (Q), the slopes (values) of the data were calculated using Equation (6) below:

$$Q_i = \frac{X_j - X_k}{j - k} \quad (6)$$

where Xj and Xk represent the data values at intervals j and k (j > k). If each interval has a single datum, then N = n(n-1)/2, where n is the number of data points. If there are several observations in one or more periods, then N < (n(n-1))/2. Sen's slope estimator is computed using Equation (7):

$$Q_{med} = \begin{cases} Q * \left[\frac{(N+1)}{2}\right], if\ N\ is\ odd \\ \frac{Q * \left[\frac{N}{2}\right] + Q * \left[\frac{(N+2)}{2}\right]}{2}, if\ N\ is\ even \end{cases} \quad (7)$$

Finally, Q_{med} is used with a nonparametric model to calculate the trend and slope magnitude. A positive Qi implies an uptrend, whereas a negative Qi suggests a downtrend. Similarly, a score of zero indicates that no trend is detected.

2.3.4 Change-Point Detection

This study used Pettitt's homogeneity tests to detect changepoint in rainfall and temperature in Lapai LGA. The Pettitt's test is capable of revealing changes that occur in the data, hence improving the overall comprehensiveness of the study (Kabbilawsh et al., 2023). As a nonparametric test, the PT is applied to identify changepoints in time series without requiring any assumptions on the pattern of distribution of the time series (Pettitt, 1979). Thus, the premise is based on the notion that observations are autonomous and evenly distributed over time (Yozgatligil & Yazici, 2016; Zhou et al., 2019).

2.3.5 Standardized Anomaly Index (SAI)

This study used the SAI to identify extremely dry and extremely wet years for rainfall in Lapai, Niger State. The SAI was computed using Equation (8):

$$SAI = \frac{X - \bar{X}}{\sigma} \quad (8)$$

Where X is the annual value of rainfall, $\bar{X}$ represent the long-term mean, and σ is the standard deviation. The thresholds for the SAI are presented in Table 1.

Table 1: SAI Classification

SAI Value	Classification
> 1.65	Extremely Wet
1.0 to 1.64	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderate Drought
-1.5 to -1.65	Severe Drought
< -1.65	Extreme Drought

3 Results and Discussion

3.1 Coefficient of Variation

The result of the annual variability of rainfall, maximum, and minimum temperature is shown in Table 2.

Table 2: Annual variability of rainfall, maximum (Tmax), and minimum temperature (Tmax)

Variable	Minimum	Maximum	Mean	Std. deviation	CV
Rainfall	365.400	1937.350	1239.647	331.064	26.71
Tmax	34.590	42.680	38.677	2.371	6.13
Tmin	9.930	16.760	13.179	1.429	10.84

From Table 2, rainfall had the highest variability, with the minimum of 365.4 mm recorded in 1999, and the highest value of 1,937 mm recorded in 1995. The mean annual rainfall was 1,239.65 mm, with a standard deviation of 331.06 mm. The coefficient of variation was 26.7%, indicating moderate interannual variability over the study period. Maximum temperature ranged from 34.59 °C to 42.68 °C, with a mean Tmax of 38.67 °C, and a standard deviation of 2.37 °C. The CV was 6.13%, indicating low variability. The minimum temperature also ranged from 9.93 °C to 16.76 °C, with a mean of 13.18 °C, and a standard deviation of 1.43 °C. The CV was 10.8%, indicating low variability.

3.2 Trends of rainfall and temperature in Lapai

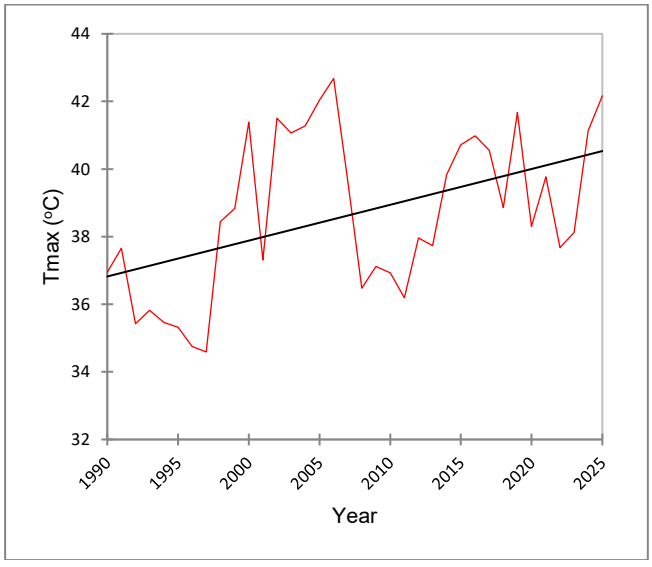
3.2.1 Trends for the Mean Annual Rainfall, Maximum and Minimum Temperature

The Modified MK was used to examine the trend of rainfall and temperature in Lapai, Niger State. The result is shown in Table 3.

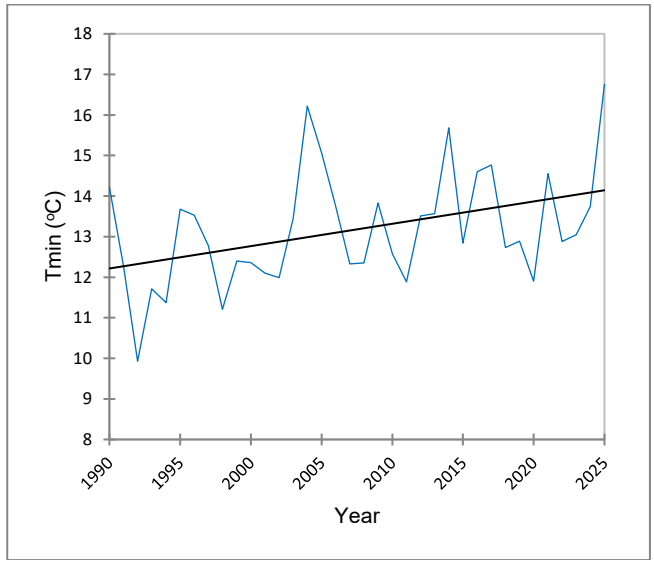
Table 3: Annual trend of rainfall, maximum, and minimum temperature in Lapai

	Rainfall	Tmax	Tmin
Z	-2.49	2.27	2.37
Kendall's tau	-0.29	0.31	0.28
S	-184.00	196.00	175.00
Var(S)	5390.00	7360.75	5389.00
p-value (Two-tailed)	0.01	0.02	0.02
alpha	0.05	0.05	0.05
Sen's Slope	-10.35	0.11	0.05

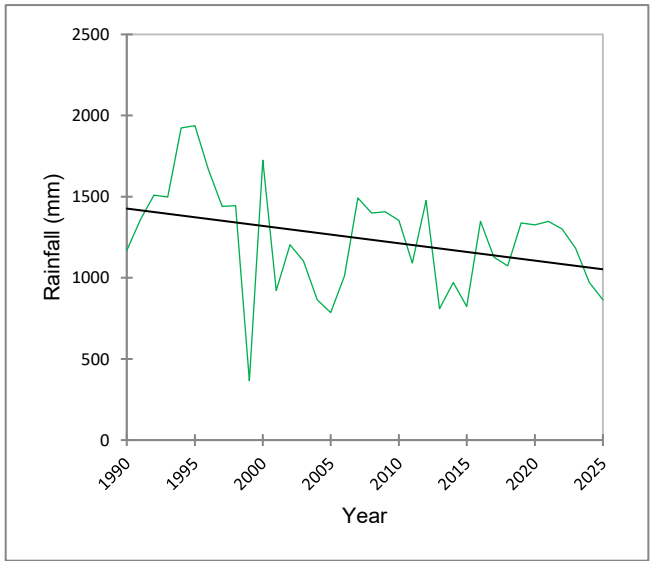
Table 3 revealed that rainfall had a significant decreasing trend ($Z = -2.49$, Kendall's $\tau = -0.29$, $S = -184$, two-tailed $p = 0.01$), declining by 10.35 mm per year. This indicates a gradual, but consistent decline over time. On the contrary, both maximum temperature (Tmax) and minimum temperature (Tmin) exhibited significantly increasing trends (Tmax: $Z = 2.27$, $\tau = 0.31$, $S = 196$, $p = 0.02$; Tmin: $Z = 2.37$, $\tau = 0.28$, $S = 175$, $p = 0.02$). However, Tmax increased by 0.11 °C/year, while Tmin increased at a slower rate of 0.05 °C/year. This suggests increasingly hotter days and warm nights. This is illustrated in Figure 2.



a) Tmax



b) Tmin



c) rainfall

Figure 2: Annual trends of rainfall, maximum, and minimum temperature in Lapai

3.2.2 Seasonal Trend of Rainfall and Temperature

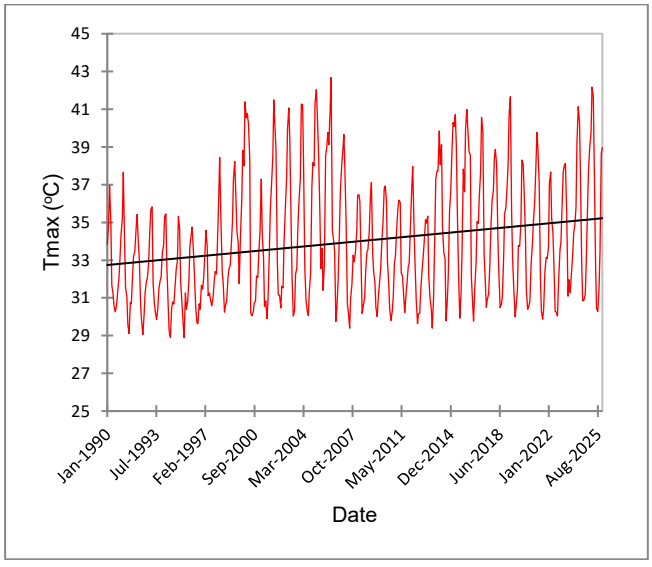
The Seasonal Mann-Kendall was used to examine the seasonal trends of rainfall, maximum, and minimum temperature in Lapai. The result is shown in Table 4 and Figure 3.

Table 4: Seasonal trends of rainfall, maximum, and minimum temperature in Lapai

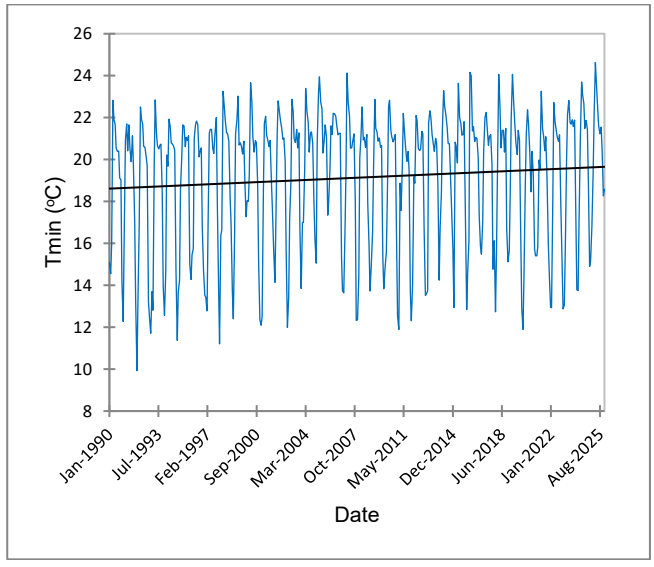
Metric	Rainfall	Tmax	Tmin
Kendall's tau	-0.133	0.310	0.182
S'	-993.000	2345.000	1378.000
Var(S')	106898.667	250134.000	142156.333
p-value (Two-tailed)	0.002	< 0.0001	0.000
alpha	0.05	0.05	0.05
Sen's Slope	-0.323	0.086	0.023

Table 4 revealed that seasonal rainfall exhibited a statistically significant decreasing trend (Kendall's τ = -0.133, p = 0.002), with Sen's slope indicating a mean decrease of -0.323 mm per season, suggesting long-term

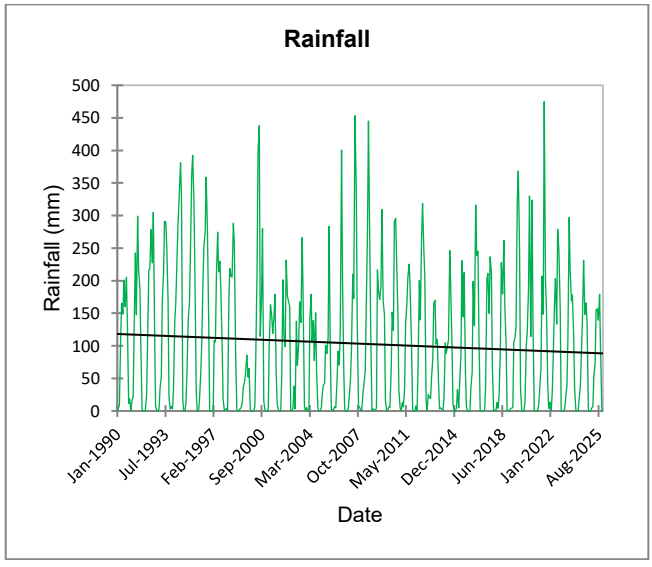
drying. Maximum temperature also exhibited a significantly increasing trend ($\tau = 0.310$, $p < 0.0001$), with Sen's slope indicating an increase of 0.086 °C per season. Minimum temperature also significantly increased ($\tau = 0.182$, $p = 0.000$), with Sen's slope indicating a moderate increase of 0.023 °C per season.



a) Tmax



b) Tmin



c) rainfall

Figure 3: Seasonal trends of rainfall, maximum, and minimum temperature in Lapai

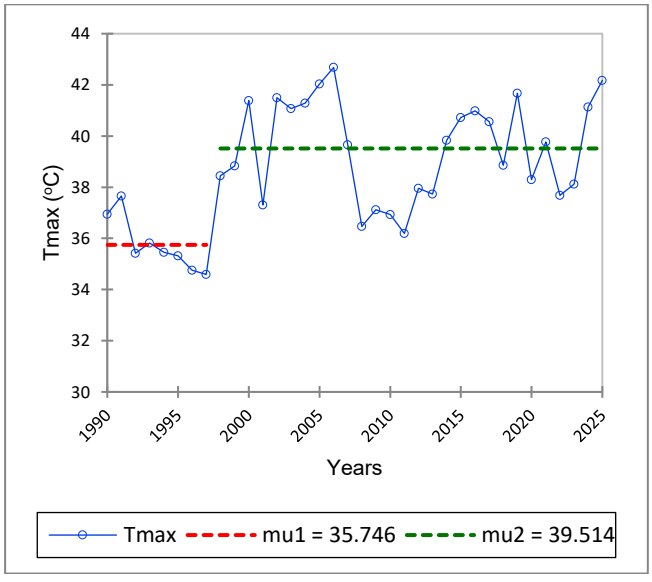
3.3 Changepoint Detection

The Pettitt's test was used to examine the homogeneity of rainfall and temperature in Lapai. The result is shown in Table 5 and Figure 4.

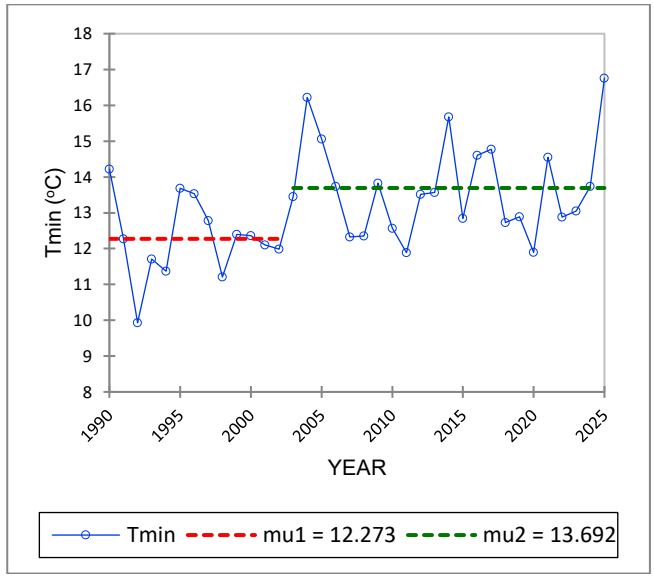
Table 5: Change-point detection for rainfall and temperature in Lapai

	Rainfall	Tmax	Tmin
K	189.000	208.000	177.000
t	1998	1997	2002
p-value (Two-tailed)	0.020	0.006	0.034
alpha	0.05	0.05	0.05

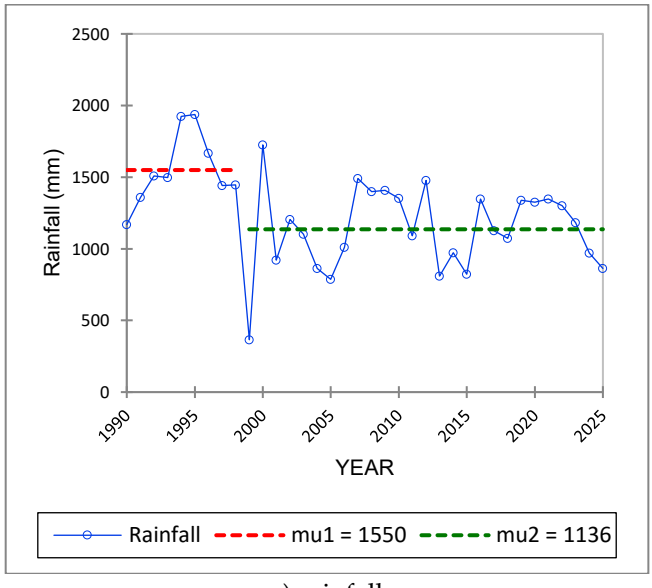
Table 5 revealed that Annual rainfall had a significant abrupt shift in 1998, with a test statistic (K = 189, p=0.020). This is linked to the shift in precipitation level (the lowest rainfall was recorded in 1999). Similarly, Tmax experienced an abrupt shift in 1997 (K=208, t=1997, p=0.006), consistent with an increase in maximum temperatures starting from 1997. The Tmin had a changepoint detected in 2002 (K=177, t=2002, p=0.034), indicating a significant increase in warm nights beginning in 2002.



a) Tmax



b) Tmin



c) rainfall

Figure 4: Pettitt's test for annual rainfall, maximum, and minimum temperature in Lapai

3.4 Standardized Anomaly Index

From Figure 5, the Standardized Anomaly Index (SAI) revealed significant variability in annual rainfall between 1990 and 2025. Extreme positive anomalies were recorded in 1994 (2.06), 1995 (2.11), 1996 (1.29), and 2000 (1.46), which indicates that rainfall in these years was significantly wetter-than-normal. However, significant negative anomalies were recorded in 1999 (−2.64), 2004 (−1.14), 2005 (−1.37), 2013 (−1.30), 2015 (−1.26), and 2025 (−1.14), indicating extreme dry conditions compared to the long-term average. The lowest anomaly was recorded in 1999, although the 1990s experienced sustained wet conditions.

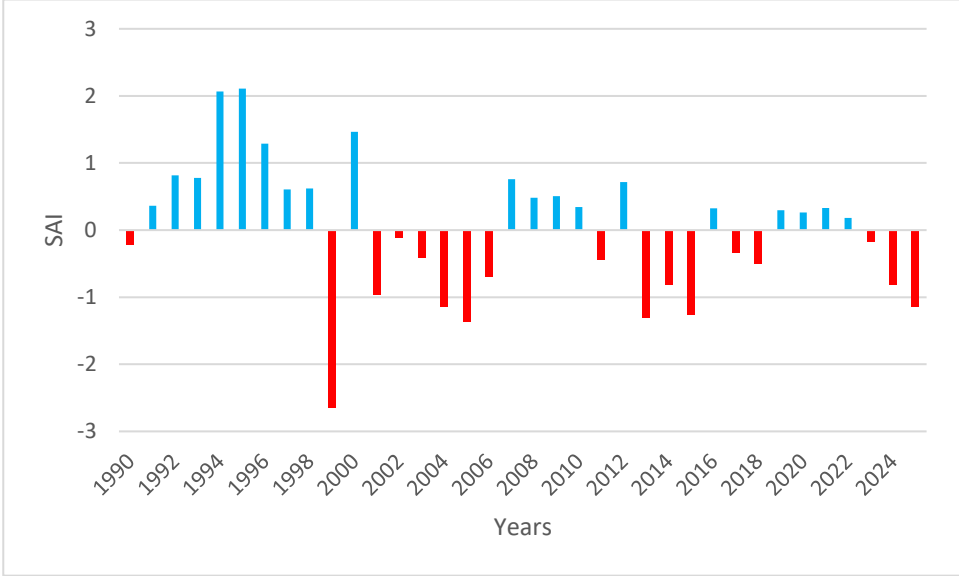


Figure 5: Standardized Anomaly Index for annual rainfall

4 Discussion

The results reveal strong evidence of climate variability and change in Lapai LGA between 1990 and 2025. The coefficient of variation (CV) shows that rainfall has moderate interannual variability (CV = 26.7%), while Tmax has low interannual variability (6.13%) and Tmin has low interannual variability (10.8%). This is in agreement with climate behavior in the Guinea Savannah region, where rainfall is more variable than temperature due to its dependency on monsoonal circulation dynamics (Asfaw et al., 2018; Bekele et al., 2017). The moderate interannual variability of rainfall in this region shows that although the amount of rainfall is within the expected range (900-1300 mm), its interannual variability is sufficiently high to affect agricultural activities in the region. The same rainfall variability has been observed in other parts of northern and central Nigeria, where interannual variability of rainfall is sufficiently high to affect crop yield (Ariko et al., 2024; Sule et al., 2020).

The Modified MK revealed a significant decrease in rainfall of 10.35 mm per annum. This decrease is significant in the region, considering its mean annual rainfall. The decline is consistent with other studies that report declining rainfall in northern Nigeria (Bello et al., 2025), as well as regional assessments of increasing aridity across West Africa (Daramola et al., 2023). Considering the reliance of most households in Lapai on rainfed agriculture, continuous decline will increase soil moisture stress, reduced growing season, and increase the frequency of agricultural drought (Abubakar et al., 2024; Morakinyo et al., 2024; Shiru et al., 2018).

However, Maximum and minimum temperatures are characterized by increasing trends. Maximum temperature increases by 0.11 °C annually, while maximum temperature increases by 0.05 °C annually. This agrees with the findings of Ahmad et al. (2025), who reported an increase in temperatures in northern Nigeria. Similarly, the IPCC (2023) projected an increase in temperatures in Nigeria and the rest of the sub-Saharan region of Africa. Thus, increasing maximum temperatures suggests intensified heating during the day, which could lead to higher evapotranspiration and soil moisture deficit (García-García et al., 2023), coupled with decreasing rainfall. Increase in temperature directly affects pests' reproduction, survival, spread, and population dynamics as well as the relationships between pests and the environment (Skendžić et al., 2021), and it is also associated with the health vulnerability experienced in the northern part of Nigeria (Ahmed et al., 2024).

The seasonal trends results support these findings. The Seasonal MK revealed a significantly decreasing trend ($\tau = -0.133$, $p = 0.002$), with increasing trends of maximum and minimum temperatures. The decline suggests that the decrease is not unique to isolated periods, but highlights consistent seasonal drying. Given that the annual rainfall in Lapai spans from April to October, the decrease during the growing season can have a negative impact on agriculture. Similar seasonal rainfall declines have been observed in other parts of northern Nigeria, where delayed onsets and early cessation have become increasingly common (Haruna et al., 2025; Abubakar et al., 2025). The simultaneous seasonal increase in Tmax (0.086°C per season) and Tmin (0.023°C per season) underscores the intensification of thermal conditions throughout the year.

The Pettitt's test revealed significant change points were detected in rainfall (1998), Tmax (1997), and Tmin (2002). The rainfall shift in 1998 closely follows the extreme negative anomaly recorded in 1999, indicating a transition toward a relatively drier regime. This period coincides with broader West African rainfall fluctuations influenced by variability in the West African Monsoon system and

Atlantic sea surface temperatures (Datti et al., 2025). The shift in maximum temperature in 1997 and minimum temperature in 2002 suggests regime transitions toward warmer conditions. Several studies reported that global precipitation changes are becoming more intense due to climate change. Specifically, Tahroudi (2025) reported that these changes involve shifts in the statistical characteristics of precipitation data over time, including potential alterations in their fundamental distributions. Thus, the temporal alignment of rainfall decline and temperature rise suggests a development of warming–drying spells in Lapai.

The result of the Standardized Anomaly Index (SAI) revealed alternating wet and dry regimes, with extremely wet periods dominating the mid-1990s and extremely dry conditions evident in 1999 and years after 2000. The prevalence of negative rainfall anomalies in the 2000s and 2010s supports the declining rainfall trend observed in the MMK test results. Conversely, Tmax anomalies show a prevalence of positive values after 2000, while Tmin shows increasingly strong positive values in recent years, especially in 2025. This supports the global warming trends observed by the IPCC (2023) and the evidence of intensification of heat conditions in Nigeria (Ahmad et al., 2025).

Thus, in conclusion, our findings have indicated that there has been a decrease in rainfall and an increase in minimum and maximum temperatures between the years 1990 and 2025 in Lapai. This supports the IPCC (2022) projections that there will be an experience of drought and high temperatures in the region under Sub-Saharan Africa. For a rural settlement such as Lapai, these observed changes in temperature and rainfall amounts might have important implications for agriculture (Ideki et al., 2024; Omokaro, 2025). The agreement between the various methods for evaluating variability (CV and SAI), trend detection (MMK and Sen's slope), and structural change detection (Pettitt test) lends support to the observed patterns as representing real climatic change processes and not short-term variability.

5 Conclusion

The study examined variability and trends of rainfall, minimum and maximum temperatures in Lapai LGA from 1990 to 2025. The study revealed moderate rainfall variability, with alternating wet and dry periods, and significantly increasing temperatures. The trends can significantly impact the livelihoods of the locals by posing risks to rainfed agriculture, reduced water availability, intensified heat stress, and increased exposure to climatic extremes. This could undermine food security, household incomes, and the resilience of the rural, agrarian population. Therefore, this study recommends the adoption of climate-smart agriculture and the promotion of drought-resistant and early-maturing crops. There is also a need for improved water conservation techniques, small-scale irrigation, agroforestry integration, and enhanced extension services. Stakeholders should prioritize evidence-based interventions in line with national climate policies. Further research should incorporate projected scenarios and vulnerability assessments targeting people whose livelihoods are reliant on rainfed agriculture.

References

Abdulkadir, M., & Iyanda, Y. T. (2016). Growth Dynamics of Land Use/ Cover Change and Spatial Distribution Pattern in Lapai, Niger State, Nigeria. Geo-Studies Forum: An International Journal of Environmental and Policy Issues, 8(2), 95–107.

Abdulkadir, M., Usman, A. I., & Suleiman, H. (2024). Impact of Fuel Subsidy Removal on Vehicular Asset Depreciation in Minna Metopolis, Niger State, Nigeria. Sokoto Journal of Geographical Studies, 1(1), 127–143. https://doi.org/10.46609/ijsser.2024.v09i01.002

Abubakar, M. L., Ahmed, M. S., & Abdussalam, A. F. (2024). Assessment of Agricultural Drought Using Vegetation Condition Index and Vegetation Health Index in Niger River Basin, Nigeria. Geosfera Indonesia, 9(2), 101–121. https://doi.org/10.19184/geosi.v9i2.45185

Abubakar, M. L., Ahmed, M. S., Ashiru, U.-K. A., Ahmed, M., Mohammed, R. Z., & Abdussalam, A. F. (2025). Assessment of spatiotemporal rainfall variability over the Niger Delta region, Nigeria: implications for water resource management. Hydrological Sciences Journal, 70(10), 1571–1584. https://doi.org/10.1080/02626667.2025.2496279

Achite, M., Ceribasi, G., Wałęga, A., Ceyhunlu, A. I., Elshaboury, N., Krakauer, N., Hartani, T., Caloiero, T., & Gul, S. (2023). Analysis of monthly average precipitation of Wadi Ouahrane basin in Algeria by using the ITRA, ITPAM, and TPS methods. Environmental Monitoring and Assessment, 195(5). https://doi.org/10.1007/s10661-023-11236-3

Ahmad, M., Ahmed, A. M., Ariko, J. D., & Abdulkadir, H. (2025). Trends of Extreme Temperature and Rainfall Using Innovative Trend Analysis in Kaduna State, Nigeria. FUDMA Journal of Sciences (FJS), 9(11), 407–420.

Ahmed, M. S., Abubakar, M. L., Lawal, A. I., & Richifa, K. I. (2024). Influence of extreme temperature on adverse pregnancy outcomes in Kaduna State, Nigeria. Science World Journal, 19(2), 409–417. https://doi.org/10.4314/swj.v19i2.17

Ariko, J. D., Elisha, I., & Sawa Bulus, A. (2024). Analysis of Rainfall Trend and its Relationship with Sorghum Yield in Sudan Savanna Region of Nigeria. International Journal of Scientific Research in Multidisciplinary Studies, 10(3), 34–44.

Asfaw, A., Simane, B., Hassen, A., & Bantider, A. (2018). Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. Weather and Climate Extremes, 19, 29–41.

Bekele, D., Alamirew, T., Kebede, A., Zeleke, G., & Melese, A. M. (2017). Analysis of rainfall trend and variability for

agricultural water management in Awash River Basin, Ethiopia. Journal of Water and Climate Change, 8(1), 127–141. https://doi.org/10.2166/WCC.2016.044

Bello, N., Garba, H., & Ako, A. A. (2025). Rainfall and Temperature Trends in Kaduna North and Their Implications for Water Resources. UMYU Scientifica, 4(2), 285–297. https://doi.org/10.56919/usci.2542.028

Dangana, K., Asiribo-Sallau, O. R., & Halilu, P. H. (2015). Vegetation Cover Change Detection of Lapai Niger State, Nigeria Using Remote Sensing Image. Ethiopian Journal of Environmental Studies & Management, 8(2), 855–873.

Daramola, M. T., Eresanya, E. O., & Erhabor, S. C. (2023). How has aridity changed over West Africa in the past four decades? Journal of African Earth Sciences, 197, 104745.

Datti, A. D., Zeng, G., Monerie, P.-A., Oo, K. T., & Chen, C. (2025). A Review of the arctic-West African monsoon nexus: How arctic sea ice decline influences monsoon system. Theoretical and Applied Climatology, 156(1), 9.

Dawodu, I. A., Ndukwu, R., Lamidi, S., & Ike, C. (2024). Exploring the Geomorphological Nature and its Consequences in Agaie & Lapai L Gas of Niger State and Environment Using GIS & LandSat-8 Imagery. Journal of Environmental Impact and Management Policy, 46, 30–41. https://doi.org/10.55529/jeimp.46.30.41

García-García, A., Cuesta-Valero, F. J., Miralles, D. G., Mahecha, M. D., Quaas, J., Reichstein, M., Zscheischler, J., & Peng, J. (2023). Soil heat extremes can outpace air temperature extremes. Nature Climate Change, 13(11), 1237–1241. https://doi.org/10.1038/s41558-023-01812-3

Gocic, M., & Trajkovic, S. (2013). Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. Global and Planetary Change, 100, 172–182.

GRID3 - Nigeria. (2024). Geo-Referenced Infrastructure and Demographic Data for Development. National Space Research and Development Agency. http://grid3.gov.ng/

Hamed, K. H., & Ramachandra Rao, A. (1998). A modified Mann-Kendall trend test for autocorrelated data. Journal of Hydrology, 204(1–4), 182–196.

Haruna, M., Muhammad, R. Z., & Abubakar, M. L. (2025). Assessment of climate variability and meteorological drought in Lere, Kaduna State, Nigeria. Science World Journal, 20(1), 78–88. https://doi.org/10.4314/swj.v20i1.11

Huang, S., Jiang, F., Dong, Q., Yu, J., Fan, K., Wang, Z., Hao, S., & Qiao, Y. (2025). The impact of climate change induced extreme weather events on microbial dynamics and public health: an in-depth review on water quality and ecosystem resilience. Frontiers in Environmental Science, 13(December), 1–22. https://doi.org/10.3389/fenvs.2025.1674490

Ibrahim, F., Ibrahim, P., Odine, A., Jirgi, A., Usman, R., Ogaji, A., & Gbanguba, A. (2016). Impact of Climate Change on Soybean Production in Lapai Local Government Area of Niger State. Asian Journal of Agricultural Extension, Economics & Sociology, 10(1), 1–6.

Ideki, O., Nwaerema, P., & Abali, T. P. (2024). Effect of Climate Variability on Crop Yield in Nigeria (1980-2020). European Journal of Applied Sciences, 12(1), 290–302.

IPCC. (2022). IPCC Sixth Assessment Report: Summary for Policymakers.

IPCC. (2023). Sections. In H. Lee & J. Romero (Eds.), Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 42–66).

Kabbilawsh, P., Kumar, D. S., & Chithra, N. R. (2023). Assessment of temporal homogeneity of long-term rainfall time-series datasets by applying classical homogeneity tests. Environment, Development and Sustainability, 1–45.

Liman, H. M., Nwaerema, P., & Dangana, K. (2024). Analysis of soil and ambient air temperature: Implication for sustainable agricultural practice in Lapai Town, Niger State, Nigeria. Discovery Nature, 1(e8dn1033), 1–8. https://doi.org/10.54905/disssi.v1i2.e8dn1033

Liman, H. M., Nwaerema, P., & Yisa, J. (2021). Impact of Climate Variability on Reservoir Based Hydro-Power Generation in Jebba Dam, Niger State, Nigeria. Hydro Science & Marine Engineering, 3(1), 1–6. https://doi.org/10.30564/hsme.v3i1.2795

Morakinyo, T. E., Ishola, K. A., Eresanya, E. O., Daramola, M. T., & Balogun, I. A. (2024). Spatio-temporal characteristics of Heat stress over Nigeria using evaluated ERA5-HEAT reanalysis data. Weather and Climate Extremes, 45, 100704.

Nazeri Tahroudi, M. (2025). Comprehensive global assessment of precipitation trend and pattern variability considering their distribution dynamics. Scientific Reports, 15(1), 22458.

Omokaro, G. O. (2025). Multi-impacts of climate change and mitigation strategies in Nigeria: agricultural production and food security. Science in One Health, 4, 100113. https://doi.org/10.1016/J.SOH.2025.100113

Pettitt, A. N. (1979). A Non-Parametric Approach to the Change-Point Problem. Applied Statistics, 28(2), 126. https://doi.org/10.2307/2346729

Sen, P. K. (1968). Estimates of the Regression Coefficient Based on Kendall's Tau. Journal of the American Statistical Association, 63(324), 1379–1389.

Shiru, M. S., Shahid, S., Alias, N., & Chung, E. S. (2018). Trend Analysis of Droughts during Crop Growing Seasons of Nigeria. Sustainability, 10(3), 871. https://doi.org/10.3390/SU10030871

Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The Impact of Climate Change on Agricultural Insect Pests. Insects, 12(5), 440. https://doi.org/10.3390/insects12050440

Sule, I. M., Ibrahim, I., Mayaki, J., & Saidu, S. (2020). Effects of Climate Variability on Crop Yield and its Implications for Smallholder Farmers and Precision Agriculture in Guinea Savanna of Nigeria. Journal of Geography, Environment and Earth Science International, 24(10), 1–13.

Yozgatligil, C., & Yazici, C. (2016). Comparison of homogeneity tests for temperature using a simulation study. International Journal of Climatology, 36(1), 62–81.

Zhou, C., van Nooijen, R., Kolechkina, A., & Hrachowitz, M. (2019). Comparative analysis of nonparametric change-point detectors commonly used in hydrology. Hydrological Sciences Journal, 64(14), 1690–1710.