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TRENDS OF EXTREME TEMPERATURE AND RAINFALL USING INNOVATIVE TREND ANALYSIS IN KADUNA STATE, NIGERIA

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ABSTRACT

This study analyzed the trends in climate extremes and their implications for the livelihoods of communities relying on rainfed agriculture in Kaduna State, Nigeria. Data on daily rainfall, minimum, and maximum temperatures were obtained from the Nigerian Meteorological Agency (NiMET) and analyzed using the RClimDex software. The trends were assessed using Innovative Trend Analysis (ITA) and the Modified Mann-Kendall (MMK) test. The results revealed decreasing rainfall trends, but increasing trends of minimum and maximum temperatures. For the temperature indices, the findings revealed a significant increasing trend for all the selected indices except for cool days (TX10 p), cool nights (TN10 p), Diurnal Temperature Range (DTR), and Cold Spell Index (CSDI), which showed a significant decreasing trend ($p<0.05$). The annual minima of daily maximum temperatures (TXn) experienced a non-significant increasing trend ($p > 0.05$). Six (6) indices revealed significantly increasing trends, while heavy precipitation days (R10 mm), total precipitation (PRCPTOT), and the Simple Daily Intensity Index (SDII) experienced significantly decreasing trends. Very heavy precipitation days (R20 mm) were not significant. These changes are likely to shorten the length of crop development, reduce yields, impair livestock productivity, and exacerbate heat stress on both humans and animals. Changing rainfall indices suggest heightened risks of flooding, erosion, soil saturation, and a shift toward a drier and more erratic rainfall regime. These results suggest an increase in climate variability, which undermines agricultural productivity, food security, and household income. The study recommends the need for adaptive approaches, such as climate-smart farming, enhanced water management, and early warning systems, to safeguard livelihoods.

Keywords: Climate Extreme Events, ETCCDI, RClimDex, Kaduna State, Livelihood

INTRODUCTION

The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC, 2023) affirmed that anthropogenic activities, primarily via greenhouse gas emissions, have definitively induced global warming, with global surface temperatures attaining 1.1 °C over the 1850–1900 baseline from 2011 to 2020. Climate change can directly influence climatic extremes by enhancing atmospheric water retention and elevating the likelihood of unprecedented global weather phenomena, including elevated temperatures, heatwaves, floods, hail, and tornadoes (Yin & Sun, 2018). These extreme climate events can adversely affect agriculture, energy, ecosystems, and human health, garnering global attention (Mistry, 2019). Consequently, numerous scholars have investigated the historical and prospective alterations of these events and the factors that instigate these changes (Javan & Movaghari, 2024; Tung et al., 2022).

A notable rising tendency of extreme temperatures is evident across the world. Nevertheless, alterations in precipitation extremes exhibit regional inconsistency, with limited statistically meaningful trends (Liang et al., 2023). Extreme rainfall intensity and frequency have continuously increased in parts of Asia, with the number of consecutive dry days decreasing in recent decades (Tung et al., 2022). In Europe, climate models predict that extreme precipitation events will become more severe across the continent, and droughts may persist for an extended period by the end of the century (Cardel et al., 2020). Also, an overview of African weather and climatic extremes in 1970–2023 by Jury (2024) highlighted regional and chronological patterns of strong dry and wet spells, connected with climatic conditions and effects. In Nigeria, Gbode et al. (2019) revealed a considerable increase in the occurrence of warm spells, warm days and nights, and a reduction in cold spells, cold days and nights across the three climatic zones. A considerable rise in annual total rainfall was also reported in various sites over the Guinea coast and Sahel zones.

Heat extremes have a significant impact on human health because they can cause dehydration and may lead to heat cramps, heat strokes, and mortality, particularly within susceptible populations like as the elderly, small children, and those with underlying diseases (Abdussalam, 2015; Ahmed, Abubakar, et al., 2024; Kunda et al., 2024). Precipitation extremes such as droughts and flooding may result in disasters such as famines and disease outbreaks, while flooding can also result in population displacement (Pizzorni et al., 2024). Consequences of climate change will differ from region to region and industry to industry. A system with greater sensitivity to climate change or variability will be more affected than one with less sensitivity (Jiang et al., 2022). A 2021 World Meteorological Organization (WMO) report found that Asia experienced the hottest year in history in 2020, having an average temperature of 1.39 °C, surpassing the 1981–2010 average. The report also noted some heat extremes in Europe, particularly a high temperature of 38.0 ºC at Verkhoyansk, Russian Federation, possibly the hottest recorded temperature ever across the Arctic Circle.

Millions of people are now facing severe food insecurity and decreased water security in many African communities due to an increase in extreme weather and climate events (IPCC, 2023). High degrees of susceptibility to current climate variability are already present in many socioeconomic groups, particularly among the poorest and most marginalized populations in developing nations (Ngcamu, 2023). There is proof that Nigeria is presently dealing with environmental issues brought on by climate change and its effects (Okon et al., 2021). Due to its higher susceptibility to drought and other meteorological extremes, as well as its lower levels of technology, socioeconomic development, and infrastructure, northern Nigeria is more sensitive to climate change than the southern regions (Farauta et al., 2011; Haider, 2019).

Using the 26 extreme temperature and precipitation indicators suggested by the Expert Team on Climate Change Detection and Indices (ETCCDI), this study attempts to investigate the features of severe temperature and precipitation in Kaduna State between 1990 and 2023. These ETCCDI indices can be grouped based on intensities, thresholds, relative thresholds, duration, etc. Additionally, the ETCCDI indices help in the computation of extreme weather events and the detection of climate change in different regions. The results of this study could significantly impact agriculture, human health, and water management in the study area. The influence on agriculture will positively contribute towards achieving Sustainable Development Goal (SDG) 2, which seeks to eradicate hunger worldwide, and also aid in achieving SDG 1 (Zero poverty). It could also aid in preparing improved early warning systems and disaster preparedness plans for the study area.

MATERIALS AND METHODS

Study Area

Kaduna State is located between Latitudes 8°57’12” N and 11°34’1” N, and between Longitudes 6°3’25” E and 8°50’13” E (Fig. 1). Wet and dry seasons are hallmarks of the state's tropical savanna climate (Aw) (Musa & Abubakar, 2024). The rainy season spans six to seven months, primarily occurring from April to October, with its highest amount in August, and has an average rainfall of roughly 1400 mm. Large dust clouds and winds from the desert to the north are characteristics of the Harmattan dry season (Abubakar, Ahmed, Abdussalam, et al., 2025). The months of March, April, and May are the hottest in Kaduna North, with highs of well over 35°C. The relative humidity typically ranges from 25% to 90% depending on the month of the year, with December and February experiencing the lowest humidity.

While the northern area of Kaduna State is Sudan Savanna, the southern portion features typical Guinea Savanna vegetation (Abubakar et al., 2024). Biotite gneisses and older granites are among the metamorphic rocks that make up the majority of Kaduna's underlying geology. Nonetheless, batholiths and Jurassic ring complexes can be seen in the southeast near Sanga (Bennett et al., 1979). In Kaduna, the majority of the soils are ferruginous and formed mainly by sedimentation and formed from granites and gneisses (Ahmad et al., 2025).

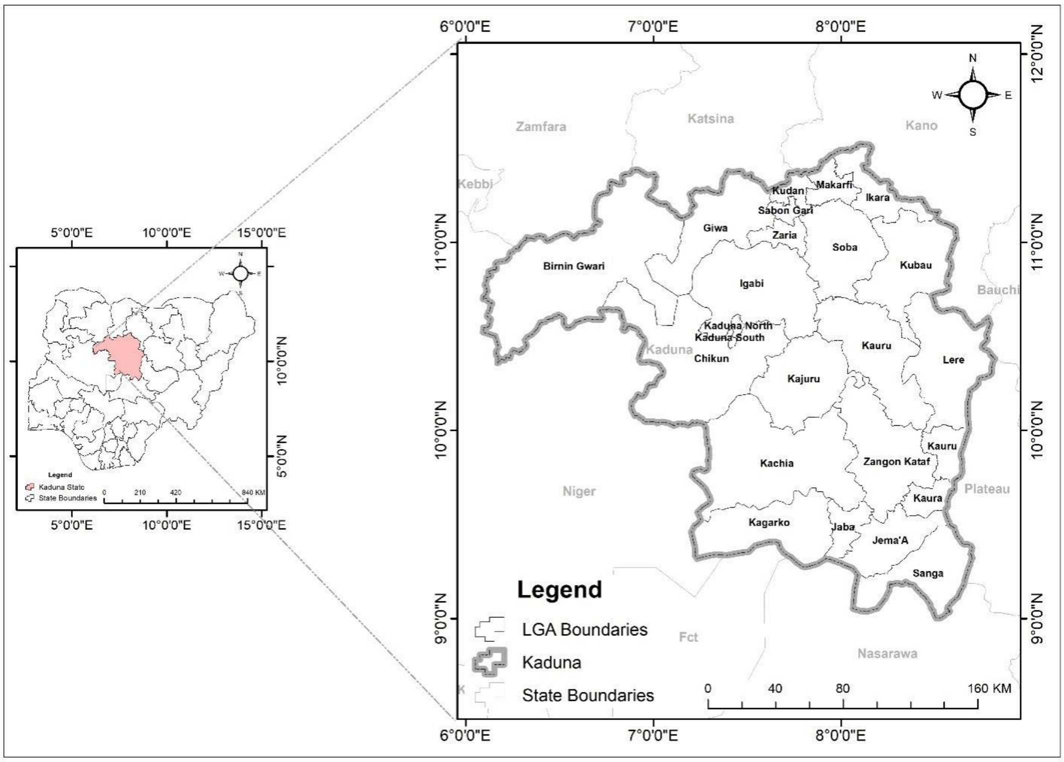


Figure 1: Nigeria showing Kaduna State
Source: Modified from GRID3 - Nigeria, 2024

Data Sources

Daily rainfall and minimum and maximum temperature records were obtained from the Nigerian Meteorological Agency (NiMET). The data was observed at the Synoptic Station located at Kaduna International Airport, covering the period between 1990 and 2023. The average of the missing values was 2.88%. These gaps were filled using the ‘*na.fill*’ function on the ‘zoo’ package on R Studio (Zeileis & Grothendieck, 2005). This method has been employed by previous researchers (Faybishenko et al., 2022; Goo et al., 2024) for filling missing time series data.

Data Analysis

Computation of Extreme Climate Indices

The duration, intensity, and frequency of extreme climate events were described using their characteristics. This study examined 23 ETCCDI-defined indices, comprising 10 precipitation and 13 temperature indices. Table 1 displays the descriptions of the 23 indices. The procedure is described in Fig. 2.

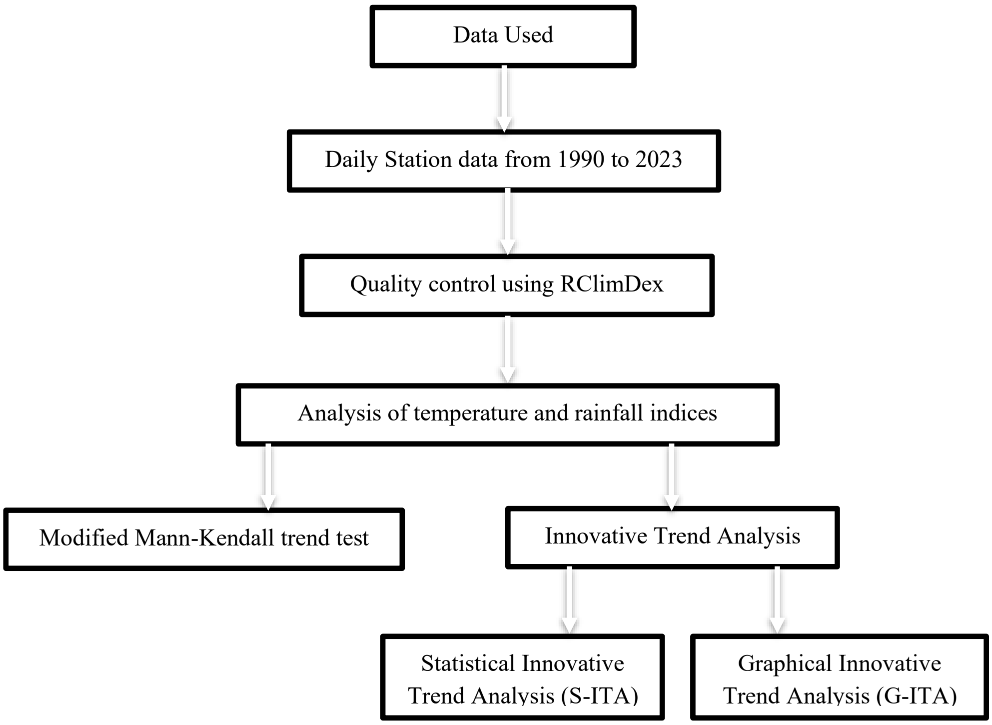


Figure 2: RClimDex User Interface Flowchart Steps to Calculate Extreme Climate Indices

Table 1: Definitions of Climate Extreme Indices and Their Influence on Livelihoods

Code	Unit	Name	Definition
TMAXmean	°C	Mean maximum temperature	Annual mean daily maximum temperature
TMINmean	°C	Mean minimum temperature	Annual mean daily minimum temperature
TXx	°C	Annual maxima of daily maximum temperature	Annual maxima value of daily maximum temperature
TNx	°C	Annual maxima of daily minimum temperature	Annual maxima value of daily minimum temperature
TXn	°C	Annual minima of daily maximum temperature	Annual minima value of daily maximum temperature
TNn	°C	Annual minima of daily minimum temperature	Annual minima value of daily minimum temperature
TN10p	%	Cold nights	Percentage of days when the daily minimum temperature <10th percentile
TX10p	%	Cold days	Percentage of days when the daily maximum temperature <10th percentile
TN90p	%	Warm nights	Percentage of days when the daily minimum temperature >90th percentile
TX90p	%	Warm days	Percentage of days when the daily maximum temperature >90th percentile
DTR	°C	Diurnal temperature range	Annual mean difference between daily max and min temperature
WSDI	d	Warm spell duration index	Annual # of days with at least 6 consecutive days when Tmax >90th percentile
CSDI	d	Cold spell duration index	Annual # of days with at least 6 consecutive days when Tmin <10th percentile
Rx1day	mm	Max 1-day precipitation amount	Annual maximum 1-day precipitation
Rx5day	mm	Max 5-day precipitation amount	Annual maximum consecutive 5-day precipitation
R95p	mm	Very wet days	Annual total precipitation from days >95th percentile
R99p	mm	Extremely wet days	Annual total precipitation from days >99th percentile
R10 mm	d	Heavy precipitation days	Annual count when precipitation ≥10 mm
R20 mm	d	Very heavy precipitation days	Annual count when precipitation ≥20 mm
CDD	d	Consecutive dry days	Maximum number of consecutive days when precipitation <1 mm

Code	Unit	Name	Definition
CWD	d	Consecutive wet days	Maximum number of consecutive days when precipitation ≥1 mm
PRCPTOT	mm	Total precipitation in wet days	Annual total precipitation from days ≥1 mm
SDII	mm	Simple daily intensity index	The ratio of annual total precipitation to the number of wet days (≥1 mm)

Modified Mann-Kendall Trend Test (MMK)
Using the "modifiedmk" package on R Studio, the Modified Mann-Kendall (MMK) was utilized to determine the importance of variations in temperature and rainfall data. The MMK gives improved precision in identifying trends in data series by correcting the variance of the tested statistic via an effective number of samples (Yue & Wang, 2004). The modified VAR(S) statistic is computed using Equation (1):

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

Here, the correction factor $\left(\frac{n}{n_e^*}\right)$ is adjusted to the autocorrelated data using Equation (2):

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

where $\rho_e(f)$ represents the autocorrelation function between the ranks of the observations and can be estimated using Equation (3):$\rho(f) = 2sin\left(\frac{\pi}{6}\,\rho_e(f)\right)$ (3)

Sen's Slope Estimator
Sen's slope estimator is a nonparametric approach that has been widely employed for estimating slope trends in data series (Bekele et al., 2017). It was developed by Sen (1968) and calculated using Equation (4):

$$f(t) = Qt + B \quad (4)$$

In Equation (4), *Qt* represents the slope, and *B* is the constant. In estimating the slope (Q), the slopes of the data series were determined using Equation (5):

$$Q_i = \frac{X_j - X_k}{j-k} \quad (5)$$

where *Xj* and *Xk* are the values of the data series for periods *j* and *k (j > k)*. If each timeframe comprises a single datum, then N = n(n-1)/2, where n is the number of data points. If there are many observations in different periods, then N < (n(n-1))/2. The estimator is determined in Equation (6):

$$Q_{med} = \begin{cases} Q * \left[\frac{(N+1)}{2}\right], if\ N\ is\ odd \\ \frac{Q*\left[\frac{N}{2}\right]+Q*\left[\frac{(N+2)}{2}\right]}{2}, if\ N\ is\ even \end{cases} \quad (6)$$

To assess the trend and slope magnitude, Q_{med} is used in conjunction with a nonparametric model. A positive Qi implies an uptrend, whereas a negative Qi suggests a downtrend. Similarly, a value of zero indicates no trend.

Innovative Trend Analysis (ITA)
Şen (2012) invented the ITA technique. In comparison to the Mann–Kendall (MK) approach, the ITA technique does not assume that the time series distribution remains normal and is not influenced by serial correlation in the time series. According to Abubakar et al. (2025a), this technique finds monotonous and sub-trends in data sets, as well as additional trend permutations across different series periods. The data is divided into two equal sub-series, which are then sorted in ascending order. The sub-series are presented on the X- and Y-axes, respectively, via a Cartesian coordinate system (Abubakar et al., 2025b). The S_{ITA} was determined using Equation (7).

$$S_{ITA} = \frac{2}{n}(\bar{x}_2 - \bar{x}_1) \quad (7)$$

where *n* is the total number of observations and $\bar{x}1$ and $\bar{x}2$ are the averages of the 1st and 2nd subseries, respectively. The trend is statistically significant if the series slope is greater (less) than the upper (lower) confidence limits (CLs). By using a probability distribution function (PDF), the significance of the ITA was evaluated using Equation (8):

$$CL_{(1-\alpha)} = 0 \pm S_{ITA^{\sigma s}} \quad (8)$$

where the standard deviation (σs) is at the level of significance of α, and where the confidence interval of the standard normal PDF has a mean of 0. S_{ITA} represents the slope of the trend evaluated by the ITA. If the S_{ITA} exceeds the significance level, the alternate hypothesis is accepted. The ITA calculations in this study were carried out via the trendchange package in R Studio following a 95% confidence level.

RESULTS AND DISCUSSION

Trends of rainfall and temperature
This study examined the trends of rainfall, minimum, and maximum temperatures in Kaduna. The result is shown in Table 2.

Table 2: Trends of Rainfall and Temperature

Period	Variable	Z_{MMK}	p-value
Annual	Rainfall	-1.66	0.094
	Maximum Temperature	3.63*	0.000
	Minimum Temperature	2.40*	0.016

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 MMK detected significantly increasing trends for maximum temperature (Z_{MMK} = 3.63, p<0.05) and minimum temperature (Z_{MMK} = 2.40, p<0.05).
Trends of climate extreme indices

Temperature Extreme Indices
Findings from the RClimDex calculation showed that the indices of daily maximum and minimum temperature of Kaduna showed a statistically significant increasing trend (P < 0.05). The result is shown in Table 3.

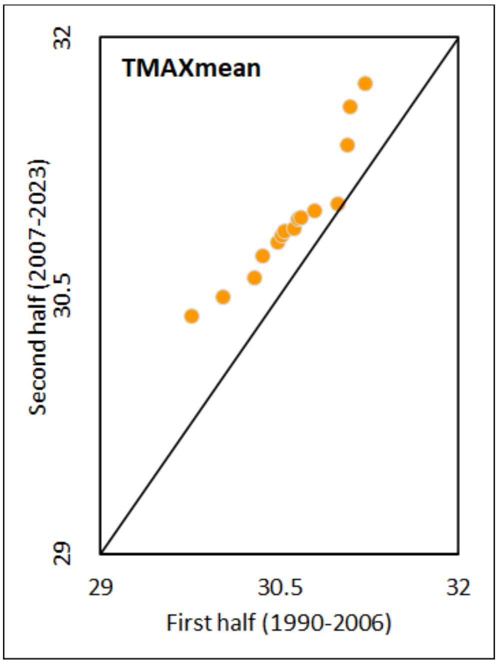
Table 3: Trends of Extreme Temperature Indices

Indices	Z	Slope	P-Value	ITA
TXx	2.47	0.019	**0.013***	▲
TNx	2.31	0.009	**0.021***	▲
TXn	0.55	0.007	0.581	▲
TNn	3.06	0.032	**0.002***	▲
TN10p	-6.10	-0.355	**< 0.0001***	▼
TX10p	-1.89	-0.163	0.059	▼
TN90p	9.23	0.620	**< 0.0001***	▲
TX90p	6.53	0.476	**< 0.0001***	▲
DTR	0.22	0.000	0.824	▼
WSDI	2.36	0.45	**0.018***	▲
CSDI	-9.86	-1.552	**< 0.0001***	▼
TMAXmean	6.18	0.028	**< 0.0001***	▲
TMINmean	11.81	0.023	**< 0.0001***	▲

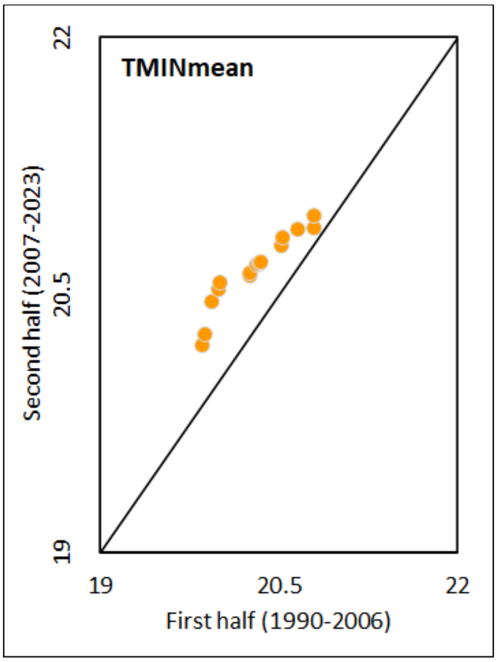
∗ = statistically significant at P ≤ 0.05, ▲ = ITA non-significantly increasing, ▲ = ITA- significantly increasing, ▼ = ITA – significantly decreasing

Mean of Annual Maximum and Minimum Temperature

The study revealed a significantly increasing trend for the mean annual maximum (TMAXmean) using ITA (S_{ITA} = 0.02, CL = ± 0.00) and MMK (Z = 6.18, p<0.05). Similarly, a significant increasing trend was detected for the mean annual minimum (TMINmean) using ITA (S_{ITA} = 0.02, CL = ± 0.00) and MMK (Z = 11.81, p<0.05) between 1990 and 202. The mean annual maximum temperature ranges from 29.77 ºC to 31.73 ºC, with a standard deviation of 0.417, while the mean annual minimum temperature ranges from 19.86 ºC to 20.96 ºC, with a standard deviation of 0.319. This result is shown in Fig. 3a and b.



a) TMAXmean

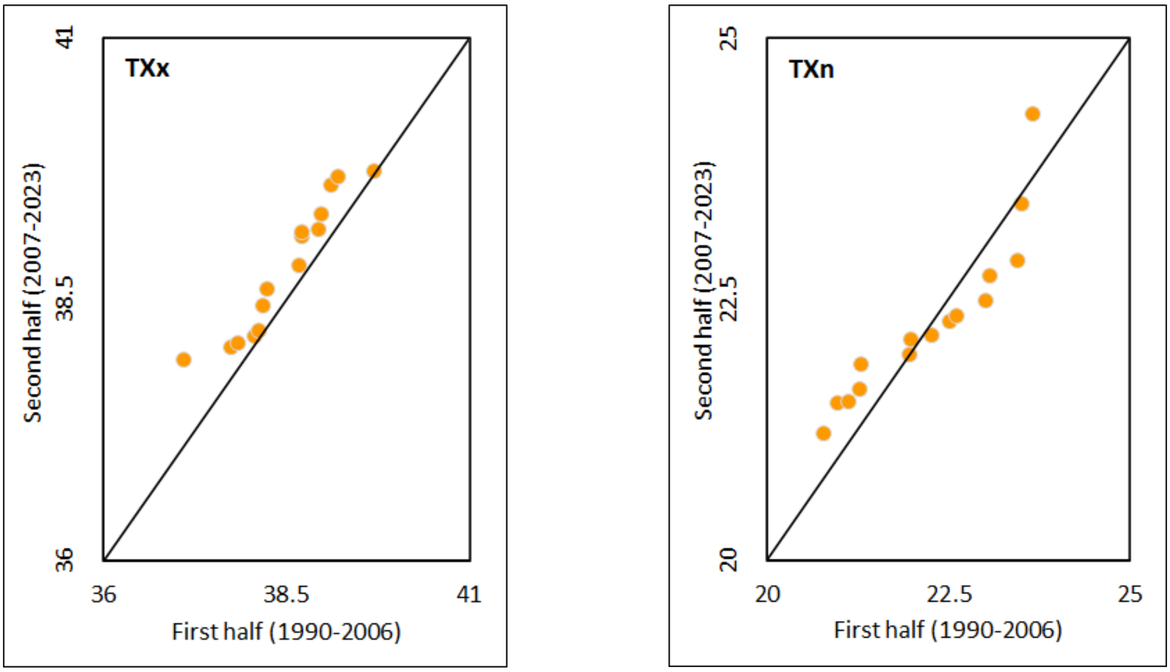


b) TMINmean

Figure 3: Mean of Annual Maximum (a) and Minimum Temperature (b)

Annual maxima and minima of daily maximum temperature

The study revealed significantly increasing trends for the annual maxima of daily maximum temperature (TXx) using ITA (S_{ITA} = 0.03, CL = ± 0.02), and MMK (Z = 2.473, p<0.05), and a non-significant increasing trend for the annual minima of daily maximum temperature (TXn) using ITA (S_{ITA} = 0.03, CL = ± 0.02), and MMK (Z = 0.552, p<0.05). The highest TXx was 39.71 °C and the lowest TXx was 37.10 °C were detected in 2019 and 1997, respectively. The standard deviation was 0.66 ºC. Whereas the highest TXn (24.27 °C) and the lowest TXn (20.78 °C) were recorded in 2016 and 1994, respectively. The standard deviation was 0.88 ºC. This result is shown in Fig. 4a and b.

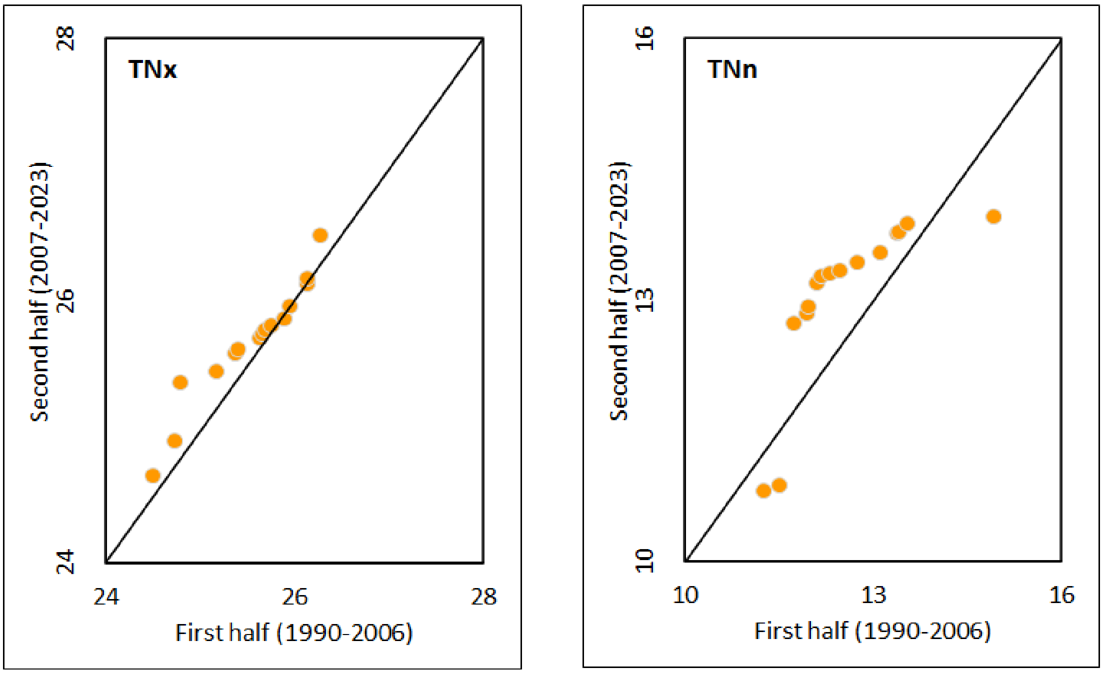


a) TXx b) TXn

Figure 4: Annual Maxima (a) and Minima of Daily Maximum Temperature (b)

Annual Maxima and Minima of Daily Minimum Temperature

The results revealed significantly increasing trends for the annual maxima of daily minimum temperature (TNx) using ITA (S_{ITA} = 0.01, CL = ± 0.00) and MMK (Z = 2.31, p<0.05). The annual minima of daily minimum temperature (TNn) were also significantly increasing using ITA (S_{ITA} = 0.03, CL = ± 0.02) and MMK (Z = 3.06, p<0.05). The highest (26.49 °C) and the lowest TNx (24.51 °C) were recorded in 2016 and 2008, respectively. The highest (14.93 °C) and the lowest TNn (10.80 °C) were recorded in 2004 and 2020, respectively. The ITA plots are shown in Fig. 5a and b.

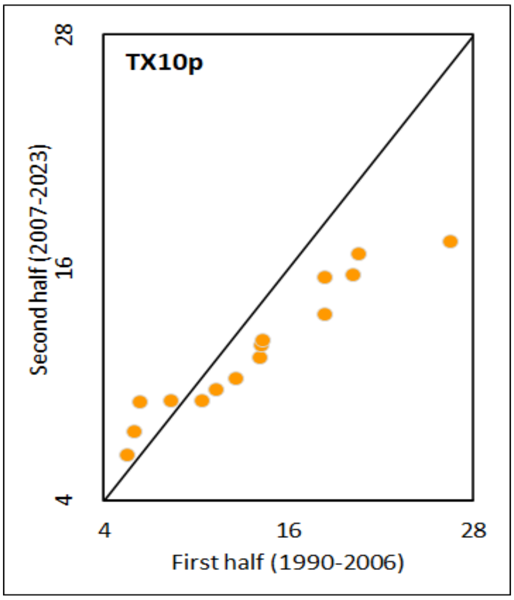


a) TNx b) TNn

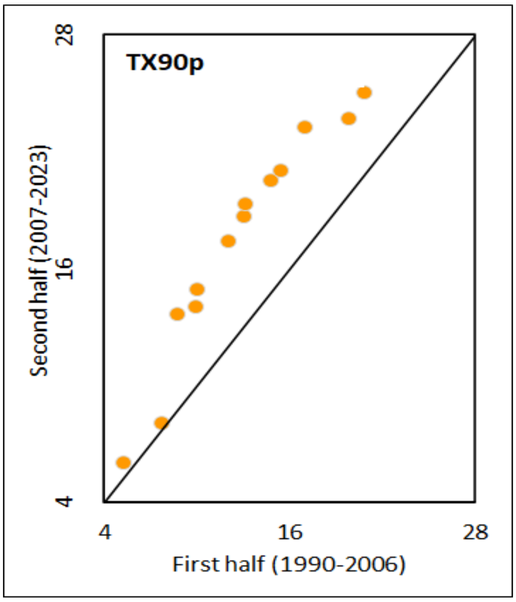
Figure 5: Annual Maxima (a) and Minima of Daily Minimum Temperature (b)

Cool Nights, Cool days, Warm Nights, and Warm Days

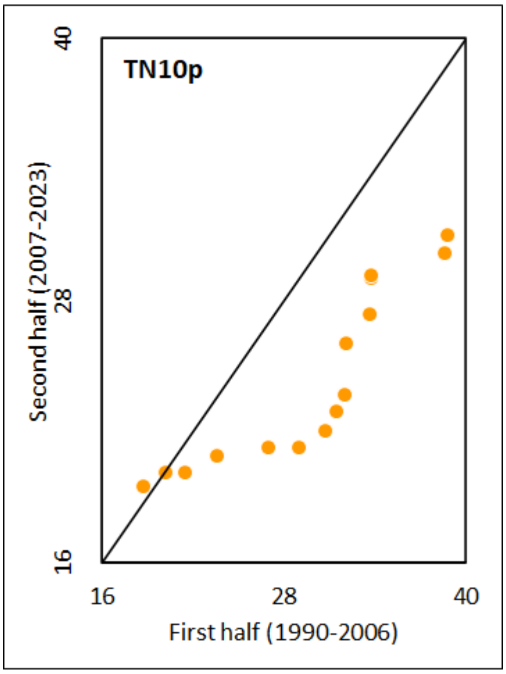
The ITA revealed a significantly increasing trend for results warm nights (TN90p) (S_{ITA} = 0.62, CL = ± 0.08), warm days (TX90p) (S_{ITA} = 0.01, CL = ± 0.00), and significantly decreasing trends for TN10p (S_{ITA} = -0.36, CL = ± 0.06) and TX10p (S_{ITA} = -0.15, CL = ± 0.03). However, the MMK revealed significantly increasing trends for TN90p (Z = 9.23, p<0.05) and TX90p (Z = 6.53, p<0.05). TN10p was significantly decreasing (Z = -6.10, p<0.05), while TX10p was not significant (Z = -1.83, p>.05) over the study period of 1990-2023. The lowest number of days with TN10p, TX10p, TN90p, and TX90p were 18.78, 5.61, 6.12, and 5.31, respectively, recorded in 2005, 2005, 2001, and 1997. The highest number of days with TN10p, TX10p, TN90p, and TX90p were 38.79, 26.57, 40.07, and 42.03, respectively, recorded in 2000, 1994, 2023, and 2021. This result is shown in Fig. 6a, b, c, and d.



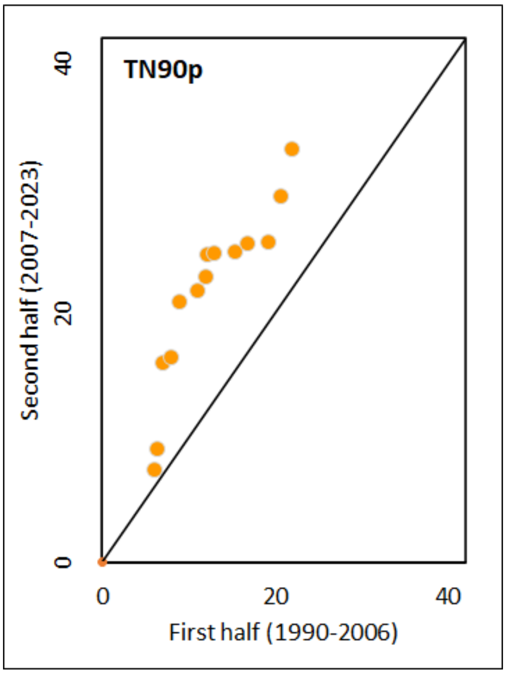
a) TX10P



b) TX90P



c) TN10P

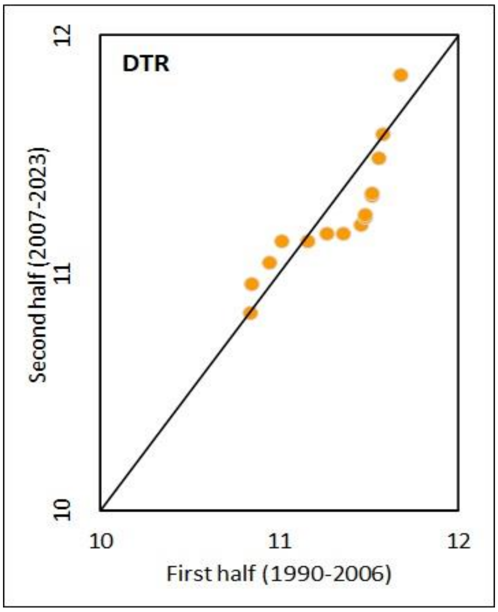


d) TN90P

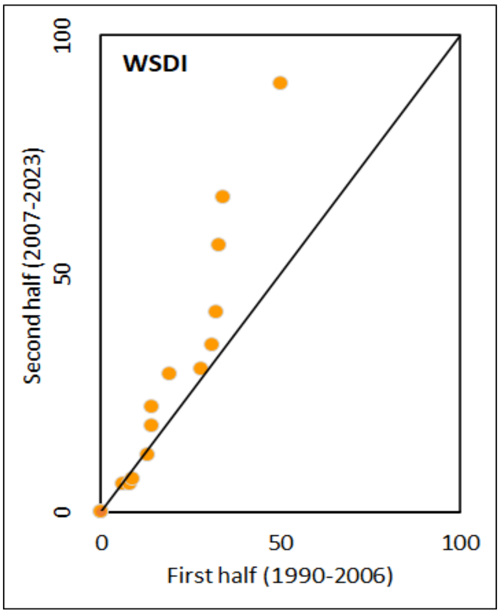
Figure 6: Trends in Annual Cool Days (a), Warm Days (b), Cool Nights (c), and Warm Nights (d)

Diurnal Temperature Ranges, Warm and Cold Spell Durations

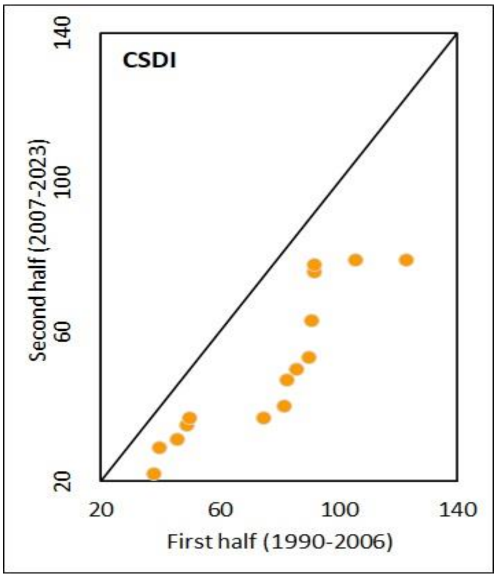
The ITA revealed a significantly increasing trend for WSDI ($S_{ITA} = 0.57$, CL = ± 0.15), and significantly decreasing trends for CSDI ($S_{ITA} = -1.72$, CL = ± 0.29) and DTR ($S_{ITA} = 0.00$, CL = ± 0.00). The MMK results revealed that cold spells (CSDI) experienced a decreasing trend, while warm spells (WSDI) experienced an increasing trend. Both are statistically significant ($p<0.05$). However, the diurnal temperature range (DTR) experienced a non-significant increasing trend ($p>0.05$). The highest (123) and lowest (22) CSDI were recorded in 2010 and 2000, respectively. The DTR ranged from the highest (11.83 ºC) to the lowest (10.83 ºC), recorded in 2021 and 2019, respectively. Lastly, the highest WSDI (90) was recorded in 2021, while the lowest (0) was recorded in 1997, 1995, 2013, and 2018. This is shown in Fig. 7a, b, and c.



a) DTR



b) WSDI



c) CSDI

Figure 7: Diurnal Temperature Ranges (a), Warm Spell (b), and Cold Spell (c) Durations

Rainfall extreme indices

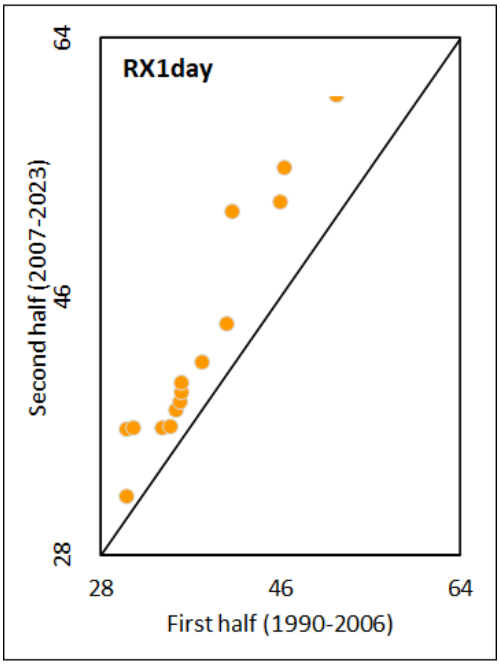
This section presents the results of the rainfall extremes computed using Rclimdex in Kaduna. The results are shown in Table 4 and Fig. 8.

Table 4: Trends of Extreme Rainfall Indices

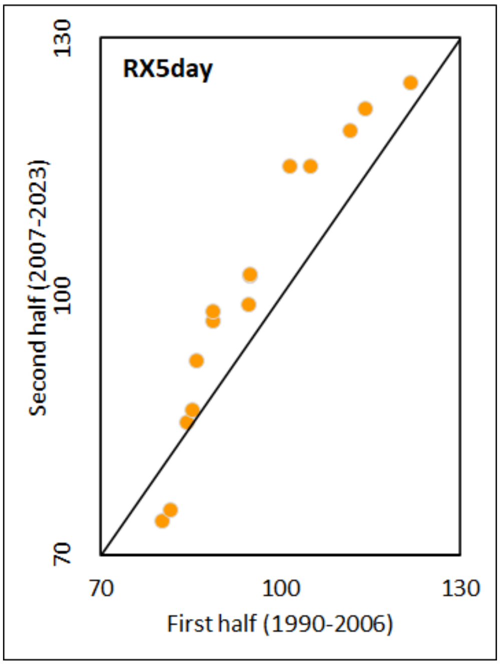
Indices	Z	Slope	P-Value	ITA
Rx1day	8.771	0.300	**< 0.0001***	▲
Rx5day	3.813	0.717	**0.000***	▲
R95p	2.757	1.528	**0.006***	▲
R99p	6.836	1.911	**< 0.0001***	▲
R10 mm	-0.545	-0.038	0.586	▼
R20 mm	-1.693	0.000	0.090	▼
CDD	1.988	0.250	**0.047***	▲
CWD	2.056	0.053	**0.040***	▲
PRCPTOT	-1.343	-1.386	0.179	▼
SDII	-2.006	-0.017	**0.045***	▼

∗ = statistically significant at P ≤ 0.05, ▼ = ITA non-significantly decreasing, ▲ = ITA- significantly increasing, ▼ = ITA – significantly decreasing

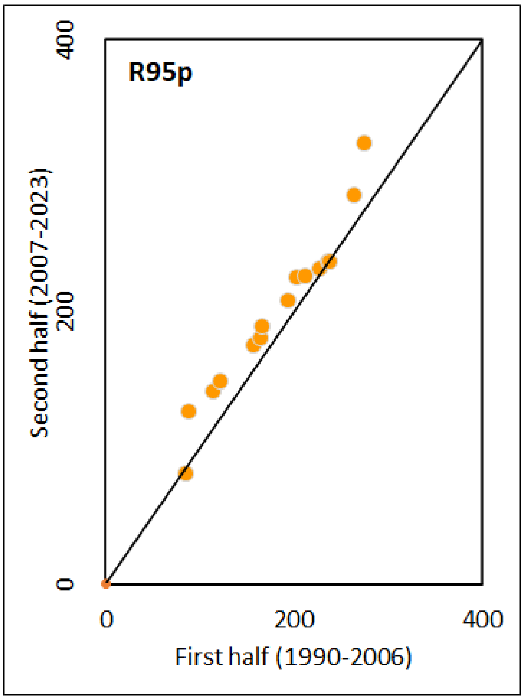
Using the ITA, significant increasing trends were detected for Rx1day (S_{ITA} = 0.31, CL = ± 0.05), Rx5day (S_{ITA} = 0.33, CL = ± 0.11), R95p (S_{ITA} = 1.16, CL = ± 0.34), R99p (S_{ITA} = 1.60, CL = ± 0.33), CDD (S_{ITA} = 0.67, CL = ± 0.10), and CWD (S_{ITA} = 0.14, CL = ± 0.04). Significantly decreasing trends were detected for R10mm (S_{ITA} = -0.12, CL = ± 0.03), PRCPTOT (S_{ITA} = -2.32, CL = ± 0.76), and SDII (S_{ITA} = -0.03, CL = ± 0.00). However, R20mm (S_{ITA} = -1.72, CL = ± 0.29) was not significant. For the MMK, the result showed significant trends in RX1day, RX5day, r95p, r99p, CDD, CWD, and SDII ($p<0.05$), while non-significant trends were detected in R10mm, R20mm, and PRCPTOT ($p>0.05$) (Table 4). The highest and lowest values of: RX1day (60.02 and 30.62 mm), Rx5day (124.78 and 73.83 mm), R95p (324.10 and 81.10 days), R99p (148.50and 0 days), R10mm (52 and 33 days), R20mm (17 and 0 days), CDD (177 and 93 days), CWD (22 and 7 days), PROCTOT (1352.30 and 977.10 mm) and SDII (11.0 and 7.60 mm) were recorded in the year: 2019 and 1996, 2023 and 2012, 2020 and 2016, 2023 and 1999, 2010 and 2013, 2010 and 1995, 2000 and 1993, 2020 and recently in 2021 and 1996, 2007 and 2008, 1997 and 2013, and lastly, 1996 and 2013, respectively (Fig. 8a-j).



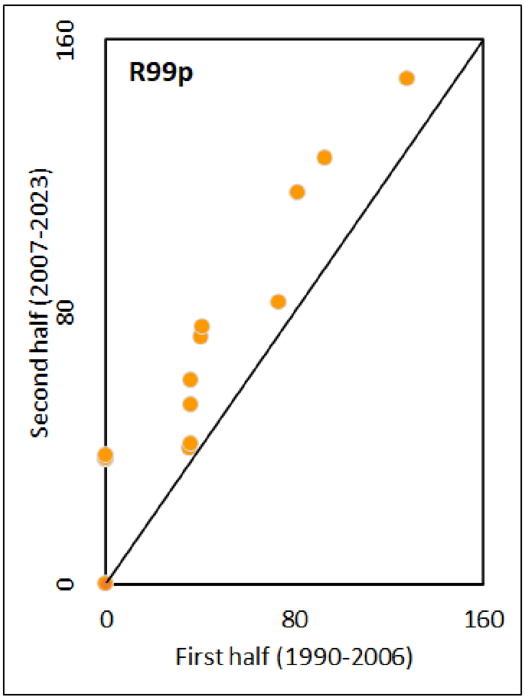
a) Rx1day



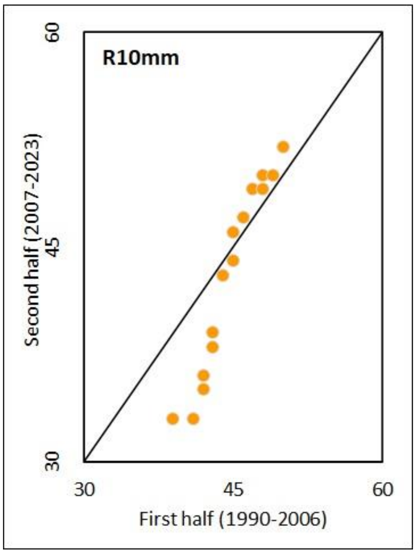
b) Rx5day



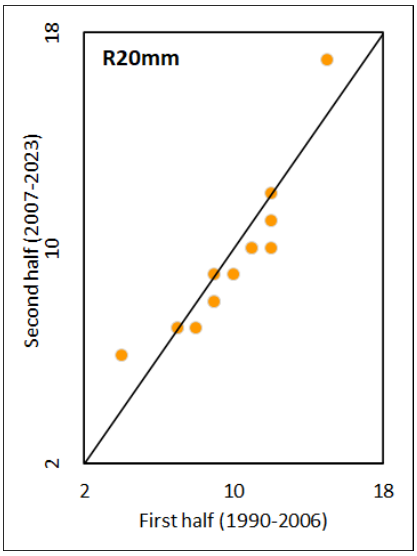
c) R95p



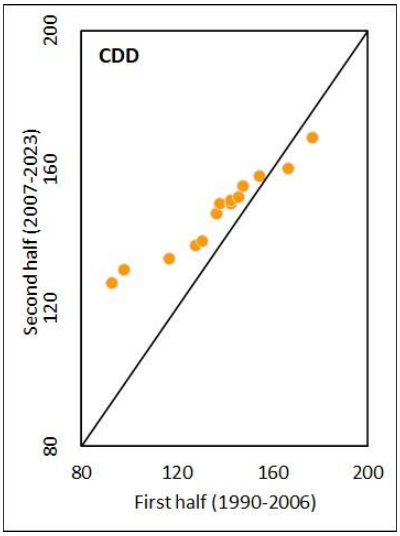
d) R99p



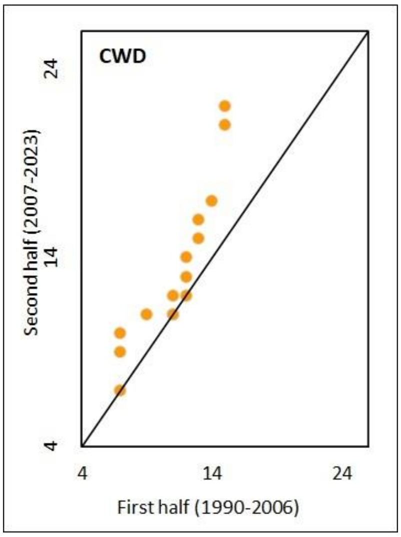
e) R10



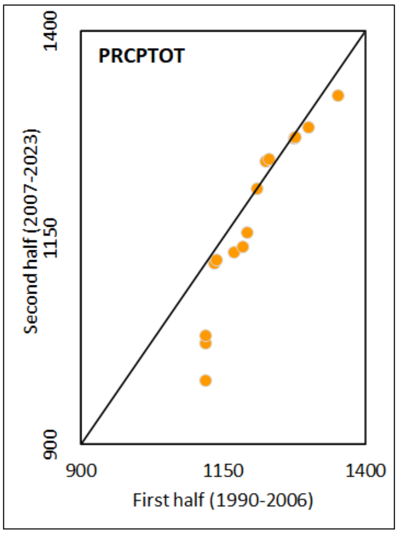
f) R20



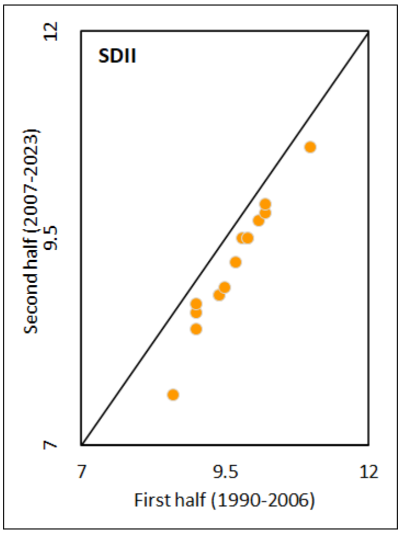
g) CDD



h) CWD



i) PRCPTOT



j) SDII

Figure 8: Max-1day Rainfall (a), Max-5 Days Rainfall Amount (b), Very Wet Days (c), Extremely Wet Days (d), Heavy Precipitation Days (e), Very Heavy Precipitation Days (f), Consecutive Dry Days (g), Consecutive Dry Days (h), Total Amount of Rainfall (i), and Simple Daily Intensity Index (j)

Increasing trends were observed for Rx1day, Rx5day, r95p, r99p, CDD, CWD, and R20mm. While other rainfall indices such as SDII, R10mm, and PRCPTOT experienced decreasing trends. These extreme rainfall indices in Kaduna State were computed between 1990 and 2023.

Discussion

This study examined climate extreme events and their influence on the livelihoods of locals depending on rainfed agriculture in Kaduna State, Nigeria. Assessing climatic extremes is crucial in identifying impacts and adaptation strategies (Ayanlade et al., 2022; Haque et al., 2024). Results of this study revealed significant increasing trends of minimum and maximum temperatures in Kaduna State. This result agrees with the findings of Abaje and Oladipo (2019), Ahmad et al. (2025), and Mande (2020), which revealed increasing temperatures in Kaduna State. Suleiman et al. (2019) also found an increase of 1.68°C and 1.72°C for maximum and minimum temperatures, respectively, in the Northern Senatorial Zone of Kaduna State, Nigeria. Studies revealed that extended durations of increasing temperatures can negatively affect crop development, reduce yields, and potentially result in crop failure, particularly for heat-sensitive species such as maize and vegetables (Haruna et al., 2025; Parthasarathi et al., 2022). Similarly, this study revealed that Kaduna State experienced a decrease in annual rainfall. This is similar to the findings of Abubakar et al. (2024), which detected a significant decrease in annual rainfall in Kaduna, Nigeria.

This study revealed increasing trends of TMAXmean and TMINmean. This increase in mean temperatures, especially during growth, can lead to reduced yield as a result of reduced grain number and weight (Kim & Lee, 2023). The result also revealed that the annual maxima and minima of daily maximum temperatures were increasing. This result is similar to the findings of Abdussalam (2015), who found a significant increase in TXx and TXn in Northern Nigeria. This increase suggests a warming trend, which can shorten the crop development period. Additionally, it can cause stress in heat-sensitive crops like maize and vegetables, especially during flowering and fruiting (Hatfield & Prueger, 2015; Wang et al., 2022). These high temperatures can also impair the health and reproduction of livestock, as persistent high temperatures disrupt feeding and hydration patterns (Godde et al., 2021; Habeeb et al., 2023). These will significantly affect the livelihoods of households relying on crop and animal production.

The results of this study also revealed an increase in warm days (TX90P), warm Nights (TN90P), and a decrease in cool days (TX10P) and cool nights (TN10P). Studies revealed that higher overnight temperatures negatively impact rice grain yield and quality by inducing premature panicle emergence, reducing pollen germination, increasing spikelet sterility, and creating chalkiness (Impa et al., 2021; Khanal et al., 2024). An increase in warm days (TX90p) increases evaporation rates, lowers soil moisture, and intensifies the demand for irrigation (Incoom et al., 2022; Malhi et al., 2021), hence presenting issues for rain-fed agriculture, which predominates in Kaduna State. The study also found an increasing trend of warm spells (WSDI) and a decreasing trend of cold spells (CSDI). Hot weather puts workers under physical strain and shortens their workdays, which can cause financial shocks for households (Khayat et al., 2022; Kroeger, 2023).

This study also identified increasing trends of extreme rainfall events (RX1day, RX5day, R95p, R99p). This result agrees with Gbode et al. (2019), who found an increasing trend of R99p in the Savannah region of Nigeria. However, the result contrasts with Abdussalam (2015) and Isa et al. (2023), who reported downward trends in RX1day and RX5day in Kaduna State. Similarly, Ahmed et al. (2024) found decreasing trends of Rx1day and Rx5day in Kano State, Nigeria. Significant increasing trends in daily (RX1day) and 5-day (RX5day) maximum rainfall, as well as heavy (R95p) and very heavy (R99p) rainfall events, suggest a higher frequency and intensity of extreme rainfall, which can wash away topsoil and reduce soil fertility, destroy crops just before harvest, damage infrastructure (Han et al., 2025; Nnabude et al., 2022). Increasing trends of CDD, CWD, and R20mm were also identified in this study. Gbode et al. (2019) also identified increasing CDD and CWD trends in Nigeria's Sahelian region. Extended dry spells impact livestock productivity, hindering farmers' access to water and verdant pastures due to diminished surface water resources and available grazing land (Haider, 2019), while increased R20mm and consecutive wet days increase the potential for soil saturation and increased flood risks (Hailu et al., 2025), potentially affecting root and plant growth, resulting in reduced grain yield (Manghwar et al., 2024; Topali et al., 2024).

The results also showed decreasing trends of SDII, R10mm, and PRCPTOT in Kaduna State, indicating a shift toward a drier and more erratic rainfall regime. This agrees with the findings of Abdussalam (2015), who found decreasing trends of R10mm, SDII, and PRCPTOT. Declining rainfall can lead to late onset and early cessation of rains, forcing farmers to change cropping calendars or plant drought-resistant varieties (Porcuna-Ferrer et al., 2024; Yeleliere et al., 2023). Considering that most households in Kaduna State rely on rainfed agriculture, rainfall decline threatens food security and income.

CONCLUSION

This study provides a clear understanding of the increased exposure of local communities to climate extremes and the implications for their livelihoods, especially those relying on rainfed agriculture. The significant increase in both minimum and maximum temperatures, as well as the increase in warm spells (TMAXmean, TMINmean, WSDI), indicates warming trends, which pose a significant risk to agricultural productivity, livestock health, and labor efficiency. Rising temperatures may lead to a reduction in grain yield, inhibit livestock feeding and reproduction, and shorten the length of the growing season, which undermines food security and the income of households.

Similarly, the study found increasing trends in extreme rainfall indices (Rx1day, Rx5day, R95p, R99p, R20mm), dry spells (CDD), and wet days (CWD), indicating a shift toward more erratic and intense rainfall patterns in Kaduna State. These extreme rainfall events heighten the risk of waterlogging, flooding, soil erosion, and damage to crops and infrastructure, exacerbating challenges faced by farmers and rural livelihoods. However, a decline in SDII, R10mm, and PRCPTOT reflects a broader pattern of decreasing rainfall and moderate rainy days, indicating a transition towards drier conditions, which negatively affect agriculture and water resources. Collectively, these climate shifts increase the vulnerability of households in Kaduna State, especially those depending on subsistence farming. The findings underscore the need for adaptation strategies such as climate-resilient crops, enhanced water and soil management, early warning systems, and livelihood diversification. Addressing these difficulties is vital not only for maintaining food security and rural incomes but also for building resilience against future climate risks.

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