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TREND AND VARIABILITY OF RAINFALL IN KADUNA USING INNOVATIVE TREND ANALYSIS: IMPLICATIONS FOR CLIMATE RESILIENCE AND LIVELIHOOD SUSTAINABILITY

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ABSTRACT
Climate variability influences the livelihoods of millions of people in sub-Saharan Africa, and it has been linked to food security in the region. This study assessed the trends and variability of rainfall and temperature in Kaduna State. Climate data was obtained from the Nigerian Meteorological Agency. The data were analyzed using Coefficient of Variation (CV), Modified Mann-Kendall (MMK), Seasonal Mann-Kendall (SMK), and Innovative Trend Analysis (ITA), which effectively detects these trends and seasonal fluctuations, providing deeper insights into the state's climate dynamics. Results revealed that annual and monthly rainfall was characterized by moderate variability (CV), while annual and monthly minimum and maximum temperatures exhibited low variability (CV<20%). For the trend analysis, the MMK revealed annual and monthly rainfall experienced non-significant decreasing trends (p>0.05), while the Seasonal Mann-Kendall (SMK) test indicated significantly decreasing trends in seasonal rainfall ($p < 0.05$). However, the ITA detected significantly decreasing rainfall at annual and monthly timescales. The Modified Mann-Kendall (MMK) test and Innovative Trend Analysis (ITA) both detected significant increasing trends in minimum and maximum temperatures in Kaduna ($p < 0.05$) at annual and monthly timescales. The study concluded that while rainfall is decreasing in the study area, both minimum and maximum temperatures are significantly increasing. The findings highlight the challenges posed by changing rainfall patterns, emphasizing the need for adaptive strategies to enhance climate resilience, particularly for agriculture-dependent communities. The study recommended that there is a need for increased stakeholder engagement to enhance the adaptation and climate resilience of millions of people whose livelihoods depend on rainfed agriculture in Kaduna State.

Keywords: Rainfall trend, Innovative Trend Analysis (ITA), climate resilience, livelihood sustainability, seasonal patterns.

INTRODUCTION
The Intergovernmental Panel on Climate Change (IPCC) defined climate variability as variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) (IPCC, 2018). In most locations worldwide, climate variability has become an obstacle to attaining the Sustainable Development Goals (Bitew & Minale, 2025). This is because climate variability induces temperature and precipitation changes that significantly impact the natural environment and multiple socioeconomic aspects of life (Abubakar et al., 2024). Increased human activities, especially the burning of fossil fuels have increased greenhouse gas levels disrupted global precipitation patterns, and shifted average temperatures (Bilgili et al., 2024; Wang & Azam, 2024). Temperature and rainfall are essential climatic variables that influence a region's socioeconomic activity (Ani et al., 2022; Asfaw et al., 2018). Communities and individuals dependent on rain-fed agriculture face significant risks from variation in climatic parameters (Ariko et al., 2024; Baba et al., 2024). Furthermore, the increasing variability of temperatures poses serious challenges to various sectors, particularly agriculture, where the persistence of hotter temperatures in both the short and long term could impact crop yields, water demand, and the abundance of pests (Zenda et al., 2024).

Climatic extreme events from natural variability in the climate system can reduce economic output and growth, especially in less developed parts of the world (IPCC, 2022). Recently, studies have linked climatic extreme events due to climate change to conflicts over rapidly depleting resources (Ayanlade et al., 2022). A common example of this is the constant and often deadly struggle between crop farmers, who are the residents, and migrating cattle herders (Efobi et al., 2025). The IPCC (2022a) added that increasing climate variability has exposed millions of people to acute food insecurity and reduced water security in many African communities. Many social groups already exhibit high vulnerability to existing climatic variability, especially among the poorest and socially marginalized segments of the population in developing countries (Ngcamu, 2023). Apart from agriculture, climate variability influences the distribution and transmission of some diseases (Tidman et al., 2021) and several other biophysical and social factors (Feyissa et al., 2018), especially in tropical regions.

In Nigeria, like in most sub-Saharan countries, climate variability is recognized as one of the most complex environmental issues today (Hordofa & Yazew, 2023). This climate variability is more pronounced in the arid and semi-arid regions, compared to the southern region with higher rainfall (Umar et al., 2019). Thus, economic impacts attributable to climate variability and climate change are increasingly affecting people's livelihoods and are causing economic and societal disruptions across national boundaries (Calvin et al., 2023). Studies have shown that the country faces environmental challenges linked to climate change and variability and their effects (Okon et al., 2021). Current evidence confirms that rural populations are more susceptible to the effects of climate variability and extreme weather events (Amare & Balana, 2023).

Kaduna State is a major agricultural hub in northern Nigeria, cultivating a diverse array of crops across the region (Abubakar et al., 2024). Additionally, the Kaduna State Bureau of Statistics

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(2018) indicated that 1.3 million households in Kaduna engage in agriculture, with about 90% relying on rainfed agriculture for their livelihood. Thus, temperature and rainfall variations would affect their livelihoods. Despite the clear evidence that climate variability poses a major threat to human existence, most climate-related studies in Kaduna state have not examined its implications for communities. Therefore, this study seeks to fill that gap

The findings of this study can provide valuable insights into the trends and variabilities of rainfall and minimum and maximum temperatures in Kaduna, as well as discuss their implications for sustainable livelihoods. This is particularly important when developing tailored adaptation strategies. Policymakers and development practitioners can use this information to design and implement locally relevant and effective adaptation options.

MATERIALS AND METHODS

Study Area

Kaduna State is located in the northwestern geopolitical zone of Nigeria. It lies between latitudes 8° 59' 9" N and 11° 31' 53" N and longitudes 6°4' 28" E and 8° 49' 54" E (Abubakar et al., 2024). It has borders with Zamfara, Katsina, and Kano to the north; Bauchi and Plateau to the east; Nasarawa to the south; and Niger to the west (Figure 1). According to the Koppen classification, Kaduna has a tropical savanna climate (*Aw*) characterized by alternating wet and dry conditions (Musa & Abubakar, 2024). The dry season runs from October to April of the following year, while the rainy season extends from April through mid-October, peaking in August with an annual average of 1323 mm. The relative humidity typically ranges between 25% and 90%, depending on the month of the year, with the lowest humidity between December and February (Abubakar et al., 2024).

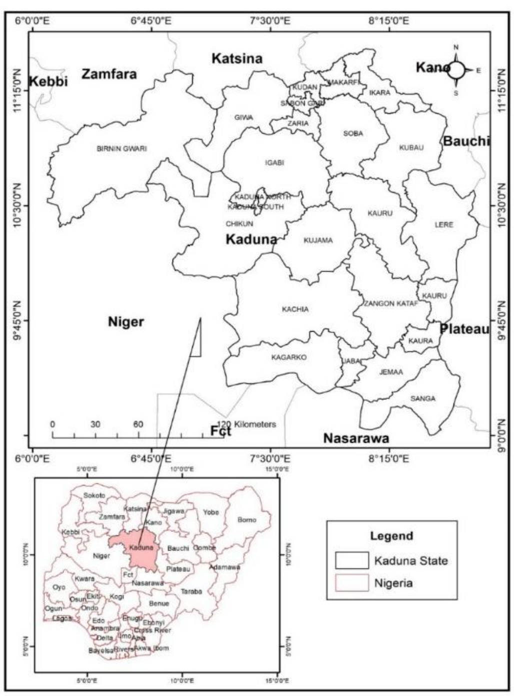


Figure 1: Map of Nigeria Showing Kaduna State
Source: Adopted from GRID3

The area lies within the Northern Guinea Savannah zone and is characterized by grassland vegetation consisting of tall grasses, scattered trees, and gallery forests. Fringe forests, "*Kurmi*" in Hausa in some localities, are presently at the mercy of increasing demands for fuel wood in the fast-growing towns and urban centres (Mohammed et al., 2024). The soil in Kaduna State is typically reddish-brown to reddish-yellow tropical ferruginous soil, which is developed primarily from granites and gneisses as parent material (Saleh, 2015). The soil also forms on many sedimentary deposits (Musa & Abubakar, 2024).

According to Jibril et al. (2024), the underlying geology of Kaduna is mainly metamorphic rocks, which include biotite gneisses and older granites. However, Jurassic ring complexes and batholiths may be observed around Sanga in the southeast. The drainage network is predominantly tributary to the Niger via the Kaduna and Gurara Rivers. Downcutting by rivers is most active in the southern and western margins of the Kaduna Plains. The most extensive floodplains are associated with the Kaduna River in the south; they are mostly too narrow to be shown on small-scale maps or are absent (Jibril et al., 2024).

Kaduna State has a projected population of 10.4 million (Kaduna Bureau of Statistics, 2015). Kaduna is blessed with rich agricultural lands, with many crops produced along the Kaduna River and its tributaries cutting through the metropolis (Bununu et al., 2015). Kaduna also has plenty of commercial and manufacturing industries such as automobile, iron works, fertilizers, furniture, and cable industries, among others. Kaduna has plenty of commercial and manufacturing industries such as automobile, iron works, fertilizers, furniture, and cable industries, among others (Saleh, 2015). Kaduna is blessed with rich agricultural lands, with many crops produced along the Kaduna River and its tributaries cutting through the metropolis (Saleh, 2015). Historically, migrating farmers were encouraged to settle in Kaduna during the colonial period to curb food shortages (Shehu, 2011). Furthermore, the favourable climate, fertile soil, and the Kaduna River are encouraging urban agriculture in Kaduna.

Data Sources

Climate data was obtained from the Central Forecasting Office (CFO) of the Nigerian Meteorological Agency (NiMet). The dataset was provided in comma-delimited (.csv) format, and Rosner Test on R was used to check for outliers. The rainfall data was used to analyze patterns and trends between 1990 and 2023.

Data Analysis

Rainfall Variability

The coefficient of variation (CV) was used to compute the annual and seasonal variability of rainfall in the NRB. The HydroTSM package developed by Zambrano-Bigiarini (2010) was used. The CV was calculated using equation (1):

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

where the standard deviation is denoted by σ and $\bar{x}$ is the mean rainfall. Values below 20% indicate low variability, values ranging from 20% to 30% indicate moderate variability, values between 30% to 40% indicate high variability, and values above 40% indicate very high variability (Bekele et al., 2017; Haruna et al., 2025).

Modified Mann–Kendall test

The MMK improves the accuracy of trend identification in time series data by using an appropriate sample size to modify the variance of the test statistics (Abubakar et al., 2025b; Hamed & Ramachandra Rao, 1998). The MMK was computed using a modifiedmk package developed by Patakamuri and O'Brien (2017). Equation (2) was used to calculate the modified VAR(S) statistic:

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

Using this, the correction factor $\left(\frac{n}{n_e^*}\right)$ is modified to the autocorrelated time series as shown in Equation (3):

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

$\rho_e(f)$ denotes the autocorrelation between the ranks of the observations. It is estimated via Equation (4):

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

Innovative Trend Analysis

This nonparametric innovative trend analysis (ITA) technique was developed by Şen (2012). In contrast to the Mann–Kendall method, this test does not require the data's normal distribution and is not affected by serial correlation in time series. According to Abubakar et al. (2025a), the ITA method allows for the identification of both monotonic and subtle trends in a time series dataset, as well as various trend combinations across different periods within the series. Two equal subseries are created from the time series data and then arranged in ascending order. The subseries are displayed on the X and Y axes, respectively, using the Cartesian coordinate system (Getnet et al., 2023). The time series show a monotonic trend or no trend if the depicted data are dispersed over the ideal 45° line (1:1). When data points are concentrated below the ideal line, the trend indicates a decline, whereas when data are clustered above the ideal line, the trend suggests an increase (Abubakar et al., 2025b). There is no trend if the scatter points are concentrated along the trend line. The S_{ITA} was determined via equation (5).

$$S_{ITA} = \frac{2}{n}(\bar{x}_2 - \bar{x}_1) \quad (5)$$

where *n* is the total size of the data event and $\bar{x}1$ and $\bar{x}2$ are the means of the 1st and 2nd subseries, respectively..

To ascertain the ITA's significance, a probability distribution function (PDF) was applied using Equation (6).

$$CL_{(1-\alpha)} = 0 \pm S_{ITA^{\sigma s}} \quad (6)$$

where CL represents the confidence limit of the ITA slope, taking into account the confidence interval of the standard normal probability density function (PDF) with a mean of 0 and a standard deviation (σs) at the α significance level. The Standardized Indicator of Test Accuracy (S_{ITA}) represents the calculated rate of change of the ITA (Abubakar et al., 2025a). The null hypothesis of no slope is rejected when the S_{ITA} exceeds the significance level. The ITA computations in this study were performed using the trend package in R at a 95% confidence level.

RESULTS

Climate variability

Table 1 shows the variabilities of rainfall and minimum and maximum temperatures using the Coefficient of Variation in Kaduna.

Table 1: Annual and Monthly Variabilities of Rainfall and Temperature in Kaduna

Annual	Variable	Minimum	Maximum	Mean	Std. deviation	CV
	Rainfall	734.67	2132.88	1449.32	364.94	0.25
	Maximum	28.52	32.79	30.62	1.27	0.04
	Minimum	17.39	20.02	18.71	0.63	0.03
Monthly	Rainfall	0.00	544.02	120.78	135.65	1.12
	Maximum	25.38	38.32	30.31	2.99	0.10
	Minimum	10.06	23.10	18.71	3.21	0.17

Table 1 shows that the minimum annual rainfall in Kaduna was 734.67 mm, recorded in 2000. The ITA computations in this study were performed using the trend package in R at a 95% confidence level. The coefficient of variation calculated was 0.25 (25%), which indicates moderate variability. The lowest annual maximum temperature was 28.52 ºC, recorded in 2000, the highest was 32.79 ºC recorded in 2000. The mean maximum temperature was 30.62 ºC, with a standard deviation of 1.27 ºC. The coefficient of variation was 0.04 (4%), indicating low variability. Similarly, the lowest minimum temperature was 17.39 ºC recorded in 2000, while the highest was 20.02 ºC, recorded in 2000. The mean annual minimum temperature was 18.71 ºC, with a standard deviation of 0.63 ºC. The coefficient of variation for minimum temperature is 0.03 (3%), indicating low variability.
For the monthly variability, the lowest monthly rainfall was 0mm, while the highest was 544.02 mm. The mean monthly rainfall was 120.78 mm with a standard deviation of 135.65 mm. The coefficient of variation was 1.12 (112%), indicating very high variability. The lowest monthly maximum temperature was 25.38 ºC, and the highest was 38.32 ºC. The mean monthly maximum temperature was 30.31 ºC, with a standard deviation of 2.99 ºC. The coefficient of variation was 0.10 (10%), indicating low variability. Similarly, the lowest monthly minimum temperature was 10.06 ºC, and the maximum was 23.10 ºC. The mean monthly minimum temperature was 18.71 ºC, with a standard deviation of 3.21 ºC. The coefficient of variation was 0.17 (17%), indicating low variability.

Trend
The annual and monthly trends of rainfall, as well as minimum and maximum temperatures, were assessed using the Modified Mann-Kendall and Innovative Trend Analysis methods. The results are presented in Table 2.

Table 2: Trends of Rainfall and Temperature

Period	Variable	Z_{MMK}	p-value	SMK	S_{ITA}
Annual	Rainfall	-1.66	0.094	0.043**	↓
	Maximum Temperature	3.63*	0.000		↑
	Minimum Temperature	2.40*	0.016		↑
Monthly	Rainfall	-0.63	0.528		↓
	Maximum Temperature	2.56*	0.010		↑
	Minimum Temperature	1.71*	0.046		↑

* / ↑ Signifies a significantly increasing trend at 0.05

** / ↓ Signifies a significantly decreasing trend at 0.05

Table 2 revealed that annual rainfall experienced a non-significant decreasing trend using the Modified Mann-Kendall technique (Z_{MMK} = -1.66, p>0.05). However, the S_{ITA} detected a significantly decreasing trend of rainfall (S_{ITA} = -8.84, CL = ± 2.44). The Modified Mann-Kendall detected significantly increasing trends for maximum temperature (Z_{MMK} = 3.63, p<0.05) and minimum temperature (Z_{MMK} = 2.40, p<0.05). Similarly, the S_{ITA} detected significantly increasing trends of maximum (S_{ITA} = 0.071, CL = ± 0.006) and minimum temperatures (S_{ITA} = 0.026, CL = ± 0.005) in Kaduna. The annual and monthly trends of rainfall, as well as minimum and maximum temperatures, were assessed using the Modified Mann-Kendall and Innovative Trend Analysis methods. The results are presented in Table 2.
For the monthly trends, the Modified Mann-Kendall technique detected a decreasing trend of rainfall (Z = -0.63, p>0.05), and significantly increasing trends of maximum (Z_{MMK} = 2.56, p<0.05) and minimum temperature (Z_{MMK} = 1.71, p<0.05) in Kaduna State. The $S_{ITA,}$ however, detected a significantly decreasing trend of rainfall (S_{ITA} = -0.061, CL = ± 0.005), and significantly increasing trends in maximum (S_{ITA} = 0.003, CL = ± 0.000), and minimum temperatures (S_{ITA} = 0.002, CL = ± 0.000) in Kaduna. The Modified MK is shown in Figure 3, while the ITA result is shown in Figure 5.

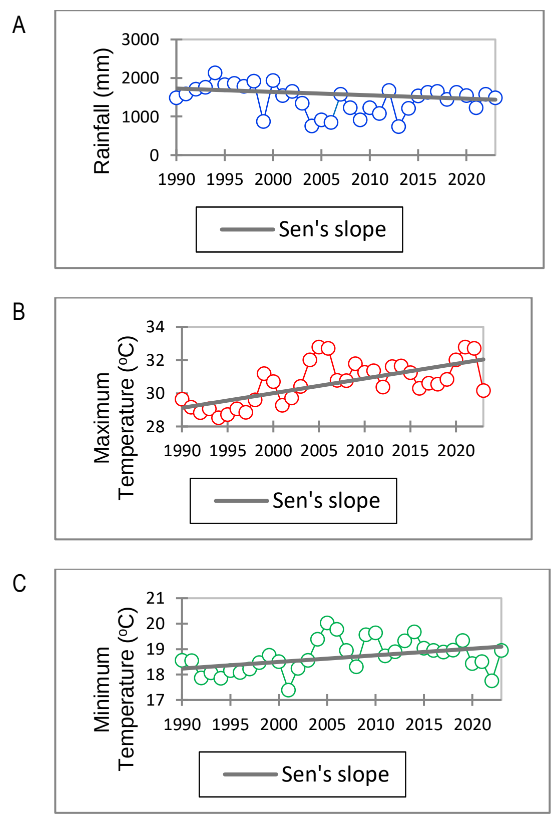
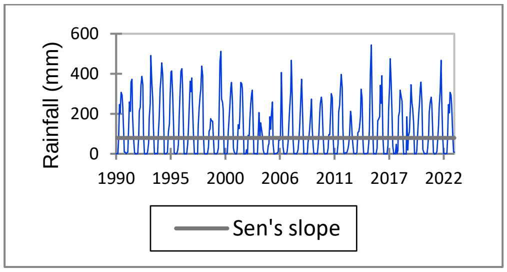


Figure 2: Annual trends of climatic variables a) Rainfall, b) Maximum temperature, and c) Minimum temperature

A


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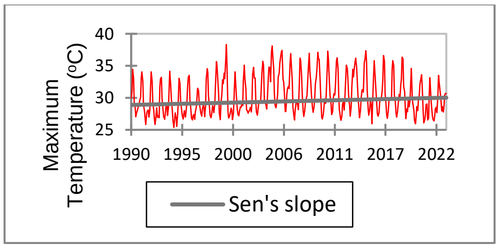

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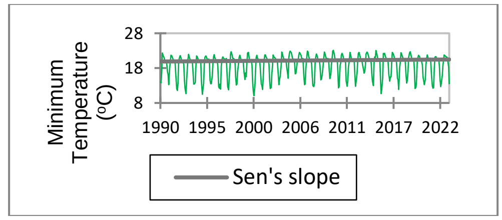
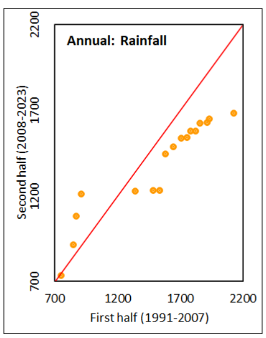
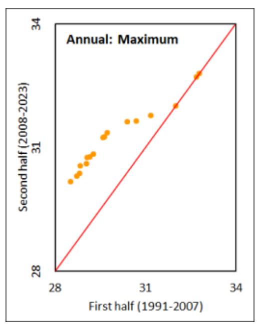


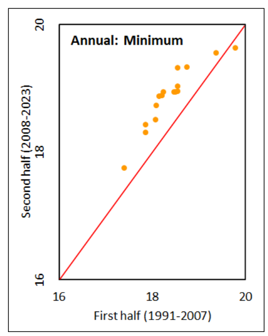
Figure 3: Monthly trends of climatic variables a) Rainfall, b) Maximum temperature, and c) Minimum temperature



a) Rainfall

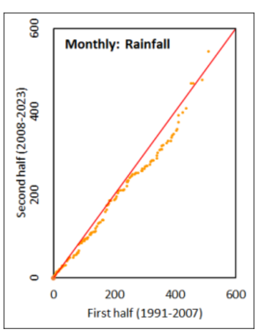


b) Maximum Temperature

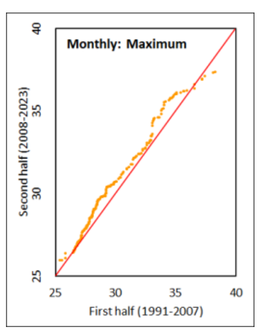


c) Minimum Temperature

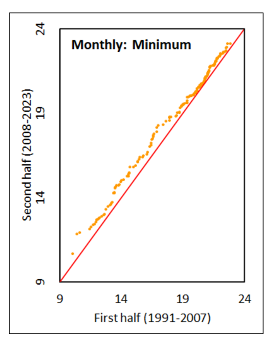
Figure 4: Annual ITA trends of climatic variables in Kaduna
Source: Author



a) Rainfall



b) Maximum Temperature



c) Minimum Temperature

Figure 5: Monthly ITA trends of climatic variables in Kaduna
Source: Author

DISCUSSION

This study assessed the annual and monthly climatic patterns in Kaduna State using rainfall and temperature time series data obtained from the NiMet. Annual rainfall exhibited moderate variability (CV = 25%), suggesting that rainfall distribution has been relatively stable over the years. This was, however, in stark contrast to the monthly rainfall distribution, which exhibited high variability (CV = 112%), indicating seasonal rainfall patterns, as some months received heavy rainfall while others experienced little to no rainfall at all. Low rainfall variability can help farmers plan their agricultural activities more effectively, as they can anticipate similar total rainfall amounts from year to year (Guido et al., 2020). The annual mean maximum and minimum temperatures were found to be relatively stable, with coefficients of variation (CV) of 4% and 3%, respectively. The monthly mean maximum and minimum temperatures exhibited moderate variability, with coefficients of variation (CV) of 10% and 17%, respectively. This means that some months experienced very high maximum temperatures (38.32 °C), while others recorded very low minimum temperatures (10.06 °C). Higher livelihood resilience among farmers helps them to adjust to temperature fluctuations using financial plans, including diversification of revenue sources or investment in technologies with climate resistance (Yang et al., 2024).

The annual rainfall trend indicated a decline, which the MMK test showed to be statistically insignificant. However, the ITA established a more pronounced decreasing pattern. Also, while the MMK test showed no significant trend in the monthly rainfall pattern, the ITA detected a decreasing trend. Decreasing rainfall can affect food production. This result agrees with the findings of Haruna et al. (2025), which revealed decreasing rainfall in parts of Kaduna State, but is in contrast with the findings of Abubakar et al. (2025a), which revealed increasing trends in annual rainfall. This could be due to the difference in the periods under study. Thus, changes in rainfall patterns can significantly impact crop yield, particularly in areas with low irrigation (Mwatu et al., 2020). Farmers may enhance their resilience by selecting drought-tolerant crops or adjusting their growing season to align with more favourable rainfall duration (Aniah et al., 2016). Therefore, the government and other stakeholders can develop policies supporting farmers through climate-smart agriculture and irrigation system subsidies (Paudel et al., 2021).

For both maximum and minimum temperatures, the MMK test detected a statistically significant increasing trend in the annual and monthly datasets. These increasing trends were both confirmed using the ITA. This result is similar to that of Muhammed et al. (2019), which found increasing trends in minimum and maximum temperatures in the region. The increasing trends of minimum and maximum temperatures can affect the livelihoods of rural communities. For example, rising temperatures alter the spatial distribution and intensity of prevailing pests and diseases, impacting livestock productivity and, in extreme cases, leading to animal mortality (Yasobant et al., 2025). For crop production, increasing trends of temperatures can cause water scarcity due to increased evapotranspiration, causing water stress and reducing crop yields (Bolan et al., 2024).

The manner of the decreasing trend in annual rainfall may suggest variability rather than a long-term change. Furthermore, the observed decline in annual rainfall can be attributed to climate variability factors such as global warming, urbanisation, and deforestation, which typically accompany the expansion of built-up areas. Kaduna State has undoubtedly witnessed massive human and infrastructural development over the years. Meanwhile, the increasing trends in both maximum and minimum temperatures can be attributed to GHG emissions, the urban heat island effect, and changes in land use.

The fact that the ITA was able to detect more significant trends using the same time series datasets further reinforced previous studies that found the ITA to be more robust and dependable in detecting trends than the MK and MMK techniques as has been determined by Abubakar et al. (2025a), Mandal et al. (2020) and Nath et al. (2024).

Conclusion

This study analyzed annual and monthly rainfall and temperature variability and trends in Kaduna State over the last 33 years (1990-2023) using the coefficient of variation, modified MK, seasonal MK, and innovative trend analysis (ITA) methods. The result of the variability studies showed that while there was a general decline in rainfall, the monthly variability (112%) was significantly greater than the annual variability (25%). Also, the annual mean maximum and minimum temperatures were found to exhibit low variability, while the monthly mean temperatures showed moderately higher variability.

The result of the trend analysis showed that the ITA was more sensitive in detecting trends when compared to the traditional MK tests. Rainfall was observed to have a decreasing trend, which was more pronounced in the ITA, while temperature (maximum and minimum) exhibited increasing trends. The findings of the study pose serious challenges to livelihoods, particularly in agriculture-dependent regions. The study also highlights the need to develop adaptation strategies such as water conservation, smart agriculture, and reforestation to help mitigate the impacts of such declining rainfall and rising temperatures. The study recommends greater stakeholder engagement to enhance the adaptation and mitigation strategies, which can significantly benefit the millions of people whose livelihoods depend on rainfed agriculture in Kaduna State.

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