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Analysis of Rainfall and Temperature Variability in Kebbi State, Northern Nigeria

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Abstract

Rainfall and temperature variability can signal climate change and pose challenges to the sustainability of natural water bodies, food security, and ecosystem services. This study aimed to assess trends in rainfall and temperature variability in Kebbi State from 1993 to 2022. The daily rainfall and minimum and maximum temperatures of Kebbi State were obtained at a spatial resolution of 1 km from fifteen (15) meteorological remote sensing stations on the NASA website. One-way ANOVA, the Mann-Kendal (MK) test and Theli-Sen's slope estimator were employed to assess the magnitude of the trend. In this study, monthly rainfall was significantly (P<0.05) varied, while in two distinct periods (1998-2003 and 2008-2013) a decrease in the total annual rainfall was recorded across the stations but from 2003-2008, a decrease of -26.93 mm was recorded at SW station, while -19.04 mm and -24.44 mm were recorded at the SW and SE stations, respectively. The maximum monthly average temperature was found to be 42.50°C in April 2022, followed by 41.35°C in 1998, 41.25°C in 2018, and the minimum was recorded at 26.54°C in January 2003. Among the stations, the MK and Sen's slope reveal a rainfall increase at a rate of +12.37 mm/year and 3.88 mm/year in stations C and B, respectively but decreases at rate of -4.12 mm/year in the station A, while temperature shows increasing trends in all the three stations, at rate of 0.028°C, 0.022°C and 0.016°C per year in stations A, B and C for NW, SW and SE respectively. The findings of this study suggest that climate change has influenced the rainfall and temperature patterns in Kebbi State, which can affect the sustainability of climate-dependent ecosystem components, including biodiversity, groundwater level, food security and other ecosystem services.

Keywords: Climate, Mann-Kendal (MK), Rainfall, Sen's slope, Temperature and Variability.

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INTRODUCTION

In semiarid areas, rainfall and temperature variability play crucial roles in regulating vegetation distribution (Cao *et al.,* 2021; Almeida-Ñauñay *et al.,* 2021), and are recognized as the direct determinants of large-scale ecosystem development (Tang *et al*., 2021). These climate-dependent changes are causing significant global warming, with Africa being particularly affected by extreme rainfall and temperature shifts (Barry *et al.,* 2018; Adeyeri *et al.,* 2019). Africa, particularly Sub-Saharan African countries, is one of the most vulnerable to climate change, primarily because of its low adaptive capacity and high exposure (Haile *et al.,* 2019). By lowering per capita food supply, rainfall variability remains the principal factor affecting food security, economic well-being and natural resources in sub-Saharan African countries (Verschuur *et al.,* 2021). Lack of water inhibits plant productivity and growth, decreasing carbon absorption and higher vulnerability to pests and diseases (Mangena, 2018). Depending on the location and future climate scenarios, the projected effects of climate change on cereal crops show a potential yield reduction of up to -35% for rice, -20% for wheat, -50% for sorghum, -13% for barley, and -60% for maize (Campbell *et al.,* 2016). The Earth's freshwater supply is primarily replenished by rainfall, which impacts surface water bodies, groundwater aquifers, and soil moisture, with a significant effect on both human well-being and natural systems (Jenifer and Jha, 2021). According to Garrett *et al.* (2013), higher temperatures have a detrimental effect on soil moisture, whereas prolonged droughts and rising temperatures can contribute to the proliferation of pests and diseases, ultimately reducing the vegetative growth, productivity, and crop yields in agriculture (Kiplagat *et al.,* 2022) and become a major threat to a country’s food security (Hosseinpour *et al.,* 2022).

Maidment *et al.* (2015) reported diverse precipitation trends in Africa, with some regions experiencing more rainfall and others showing a decreasing trend. Asfaw *et al.* (2018) investigated rainfall and temperature variability in the Woleka sub-basin, in north-central Ethiopia, and revealed an intra and inter-annual variability with a decline in rainfall at a rate of 13.12 mm per decade. In Nigeria, researchers have studied rainfall and temperature changes using rain gauges and stations, observing variations in timing, duration, and intensity of rainfall across different regions (Oluwadare and Oluwadare, 2023). According to Suleman *et al.* (2022), there were variations in annual and seasonal rainfall and temperature in several locations in Nigeria, including Onitsha, Kafanchan, Ebonyi, Abuja, Ikeduru, Kwara, Northeast, and South-southern regions, with both increasing and decreasing trends observed. Consequently, this could exacerbate environmental degradation and water scarcity, leading to negative effects on food security, human health, economic development, and communal conflict (Balogun *et al.,* 2016; Umar and Ankidawa, 2016). Excessive rain can lead to flash floods, landslides, and damage to infrastructure, endangering property. Precise measurement and monitoring of rainfall enables timely warnings and effective disaster management strategies to minimize the impacts of extreme rainfall events (Kundzewicz *et al.,* 2014). Inadequate rainfall and increase in temperature can lead to droughts that would severely affect agriculture, potentially resulting in crop failures and food shortages. Understanding fluctuations in rainfall and temperature is extremely important for managing water resources and planning adaptive strategies in agriculture (Mathew *et al.,* 2021). Researchers across Africa and Nigeria, in particular, have found that analyzing trends and mutations in precipitation and temperature is an effective way to monitor climate change and variability (IPCC, 2007).
Satellite-based rainfall and temperature estimation products, such as Precipitation Estimation from Remotely Sensed Information Artificial Neural Networks (PERSIANN) (Sorooshian *et al.,* 2007), Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM) have contributed to the analysis of rainfall and temperature trends worldwide (Huffman *et al.,* 2007). Although the Nigerian Meteorological Agency (NiMet) remains a network of weather stations across the country and provides long-term climatic

data, this study employed remote sensing technology to generate rainfall and temperature data from various places that cover the entire Kebbi State, Nigeria. The analysis of rainfall and temperature variability in Kebbi State, Northern Nigeria has not been directly addressed. However, several studies have examined climate variability in different regions of Nigeria, which can offer insights into the potential patterns in Kebbi State. For instance, Rindap (2020) reported an increase in temperature and variability of rainfall patterns in northeastern, Nigeria. Similarly, Olufemi *et al.* (2020) and Buba and Ibrahim (2018) discuss climate variability trends in Nasarawa State and northern Nigeria, indicating an increasing trend in temperature and a decrease in rainfall and other climatic parameters. Parametric and non-parametric trend analyses are used globally by researchers to assess the possible trends of climate variables and hydrological time series (Foorotan, 2019). However, multiple regression models, Sen's slope estimator and Mann-Kendall test are mostly used (Zuzani *et al.,* 2019). This study aimed to assess the spatiotemporal trends of rainfall and temperature variability in Kebbi State, Northern Nigeria, to serve as the basis for establishing the presence of climate variability from 1993 to 2022. Although the literature does not specifically address climate variability in Kebbi State, the studies suggest a regional trend of increasing temperatures, which is consistent with global warming projections.

MATERIALS AND METHODS

Study Area

The study area is Kebbi state, located in the extreme north-western part of Nigeria (Figure 1). It covers a geographical land area of approximately 36777 km^2 and is bordered by the Nigerian states of Niger, Sokoto, and Zamfara to the south, north, and east, respectively, as well as the nations of the Niger Republic to the west and the Benin Republic to the south-west. The state is characterized by a single rainy season lasting from April to October in the south and May to September in the north, while the dry season lasts for the remaining period of the year with a harmattan season from November to February (Aleiro *et al.,* 2018; Salisu *et al.,* 2024). Average temperatures range from 21°C to 40°C and the rainfall varies from approximately 720 mm in the northern part to about 1000 mm in the southern parts of the state (Aleiro *et al.,* 2018; Salisu *et al.,* 2024). In some parts of the southeast, the vegetation of the State is characterized by the Northern Guinea Savanna ecological zone, while the Northwestern and southwestern parts are found within the Sudan Savanna vegetation zone (Salisu *et al.,* 2024). The land is a semi-arid type, characterized by frequent weathering and leaching because of poor soil structure and low organic matter content. The vegetation of the area received serious degradation as a result of desert encroachment, human activities like deforestation, firewood fuel extractions, livestock grazing, bush burning, excavation of soil for house construction and infrastructural development.

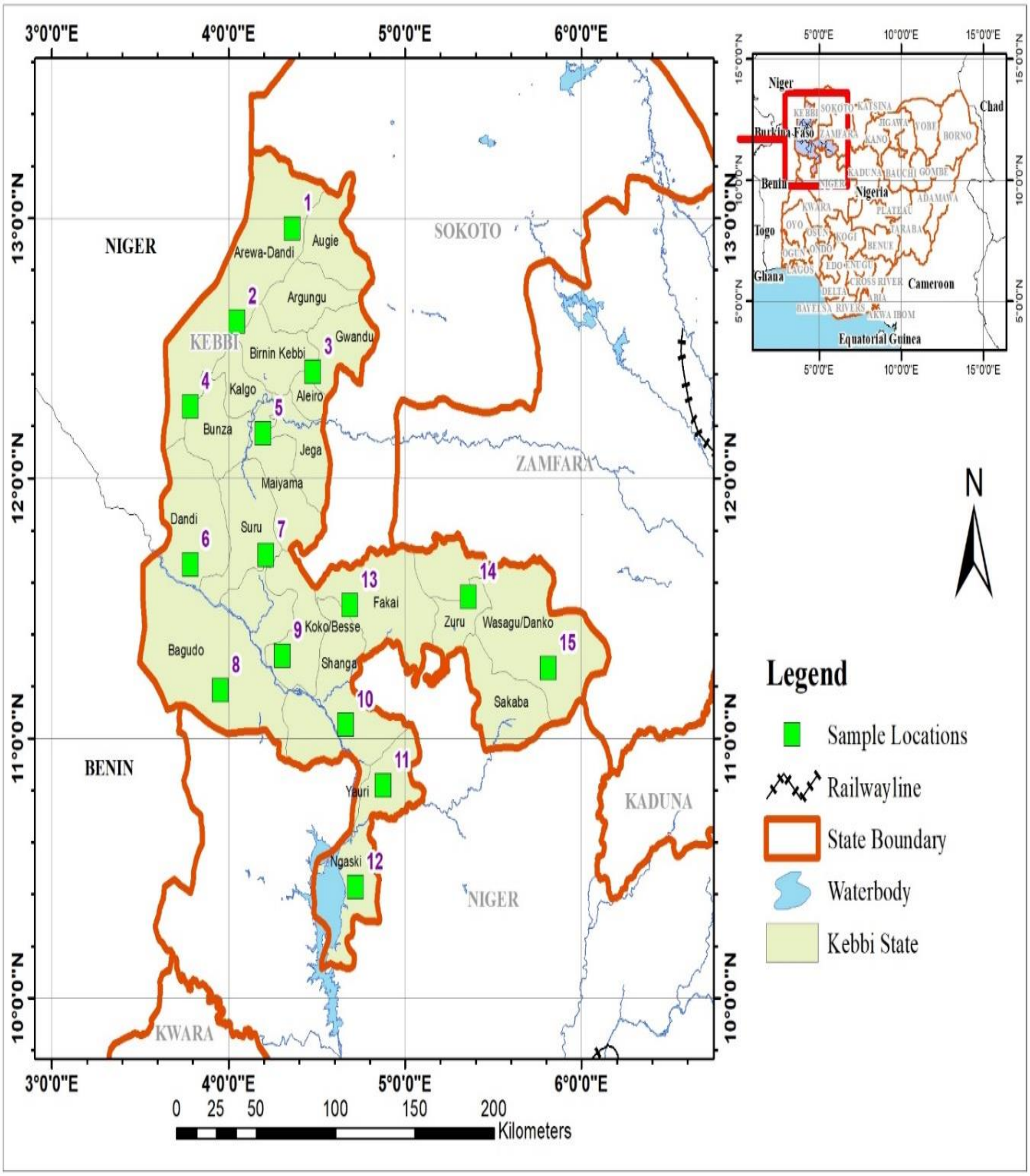

Figure 1: Map of Study Area with Sampling Locations (Salisu *et al.,* 2024)

DATA COLLECTION

Climate Data

The Daily data for the minimum and maximum temperature as well as the monthly rainfall for Kebbi State were obtained from fifteen (15) meteorological remote sensing stations (Table 1) at 1 km spatial resolution from National Aeronautic and Space Administration power access climate data (https://power.larc.nasa.gov/data-access-viewer) for 29 years (1993 to 2022) and validated using data obtained from the Nigerian Meteorological Agency (NiMet), Yauri station, Nigeria. The 3-year data sequence for all the survey points was analyzed by running a significant test at a 95% level to check the homogeneity of the data.

Table1: Coordinates of the Meteorological Remote Sensing Stations

Station	X (Longitude)	Y (Latitude)	Elevation (m)	Period Covered
1	4°.36′54′	12°.56′28′	207	1993-2022
2	4°.05′49′	12°.60′40′	207	1993-2022
3	4°.47′58′	12°.40′60′	221	1993-2022
4	3°.49′12′	12°.27′60′	212	1993-2022
5	4°.52′42′	12°.17′55′	268	1993-2022
6	3°.59′32′	11°.60′58′	192	1993-2022
7	4°.38′51′	11°.60′47′	224	1993-2022
8	3°.60′04′	11°.18′45′	282	1993-2022
9	4°.54′46′	11°.31′60′	202	1993-2022
10	4°.60′60′	11°.05′29′	139	1993-2022
11	4°.60′58′	10°.51′59′	139	1993-2022
12	4°.08′60′	10°.42′48′	276	1993-2022
13	4°.56′60′	11°.51′20′	219	1993-2022
14	5°.04′34′	11°.54′32′	270	1993-2022
15	5°.28′12′	11°.27′03′	335	1993-2022

DATA ANALYSIS

The seasonal data of this study was analyzed using one-way ANOVA and the yearly variation was analyzed using the Mann-Kendall test and Sen's slope estimator recommended by the World Meteorological Organization to detect trends in long-term historical data.

RESULTS

Monthly Variation of Temperature and Precipitation

In 1993, it was observed that total monthly precipitation gradually increased in all the locations from the minimum in March to a maximum average of 216.98 mm in July, followed by August with 183.57 mm and then declined continuously to a minimum amount in December (Figure 2). A maximum total precipitation of 863.60 mm was recorded in location C and a minimum of 679.50 mm were found in location A, but the results between the location was not statistically ($p > 0.005$) at 95% confidence level. The precipitation pattern of year 1998 slightly differs from the pattern of 1993, where the total monthly precipitation increases from a minimum in January to a maximum of 218.55 mm in August, which followed by 199.96 mm in July and then declined continuously to October, but no amount of precipitation recorded in November and December (Figure 3). Station A recorded the lowest precipitations of 758.06 mm, while the highest total amount of precipitations was recorded in station C. The results revealed a non-statistically significant ($p > 0.005$) difference between the stations. In 2003, there was no precipitation recorded in station A and B during the month of December, but in both stations maximum precipitation was recorded in the month of August, followed by June, July, September, May and then October, while the minimum precipitation was recorded in the month of January (Figure 4). A total annual precipitation of 884.72 mm was recorded in station C, followed by 840.71 mm in station B and the lowest amount of 704.73 mm was found in station A. The results revealed an insignificant ($p > 0.005$) difference between the stations. Total monthly precipitation of the year 2008 increased from a minimum in March to a peak point of 924.75 mm in August and then declined continuously (Figure 5). Stations A and B shared a similar pattern of the order of increase, in which maximum precipitation was recorded in August, followed by September, June and July, and no precipitation found in the months of January and February. Station C differs slightly from the two other stations (A and B), where precipitation was found to be maximum in August, followed by September, July and June (Figure 5). The annual precipitation was found to be maximum in station C (924.75 mm), followed by station B (813.78 mm) and station C recorded the lowest precipitation of 763.36 mm. The results were not-statistically significant ($p> 0.005$) difference between the stations. In year 2013, maximum precipitation of 851.85 mm was recorded in August, followed by 147.14 mm in July and September (Figure 6) and less than 2 mm of precipitation was recorded in January, February, November and December. A minimum annual precipitation of 609.99 mm was recorded in station A and a maximum was found to be in station C with 851.85 mm. The variation of precipitation between the stations was not statistically significant ($p > 0.005$). The monthly precipitation in 2018 increases continuously from a minimum in February to a maximum of 231.04 mm in August, followed by 175.83 mm in July, and then declines continuously to a minimum in October, with no precipitation found in November, December and January (Figure 7). Like the previous years, maximum precipitation was recorded in station C, followed by station B and A with 972.53 mm, 886.72 mm and 737.07 mm, respectively. Although, there are variations in the amount of precipitation among the stations, the results were not statistically significant ($p>0.005$). There was no precipitation recorded in the months of February, November and December, 2022. Maximum precipitation was recorded in August (292.90 mm), followed by September with 184.77 mm, while the minimum precipitation was recorded in January (Figure 8). The total maximum annual precipitation of 948.09 mm was recorded in station C and the results were not statistically significant ($p> 0.005$) difference between the stations.

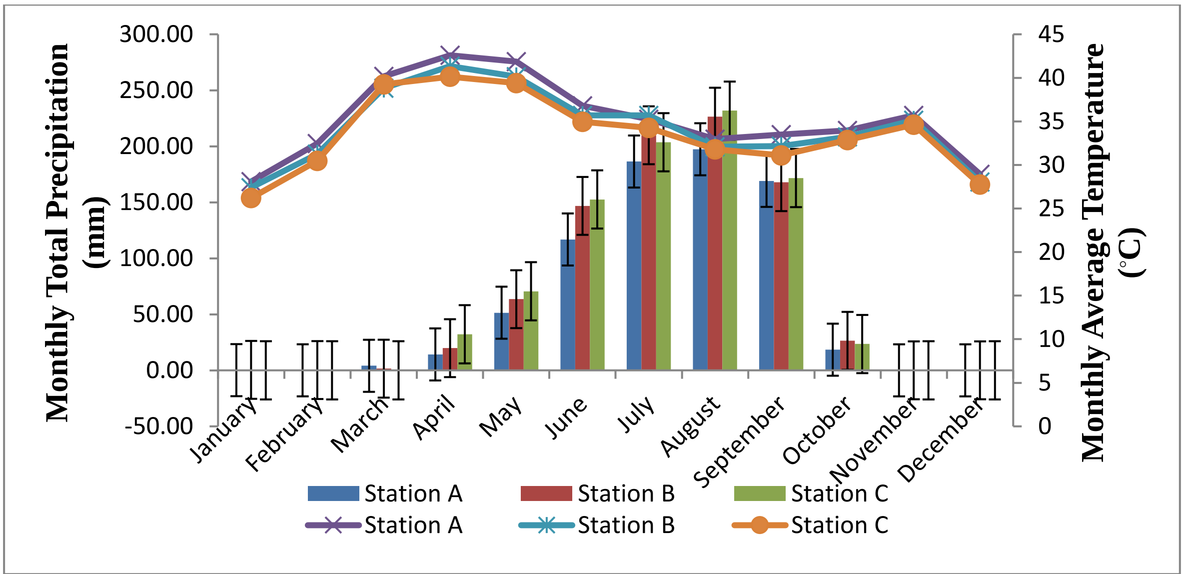

Figure 2: Total Monthly Precipitation and Monthly Average Temperature of Stations A, B & C of Year 1993

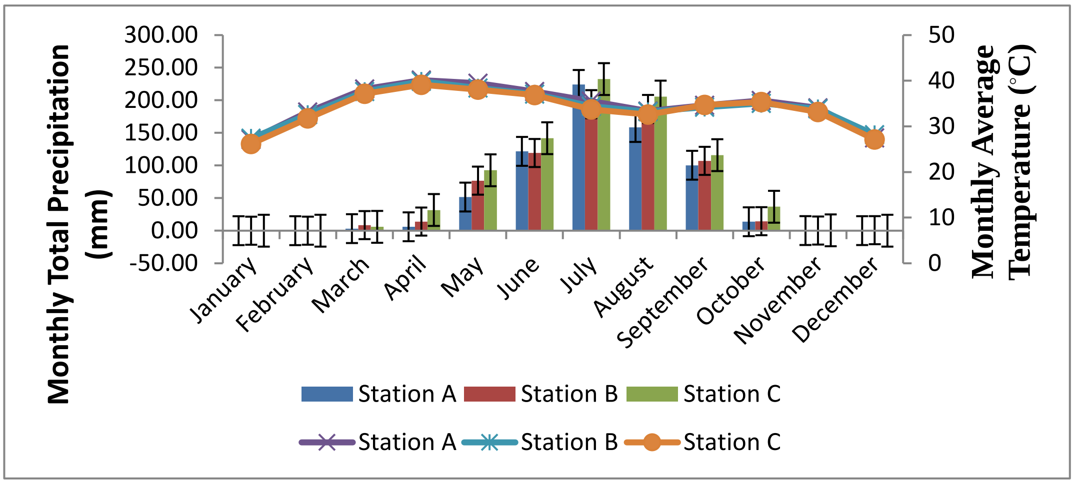

Figure 3: Total Monthly Precipitation and Monthly Average Temperature of Stations A, B & C of Year 1998

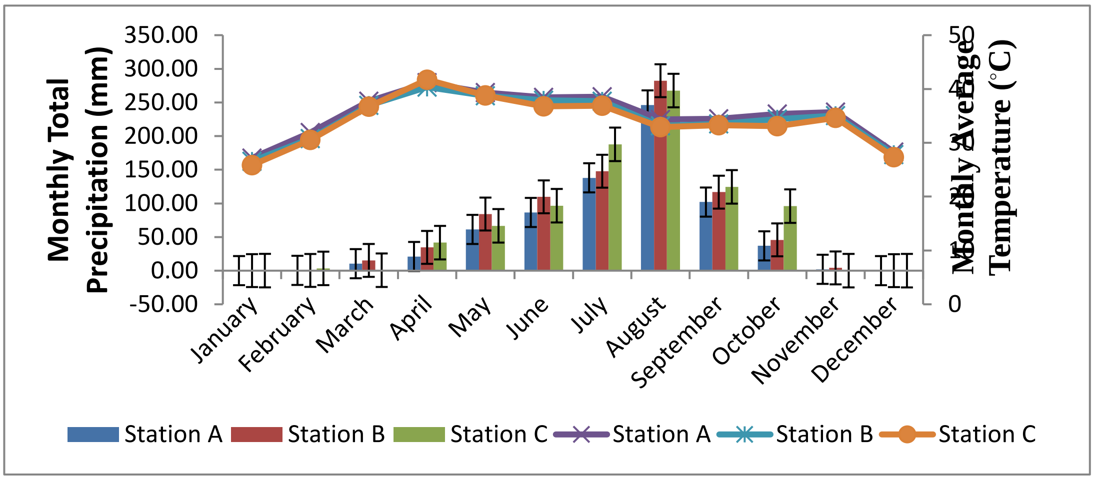

Figure 4: Total Monthly Precipitation and Monthly Average Temperature of Stations A, B & C of Year 2003

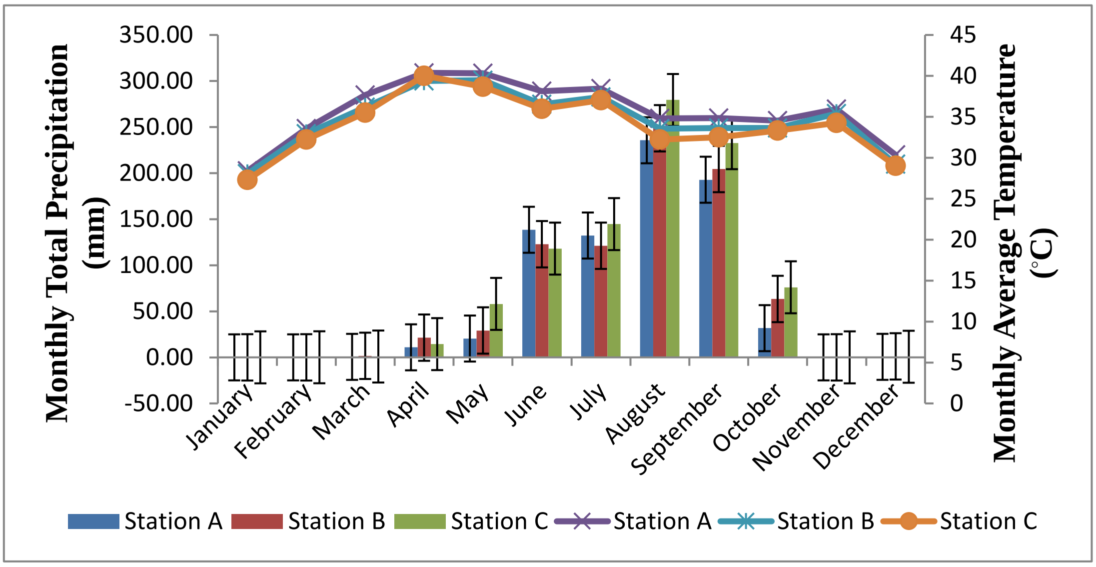

Figure 5: Total Monthly Precipitation and Monthly Average Temperature of Stations A, B & C of Year 2008

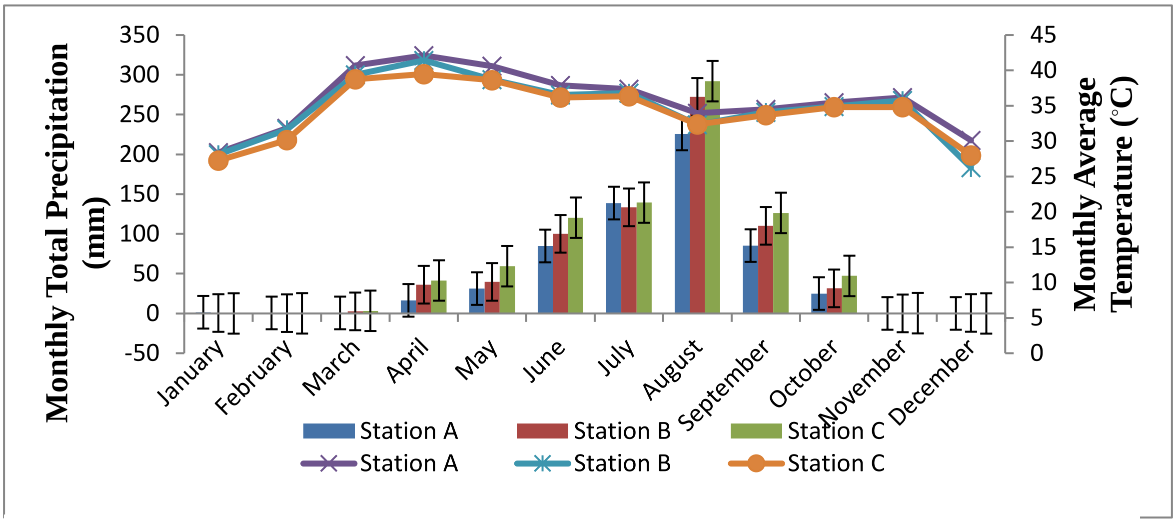

Figure 6: Total Monthly Precipitation and Monthly Average Temperature of Stations A, B & C of Year 2013

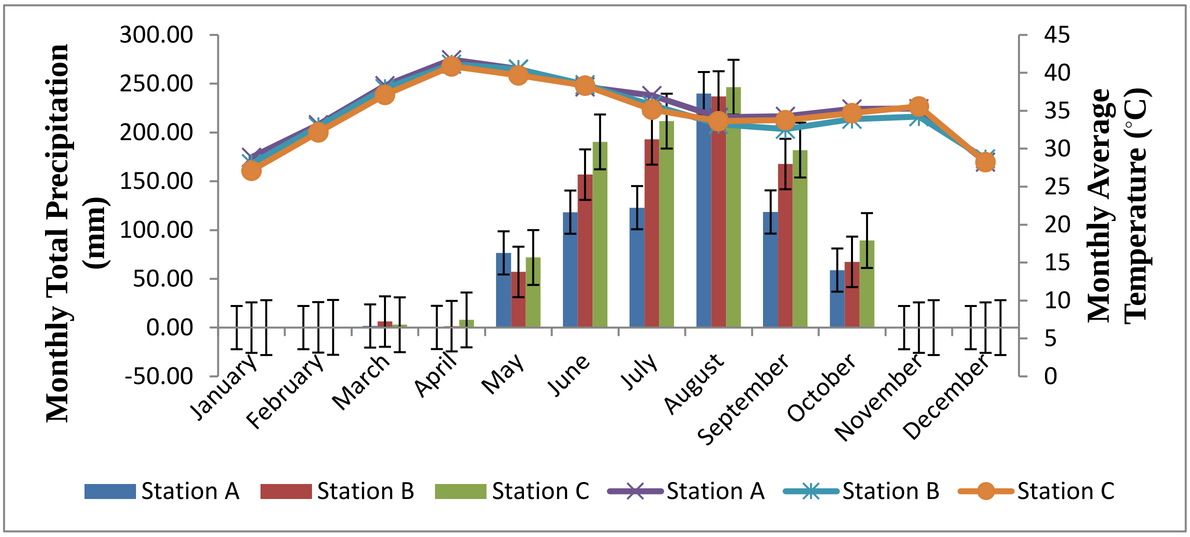

Figure 7: Total Monthly Precipitation and Monthly Average Temperature of Stations A, B & C of Year 2018

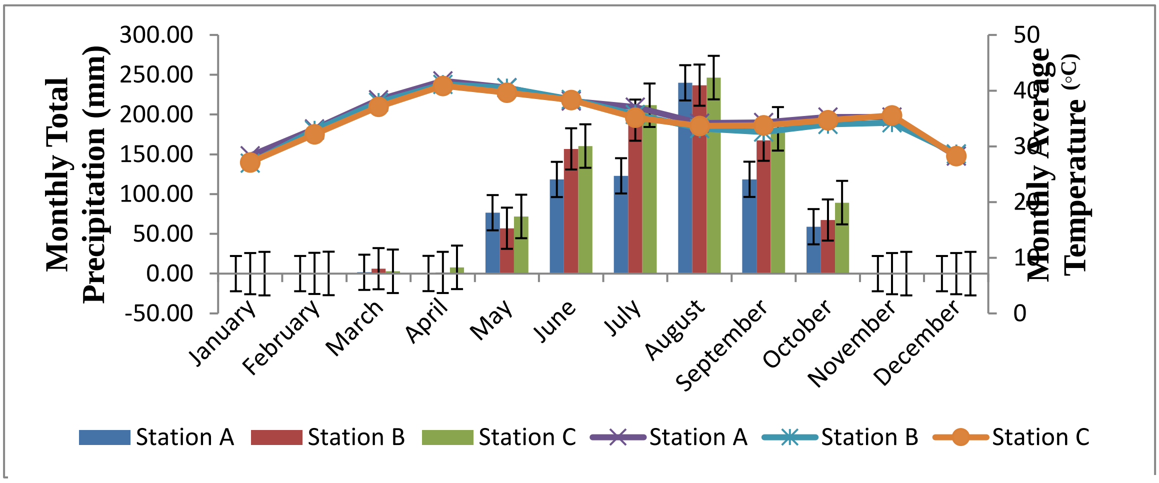

Figure 8: Total Monthly Precipitation and Monthly Average Temperature of Stations A, B & C of Year 2022

Annual Rainfall and Temperature Variability in Kebbi State

The annual rainfall in Kebbi State exhibited a variable trend, while the average annual temperature continued to rise (Figure 9). From 1993 to 2022, a consistent pattern of high rainfall in July, August, and September was recorded. Among the three stations, northwestern Kebbi state recorded the lowest annual rainfall of 679.50 mm in 1993, while a maximum of 802.17 mm in 2022 followed by 763.36 mm in 2008. In the southwestern and southeastern Kebbi state, the maximum amount of annual rainfall was recorded in 2022 followed by 2018. Conversely, the lowest amounts of annual rainfall of 722.66 mm in 1993 and 851.85 mm in 2013 were recorded in the southwestern and southeastern Kebbi state, respectively. ANOVA was employed to analyze the spatial variations of rainfall and temperature. The results indicated a significant (P<0.05) difference in mean annual rainfall among the three stations.

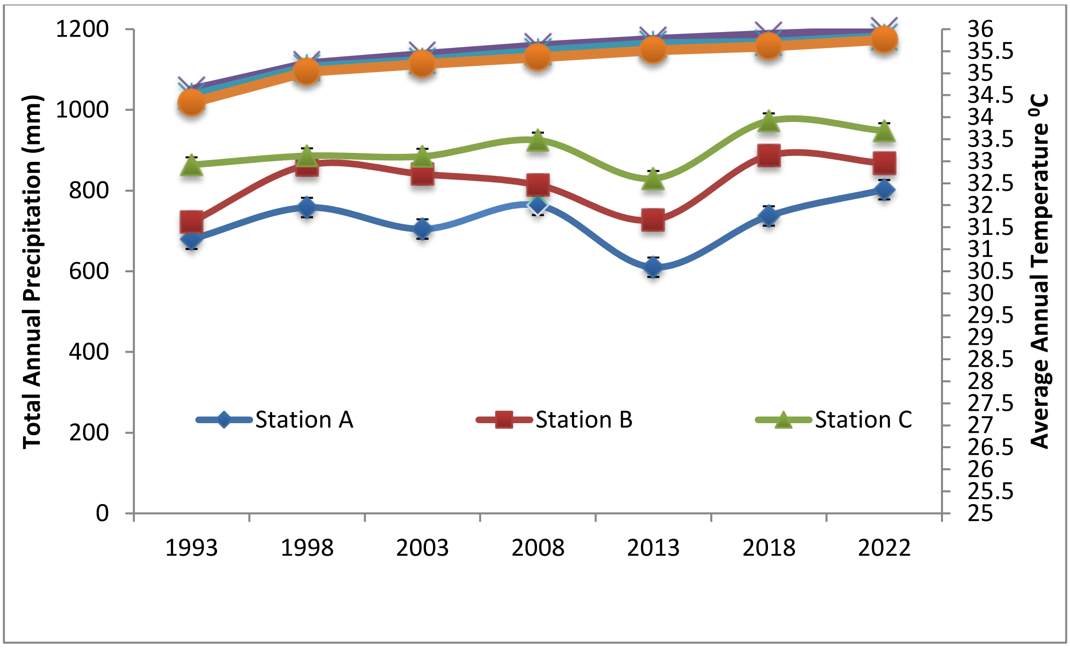

Figure 9: Yearly Variation of Average Temperature and Total Precipitation

Spatiotemporal Trend of Precipitation and Temperature

According to MK and Sen's slope analysis, for the29 years of the study, the rainfall at the station C shows an increase of +12.37 mm/year (Figure 10), while the station B experiences an increase of 3.88 mm/year (Fig.11). However, the station A experienced a decrease of -4.12 mm/year (Figure 12). Additionally, at all three stations, the temperature demonstrated an increasing trend, with the station A showing an increase of 0.028°C per year (Figure 13), station B showing an increase of 0.022°C per year (Figure 14), and station C showing an increase of 0.016°C per year (Figure 15).

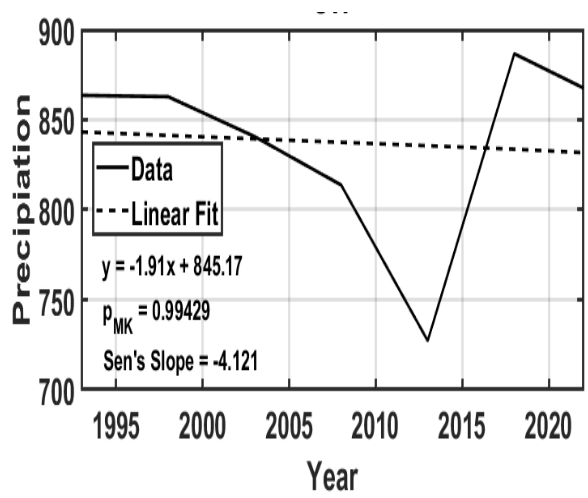

Figure 10: Precipitation trend in location A

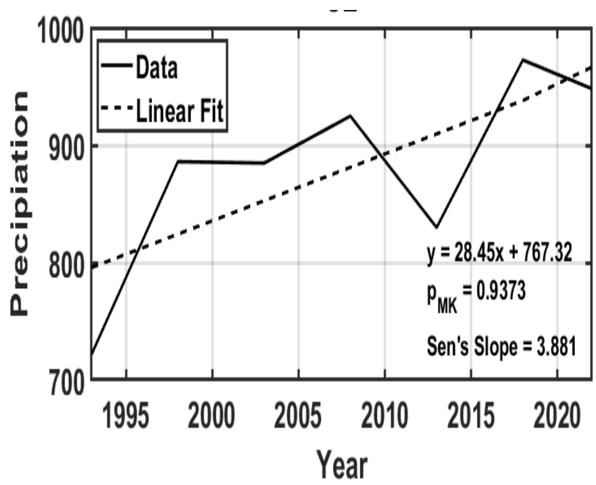

Figure 11: Precipitation trend in location B

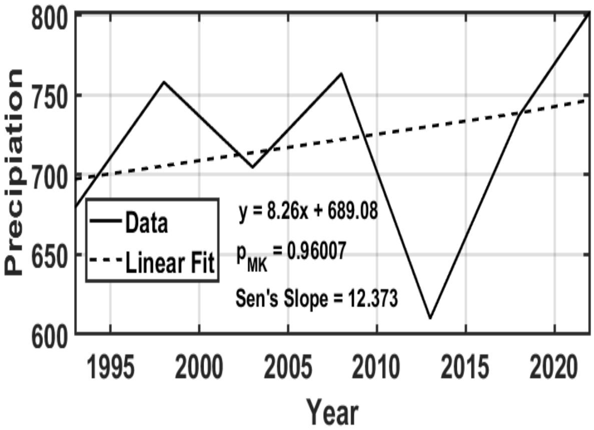

Figure 12: Precipitation trend in location C

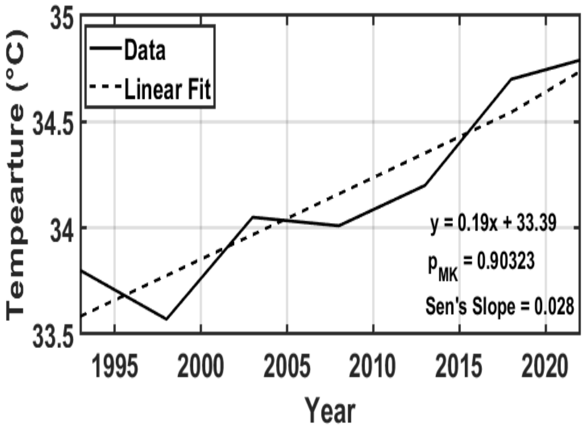

Figure 13: Temperature trend in location A

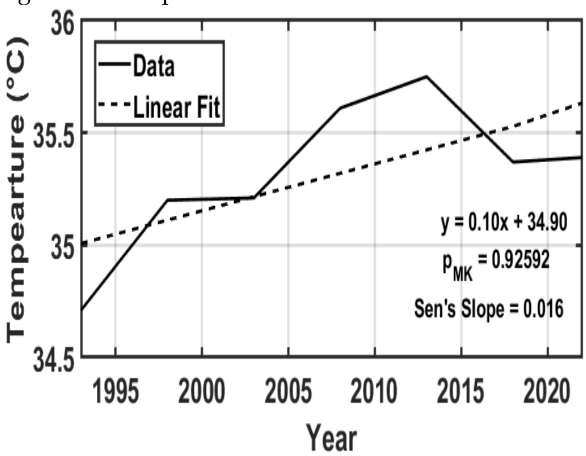

Figure 14: Temperature trend in location B

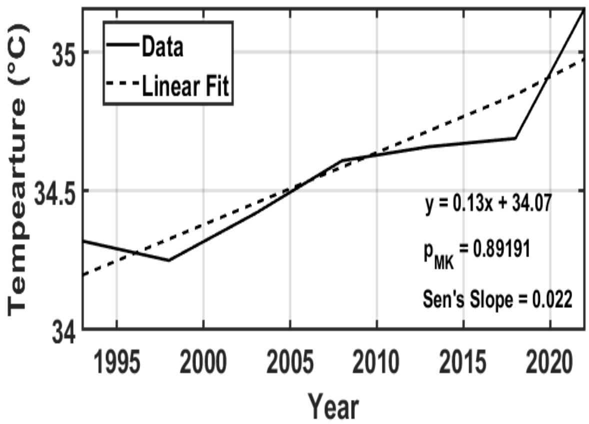

Figure 15: Temperature trend in location C

DISCUSSION

The present study revealed that from 1993 to 2022, there was a linear increase in temperature and seasonal and inter-annual rainfall variability in different parts of Kebbi State that demonstrated climate change. The average maximum temperature of 40.98°C and 39.62°C were recorded over multiple years in April and March, respectively, making them the hottest months in the Kebbi state, while the consistently high amount of rainfall recorded in July, August and September exhibits a period of extreme wet conditions. These findings are in line with those of the Climate-Smart Agriculture Profile for Kebbi State (2023). However, the results of this study agree with the findings of Umara *et al.* (2024), who reported increasing trends in annual precipitation and average temperature at Doguwa and Rano stations. Similarly, Ibrahim *et al.* (2020) reported that the rainfall in the Savannah Zones of Nigeria shows a significant upward trend of 3.59 mm yr^{-1} at Yelwa station, 9.84 mm yr^{-1} at Bauchi station, 17.13 mm yr^{-1} at Kano station, 3.98 mm yr^{-1} at Sokoto station, and 3.11 mm yr^{-1} at Katsina station. Byakatonda *et al.* (2018) also reported that semi-arid regions experienced greater climate variability, including extreme weather events. According to Ismail and Oke (2012) the total annual precipitation in Birnin Kebbi significantly shows a fluctuation upward trend of 1.03 mm $year^{-1}$, 10.33 mm $year^{-1}$ and a downward trend of -9.04 mm $year^{-1}$ between 1915 and 1946, 1947–1977 and 1978–2007, respectively. The result of Ismail and Oke (2014) is contrary to the findings of this study, by reporting a downward trend of rainfall in Sokoto, Kano, Kebbi, Kaduna and Katsina, at a slope of -0.94, -6.91, -0.94, -0.84 and -5.66 mm $year^{-1}$, respectively.

This study revealed that the temperature analyzed for 29 years increased at a rate of 0.028°C per year, 0.022°C per year, and 0.016°C per year at stations A, B and C, respectively. These findings are similar to those of Garba and Udokpoh (2023), who reported increasing trends in the annual maximum and minimum average temperature of Akwa-Ibom at rates of 0.031^{o}C per year and 0.013^{o}C per year, respectively. According to Ragatoa *et al.* (2018), the temperature of Kaduna, Yelwa and Calabar stations increased at a rate of 0.015 $year^{-1}$, 0.017 $year^{-1}$ and 0.039 $year^{-1}$, respectively. It is important to understand that for Nigeria, increased temperatures are constant because of the climate change impacts that resulted in an increase in global warming and irregular rainfall patterns (SPP, 2023). Gebrechorkos *et al.* (2019) also reported a significant increase in the inter-annual and seasonal trends on maximum and minimum temperatures in different parts of Ethiopia. Asfaw *et al. (*2018) also reported that the minimum and maximum temperatures were linearly increasing by 0.067°C and 0.026°C per decade, respectively, in north-central Ethiopia. Similarly, Birara *et al.* (2018) found a significant increase of 0.03°C and 0.05°C per year in the annual maximum and minimum temperatures, respectively, in the Tana areas of Ethiopia. The literature shows different rates of temperature change owing to regional variations and study periods.

The climate is continuously changing with a warming rate of 0.2 °C per decade, which will result in a 1.5 °C increased temperature during 2030–2052 compared to 1850–1900 pre-industrial levels (Hasan and Kumar, 2021). Variability in precipitation patterns and rising temperatures can significantly amplify the occurrence of extreme climate events, resulting in significant impacts on vegetation cover, biodiversity, food security and groundwater levels. The fluctuation of climate conditions can result in continuous variations in plant community composition and structure, contributing to biodiversity decline in natural ecosystems (García-Palacios *et al.,* 2018; Soroye *et al.,* 2020; Trisos *et al.,* 2020). The increase in the frequency and intensity of drought has caused serious changes and threats to the ecosystem, resulting in a decrease in ecosystem services and agricultural food production, ultimately affecting the local population (Lu *et al.,* 2024). Hasan and Kumar (2021) found that an increase of 0.35°C in temperature may result in a decrease of approximately 2.75% in crop yield. Additionally, changing land use and uncontrolled human and livestock population expansion could further complicate the challenges posed by the increased climate variability in the area (Sawa *et al.,* 2015). By understanding the patterns of rainfall and precipitation variations, stakeholders can make informed decisions about climate-related activities to identify the optimal planting times, water management, irrigation needs, and selection of climate-resilient and high-yield crop varieties to improve food security and the economy.

CONCLUSION

The findings revealed fluctuations in annual rainfall and a steady temperature rise, consistent with the broader national trend. However, fluctuations in seasonal and inter-annual rainfall were observed across Kebbi State, with notably high rainfall amounts recorded in July, August, and September. Nonetheless, a closer examination of the overall patterns revealed a pattern of inconsistency. Based on the findings of this study, decision-makers can determine the most suitable times for crop planting, managing water resources, and selecting climate-resistant, high-yield crop varieties to promote food security and the economy.

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