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Impacts of Temperature and Precipitation Variability in Northeast Nigeria: a Case Study of Yobe State.

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Abstract: *Understanding the impacts of temperature and precipitation variability is important to successful climate change mitigation and adaptation strategies. Given the increasing effects of global warming which have manifested in extreme weather events such as heatwaves, droughts and floods in the study area. The study of its impacts became necessary as it threatens agricultural production, human health and other socio-economic activities. This study investigated the variability in temperature and precipitation in northeast Nigeria, using Yobe State as a case study. Temperature and Precipitation data for forty years (1981-2020) were obtained from two Nigerian Meteorological stations (Potiskum and Nguru) and the data were used for the study. The data were analyzed using basic statistical tools, Standardized Precipitation Index (SPI) and Standard Anomaly Index (SAI). The results obtained showed that the study area is fast warming. The analyzed maximum and minimum temperatures indicated that there was a steady increase in temperature in the study area. The magnitude and precipitation pattern in the study area have changed over the studied period and their variability will continue with the increasing global warming. Precipitation in Nguru is declining and the temperature is fast rising. Agricultural activities such as crop production, fishing and animal rearing were grossly affected due to the abysmal shrinking of the Nguru and Gashua rivers. Irrigation farming and water availability were also affected due to the lowering of the groundwater table. Extreme weather conditions such as droughts, floods and heatwaves were observed to be increasing in the study area and their effects were exacerbated by desertification and deforestation processes. Massive tree planting should be encouraged by both the public and the government to reduce desertification and increase evapotranspiration in the study area. By extension, the obtained results are a reflection of the impact of climate variability in northeastern Nigeria.*

Keywords: *Precipitation, temperature, desertification, global warming, flood, drought.*

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1.0 Introduction

Temperature and rainfall are the two main indicators of climate change and they have a great influence on the weather system. Their variabilities have a direct bearing on natural phenomena such as drought, flood, heat waves, and wild and bush fires. In recent times research has shown that the frequency and the intensity of drought, flood and heatwaves have increased due to climate change. The 2021 reports from the National Aeronautics and Space Administration (NASA) showed that the rising temperature will increase evaporation which might lead to frequent and intense storms, and it will contribute to drying over some land areas. The report further stated that the storm-affected areas might witness an increase in precipitation and flood risks, while areas far from those areas will experience less precipitation and an increased risk of drought (NASA, 2021). The rising temperature will lead to food insecurity, health risk, poor access to quality drinking water and poor agricultural production. A decrease in soil moisture which is caused by low convective precipitation often leads to warming of the lower troposphere (Unkasevica and Tosic, 2009). Temperature and precipitation variability contributes to environmental migration mostly in Africa where people directly rely on agriculture for food, income, trade and livelihood. Any climatic perturbations will have a catastrophic consequence on the economy of the people. The United Nation's Intergovernmental Panel on Climate Change Six Assessment Report states that the total atmospheric water vapor is increasing by about two percent per decade. This report was also confirmed by the data from satellites, weather balloons, and ground measurements (NASA, 2021). Northeastern Nigeria is composed of Gombe State, Bauchi State, Taraba State, Adamawa State, Yobe State, and Borno State. A large population of the people in northeastern Nigeria depends on agriculture for their livelihood. The annual amount of precipitation determines their agricultural productivity. An increase in the amount of annual precipitation means that there will be an increase in crop production and livestock, and any decline in precipitation will lead to poor crop production. Eze *et al*. (2018) reported that in northern Nigeria, farmers obtained bumper harvests during the years of abundant rainfall and when there was a rainfall deficit, the farmers suffer crop failure, which resulted in famine and the death of livestock. Many studies have been conducted on climate change (Ayinde et al., 2011; Abaje *et al*., 2013; Olagunju, 2015; Abdullahi 2018; Eze *et al*., 2018; Liu *et al*., 2018; Oyinloye *et al*., 2018; Um *et al*., 2018; Yue *et al*., 2018), they have all looked at the issue of climate change on the continental and country scales, but the regional and local analysis is more relevant to devising effective and substantial adaptation and mitigation strategies. Yobe and Borno states are located within the Chad Basin. Dambazzau (2014) reported that Nigeria is estimated to be losing about 1400 square miles of land to desertification in the northeast, especially in Borno and Yobe States. Eichelberger (2014) also noted that Lake Chad has lost more than 90% of its original size due to droughts. According to NASA, the surface area of Lake Chad has reduced from 26,000 square kilometers in 1963 to less than 1,500 kilometers in recent times (Fig. 1). Lake Chad is a great source of water for crop production, animal rearing and fishing for people in both Yobe and Borno States. Its shrinking has caused a great decline in agricultural activities coupled with environmental degradation. In the context of this study, climate change is defined as a significant variation in the climatic condition of an area or region over a long period, preferably three or more decades. Climate change refers to all forms of inconsistency in climate. Its effects are mostly noticed when there is an acute change in annual mean temperature and precipitation. The Earth's climate is not fixed, it is variable because of the dynamic nature of the planet. Extreme changes in temperature and precipitation often lead to droughts and floods. The study of climate variability at local and regional scales is very important to the people in local communities whose economic activities especially, agriculture and trades depend on climatic situations. To understand the variability in climate, there is a need to study past climatic records and apply the information obtained as reference data before mitigation and adaptation to climate change. Northeastern Nigeria is an agrarian area where about 85% of the population are farmers and they rely on agriculture for their livelihood. It is located within the semi-arid region and it's much exposed to environmental hazards such as floods, heatwaves, aridity, drought and desertification (Olagunju, 2015). Desertification can be defined as land degradation caused by climatic variation and anthropogenic activities in semi-arid and arid regions. Haider and Adnan (2014) observed that aridity and areal extent in dry land will increase in coming years due to high spatial and temporal variability of precipitation over the globe. Northeast Nigeria being a vulnerable region to climate variability deserves adequate information on climatic variability and adaptation strategies to adapt and become resilient to climate change. Extreme weather with persistent recorded floods in many parts of Nigeria that occurred in 2019 (NiMet, 2021). The climatic feature of northeast Nigeria can be divided into two: dry and wet seasons. The seasons are influenced by the position of the Inter-tropical Convergence Zone (ITCZ). When the ITCZ migrates southward between October and May, the northeast of Nigeria experiences a dry season and when it migrates northward direction between June and September, the northeast experiences precipitation. Precipitation in the context of this study refers to rainfall and other forms of water that fall from the troposphere.

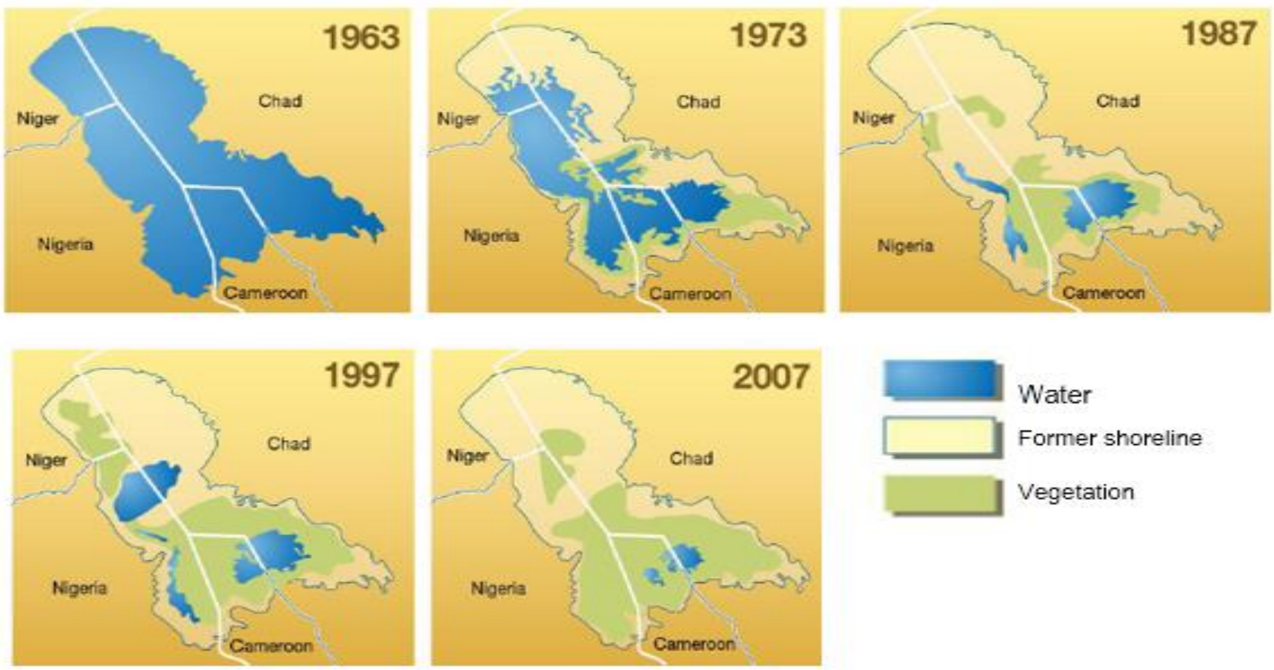

Fig. 1: Shrinking of Lake Chad due to climate variability. (Source: NASA)

This study assesses the trends in the annual rainfall, maximum and minimum temperatures from two meteorological stations in Yobe State (Nguru and Potiskum) and it uses the results obtained from the analysis of the data to evaluate the variability in temperature and precipitation in northeast Nigeria, using Yobe State as a case study. The study is focused on providing updated information on climate variability and making recommendations for mitigation and adaptation strategies. The results of the study are expected to be useful for Policy making on agriculture and environmental protection.

2.0 Materials and Methods

2.1 Study Area

Yobe state is located within latitudes $10^o 30'$ N and $13^o 25'$ N and on longitudes $9^o 35'$E and $12^o 30'$E. It has a population of about 2.6 million according to the National Population Census (NPC) results of 2006. Yobe state is located in the semi-arid region of Nigeria (Fig. 2). Its annual rainfall ranges from 500 mm to 1000 mm (Agada *et al*., 2011).

The climate of the study area is characterized by a short wet season (June – September) and a long dry season (October – May), with high temperatures of about 39 to 45 ^{o}C. During the rainy season, temperatures fall to 25^{o}C (Agada *et al*., 2011).

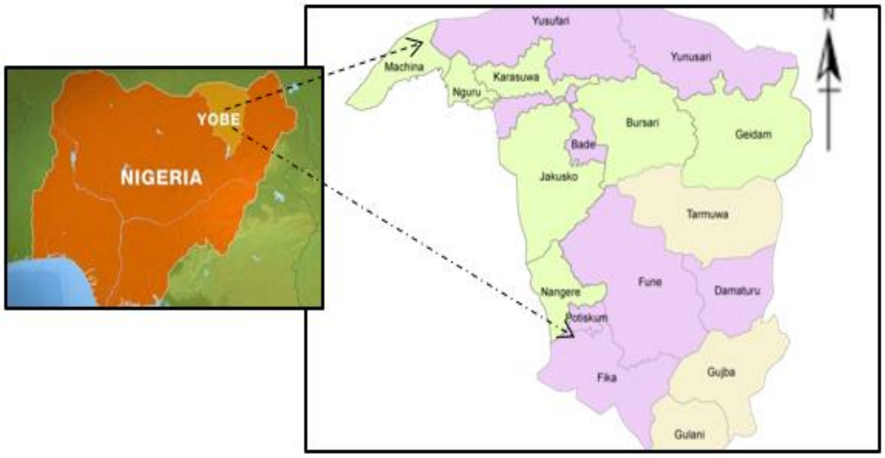

Fig. 2. Map of Nigeria showing the study area.

2.2 Data collection

Precipitation data with maximum and minimum temperature data for forty years (1981-2020) were collected from Nigeria meteorological agency (NiMet) Nguru and Potiskum stations. The data obtained were analyzed and used for the assessment of the effects of climatic variability in the study area.

2.3 Data analysis

Time series analysis and basic statistics such as maximum, minimum, mean and standard deviation were used to evaluate the data obtained. The Standard anomaly index (SAI) was calculated using equation (1),

$$SAI = \frac{x_i - x_m}{\sigma} \qquad (1)$$

where, x_i is the mean temperature for each year and x_m is the long-term mean temperature. σ is the standard deviation of the annual maximum temperature for the long term. Periods below the long-term average were considered cooling periods and periods above the long-term average were considered warming periods. The standard anomaly index of the temperature was compared to the threshold risk levels (Table 1).

The precipitation data were analyzed using the Standardized Precipitation Index (SPI)

which is based on Gamma Distribution Function (GDF).

Table 1. Standard Anomaly Index

S/N	Event	Interpretation
1	SAI ≥ 2.0	Extremely hot
2	SAI $\geq 1.5 < 2$	Very hot
3	SAI $\geq 1.0 < 1.5$	Moderately hot
4	SAI $< 1.0 > -1.0$	Near normal
5	SAI $\leq -1.0 > -1.5$	Moderately cold
6.	SAI $\leq -1.5 > -2.0$	Very cold
7.	SAI ≤ -2.0	Extremely cold

(Source: Marck, 2015)

The probability density function of the gamma distribution is defined as,

$$g\ (x) = \frac{1}{\beta^{\mu}\Gamma(\mu)} x^{\mu-1} e^{-\frac{x}{\beta}} \text{ for } x > 0 \qquad (2)$$

Where $\mu > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, $x > 0$ is the amount of precipitation, and $\Gamma(\mu)$ is the gamma distribution. The gamma distribution parameters μ and β for each station and time scale are estimated using the following expressions.

$$\mu = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (3)$$

$$\beta = \frac{x}{\mu} \quad (4)$$

where

$$A = In\,(x) - n^{-1}\sum In(x) \quad (5)$$

And n = number of precipitations observed. Integrating equation 2 concerning x, and using the estimates of μ and β, we obtain a cumulative probability G(x) of a given amount of precipitation for a given time scale as,

$$G(x) = \int_0^x g(x) = \frac{1}{\beta^{\mu}\Gamma(\mu)}\int_0^x x^{\mu-1}e^{-\frac{\mu}{\beta}}dx \quad (6)$$

Assuming $t = \frac{x}{\beta}$, and substituting it into equation 6, we have,

$$G(x) = \frac{1}{\Gamma(\mu)}\int_0^x t^{\mu-1}e^{-t}dt \quad (7)$$

Equation 7 is the incomplete gamma function. The gamma distribution function is not defined for $x = 0$. The probability of zero precipitation $q = p(x = 0) > 0$, is positive. Hence, the cumulative probability becomes,

$$F(x) = q + (1-q)G(x) \quad (8)$$

where $F(x)$ is the true probability of non-exceedance and q is the probability of $x = 0$. If ϕ is the sample size and η is the number of zero in the sample, then q can be estimated as,

$$q = \frac{\phi}{\eta} \quad (9)$$

The transformation of the cumulative probability distribution $F(x)$ will yield the standard precipitation index. The SPI values and their interpretations are shown in Table 2.

The analysis of the temporal trend in the standard anomaly index of the temperature and the standardized precipitation index was done using the Mann-Kendall test (Koudahe *et al*., 2017). It is a non-parametric method for trend analysis. This test is based on a null hypothesis H_0 which assumes that there is no trend. It is tested against the alternative hypothesis H_1 which assumes that there is a trend. The Mann-Kendall test statistic S is given by equation 10

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} \text{sign}\,(x_k - x_j) \quad (10)$$

where x_k is the data value at time k, n is the length of the dataset and the sign ( ) is the sign function which can be determined as:

$$\text{sign}\,(x_k - x_j) = \begin{cases} 1\ if\ (x_k - x_j) > 0 \\ 0\ if\ (x_k - x_j) = 0 \\ -1\ if (x_k - x_j) < 0 \end{cases}$$

For n > 10, the test statistic Z approximately follows a standard normal distribution.

$$Z = \begin{cases} \frac{S-1}{\sqrt{S_v}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S-1}{\sqrt{S_v}} & if\ S < 0 \end{cases} \quad (11)$$

where S_v is the variation of statistic S. A positive value of Z indicates that there is an increasing trend in the time series and a negative value indicates a decreasing trend.

Table 2: SPI values and their interpretation

SPI Values	Interpretation
≥ 2.0	extremely wet
1.5 to 1.99	severely wet
1.0 to 1.49	moderately wet
0.99 to -0.99	near normal
-1.0 to -1.49	moderately dry
-1.5 to – 1.99	severely dry
≤ 2.0	extermely dry

(Source: Koudahe *et al*., 2017)

3.0 Results and Discussion

The red line in Fig. 3 shows the trend direction in the result of the analyzed precipitation data obtained from Potiskum. The Mann-Kendall test for the precipitation data from Potiskum showed that there was no significant increase in precipitation trend between 1990 and 2020 (Fig. 3). Therefore, the null hypothesis H_0 is accepted and the alternate hypothesis H_1 is rejected at a 95% confidence interval. But there was variability in the amount of precipitation from one particular year to another (Fig. 3).

The Standardized precipitation index (SPI) of Potiskum in 2012 was 2.94 and it showed that 2012 had the highest amount of rainfall in the past three decades, and during that year there was massive flooding in Nguru and its environs which led to the destruction of social-economic activities (NEMA, 2012). Large farmlands and several houses were submerged in 2012 due to extreme rainfall. The year 1994, 1998 and 2001 had SPI values of 1.14, 1.0, and 1.2 respectively which indicate moderate rainfall, while 1996, 1997, 1999, 2003, 2005, 2008, 2013, 2014, 2015, 2016, 2017, and 2018 experienced near normal rainfall amount since there SPI values were less than 1.0 (Fig. 3).

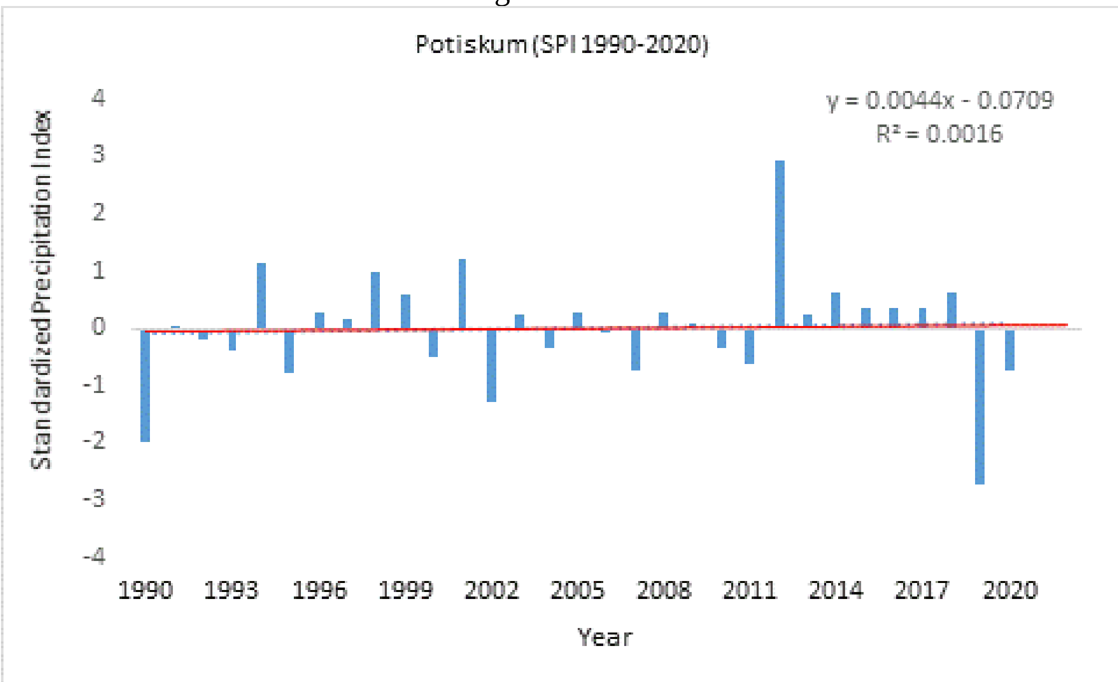

Fig.3. Standardized Precipitation Index for Potiskum (1990-2020)

There were drought occurrences in 1992, 1993, 1995, 2000, 2002, 2004, 2007, 2010, 2011, 2019 and 2020 since their SPI values were negative. The droughts were severe in 1990 and 2019 (Figure 3). The Mann-Kendall test for the precipitation data from Nguru showed that there was a decline in the trend of precipitation (Figure 4). Therefore the null hypothesis H_0 is rejected and the alternative hypothesis H_1 is accepted at 95% confidence interval. The result showed that there is a remarkable reduction in the amount of rainfall in Nguru and its environs and it has affected the socio-economic activities of the people in the area. There were drought episodes between 1991 and1994, 2001 and 2004, 2008 and 2009, and between 2016 and 2019. The droughts of 2003, 2017, and 2018 were severe (Fig. 4). The results showed that the precipitation in Nguru for the past 30 years (Fig. 4) varies remarkably and has contributed to the occurrence of extreme weather events in the study area. The Precipitation variability has both economic and environmental implications. The reduction in the amount of rainfall in the study area has contributed immensely to the severe shrinking of both Nguru and Gashua rivers in recent times. A greater portion of both rivers had dried off and this situation has imposed great economic hardship on the people of the area and its environs whose main livelihood is agriculture. Irrigation farming which is mostly practiced in the area during the dry season is faced with acute water shortage problems as the provision of irrigation water is grossly limited by the shrinking of the rivers and lowering of the groundwater table in the study area.

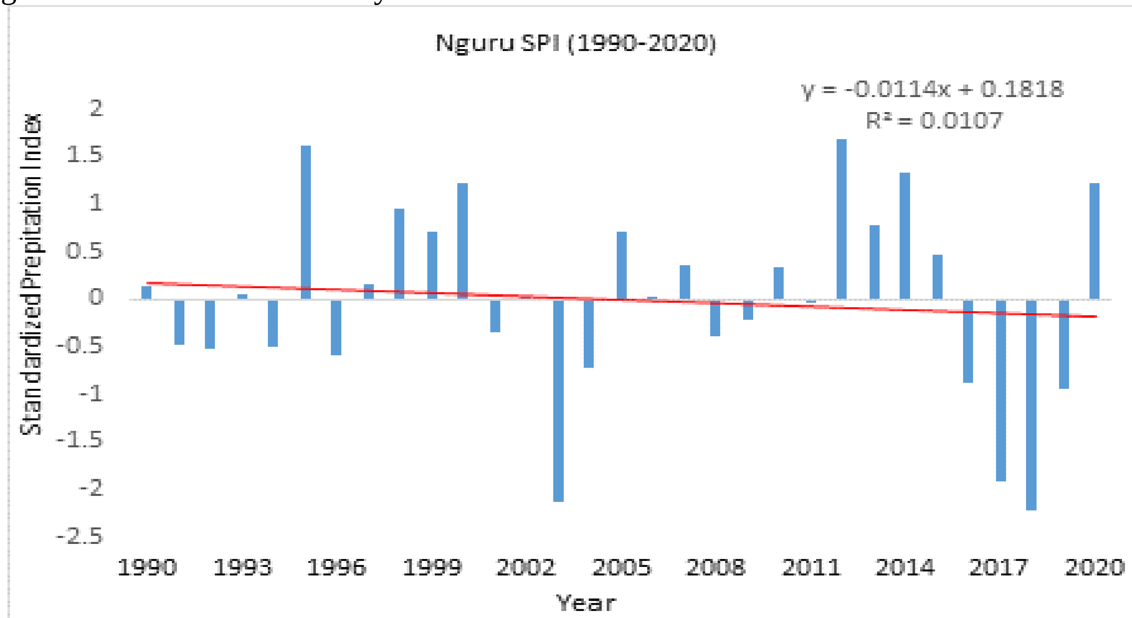

Fig. 4. Standardized Precipitation Index for Nguru (1990-2020)

The frequent drought episodes in the study area and shortage in the amount of rainfall extend to the whole Lake Chad Basin and equally the entire northeast region of Nigeria. The Hadeija Nguru river and the Yobe river are tributaries to Lake Chad, but their inability to supply water to Lake Chad has also affected the volume of water in Lake Chad. Farming activities and animal rearing are grossly affected by this climate variability. Livestock in the study area is faced with an acute shortage of grazing land and water availability. Reduction in agricultural productivity has led to a geometric increase in food prices and famine in the study area. The challenges caused by the variability in climate have made the youths in the area less engaged in recent time, and it has opened a floodgate for the crime.

The results of the analyzed average maximum temperature data from Nguru (Figure 5) showed that the area has experienced an increase in average maximum temperature for over a decade (2010-2020). This prolonged increase in maximum temperature is evidence of global warming. The year 1987 and 2017 had the highest maximum temperature anomaly index with values 2.3 and 2.4 respectively, indicating that the periods were extremely hot. This increase in average maximum temperature is in agreement with the prediction made by the IPCC 2007, which stated that the global mean surface temperature will likely rise by 1.1 to 6.4 ^oC during the 21st century. The steady increase in temperature must have impacted humans, livestock and crops in the area negatively. The results of the analyzed average minimum temperature data from Nguru (Figure 6) also showed that the area has experienced an increase in average minimum temperature with an annual temperature growth of 0.56 %. The increase in the minimum temperature (Figure 6) is greater than that of the maximum temperature (Fig. 5). The results of the analyzed standardized average maximum temperature anomaly index for Potiskum showed an increased temperature trend (Fig. 7).

The temperature trend has a slope of 0.09 and the coefficient of determination R^2 is 0.3682 which is about 37% (Fig. 7). Therefore, the percentage of variation in the average maximum temperature is 37. The upward maximum temperature trend showed that the area is warming and the increase in temperature most have impacted agricultural activities and other socio-economic activities in the study area. The standardized minimum temperature anomaly index of Potiskum showed that the minimum temperature in Potiskum and its environs are fast risings (Fig. 8). The results of the study showed that the minimum temperatures of both Nguru and Potiskum are fast rising than the maximum temperatures. This rapid increase in minimum temperature showed that the study area is warming at an alarming rate. And it must have impacted both human and livestock health negatively. The increase in temperature in the study area must have contributed to the water crisis, increase in the frequency of extremes of heat and decline in agricultural production.

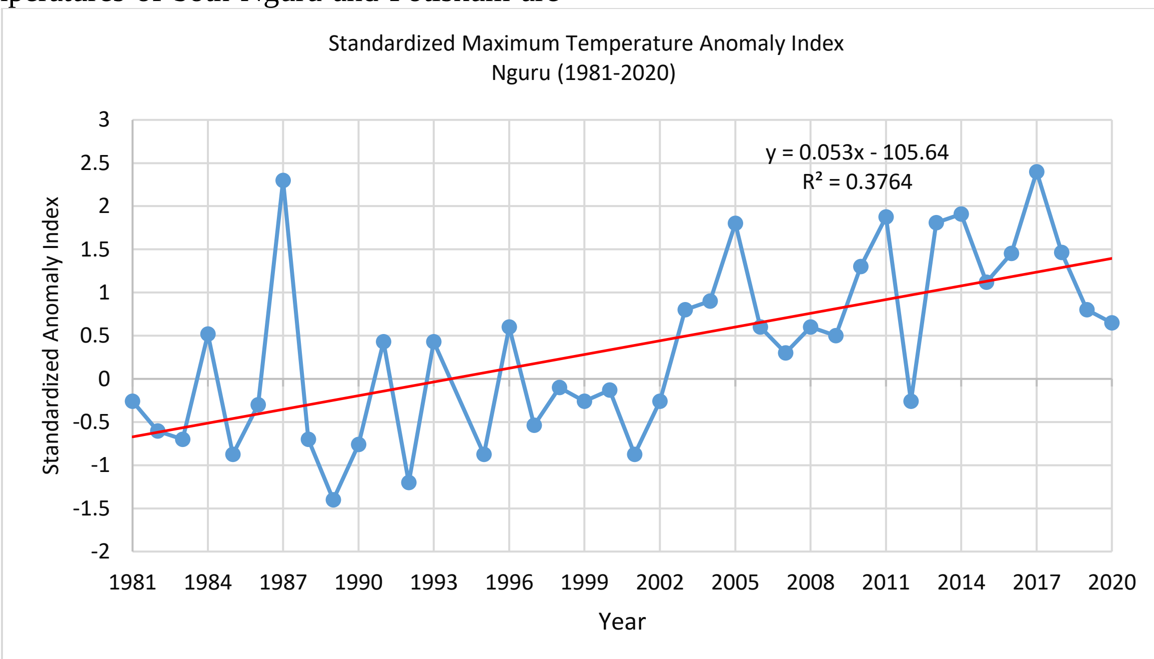

Fig.5. Standardized average maximum temperature anomaly index for Nguru.

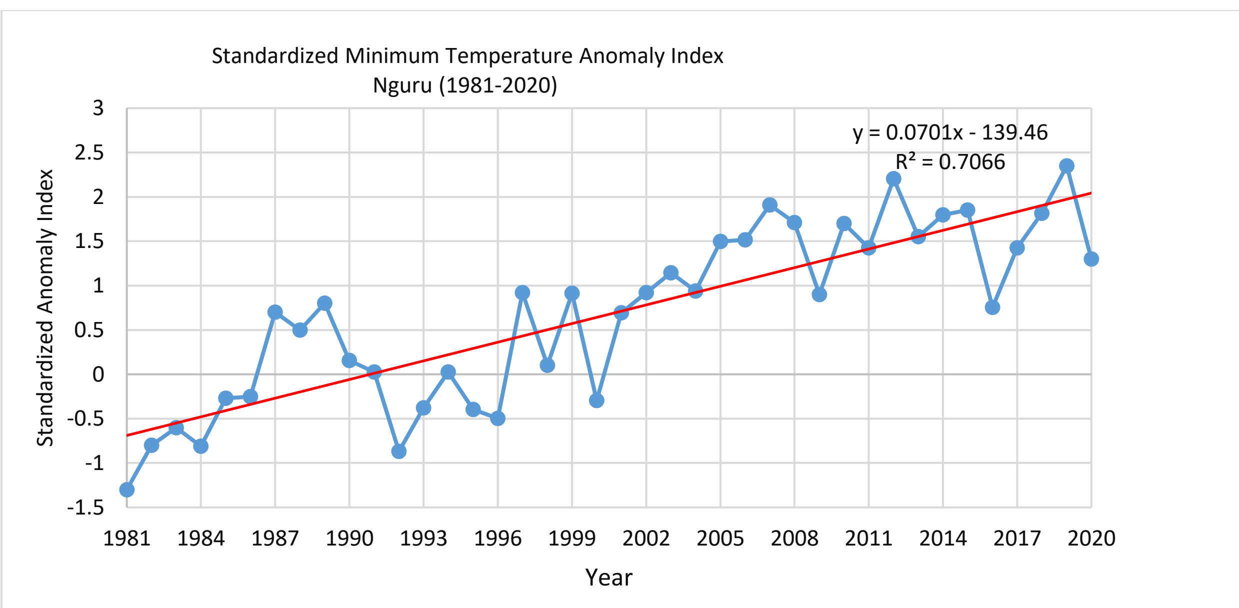

Fig. 6.: Standardized average minimum temperature anomaly index for Nguru.

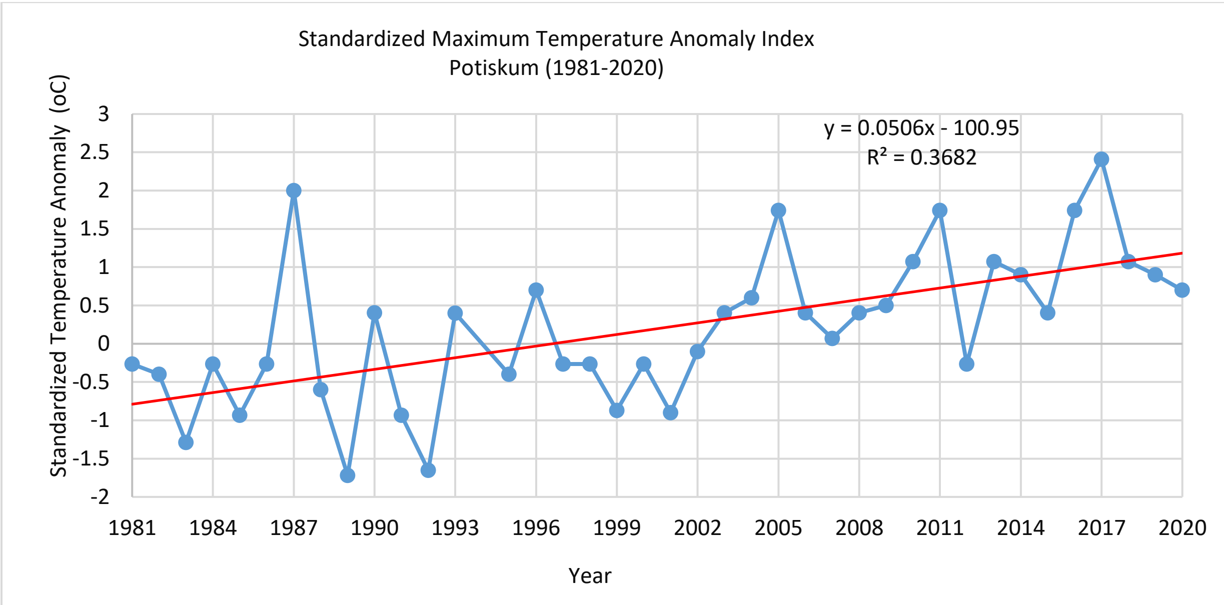

Fig. 7. Standardized average maximum temperature anomaly index for Potiskum

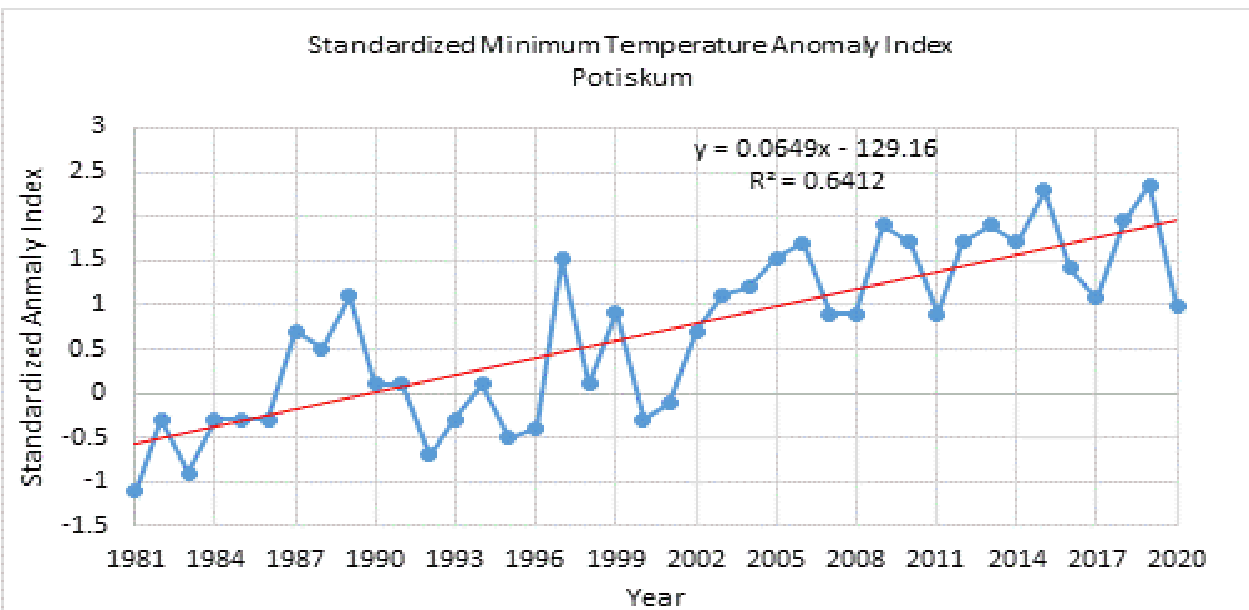

Fig. 8. Standardized average minimum temperature anomaly index for Potiskum

The analysis of the temperature data for 40 years has shown that the maximum and minimum temperatures have increasing trends. These increasing trends in temperatures might have influenced the rainfall pattern and water availability in the study area and also have facilitated the frequent occurrence of floods and droughts in the study area. The results reflected the present climatic features of the northeastern part of Nigeria. An image obtained from National Oceanic and Atmospheric Administration (NOAA) validates the findings of this study (Fig. 9). It shows that the study area is warming, and hence the need for understanding the impacts of climate change in the study area is highly imperative.

With the knowledge of nature and the degree of climatic variability in the study area, efforts geared towards climate change mitigation and adaptation strategies will be successful. The results of the increasing temperature observed in this study area are in agreement with the NiMet's report which shows that Nguru had temperatures above 44°C for Eighty (80) days in 2020 and Potiskum had temperatures above 43°C for 52 days in 2020 (NiMet, 2020). Yobe State recorded the second highest solar radiation of 402.8 Wm^{-2} /day after Kebbi State which recorded the highest value of 403.9 $Wm^{-2\,2}$ /day (NiMet, 2020). Precipitation and temperature variability were observed during the studied period (40 years). Precipitation in the study area has changed in amount, intensity, frequency and pattern over the years as observed in the analyzed data. The results of this study confirm the observation of Bonaventure and Amadi (2017) who indicated that youths from Yobe, Borno, Gombe and Adamawa States no longer engage themselves in farming due to low crop yield caused by climate change. Reduction in food security could cause hunger and crime. Heavy precipitation occurred even when the total amount of rainfall was small causing floods and crop destruction (Fig. 10).

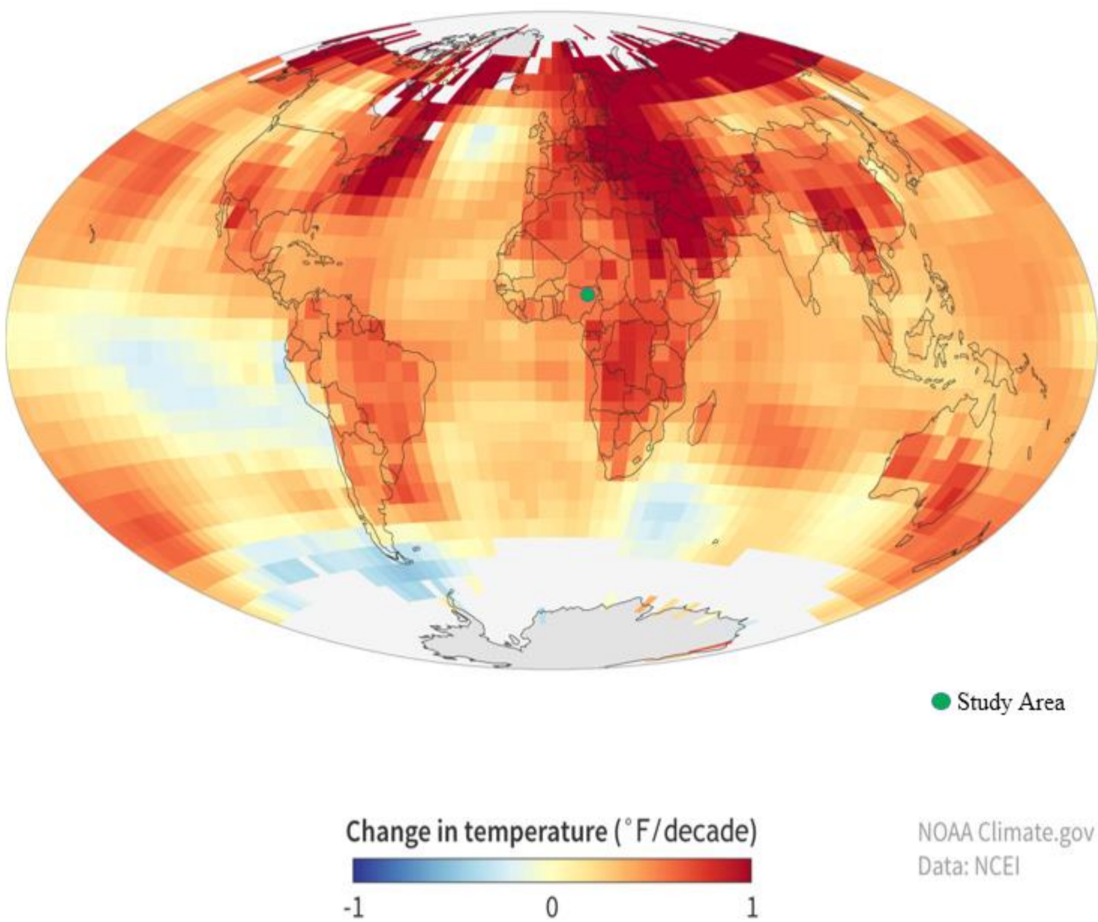

Fig. 9. Trends in global average surface temperature between 1990 and 2020 in degrees Fahrenheit per decade. Yellow indicates little to no change, while orange and red show places that warmed, and blue shows places that cooled. (Source: NOAA, 2021).

Fig. 10: A Flood scene in Nguru, Yobe State in 2020.

4.0 Conclusion

The detailed analysis of both precipitation and temperature data for 40 years in the study area indicates that the annual minimum and maximum temperatures exhibit increasing trends. The trend for precipitation in Nguru is decreasing and the precipitation trend in Potiskum does not have any remarkable change. The rainfall frequency, pattern, amounts and intensity in Nguru have remarkably changed due to global warming. Also, the trend of rainfall distribution, in both Nguru and Potiskum had their highest precipitation in 2012. The results of the study showed that the precipitation in the study area varied from year to year and from one decade to another, and the changes in its amount, intensity and frequency affect agricultural production, socio-economic activities and the environment. Nguru had severe droughts in 2003 and 2018, while Potiskum had its severe droughts in 1990 and 2019 during the studied period. The increase in the temperatures of the study area is a clear manifestation that the area is warming, and the situation has influenced growing trends in extreme weather events such as droughts, heatwaves, and floods. The increase in temperatures in the study was influenced by the processes of desertification and deforestation. Higher temperatures often cause an increase in evaporation and drying of vegetation. It leads to extreme heat events which are associated with health hazards. By extension, the results obtained from this study are reflections of the climatic situation in northeastern Nigeria, entire northeastern Nigeria is warming as a result of climate change and the warming effect has caused an increase in the frequency and intensity of extreme weather events such as droughts, heatwaves and floods in the area. The variability in precipitation and temperature has led to a significant decline in agricultural production, an increase in food prices, starvation, famine, crime and an increase in the clashes between farmers and herders caused by climate change migration and competition over available arable land resources.

The findings of this study showed that a thorough understanding of climate change is very important for effective adaptation and mitigation strategies. We therefore recommend that the government and the public should engage in intensive afforestation project to reduce desertification in the study area.

5.0 Acknowledgement

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