https://dx.doi.org/10.4314/dujopas.v10i2a.25
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 10 No. 2a June 2024*

Anomalies and Trends Assessment for Rainfall and Temperatures in Zaria and Environs, Kaduna State, Nigeria

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Abstract
The study area is located within the region of a very high climatic variation which may impact negatively to the immediate environment. The study aimed to assess meteorological parameters such as rainfall and temperatures to prepare for the occurrence of future climatic extremes. The study used anomaly and linear trends on the variables to determine climate change. The study made use of meteorological variables recorded for the period of 30 years (1991-2020). Anomaly was used in determining the annual amount of rainfall (surplus or deficit/dry); warm, cool or normal temperatures. Linear trend analysis was carried out on meteorological variables to determine an increase or decrease during the three decades under review. The result from the anomaly showed many years of wet/surplus while few years of deficit/dry. Temperatures showed the years with warm or cool temperatures. Rainfall shows 12 years of wet and 18 years of dry. Out of 12 years with wets, 11 years were between 2001-2017. Maximum temperature shows 17 years warmer than normal; 13 years shows cooler than normal. Out of 17 years that showed warmer maximum temperatures, 16 years were between 2001-2020. The minimum temperature shows 13 years with a warmer minimum temperature. Out of 13 years with warm, 12 years were between 2001-2020. Average temperature shows 17 years with warm while 13 years with cool. Out of the 17 years with warm, 12 years were between 2001-2020. Results from the trend analysis revealed that rainfall, average temperature, and maximum and minimum temperatures had positive trends with 8.86mm, 0.992℃, 0.143℃ and 0.0639℃ respectively.

Keywords: Rainfall, Temperatures, Anomaly methods and Trends Analysis

INTRODUCTION
One of the most crucial research topics in recent years is the detection of climate anomaly which affects human activities (Abaje *et al.,* 2012). The most severe impacts caused by climate anomalies in various regions include irregularities of seasons and shifts between rainy and dry seasons which are no longer forecasted accurately. Subsequent temperature increase is

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followed by extreme events such as El-Nino, La-Nina, tornados, floods and droughts (IPCC, 2013). Africa is the continent predicted with the greatest future severity of climate variability in the world as a result of poverty and the inability to provide equipment, and quality data for making conclusions after meteorological assessments (Olofintoye & Sule, 2010). Hoegh-Guldberg et al. (2018) predicted that rising global temperature above 2°C will increase the occurrence of droughts in the mid-latitude regions. The spatial and temporal pattern of temperature and rainfall across Nigeria from 1971-2000 using the Standard Anomaly Index (SAI) indicated a statistically significant increase in temperature in the vast majority of the country (Akinsanola & Ogunjobi, 2014) As climate change causes climate anomaly, it is referred to the irregularity or deviation in climate patterns that occur in a particular geographical location within a certain period of time (IPCC, 2007b). Climate anomalies are the main causes of weather extremes such as flooding and drought, wildfires, and airline crashes causing a human loss in many areas (Wakura *et al.*, 2007). Therefore, anomaly detection is very important as it is the background issue in climate science because most climate data analyses depend on anomaly detection as the first step (Wu *et al.*, 2018). Trends in meteorological variables such as rainfall and temperature have continued to receive the interest of researchers as a way to forecast their occurrence and for water resources management (Ahmad *et al.*, 2015). Precipitation increases of about 2-3% for each degree of global warming may be expected for the tropical humid zones (FRN, 2003; Oladipo, 2011). In the northern part, annual rainfall amounts have been on the increase especially from the late 1990s (Abaje *et al.*, 2013).

Nigeria is generally characterized by a high-temperature regime almost throughout the year. The far south has a mean maximum temperature of about 32°C while in the North (between February and May) it is about 42°C (NIMET, 2015). However, the mean minimum temperature in the South is 21°C and about 13°C in the North. Analysis of surface temperature data of Nigeria for the period 1981 to 2017 shows an increasing trend in annual mean maximum and minimum temperature over the last few decades (NIMET, 2017). The annual rainfall in Nigeria is greater than 3500mm from the very coastal area to less than 600mm in the Northeastern (Nguru and Maiduguri) and Northwestern (Katsina and Sokoto) parts of the country (NIMET, 2012; Abaje *et al.*, 2012). The length of the rainy season decreases from 9-12 months in the North, 6-8 months in the central part (Kaduna inclusive), to about 2-3 months in the extreme Northeastern part of the country (Odekunle *et al.*, 2008; NIMET, 2012). The period of the rainy season in the country has been reduced from 1941 when the onset and cessation were generally normal to 1971 when signals of late onset and early cessation of the rainy season set in. Since then, the length of the rainy season has remained shrinking while annual rainfall is about the same, thereby giving rise to high-impact rainfall (NIMET, 2012).

MATERIALS AND METHODS

The data used in this study were obtained from secondary sources. Cumulative annual rainfall and temperatures (maximum and minimum) data used for the study were obtained from the Institute for Agricultural Research (I.A.R) Ahmadu Bello University, Zaria.

The Study Area

Zaria is located in Kaduna State, Nigeria at Latitude 11° 4' 54.91'' N and Longitude 7° 42' 57.44'' E. The description of the climate in the study area as stated by Iguisi and Abubakar (1998) as a zone of dry climate, depicted by strong seasonality in rainfall and temperature occurrences. The region has two distinctive seasons which include the dry/harmattan season (October to May) and the wet season (April to November). The area has average annual rainfall from 1050mm to 1250mm. The mean monthly temperature is about 27°C. Temperature varies and it is highest between March and May at 28.9°C, which exhibits hot and dry periods while it is

lowest in December and January at about 22°C. Rainfall is reliable throughout May to September while absent from November to March. The rainy months are associated with the northward movement of the Inter-Tropical Discontinuity (ITD) across Kaduna state. The southward migration of the ITD across Kaduna state is associated with the dry and dusty winds of harmattan (Water and Power Development Company, 1991).

The highly leached ferruginous tropical soils that were formed on weathered layers of loose rocks overlain by a narrow deposit of silt dispersed by wind from tropical continental air mass are the major types of soils in the area (Wright & McCurry, 1970). The study area is a composition of a natural vegetation belt referred to as the Northern Guinea Savanna. Due to the rapid urbanization and other anthropogenic activities, coupled with poor management practices, the vegetation cover is hardly present. The most recognized tree plant species are *Mangifera indica, Parkia bislobose, Afzelia africana,* and *Daniella oliveri* used for making mortar and pistil while *Acacia balanites* are also present in the area. The Galma River is the major channel of drainage in Zaria since all other rivers and streams drain or discharge into it (Water and Power Development Company, 1991). The Galma River originates or has its source in Jos Plateau area, west of Shere Hills. The river flows in a North-West direction on latitude 10.6^0 N and North-West-North towards longitude 7.7^0 E, then South- West towards Zaria. The most dominant land use practices along the Galma River comprise cultivation, irrigation and animal rearing. The highland areas are of advantage to crops like maize, millet, guinea corn, ground nut and soya beans especially in the rainy season while the fadamas (low lands) are grounds of irrigated crops like onions, sugarcane, tomatoes, carrots, cabbage, pepper, spinach, bananas, okra, cucumber, lettuce, green beans and other perishable vegetables are grown throughout the year.

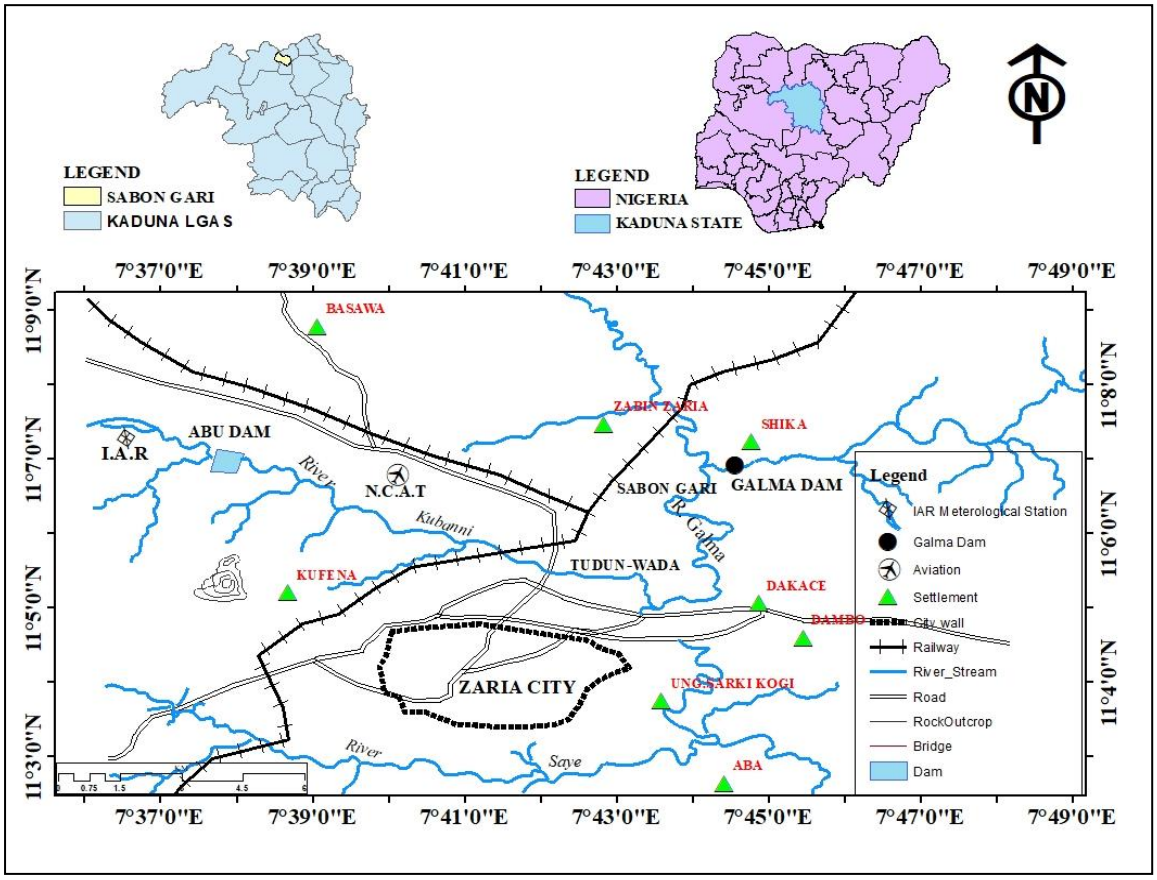

Figure 1: The Study Area meteorological Stations
Source: Adapted from Zaria Topo Sheet 102 S. W

METHODS

Anomalies of Meteorological Variables

Anomalies were determined by establishing the mean value of the meteorological variables over 30 years (climate normal). Climate normal is the average of the three decades of meteorological years as agreed by NIMET (2010). The anomaly was derived by subtracting the climate normal from the annual average of each meteorological year as shown in equation 1 below:

$$A = x_i - \mu 30 \quad (1)$$

Where A is the anomaly, $\mu 30$ is the normal climate and x_i is the mean/average value of the meteorological parameters.

Trends in Meteorological Variables

Linear trend analysis was used on rainfall, and temperature (maximum, minimum and average) data to determine the pattern of variation in their occurrence. Thus, the rate of increase or decrease is indicated by the linear trend time equation as in equation 2 below:

$$Y(t) = a + ßt \quad (2)$$

Where t is the time index and the independent variable, a and $ß$ (alpha and beta) are the intercept and slope of the trend line usually estimated using simple regression and Y is the dependent variable.

$$Y_t = ß_0 + ß_1 t + e_t \quad (3)$$

Where $ß_0$ is the constant, $ß_1$ is the average change from one period to the next, t is the value of the unit time and e_t is the error term (Kingsley et al., 2020).

RESULTS AND DISCUSSION

The anomalies of the meteorological variables for the three decades (1991-2020) were calculated based on how climatic parameters deviate from the established climate normal. The established normal rainfall, maximum, minimum and average temperatures during the study period were: 1089.216mm, 32.62℃, 19.13℃ and 25.86℃ respectively. When a climate parameter deviates from the climate normal, it is referred to as a climate anomaly.

Rainfall Anomaly (1991-2020)

Figure 2 shows the average rainfall records for thirty years which signifies normal rainfall (1089.216mm); The Figure shows a positive anomaly in years with rainfall higher than normal (wet) and, a negative anomaly in years having lower than normal (dry). 12 years were recorded as wets because rainfall records were higher than normal; while 18 years recorded as dry due to the fact that rainfall recorded in those years was less than normal. The year with the greatest wet of 1454.9 mm was 2015; while the year with the least wet was 2007 having 1093.1 mm.

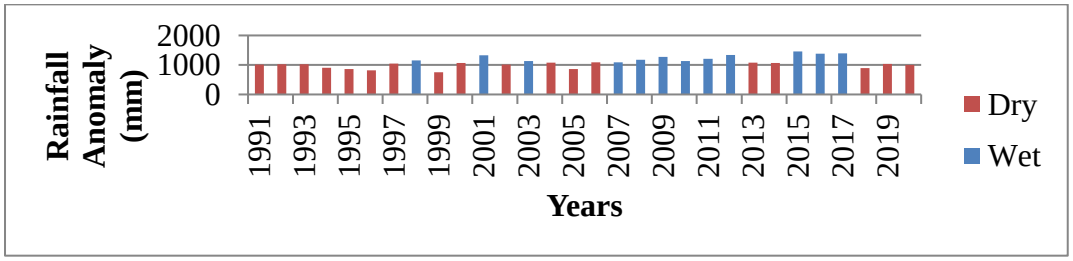

Figure 2: Rainfall Anomaly (1991-2020)
Source: Authors' Computation, 2021

The greatest dry of 342.2mm occurred in 1999; while the least dry of 0.71 mm occurred in 2006. It can be concluded that the occurrence of wet years from 1991-2020 ranged from 3.9mm to 361mm; while the dry years ranged from 0.72mm to 341.5mm. There was a definite pattern in the occurrence of wet years from 2007 to 2012, while there was a definite pattern in the occurrence of dry years during the period 1991-1997. Similarly, 2000 recorded a rainfall deficit of 19.7mm, 2001 wets or surplus of 233mm while 2002 recorded a rainfall deficit of 81.6mm, a surplus of 46.1mm recorded in 2003 and 2004 recorded a deficit of 14.3mm. 2005 recorded a deficit of 225.5mm, and 2020 recorded a deficit of 89mm. The results of rainfall anomaly from 1991-2005 which recorded three years wets corresponded to the work of Sawa and Adebayo (2011), who reported that in the period of 1976-2005, Northern Nigeria became drier where the rain started late and ceased early as a result length of rainy season decreased. The result also tallies with Abaje *et al.* (2019) that the plotted annual standard deviation for the rainfall anomalies in Northern Kaduna State from 1971-2016 revealed that out of the 46 years of review, 8 years experienced wetter rainfall while 7 years experienced drier conditions (or droughts). It is important to note that out of the 8 years that experienced wetter conditions, 5 years were in the last two decades, 2001-2010 and 2011-2016. The mean annual rainfall anomalies over Nigeria from 1986 to 2015 according to the Nigeria Climate Review Bulletin showed that rainfall has increasing wet years, though not at a steady rate (NIMET, 2016).

Anomalous Maximum Temperature (1991-2020)

Figure 3 shows the anomalies of maximum temperature, during the thirty years (1991-2020). The climate normal for maximum temperature over thirty years is 32.62℃. Fig. 3.2 presented 2011 as the warmest year recording 3.62℃ higher than normal, while 2013 is the second warmest year with 3.2℃ higher than the established normal maximum temperature (32.62℃). The recorded warmer maximum temperature than normal is between 0.3℃- 3.3℃. The year 1996 was the coolest maximum temperature than the normal maximum temperature by -5.2℃. 2002 was the year recording the least cool of -0.02℃ cooler than normal maximum temperature. The 3.2℃ warmer temperature obtained in this research is higher than the 3.0℃ obtained by Adamu, (2013) in Zaria LGA but lower than the value of 15℃ obtained by Attah (2013) in the lower Kaduna Catchment.

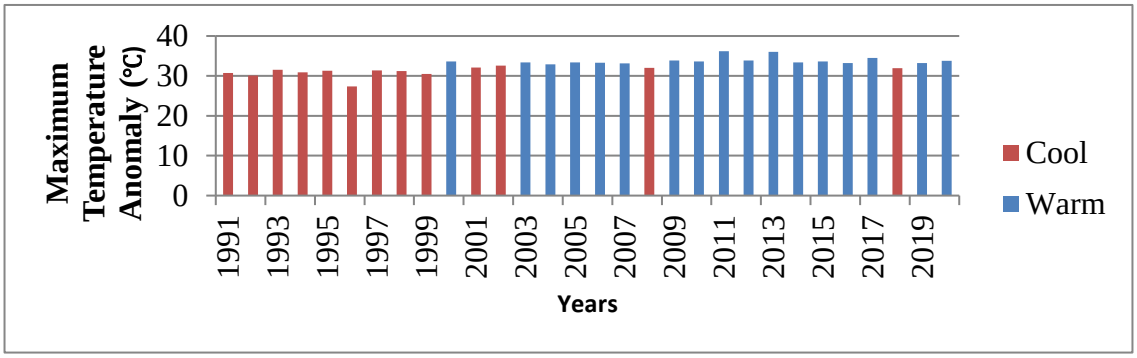

Figure 3: Maximum Temperature Anomaly (1991-2020)
Source: Authors' Computation, 2021

The coolest year was 1996 5.2℃ cooler than normal; other years that recorded cooler maximum temperature than normal had values between -0.02℃ to -5.2℃. There was a relatively definite directional pattern in the warmer maximum temperature years 2003-2007, and 2009-2017 and a definite pattern in the cooler maximum temperature years 1991-1999. However, 17 years had a positive anomaly of maximum temperature (warmer than normal), and 13 years had a negative anomaly of maximum temperature (cooler than normal).

Anomaly of Minimum Temperature (1991-2020)

Figure 4 presents the anomaly of minimum temperature (1991-2020). The climate normal for minimum temperature over thirty years was 19.13°C. Furthermore, Figure 3 shows years warmer than normal (positive anomaly) and years cooler than normal (negative anomaly).

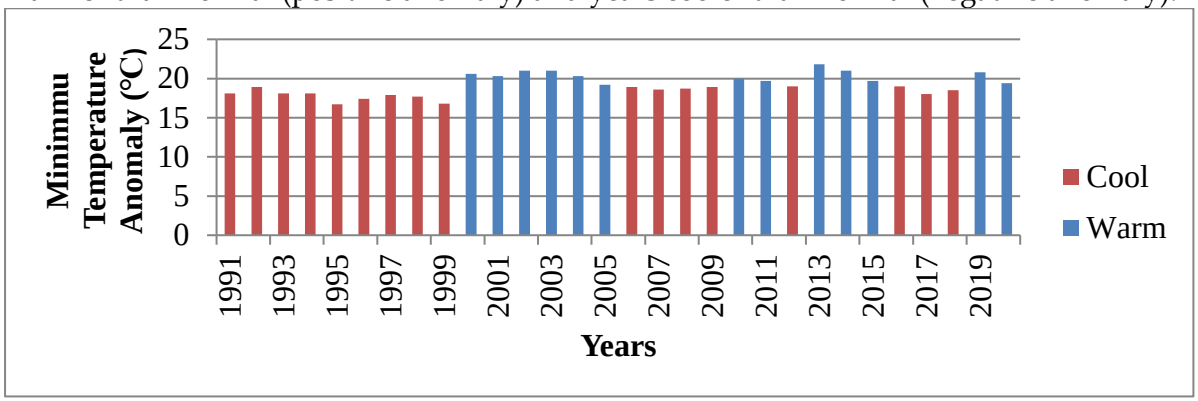

Figure 4: Minimum Temperature Anomalies (1991-2020)
Source: Authors' Computation, 2021

Figure 4 shows the minimum temperature anomaly during the period of thirty years (1991-2020). The warmest year, 2013 recorded 2.67°C warmer than normal minimum temperature (19.13°C). It was followed by 2002, 2003 and 2014 having values of 1.87°C warmer than normal. Similarly, 2005 was the least warm year with a minimum temperature value of 0.07°C warmer than normal. This simply explained those years that recorded warmer minimum temperatures than normal had values between 0.07°C and 2.67°C. However, 1995 had the highest deficit of -2.43°C lower than normal; but 2012, and 2016 had the lowest deficit of -0.13°C lower than normal. This simply explained that years that recorded deficit minimum temperature than normal recorded values between -0.13°C to -2.43°C. There was a relatively definite directional pattern in the less warm minimum temperature years 1991-1999. A series of non-directional patterns in minimum temperature is observed from 2000-2005. However, 13 years recorded warmer minimum temperatures than normal; while 17 years recorded less warm minimum temperatures than normal. 2013 was 2.67°C warmer than the normal minimum temperature (19.13°C). This value (2.67°C) is higher than 1.2°C obtained by Adamu, (2013) in Zaria but lower than the value of 8.20°C obtained by Attah (2013) in the lower Kaduna Catchment.

Anomaly of Average Temperature (1991-2020)

Figure 5 presents the anomaly of average temperature, during thirty years (1991-2020). The climate normal for average temperature is 25.86°C. Figure 4 shows a positive anomaly in years warmer than normal average temperature and, a negative anomaly in years cooler than normal average temperature. The warmest year was 2013 with an average temperature value of 3.05°C warmer than normal. It was followed by 2011 with a record of 2.09°C and 2003, 2014 recorded a value of 1.32°C warmer than the normal average temperature.

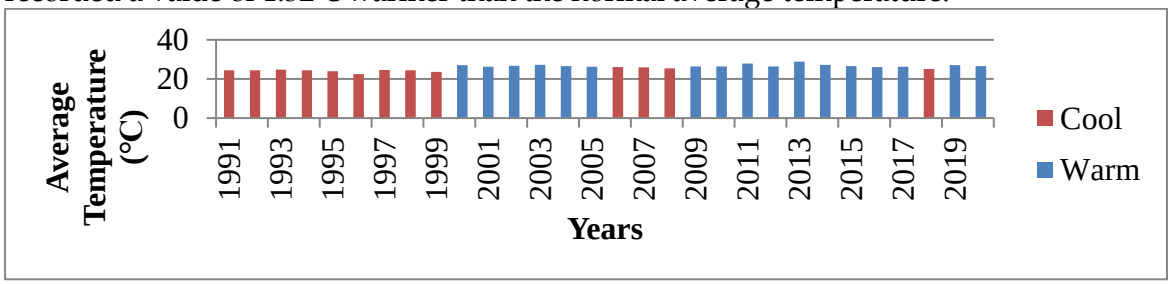

Figure 5: Average Temperature Anomalies (1991-2020)
Source: Authors' Computation, 2021

On the contrary, 2006 was the year that recorded the least warm 0.25℃ cooler than the normal average temperature, followed by 2007 with a record of 0.01℃ cooler than the normal average temperature. 1996 was the coolest year recorded a value of 3.46℃ cooler than the normal average temperature. This clearly explained those years which recorded warmer average temperatures than normal recorded values between 0.2℃ - 3.04℃. Years that recorded the coolest average than normal recorded values between -0.24℃ to -3.46℃. Lastly, 17 years recorded warmer than average normal temperature; while 13 years recorded cooler average temperature than normal. There was a definite pattern in the occurrence of cool average temperature from 1991-1999 and warm average temperature from 2009-2017. The study tallies with that of Abaje (2019) which plotted standard deviation for the temperature anomalies, decadal sub-period analysis of temperature in Kaduna State showed more years with warm average temperature from the beginning (1971) to the end of the study period (2016).

Linear Trend in Rainfall 1991-2020

Figure 6 shows the linear trend in rainfall from 1991-2020. From the Figure, the length was thirty (30) and an increase in the time series data caused increase in rainfall. The fitted trend equation (Yt = 951.9+8.86*t) indicated that rainfall increases at the rate of 8.86mm year^{-1}.

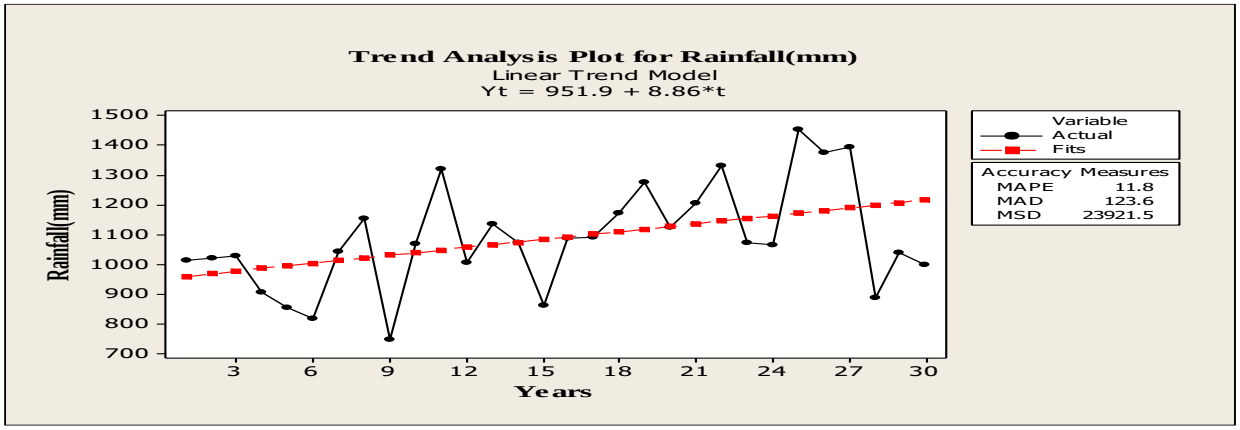

Figure 6: Positive Trend in Rainfall (1991-2020)
Source: Authors' Computation, 2021

Figure 6 revealed the trend line indicating a fluctuating pattern in rainfall recorded for thirty years. The first four years (1991-1993) show a continuous increase while the last three years (2018-2020) show a continuous decrease. However, on a general observation with regard to the years under study, rainfall is on the increase. The result tally with that of Abaje et al. (2019) that trends of the annual rainfall for the northern parts of Kaduna State represented by Zaria Meteorological Station for the period of study (1971-2016) indicates an increase of approximately 264.51mm at the rate of 5.75mm year^{-1} which is less than the value (8.86mm year^{-1}) obtained from this study. The increasing rainfall over recent years is in agreement with the findings of Odekunle *et al.* (2008), Abaje *et al.* (2012), and NIMET (2015 and 2017) that the Northern part of the country, especially the Sudano-Sahelian ecological zone is now experiencing wetter conditions in recent years.

Trend in Maximum Temperature (1991-2020)

Figure 7 presents the trend in maximum temperature (1991-2020). The Figure revealed that the length was thirty (30) years. Maximum temperature is said to have a positive trend due to the fact that a positive trend is an increase in one set of data (time/years) causing the other set of data to increase.

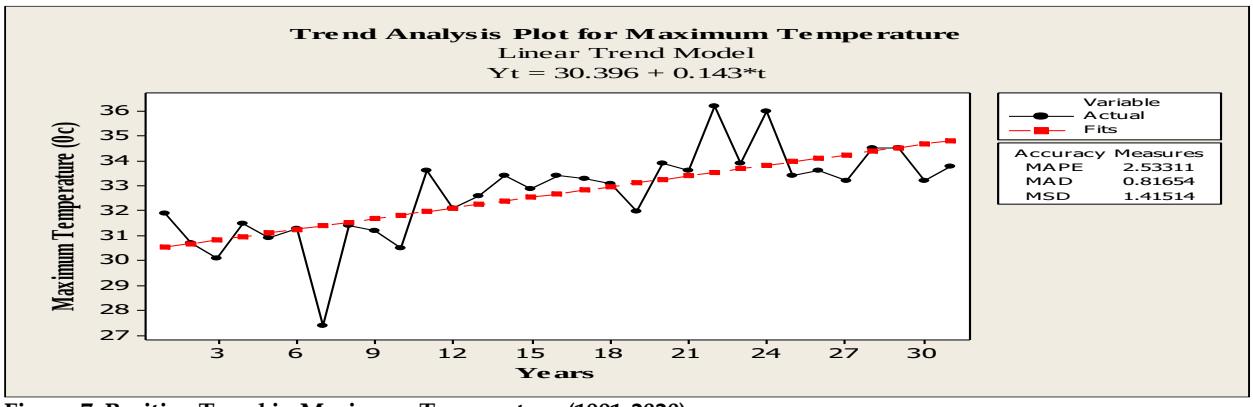

Figure 7: Positive Trend in Maximum Temperature (1991-2020)
Source: Authors' Computation, 2021

Figure 7 shows an increase in the maximum temperature. The fitted trend equation (Yt = 30.396+ 0.143*) is an indication that maximum temperature increases by 0.143℃ year^{-1} during the period of 30 years (1991-2020). Maximum temperature revealed a fluctuating pattern; the first year (1991) shows an increase while the reverse is the case for the last two years (2019-2020) which shows a decrease. However, on a general observation with regards to the years under study, maximum temperature is on the increase. The result of increasing trend of maximum temperature tally with the analysis of surface temperature data of Nigeria for the period 1981 to 2017 shows an increasing trend in annual mean maximum temperature over the last few decades (NIMET, 2017).

Trend in Minimum Temperature (1991-2020)

The trend in minimum temperature during the period of thirty years (1991-2020) revealed that the length was thirty (30) years. The minimum temperature is said to have a positive trend because a positive trend is an increase in one set of data (years) causing the other set of data to increase. The increase in the time series data causes an increase in the minimum temperature. Figure 8 shows the trend in minimum temperature during the period of thirty years (1991-2020). The trend equation (Yt = 18.146+ 0.0639*t) is an indication that minimum temperature increases by 0.064℃ year^{-1}. Minimum temperature revealed a fluctuating pattern, the first three years (1991-1992) show an increase, 1993-1999 show decreasing pattern (2000-2015) which shows an increase while the reverse is the case for the last year 2019-2020. However, on a general observation with regards to the years under study, minimum temperature is on the increase. Furthermore, in comparison with the results from the trend in maximum and minimum temperatures, maximum temperature had a higher value of increment (0.143℃) than minimum temperature with less value of increment (0.0639℃).

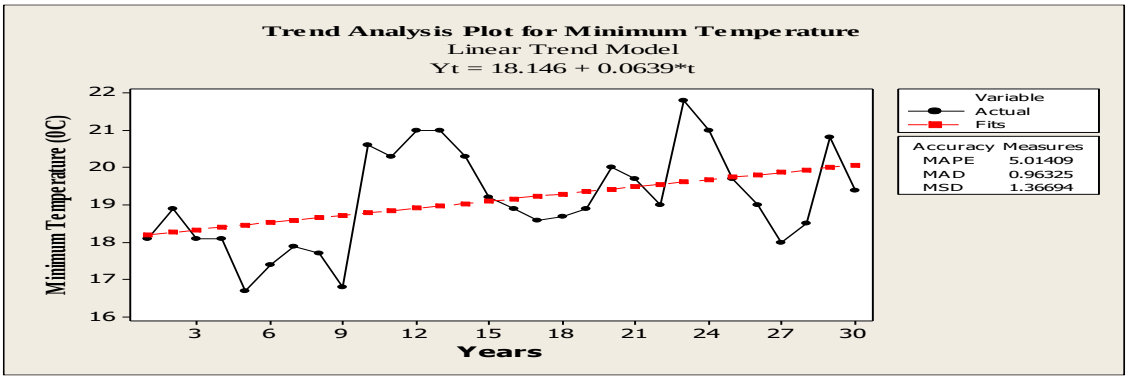

Figure 8: Positive Trends in Minimum Temperature (1991-2020)
Source: Authors' Computation, 2021

The findings supported the results from the work of Adamu et al. (2024) that maximum temperature increases higher than minimum temperature. The result of increasing trend of minimum temperature tally with the analysis of surface temperature data of Nigeria for the period 1981 to 2017 showed an increasing trend in annual mean minimum temperature over the last few decades (NIMET, 2017).

Trend in Average Temperature (1991-2020)

The trend in average temperature during the period of thirty years (1991-2020) revealed that the length was thirty (30) years. Figure 8 presented the result of a linear trend in average temperature for the periods of thirty years (30), average or mean temperature is said to have a positive trend because a positive trend is an increase in one set of data (time/years) causing the other set of data (average temperature) to increase.

Figure 9 revealed the fitted trend equation (Yt = 24.323+ 0.992*) is an indication that for the past thirty years (1991-2020), the average temperature has increased by 0.992℃ year^{-1}. This result corroborates Abaje et al. (2019) assessment of temperature (1971-2006) in Zaria (Northern Zone); Kaduna State which shows the mean increase in average temperature for the study area is 1.03℃. The average temperature of the study area revealed a fluctuating pattern, the first four years (1991-1994) show a continuous increase while the reverse is the case for the last six years (2005-2020) which shows a continuous decrease.

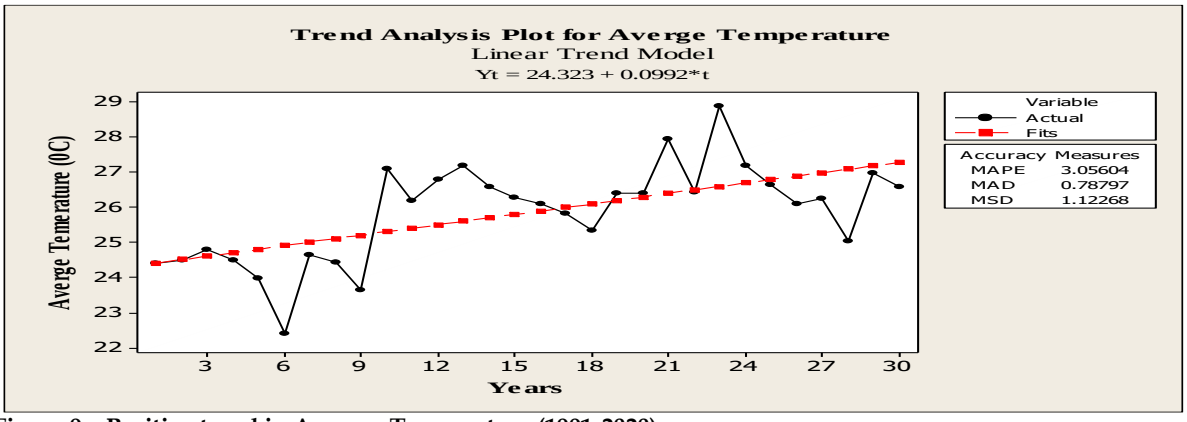

Figure 9: Positive trend in Average Temperature (1991-2020)
Source: Authors' Computation, 2021

Figure 9 further revealed that the average temperature in the study area is generally on the increase across the years under study. The findings also agree with the International Panel on Climate Change (IPCC) which identified that temperature trends on a global scale revealed a warming of 0.85℃ (0.65℃-1.06℃) (IPCC, 2013). This finding is in line with the findings of IPCC (2014) which said that the trend of global temperature from 1951-2012 is 0.12℃ (0.08℃ to 0.14℃) per decade. This increase in temperature is clear evidence of increasing warming of the earth's atmosphere. This study also conforms to the report of NIMET (2015 and 2016); and Abaje *et al.* (2016) in which the trend analyses revealed a higher rate of temperature increase in Nigeria.

CONCLUSION

The research revealed an anomaly which is the deviations from normal (mean of time series) by meteorological parameters under review. Rainfall shows 12 years of wet and 18 years of dry. Out of 12 years with wets, 11 years were between 2001-2017. Maximum temperature shows 17 years warmer than normal; 13 years shows cooler than normal. Out of 17 years that showed warmer maximum temperatures, 16 years were between 2001-2020. The minimum temperature shows 13 years with a warmer minimum temperature. Out of 13 years with

warm, 12 years were between 2001-2020. Average temperature shows 17 years with warm while 13 years with cool. Out of the 17 years with warm, 12 years were between 2001-2020. The trend in these variables shows an increase in rainfall at the rate of 8.86mm year^{-1}, maximum temperature increases by 0.143℃ year^{-1}, minimum temperature increases by 0.064℃ year^{-1} and average temperature increases by 0.992℃ year^{-1}. This implies that all the meteorological variables increase during the period under review.

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