FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 1, No. 2, 2024
Print ISSN: 1595-9686
EISSN: 1595-9708

RAINFALL AND TEMPERATURE DYNAMICS IN THE CONTEXT OF CLIMATE CHANGE IN THE SUDAN SAVANNA ECOLOGICAL ZONE OF KATSINA STATE, NIGERIA

[1]Kabir Abubakar, [1]I.B. Abaje and [2]Rabi'u Tukur
[1]Department of Geography, Federal University Dutsin-Ma Katsina State, Nigeria.
[2]Department of Environmental Resource Management, Federal University Dutsin-Ma Katsina State, Nigeria
kabubakar2@fudutsinma.edu.ng
https://doi.org/10/33003/jees.2024.0102/08

ABSTRACT
This research explored the dynamics of rainfall and temperature patterns in the context of climate change within the Sudan savanna ecological zone of Katsina State, Nigeria. The study analyzed rainfall and temperature data spanning 60 years (1961-2020). Linear regression, standard deviation, and second-order polynomial curve fitting were used to determine the trend of the climate data. Cramer's test was used to determine the decadal rainfall and temperature trend. The study period was further subdivided into two non-overlapping climatic subperiods (1961-1990 and 1991-2020), and the students' t-test (td) was used to determine the relative contribution of the two subperiods to the rainfall and temperature features of the study area. The trend analysis results revealed increased rainfall and temperature in recent years. The Cramer's and t-test findings indicated a significant rise in monthly and annual rainfall and temperature over the last three decades, underscoring clear evidence of climate change in the study area. These changes highlight the substantial ecological alterations driven by rising global temperatures, threatening the survival of the human race. The study emphasized that awareness programmes on recent changes in temperature and rainfall should be enhanced; greenhouse gas emissions in the atmosphere that have warming effect should be reduced; and government policies related to agriculture, water resources, and other related sectors should take into account the increasing nature of temperature and rainfall amount in recent years.

Keywords: Climate Change, Trends, Rainfall, Temperature, Sudan Savanna

INTRODUCTION

Climate change is one of the most pressing global challenges today, posing a serious threat to humanity's survival and sustainable development. It affects nearly every part of the biosphere, and its impacts are becoming increasingly evident worldwide. According to the most recent report by the Intergovernmental Panel on Climate Change (IPCC, 2021), scientists are observing widespread changes across the entire climate system and in all regions worldwide. Climate change manifests as rising temperatures and prolonged droughts, increasing evapotranspiration and posing a significant risk to natural vegetation, particularly in vulnerable areas (IPCC, 2014).

Despite being among the least responsible for global emissions, Africa is disproportionately vulnerable to climate change's effects due to its heavy reliance on climate-sensitive natural resources and limited capacity to mitigate them. The IPCC (2019) highlights that millions of Africans face heightened risks of extreme weather events such as droughts and floods, projected to intensify as global temperatures rise. This threatens critical resources like crops and water supplies while also exacerbating the spread of diseases. Climate variability has become increasingly pronounced in Nigeria since the late 1960s and 1970s (Abaje & Giwa, 2010; NiMet, 2015).

In Nigeria, a country with rich biodiversity and significant dependence on its forests for ecological and socioeconomic services, climate change poses serious challenges to the sustainable development of the human race. Increased temperatures lead to heat stress and affect people's health and economic status. At the same time, unpredictable rainfall patterns result in water stress during dry periods and flooding during heavy rains, contributing to higher mortality and shifts in species composition (Allen et al., 2010). The Sudan Savanna ecological zone in Katsina State, Nigeria, has been hard-hit by the effects of climate change on its rich biodiversity. People in the area are under severe threat, facing the risk of a decline in crop yield, affecting the environment and livelihood due to drought, extreme temperatures, and excessive evapotranspiration. These challenges are compounded by changing rainfall patterns, fluctuating temperatures, and shifts in groundwater conditions (Abaje & Giwa, 2010; NiMet, 2012).

Previous studies in Katsina State have examined various impacts of climate change, including perceptions of climate variability and adaptation strategies among local communities. Abaje et al. (2014) found that residents were acutely aware of climate change, noting increased temperatures, erratic rainfall, and extreme weather events such as droughts and floods. Local communities attributed these changes to deforestation, bush burning, and environmental degradation. Similarly, Lawal and Yahaya (2018) reported a significant decline in woody vegetation due to decreased rainfall and recurring droughts in semi-arid areas of Katsina State. This calls for analyzing the recent changes in temperature and rainfall over the Sudan Savanna of Katsina State to facilitate appropriate strategies to ameliorate the scourge of climate change. This is because the implications of these changes for agriculture, water resources, ecological systems, food security, and human health, among others, will certainly be different in Katsina State.

MATERIALS AND METHODS

Description of the study area

The study area is located in the north-central part of Katsina State, between Latitudes 12°20′01″ and 12°50′00″ North and Longitudes 7°20′00″ and 7°55′02″ East. It borders Batagarawa LGA to the North, Danmusa LGA to the South, Kankia and Bindawa LGAs to the East, and Safana and Batsari LGAs to the West.

The region experiences a tropical continental climate, classified as "Aw" by Köppen due to its distinct wet and dry seasons. Heavy rainfall occurs between July and August (Abaje et al., 2014), with annual totals ranging from 550 mm in the North to approximately 1000 mm in the South. The state's erratic rainfall patterns often lead to flooding, significantly impacting the local economy (Abaje et al., 2016).

The climate is dominated by the influence of two major air masses: the Tropical Maritime (mT) air mass and the Tropical Continental (cT) air mass. The mT, which is relatively warm and moist, originates from the Atlantic Ocean and is associated with Southwest winds in Nigeria. The cT, on the other hand, is relatively cool and dry. It originates from the Sahara Desert and is associated with the dry, cool, and dusty Northeast Trade winds known as the Harmattan (Abaje et al., 2018; Abaje & Oladipo, 2019). These air masses, mT and cT, meet along a slanting surface known as the Inter-tropical Discontinuity (ITD). The movement of the ITD determines the seasons. The rainy season begins around late May when the ITD moves north of the study area. The movement of the ITD continues northwards across the region; by August, the whole region is under the influence of the mT air mass. This marks the peak of the rainy season in the study area. The southward migration of the ITD initiates the dry season. From October, the ITD starts moving towards the south, and by January/February, the region will be under the effects of the cT air mass. This marks the peak of the dry season in the study area (Ati et al., 2022; Abaje, 2023).

Four distinct seasons characterize the climate: the Dry and Cool season (*Rani*), lasting from mid-November to the end of February, featuring the lowest air temperatures; the Dry and Hot season (*Bazara*) from March to mid-May; the Wet and Warm season (*Damina*) from late May to October, when over 90% of the annual rainfall occurs; and the Dry and Warm season (*Kaka*), beginning at the end of the rains around mid-November with the onset of Harmattan. The mean annual temperature is approximately 27°C, with the hottest temperatures (around 40°C) typically occurring in April and May, while the coolest period is from December to February (NiMet, 2015). Evapotranspiration is high throughout the year, particularly during the dry season. The relative humidity is generally below 40%, rising to 60% or more during the rainy season (Abaje et al., 2017; Abaje, 2023).

The soil is light brown, sandy, and reddish, with medium fertility, making it easy to cultivate. The vegetation is characteristic of the Sudan-Sahelian zone, part of the Sudan savanna belt that extends across northern Nigeria, including areas such as Sokoto, Katsina, Kano, and Borno (Abaje, 2007).

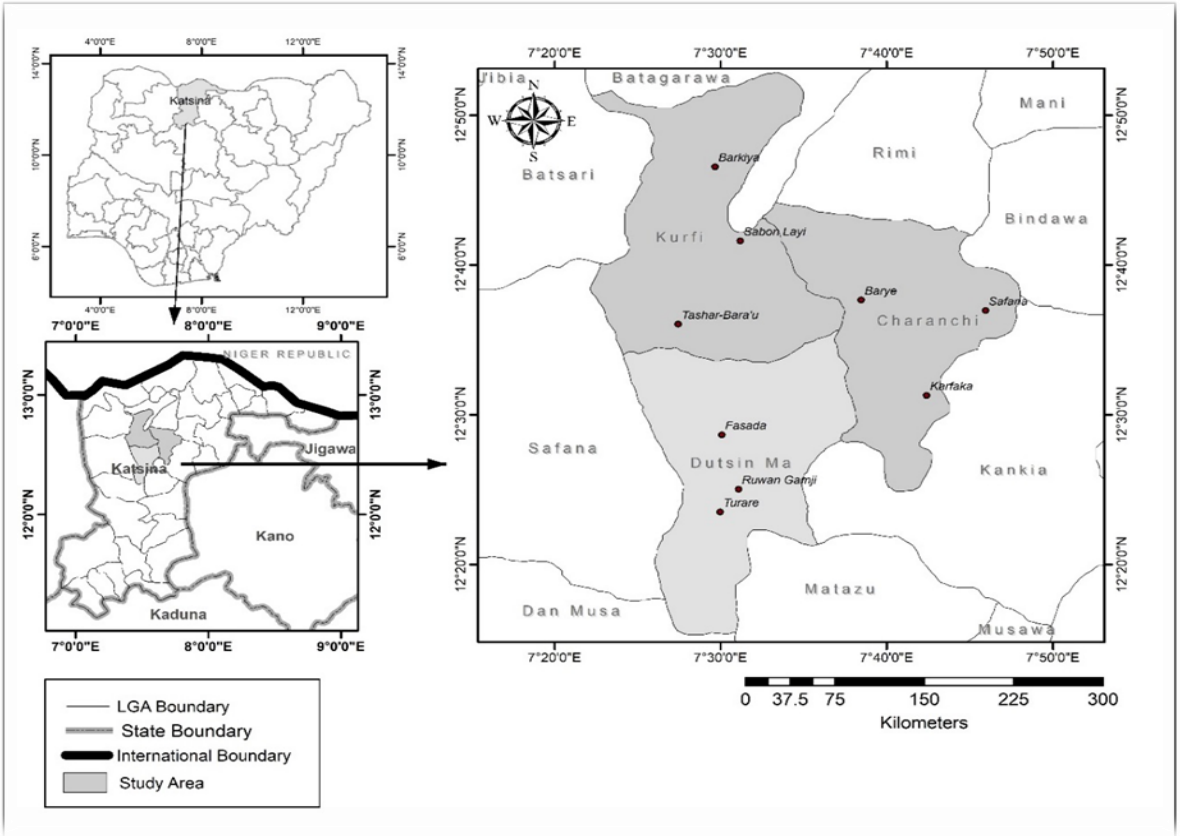


Figure 1: Katsina State Showing the Study Area

Data Collection

This research used rainfall (mm) and temperature (°C) data for a period of sixty years (1961-2020), obtained from the Nigerian Meteorological Agency (NiMet) archive, Abuja. This study used only the rainfall total for May to October and the annual. Temperature totals for the months of January to December and the annual were equally used.

The standardized coefficient of Skewness (Z_1) and Kurtosis (Z_2) statistics, as defined by Brazel and Balling (1986), were used to test for the normality in rainfall and temperature series for the study area. The standardized coefficient of Skewness (Z_1) and Kurtosis (Z_2) was calculated as follows:

The standardized coefficient of Skewness (Z_1) was calculated as:

$$Z_1 = \left[\left(\sum_{i=1}^{N} (x_i - \bar{x})^3 / N \right) \Big/ \left(\sum_{i=1}^{N} (x_i - \bar{x})^2 / N \right)^{3/2} \right] \Big/ \left(6/N \right)^{1/2} \quad \text{(eq.1)}$$

and standardized coefficient of Kurtosis (Z_2) was calculated as:

$$Z_2 = \left[\left(\sum_{i=1}^{N} (x_i - \bar{x})^4 / N \right) \Big/ \left(\sum_{i=1}^{N} (x_i - \bar{x})^2 / N \right) 2 \right] - 3 \Big/ \left(24/N \right)^{1/2} \quad \text{(eq. 2)}$$

Where $\bar{x}$ is the long-term mean of x_i values and N is the number of years in the sample if the absolute value of Z_1 or Z_2 is greater than 1.96 then a significant deviation from the normal curve is indicated at 95% confidence level.

Walsh and Lawler's (1981) statistics was used to determine the Relative Seasonality Index (*RSI*) of the rainfall series. This was done to determine the class into which the climate of the study area can be classified. The relative seasonality index was calculated as follows:

$$RSI = \frac{1}{R} \sum_{n=1}^{n=12} \left| \bar{x}_n - \frac{R}{12} \right| \quad \text{(eq. 3)}$$

Where $\bar{x}$ = the mean rainfall for month n;
R = mean annual rainfall

This index can vary from zero (if all the months have equal rainfall) to 1.83 (if all the rainfall occurs in a single month). The proposed Relative Seasonality Index classes by Walsh and Lawler (1981) are presented in Table 1

Table 1: Seasonality Index Classes

Rainfall Regime	RSI Class Limits
Very equable	≤ 0.19
Equable but with a definite wetter season	0.20–0.39
Rather seasonal with a short drier season	0.40–0.59
Seasonal	0.60–0.79
Markedly seasonal with a long drier season	0.80–0.99
Most rain in 3 months or less	1.00–1.19
Extreme, almost all rain in 1–2 months	≥1.20

To ascertain the nature of trends and measurement of average rainfall and temperature variability, the standard deviation, which provides the deviation from normality for rainfall and temperature, was determined. The standard deviation is given as:

$$\delta = \sqrt{\sum \frac{(x - \bar{x})^2}{N}} \quad \text{(eq.4)}$$

$\bar{x}$ = mean value of rainfall and temperature observations
n = number of rainfall and temperature observations of samples
δ = standard deviation

Linear regression analysis was used to analyze the linear trends of rainfall and temperature data in the study area using Microsoft Excel (2013). Changes in rainfall and temperature per year for the study period were also calculated using Microsoft Excel (2013). Second-order polynomial curve fitting was used to determine the non-linear rainfall and temperature trend. This was done to make a derivable decision concerning the increase or decrease in the distribution of rainfall and temperature from 1961 to 2020 in the study area. The formula for the linear regression is given as:

$$y = a + bx \quad \text{……………………………} \quad \text{(eq. 5)}$$

where a the intercept of the regression line on the y-axis; b is the slope of the regression line. The values of a and b can be obtained from the following equations:

$$a = \frac{\sum y - b\left(\sum x\right)}{n} \quad \text{……………………………} \quad \text{(eq. 6)}$$

$$b = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{n\left(\sum x^2\right) - \left(\sum x\right)^2} \quad \text{……………………………} \quad \text{(eq. 7)}$$

To further examine the nature of the trends, a second-order polynomial curve fitting was used to determine the rainfall non-linear trends. The equation is of the form:

$$y = a + b_1 x + b_2 x^2 \quad \text{……………………………} \quad \text{(eq. 8)}$$

To evaluate the three unknowns (a, b_1, b_2), the normal equations become a set of 3 simultaneous equations:

$$\sum y = na + b_1\left(\sum x\right) + b_2\left(\sum x^2\right) \quad \text{……………………………} \quad \text{(eq.9)}$$

$$\sum xy = a\left(\sum x\right) + b_1\left(\sum x^2\right) + b_2\left(\sum x^3\right) \quad \text{……………………} \quad \text{(eq. 10)}$$

$$\sum x^2 y = a\left(\sum x^2\right) + b_1\left(\sum x^3\right) + b_2\left(\sum x^4\right) \quad \text{…………………} \quad \text{(eq. 11)}$$

Here $\sum xy$ is the sum of the products obtained by multiplying each value of x by the corresponding value of y, $\sum x^2 y$ is the sum of the products obtained by multiplying the square of each value of x by the corresponding value of y, and $\sum x^2$, $\sum x^3$, and $\sum x^4$ are the sums of the second, third, and fourth powers of the x's, respectively.

The temperature and rainfall series were subdivided into decadal non-overlapping sub-periods (1961-1970, 1971-1980, 1981-1990, 1991-2000, 2001-2010, and 2011-2020). Cramer's test, as defined by Lawson et al. (1981), was used to identify the trend in temperature and rainfall series in the study area. This is given as:

$$t_k = \left(\frac{n(N-2)}{N - n\left(1 + \tau_k^2\right)}\right)^{1/2} \tau_k \quad \text{……………………………} \quad \text{(eq.12)}$$

Where t_k is a standardized measure of the difference between mean given as:

$$\tau_k = \frac{\bar{x}k - \bar{x}}{\delta} \quad \text{…… ……………………………} \quad \text{(eq.13)}$$

Where $\bar{x}k$ is the mean of the sub-period of n-years. $\bar{x}$ and δ are the mean standard and deviation of the entire series, respectively, and t_k is the value of the student *t*-distribution with N-2 degrees of freedom. It is then tested against the students-distribution table at a 95% confidence level appropriate to a two-tailed test. When the tk level is outside the bounds of the two-tailed probability of the Gaussian distribution (equal to 1.96 at a 95% confidence level), a significant shift from the mean is attained.

The study period was subdivided into two non-overlapping subperiods (1961-1990 and 1991-2020). The students' t-test (*td*), as defined by Brazel and Balling (1986), was used to determine the relative contribution of the two subperiods to the rainfall and temperature features of the study area.

$$t_d = \frac{(\overline{X}_2 - \overline{X}_1) - (\mu_2 - \mu_1)}{\left[\frac{N_2 S_2^2 + N_1 S_1^2}{N_2 + N_1 - 2} \cdot \frac{1}{N_2} + \frac{1}{N_1}\right]^{1/2}} \quad \text{..................(eq.14)}$$

Where (X_2-X_1) represents the differences in group means, (u_2-u_1) is the expected differences (set equal to 0), N_2 and N_1 are the number of cases within each sub-sample, and S_2 and S_1 are their standard deviation. When t_d is outside the bounds of the Gaussian distribution, equal to 1.96 at a 95% confidence level, a significant shift from the mean is assumed.

RESULTS AND DISCUSSION

Observed Changes in Rainfall (1961-2020)

Table 2 presents the general statistics of the study area's monthly (May to October) and annual rainfall.

Table 2: General Statistics and Trends of Rainfall (1961-2020)

Statistics	May	June	July	Aug	Sep	Oct	Annual
Mean	32.43	80.10	155.51	205.19	89.43	14.21	584.97
Standard Dev. (δ)	29.74	40.44	66.61	75.77	46.50	21.57	160.84
Skewness (Z_1)	0.70	0.21	0.95	0.31	0.09	1.68	-0.03
Kurtosis (Z_2)	-0.80	-0.96	0.76	-0.59	0.51	1.79	0.02
Minimum Value	0.	16.1	39.8	71.3	1.5	0.00	240.6
Maximum Value	95.4	159.3	341	395.2	216	77.7	979
Trend (mm/year)	0.48	0.15	0.30	0.12	0.09	-0.05	0.74
Total Change (mm/year)	28.8	9.00	18.00	7.20	5.40	-3.00	44.4

The results of Z_1 and Z_2 show that all the months and the annual rainfall data series were accepted as indicative of normality at the 95% confidence level. As a result, the data was used without any transformation. The result of the calculated *RSI* was 1.15, which means that most of the rainfall in the study area is within 3 months or less. This finding is in agreement with the results obtained in the studies of the occurrence of droughts in the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria by Abaje et al. (2010) where effective rainfall in this region was within 3 months or less.

The mean annual rainfall for the 60 years (1961-2020) is 584.97 mm, while the highest mean monthly rainfall distribution is 205.19mm (August), and the lowest mean monthly rainfall is 14.21 mm (October), as indicated in Table 2. The annual standard deviation is 160.84 mm. The maximum value of annual rainfall of 979 mm was recorded in 1964, while the minimum value of 240.6 mm was recorded in 1985, which coincided with the Sahelian Drought of the 1980s that ravaged the country (Abaje, 2023). The month with the highest amount of rainfall is August.

Monthly and Annual Rainfall Trends

The linear trends of the monthly rainfall series for the 60 years (1961-2020) (see Appendix I), indicate an increase of 28.8 mm at the rate of 0.48mm per year in May, an increase of 9.00 mm at the rate of 0.15 mm per year for the study period in June, an increase of 7.20 mm at the rate of 0.30 mm per annum in July, an increase of 7.20 mm at the rate of 0.12 mm per year was recorded in August; in September there was an increase of 5.40 mm at the rate of 0.09 mm per year, in October, there was a decrease of 3.00 mm at the rate of 0.05 mm per year for the 60 years. Based on the second-order polynomial curve fitting, the trends showed that May, June, July, August, and September experienced increasing trends from the beginning of the data, and a decreasing trend was experienced in October for the study period.

Figure 2 shows the graphical presentation of the annual trends and fluctuations of the rainfall series in the study area. The linear trend line shows an increase of approximately 19.2 mm at 0.32 mm annually. This means that the annual rainfall keeps increasing from 1961 to 2020. This result agrees with the findings of Ati et al. (2022), which showed that rainfall has significantly increased in recent years. The polynomial curve fitting and the standard deviation have generally shown an increasing trend in recent years. The general increase in the annual rainfall yield results from a substantial increase in May to August rainfall, which may be attributed to climate change.

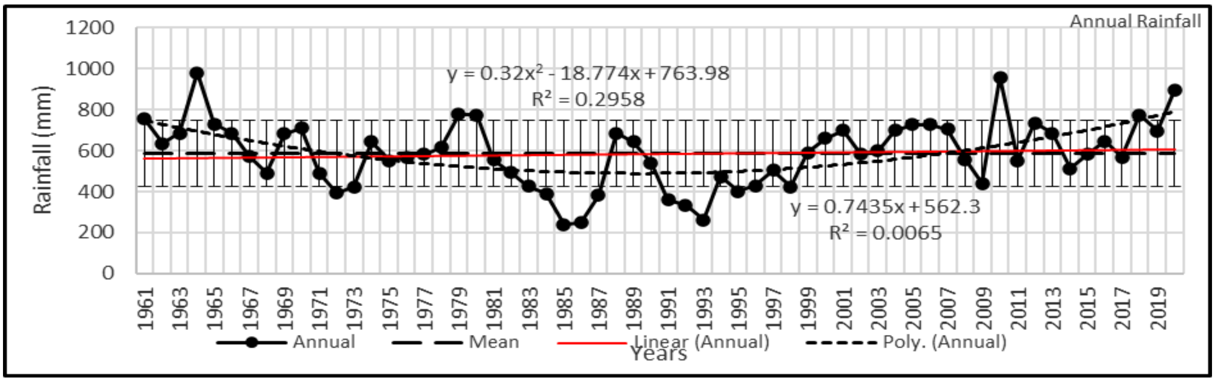


Figure 2: Trend of Annual Rainfall (1961-2020)

Decadal Rainfall Trend

The results of the 10-year decadal sub-period analysis (Cramer's test) of the rainfall are presented in Table 3. The negative values indicate a decrease in rainfall, while the positive values indicate an increase in rainfall. The results revealed that the negative t_k values of -2.06 and -2.09 for 1981-1990 and -2.30, -2.08, and -2.26 for the sub-period 1991-2000 indicate a significant decrease in rainfall for those months. Four decades (1961-1970, 1971-1980, 2001-2010, and 2011-2020) have positive tk values, indicating that annual rainfall has increased in recent years. The highest annual reduction was recorded in the sub-period 1991-2000 with a t_k value of -2.26. This resulted from a significant decrease recorded in June and August, which was -2.30 and -2.08, respectively. In 1981-1990, the sub-period recorded a significant decrease in annual rainfall with a value of -2.09. All the months in the 1981-1990 sub-period recorded a decrease, with May having a significant value of -2.06. The sub-period 2001-2010 recorded an increase with an annual value of 1.65; all the months in this period recorded an increase in rainfall except October, which recorded a decrease with a value of -0.10. The sub-period 2011-2020 was equally of increasing annual rainfall with a value of 1.57. All the months of this sub-period recorded an increase in rainfall, with July having the highest t_k value of 1.56. The highest increase in annual rainfall was recorded in the sub-period 1961-1970, with a value of 1.95. All the months in this sub-period recorded an increase in rainfall, with August having the highest value of 1.84. This follows Odekunle *et al*. (2012), NiMet (2015 and 2017), Ati et al. (2022), and Abaje (2023), who state that the northern part of the country, particularly the Sudano-Sahelian Ecological Zone, has been experiencing wetter conditions recently. This is consistent with the rising rainfall in recent years.

Table 3: Decadal Sub-Periods Rainfall Trend

Sub-Period	May	June	July	August	Sept	Oct	Annual
1961-1970	-0.90	1.24	1.33	1,84	0.99	0.96	1.95
1971-1980	0.24	-0.81	0.29	0.03	-0.24	0.73	-0-01
1981-1990	-2.06*	-0.69	-1.50	-1.56	-0.99	-0.60	-2.09*
1991-2000	0.30	-2.30*	-1.85	-2.08*	0.25	-1.36	-2.26*
2001-2010	1.29	1.47	0.39	1.42	0.29	-0.10	1.65
2011-2020	1.44	1.52	1.56	0.61	-0.30	0-45	1.57

Significant at P<0.05

30-Year Non-Overlapping Sub-Period Rainfall Trend

The results of the students' t-test (td) between the two non-overlapping sub-periods (1961-1990 and 1991-2020) are presented in Table 4. The result indicates an increase in mean rainfall in the sub-periods 1991-2020; in May, an increase of 19.08 mm was recorded in this period as compared to the previous period. In June, the increase recorded was 1.64 mm, whereas in September, the increase recorded was 2.19 mm. This is also the case for annual rainfall in the sub-period of 1991-2020, with an increase of 14.46 mm. However, in July, August, and October, a decrease of -6.75mm, -0.89mm, and -4.79mm were recorded in the same sub-period. The result indicated that the study area received higher rainfall in the recent sub-period, and the changes between the two sub-periods were significant in May.

Table 4: 30-Year Non-overlapping Sub-periods (1961-1990 and 1991-2020)

Month	Sub-periods	Mean (mm)	Standard Deviation (mm)	t_d
May	1961-1990	23.90	23.80	2.56*
	1991-2020	42.98	32.33	
June	1961-1990	79.28	40.98	0.15
	1991-2020	80.92	40.57	
July	1961-1990	155.96	72.23	-0.05
	1991-2020	155.07	61.72	
August	1961-1990	208.57	76.32	-0.34
	1991-2020	201.82	76.36	
September	1961-1990	88.33	44.09	0.18
	1991-2020	90.52	49.52	
October	1961-1990	16.60	25.33	-0.84
	1991-2020	11.81	17.13	
Annual	1961-1990	577.74	166.14	0.34
	1991-2020	592.20	160.97	

*Significant at P<0.05

Observed Changes in Temperature (1961-2020)

The general statistics of the monthly (January to December) and annual temperature of the study area are presented in Table 5. The results of Z_1 and Z_2 show that all the months and the annual were accepted as indicative of normality at the 95% confidence level. Consequently, the data were used in their original form. The temperature has risen from the beginning of the study period to recent years. This is unequivocal evidence of the recent increase in atmospheric heat (also known as global warming). This is consistent with NiMet's 2016, 2017, 2019, and 2021 findings, which found that northern Nigeria has experienced a faster rate of temperature increase in recent years based on trend analyses. Additionally, it concurs with the IPCC's Fifth Assessment Report that throughout the past 20 years, there have been more warm days and nights across Africa, with greater change (IPCC, 2021).

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 1, No. 2, 2024
Print ISSN: 1595-9686
EISSN: 1595-9708

Table 5: General Statistics and Trends of Temperature (1961-2020)

Statistics	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average
Mean ($\bar{x}$)	21.73	24.57	28.51	31.24	30.94	28.90	26.51	25.59	26.53	27.24	24.55	21.99	26.53
Standard Dev. (δ)	1.50	1.74	1.44	1.09	1.20	1.22	0.97	0.85	1.15	1.11	1.35	1.28	0.62
Skewness (Z_1)	0.12	-0.37	0.30	0.36	0.05	0.14	0.32	0.08	-1.47	0.53	0.51	0.19	0.25
Kurtosis (Z_2)	-0.42	-0.09	0.55	-0.50	0.13	-0.68	0.41	-0.69	5.70*	-0.27	-0.12	0.17	-0.60
Minimum Value	18.6	19.9	25.25	29.2	27.5	26.8	24.6	24.00	21.3	25.5	21.5	18.6	25.19
Maximum Value	25.6	27.9	32.5	33.8	33.5	31.65	28.8	27.5	28.7	30.00	27.70	25.7	27.99
Trend (^oC/year)	-0.01	-0.00	0.02	0.03	0.05	0.05	0.04	0.03	0.04	0.04	0.04	0.01	0.02
Total Change (^oC/yr)	-0.60	-0.00	1.20	1.80	3.00	3.00	2.40	1.80	2.40	2.40	2.40	0.60	1.20

Significant at $P<0.05$

Trends Analysis of Annual Temperature

Appendix II presents the monthly temperature trend, while Figure 3 shows the annual temperature trend. The linear trend line equations for the monthly and annual temperatures for the study period indicate an increase in temperature. Estimating changes in the monthly temperatures (Appendix II) expressed in ^{O}C for the 60 years of the study indicates a decrease of 0.6^{O}C at 0.01^{O}C and 0.42^{O}C at the rate of 0.007^{O}C in January and February, respectively. An increase of 1.20^{O}C at the rate of 0.2^{O}C per year in March, an increase of 1.8^{O}C at the rate of 0.03^{O}C in April, an increase of 3.00^{O}C at the rate of 0.05^{O}C was recorded in May. In June, July, August, and September, an increase of 3.00^{O}C at the rate of 0.05^{O}C, 2.4^{O}C at the rate of 0.04^{O}C, 1.8^{O}C at the rate of 0.03^{O}C, and 2.4^{O}C at the rate of 0.04^{O}C per year were recorded, respectively. In October and November, an increase of 2.46^{O}C at 0.041^{O}C and 2.22^{O}C at 0.037^{O}C was recorded, respectively. In December, a decrease of 0.6^{O}C at 0.012^{O}C per year was recorded. The polynomial curve fitting and the standard deviation have generally shown an increasing trend in recent years.

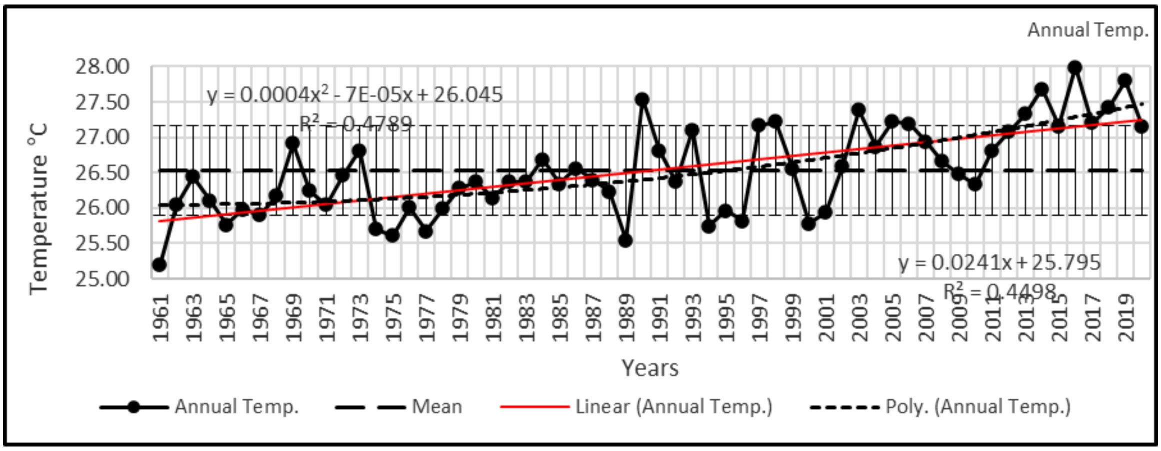


Figure 3: Trend of annual temperature (1961-2020)

Decadal Sub-periods Analysis of Temperature

The decadal sub-period analysis of the temperature of the study area in Table 6 showed an increasing trend from the first decade to the recent decade. The t_k values show that the temperature in 1961-1970 decreased, with the most significant decrease recorded in June with a tk value of -2.32, followed by August with a t_k value of -2.25, respectively. The sub-period of 1971-1980 also had a decreasing temperature, with a significant decrease in May, June, July, and August. The sub-period 1981-1990 was decreasing temperature even though the decrease was insignificant. The sub-period 1991-2020 also recorded an insignificant decrease in temperature, while the sub-period 2001-2010 recorded an insignificant increase in temperature. The sub-period 2011-2020 was that of increasing temperature, with the most significant increase recorded in October with a tk value of 2.68, followed by November with t_k value of 2.63. Other months with significant increases in the 2011-2020 sub-period are June, July, April, September, and May, with values of 2.49, 2.46, 2.20, 2.19, and 2.11, respectively. This increase in temperature is clear evidence of increasing warming of the earth's atmosphere. It is in line with reports of NiMet (2015 and 2016), Abaje et al. (2016), Abaje and Oladipo (2019), and Ati et al. (2022) that the temperature of the country, especially northern Nigeria, has been increasing in the recent years.

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 1, No. 2, 2024
Print ISSN: 1595-9686
EISSN: 1595-9708

Table 6: Decadal Sub-periods Analysis of Temperature

Sub-period	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Average
1961-1970	1.26	0.62	-0.99	-1.88	-2.11*	-2.32*	-1.97*	-2.25*	-1.97*	-2.25*	-1.52	1.65	-1.98*
1971-1980	0.47	1.20	-0.14	-1.54	-2.07*	-2.19*	-2.22*	-1.96*	-1.64	-1.91	-1.43	-0-08	-1.92
1981-1990	-0.57	-0.64	-0.55	0.01	-0.08	-0.46	-0.28	0.96	-1.33	-0.87	0.02	0.08	-0.59
1991-2000	-0.22	-1.94	-0.85	0.01	1.08	1.44	0.36	-1.19	0.64	1.52	-0.38	-1.07	-0.40
2001-2010	-0.49	0.12	0.87	1.03	1.40	1.21	1.53	2.06*	1.81	-0.12	-0.51	-1.07	1.18
2011- 2020	-0.53	0.94	1.53	2.20*	2.11*	2.49*	2.46*	1.71	2.19*	2.68*	2.63*	-0.80	2.73*

*****Significant at P<0.05

Thirty Years Non-Overlapping Sub-Period Analysis of Temperature

Table 7 presents the student t-test results for the two subperiods (1961-1990 and 1991-2020). The result revealed that January and February recorded a decrease in the mean temperature, though not significantly, while December showed a significant decrease in temperature. In March, there was an insignificant increase in the mean temperature in the recent period. The months of April, May, June, July, August, September, October, and November showed significant increases in temperature in the recent period. This proves that the temperature is increasing in recent years, leading to global warming. This finding also corroborates the reports by NiMet (2015 and 2016), Abaje et al. (2016), Abaje and Oladipo (2019), and Ati et al. (2022) that the temperature of the country, especially northern Nigeria, has been increasing in the recent years.

Table 7: 30-Years Non-overlapping Sub-periods Analysis (1961-1990 and 1991-2020)

Month	Sub-periods	Mean (^{O}C)	Standard Deviation (^{O}C)	t_d
January	1961-1990	21.91	1.45	-0.93
	1991-2020	21.54	1.54	
February	1961-1990	24.78	1.38	-0.94
	1991-2020	24.36	1.97	
March	1961-1990	28.26	1.22	1.30
	1991-2020	28.75	1.61	
April	1961-1990	30.82	0.86	3.20*
	1991-2020	31.67	1.14	
May	1961-1990	30.31	0.65	4.67*
	1991-2020	31.58	1.30	
June	1961-1990	28.13	0.88	6.28*
	1991-2020	29.68	1.00	
July	1961-1990	25.98	0.78	5.01*
	1991-2020	27.05	0.83	
August	1961-1990	25.22	0.83	3.58*
	1991-2020	25.95	0.71	
September	1961-1990	25.89	1.19	5.04*
	1991-2020	27.17	0.67	
October	1961-1990	26.60	0.71	5.39*
	1991-2020	27.89	1.07	
November	1961-1990	24.12	1.00	2.54*
	1991-2020	24.98	1.52	
December	1961-1990	22.33	1.29	-2.05*
	1991-2020	21.66	1.20	
Annual	1961-1990	26.20	0.46	4.70*
	1991-2020	26.86	0.60	

*Significant at P<0.05

CONCLUSION AND RECOMMENDATIONS

The estimation of changes in the temperature and rainfall for the whole study period from the linear trend line equation showed an average increase of 1.2 ^{O}C at the rate of 0.02 ^{O}C for the 60 years. The plotted standard deviation for the rainfall and temperature anomalies and decadal analysis for the rainfall and temperature in the study area showed an increasing trend from the beginning to the end of the data set (1961-2020). This indicates that the study area has been experiencing increasing wetness and warming over recent years and, hence, climate change. The changes in rainfall patterns in recent times may be attributed to the increase in atmospheric temperature in recent years, which has increased evapotranspiration and, consequently, condensation and precipitation. Based on the findings of this study, the following recommendations were offered: The government should advance a system for continuous monitoring of climate trends, including rainfall and temperature changes. This information is crucial for developing adaptive strategies and responding proactively to emerging climate patterns.

REFERENCES

Abaje, I.B. & Giwa, P.N. (2010). Flood risk assessment and vulnerability in Kafanchan town, Jema'a local government area of Kaduna State, Nigeria. *International Journal of Sustainable Development*, 3(1), 94-100.

Abaje, I.B. (2007). *Introduction to Soils and Vegetation*. Kafanchan: Personal Touch Productions.

Abaje, I.B. (2023). Geo-Statistical Analysis of Meteorological Drought and Recurrence Intervals in the Context of Climate Change Over Extreme Northeastern Region of Nigeria. *Tanzania Journal of Science,* 49 (1), 152–166. DOI: https://dx.doi.org/10.4314/tjs.v49i1.14

Abaje, I.B. and Oladipo, E.O. (2019). Recent Changes in the Temperature and Rainfall Conditions Over Kaduna State, Nigeria. *Ghana Journal of Geography,* 11 (2), 127-157. https://www.ajol.info/index.php/gjg/article/view/191996/181128

Abaje, I.B., Achiebo, P.J. and Matazu, M.B. (2018). Spatio-Temporal Analysis of Rainfall Distribution in Kaduna State, Nigeria. *Ghana Journal of Geography,* 10 (1), 1-21. DOI: https://dx.doi.org/10.4314/gjg.v10i1.1.

Abaje, I.B., Ati, O.F. & Iguisi, E.O. (2012). Recent trends and fluctuations of annual rainfall in the Sudano-Sahelian ecological zone of Nigeria: Risks and Opportunities. *Journal of Sustainable Society*, 1(2), 44-51.

Abaje, I.B., Sawa, B.A. & Ati, O.F. (2014). Climate variability and change, Impacts and adaptation strategies in Dutsin-Ma Local Government Area of Katsina State, Nigeria. *Journal of Geography and Geology,* 6 (2), 103-112.

Ati, O.F., Aremu, K., Olatunde, A.F., Abaje, I.B. and Oladipo, E.O. (2022). Meteorological Drought and Temperature in Sudano-Sahelian Region of Nigeria under Increasing Global Warming. In S.A. Harris (Ed.), *The Nature, Causes, Effects and Mitigation of Climate Change on the Environment*. https://doi.org/10.5772/intechopen.94777. London: Intechopen Limited.

IPCC (2014). Summary for policymakers. In Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., ….White, L.L. (Eds.). Climate Change 2014: Impacts, Adaptation, and Vulnerability (pp. 1-32.). Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC. (2019). WGIII. A Contribution of Working Group III Assessment Report by Working Group III (WG III). An assessment of options for adapting and mitigating climate challenges through limiting or preventing Greenhouse emissions.

IPCC. (2021). AR6 Synthesis Report. A Contribution of Sixth Assessment Report by working Group III. Assesses options for mitigating climate challenges through limiting or preventing Greenhouse emissions.

Lawal, A. and Yahaya, Z.I. (2018). Perspectives of Farming Communities on Effect of Desertification and Climate Change on Woody Vegetation in Semi-Arid Areas of Katsina State Dutse Journal of Pure and Applied Sciences (DUJOPAS), Vol. 4 No. 2 December 2018.

Nigerian Meteorological Agency, NiMet (2012). 2012 Nigeria Climate Review (59 pp.). Nigerian Meteorological Agency (NIMET), Abuja.

Nigerian Meteorological Agency, NiMet (2015). Evidence of climate change. 2015 Nigeria Climate Review Bulletin (pp 3-8). Nigerian Meteorological Agency (NiMet), Abuja.

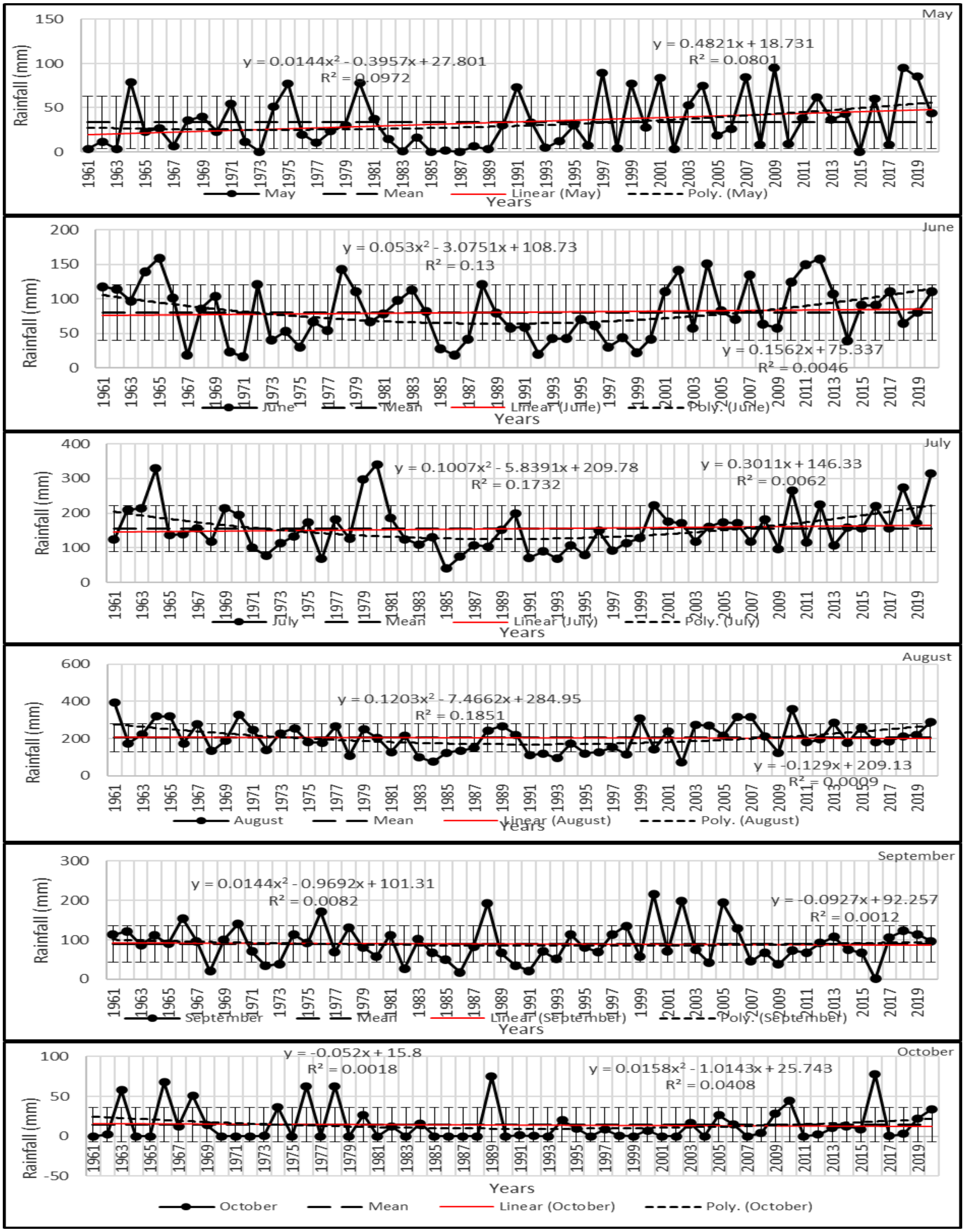
Nigerian Meteorological Agency, NiMet (2016). Evidence of climate Change. 2016 Nigeria Climate Review Bulletin, (pp 5-11). Nigerian Meteorological Agency (NiMet), Abuja.

Nigerian Meteorological Agency, NiMet (2017). Evidence of climate change. Climate Review Bulletin 2017, (pp 2-12). Nigerian Meteorological Agency (NiMet), Abuja.

Odekunle, T. O., Andrew, O., &Aremu, S. O. (2012). Towards a wetter Sudano-Sahelian ecological zone in twenty-first century Nigeria. Weather, 63(3), 66-70.

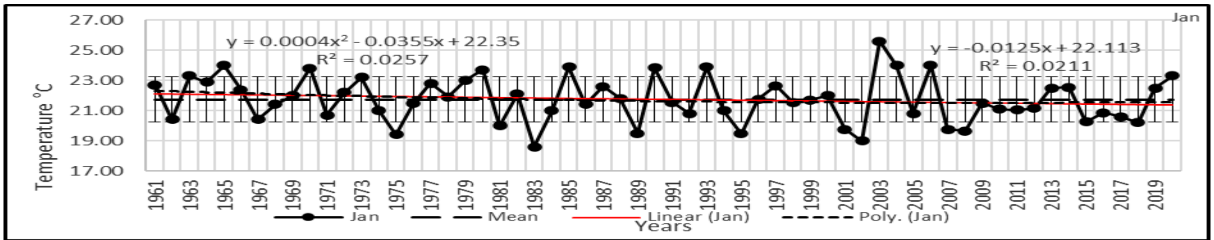
FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 1, No. 2, 2024
Print ISSN: 1595-9686
EISSN: 1595-9708

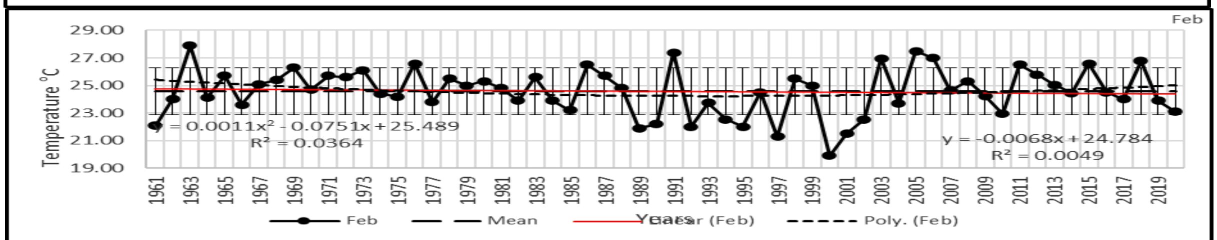
Appendix I: Monthly Trends of Rainfall Series for the 60 Years (1961-2020)

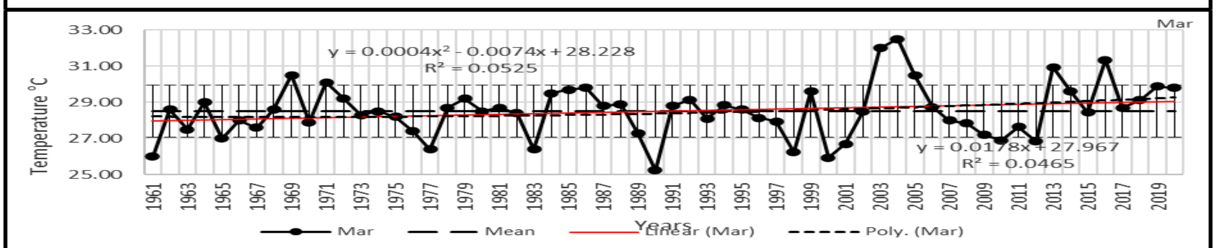


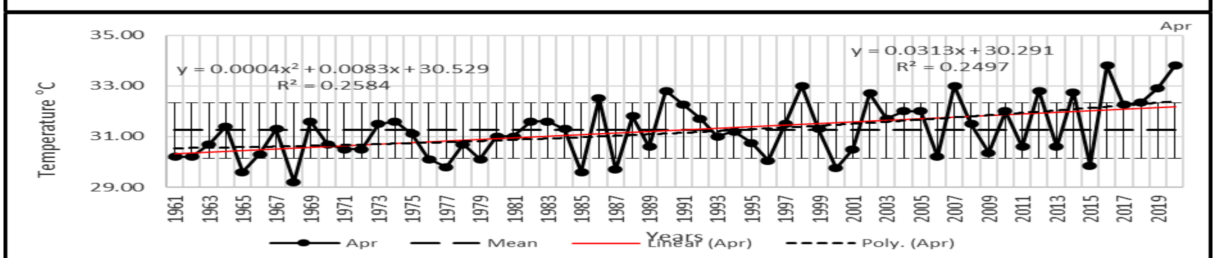
FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 1, No. 2, 2024
Print ISSN: 1595-9686
EISSN: 1595-9708

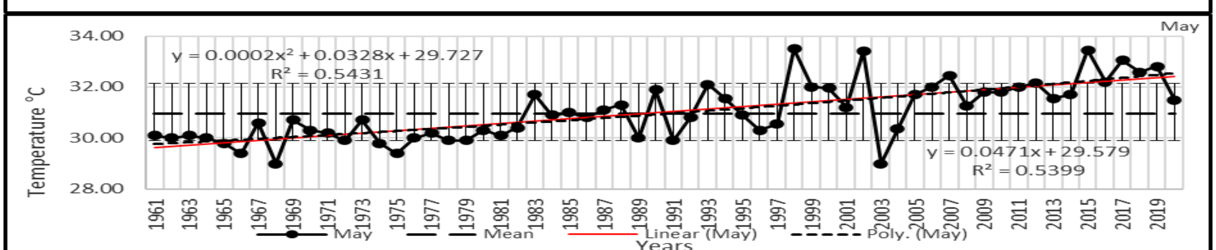
Appendix II: Monthly Trends of Temperature (1961-2020)

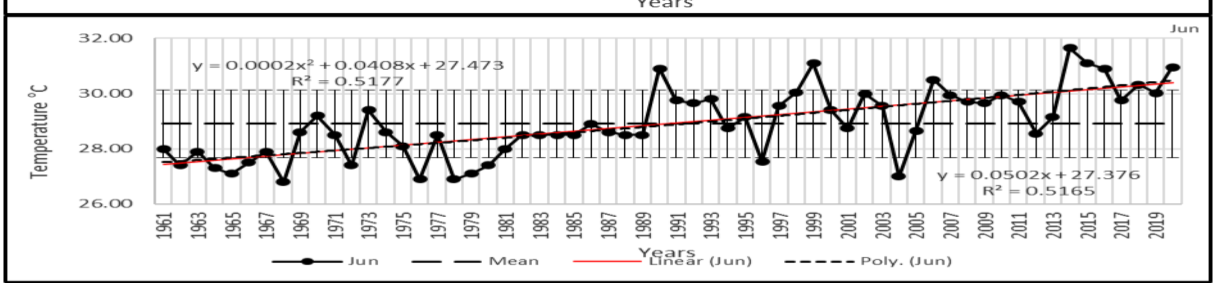












FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 1, No. 2, 2024
Print ISSN: 1595-9686
EISSN: 1595-9708

Appendix II Cont.