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Geo-Statistical Analysis of Meteorological Drought and Recurrence Intervals in the Context of Climate Change Over Extreme Northeastern Region of Nigeria

Iliya B. Abaje
Department of Geography, Federal University Dutsin-Ma, P.M.B. 5001 Dutsin-Ma, Katsina State, Nigeria. E-mail: abajebest@gmail.com
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Abstract

This study examined the occurrence of meteorological drought in the context of climate change over the extreme northeastern region of Nigeria using rainfall and temperature data spanning a period of 60 years (1961-2020) and 40 years (1981-2020), respectively. Linear regression, 5-year moving average and Cramer's test were used to examine the changes in the rainfall and temperature. Rainfall Anomaly Index was used in depicting periods of different drought intensities in the region. The trend analysis of the climate data revealed that the region has been experiencing increasing rainfall and temperature in recent years. Findings also revealed that the droughts of the 1980s were more severe than the Great Sahelian Droughts of 1968-1973. The year 1987 was the driest in the whole period of study (1961–2020). Contrariwise, about 81% of the region from 2000 to 2020 experienced normal to very wet conditions. The mean probabilities of mild, moderate, and severe droughts in the area were 0.14 (recurrence interval of 8 years), 0.11 (recurrence interval of 11 years), and 0.07 (recurrence interval of 16 years), respectively. This study concludes that the number of drought occurrences has decreased in recent years. Therefore, government policies related to agriculture and water resources development in the area should take into account the increasing rainfall and temperature in recent years.

Keywords: Climate Change, Meteorological drought, Rainfall, Recurrence Interval, Severe Drought, Temperature.

Introduction

The global climate has been changing with attendant consequences in terms of floods, droughts, heat waves, flooding in the coastal areas, and other related climate extremes that always result in socioeconomic impacts on public health, water resources, transportation, food security, and energy, among others (Nigerian Meteorological Agency, NiMet 2018). Rainfall and temperature are the most fundamental indicators of climate change. Thus, the changes in the climatological average of these fundamental indicators are clear evidence of a changing climate (Abaje and Oladipo 2019, NiMet 2021, Ati et al. 2022). For instance, a significant wet year in any region may be accompanied by flood events due to the fact that the soil is saturated. In the same way, a significant dry year may pose possible risks for drought and drought-related disasters (NiMet 2021). Higher temperatures on the other hand not only encourage drought conditions but also intensify them. What might have been a mild or moderate drought in a cooler environment may become a severe or extreme drought in a warmer environment as a result of increased evapotranspiration leading to the drying out of the upper layers of soils (Delk 2020).

Drought occurs in virtually all the climatic zones of the world but it varies in terms of its magnitude, severity, duration and geographical coverage. It is generally defined with respect to the long-term average climate of a given region (Dai 2013, Henchiri et al. 2021). Drought, like a hurricane, flood, earthquake, or tornado, is both a hazard and a natural disaster (Paulo and Pereira 2007). It is a hazard because it is a natural accident of unpredictable occurrence but of recognizable recurrence; it can then be referred to as a natural disaster because it corresponds to the failure of the precipitation regime resulting in the disruption of the water supply to the natural and agricultural ecosystems as well as to other human activities (Paulo and Pereira 2007).

Drought episodes have been recurring in Africa for many years, and Nigeria, especially the northern part, is not an exception. The Great Sahelian Drought of 1968 to 1973 (attained its peak in 1973) and the droughts of the 1980s (with peak in 1987) that ravaged the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria led to crop failures and food shortages (Oladipo 1993, Abaje 2010, Abaje et al. 2013). These, in turn, triggered famine in many parts of the country, resulting in malnutrition, different health problems, mass migration of people and animals, and loss of lives.

Studies dealing with some aspects of drought in various parts of northern Nigeria have been undertaken by Oladipo (1993), Abaje (2010), Abaje et al. (2013), Achugbu and Anugwo (2016), Olatunde and Aremu (2016), Eze (2018), Sadiq et al. (2020) and Ati et al (2022) among others. Most of these studies concentrated on the impacts of drought on agriculture, water resources, public health, and the extent of drought. Drought which is a multifaceted extreme climate event has caused widespread crop failure, death of livestock, famine, and other hardships that resulted in the loss of human lives in the study area. Besides rainfall, the temperature is another important climatic parameter. An increase in temperatures, for example, would not only encourage drought conditions but also intensify them. These two parameters are the most fundamental indicators of climate change.

Based on the aforementioned, vital information pertaining to the intensity of droughts, absolute probability of occurrence, and recurrence intervals of droughts (mild, moderate, and severe droughts) using the Rainfall Anomaly Index in the context of recent changes in climate over the extreme northeastern region of Nigeria is still missing. It is this missing link that this study seeks to address in order to suggest measures on how the impacts of this extreme climate event can be minimized at all levels. In addition, the study will be of great knowledge and guidance for future research in the area and northern Nigeria as a whole.

The aim of this study, therefore, was to analyze and determine the occurrence of meteorological drought over the extreme northeastern region of Nigeria in a changing climate taking into consideration the trends of climatic parameters, intensity of droughts, drought probabilities and recurrence intervals in the region.

Materials and Methods

Description of the study area

The study area (Figure 1) consists of Borno and Yobe States, located between Latitudes 10°11'N and 13°53'N and Longitudes 10°14'E and 14°30'E. The climate of this area is the tropical wet/dry type which has been classified as the Köppen Aw climate (Köppen 1936). Rainfall in this area occurs between the months of April and October with a peak in August. The climate is dominated by the influence of two major air masses, namely 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 (Odekunle 2010, Abaje and Oladipo 2019). These two 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 April/May when the ITD moves north of the study area. The movement of the ITD continues northwards across the region and 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 dry season is initiated by the southward migration of the ITD (FRN 2018). From October, the ITD starts moving towards the south, and by January/February the region is under the effects of the cT air mass. This marks the peak of the dry season in the whole region (Ati et al. 2022).

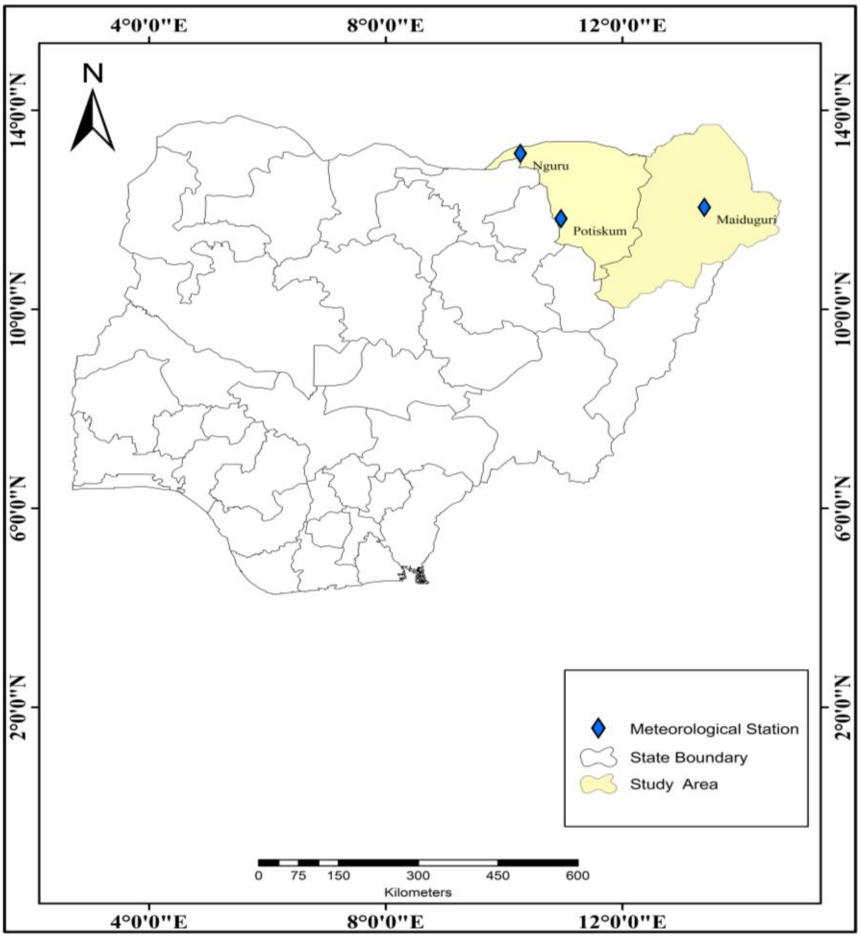

Figure 1: Map of Nigeria showing the study area.

The geographical location of the study area (northeastern part of Nigeria) in relation to the distance in which the mT air mass has to travel before reaching the area and also its proximity to the Sahara Desert make this area the driest part of the country (FRN 2018). Temporal characteristics of temperature in this area are steadier than those of rainfall; however, the highest diurnal ranges of temperature are in the dry season. The highest air temperature normally occurs in the month of April and the lowest in the months of December and January (Abaje 2010, Ati et al. 2022). Evapotranspiration is generally high throughout the year, and the highest amount occurs during the dry season. The mean annual total number of sunshine hours in the study area is high when compared to the southern part of the country (Abaje et al. 2017, Ati et al. 2022).

The whole study area is covered by Savanna vegetation consisting of Sudan and Sahel vegetation types with the density of trees and other plants decreasing northwards. The soils are the reddish, porous and friable sandy clays in the southern part and the lacustrine soils of the Chad Basin and regosols in the extreme northern part (Ayuba et al. 2007). The soils which have been developed from aeolian and many sedimentary deposits with little profile development are highly vulnerable to both water and wind erosion (Abaje 2007).

Data collection

Rainfall (mm) and temperature (°C) data spanning a period of 60 years (1961– 2020) and 40 years (1981–2020), respectively for the three meteorological stations in the region were used in this study (Table 1). These are secondary data that were sourced from the archive of the Nigerian Meteorological Agency, Abuja and the Climatic Research Unit (CRU) of the University of East Anglia and National Centre for Atmospheric Science (NCAS) (https://crudata.uea.ac.uk/cru/data/hrg/cru_ts_4.04/ge/). In this very study, only the rainfall totals for the monthly growing season, April-October, were used for analysis. This is because 95% of the annual rainfall is received in these months. The stations are Potiskum, Maiduguri and Nguru. These stations were chosen because they have a long period of recorded rainfall and temperature data; they have no missing data for the period of study; and since their establishment, they have not been relocated.

Table 1: Meteorological stations and period of data used

Station	Station No.	Latitude	Longitude	Altitude	Climate parameter	Period	No. of years
Potiskum	1111.40	11°43'N	11°07'E	487.68 m	Rainfall (mm)	1961-2020	60
					Temperature (°C)	1981-2020	40
Maiduguri	1113.50	11°51'N	13°05'E	348.00 m	Rainfall (mm)	1961-2020	60
					Temperature (°C)	1981-2020	40
Nguru	1210.52[E]	12°58'N	10°28'E	341.00 m	Rainfall (mm)	1961-2020	60
					Temperature (°C)	1981-2020	40

Data analysis

Test for the normality of the rainfall and temperature data was done using the standardized coefficients of Skewness (Z_1) and Kurtosis (Z_2) statistics as defined by Brazel and Balling (1986). The standardized coefficient of Skewness (Z_1) was computed as:

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

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

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

Where: $\bar{x}$ = the long-term mean of x_i values; N = the number of years in the sample.

These statistics were used to test the null hypothesis that the individual temporal samples came from a population with a normal (Gaussian) distribution. 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) statistic was used to determine the Relative Seasonality Index (RSI) of the rainfall series. This was done in order to find out the class into which the climate of the study area can be classified. The Relative Seasonality Index was calculated as:

$$RSI = \frac{1}{\overline{R}} \sum_{n=1}^{n=12} \left| \overline{x}_n - \frac{\overline{R}}{12} \right| \quad 3$$

Where: $\overline{x}_n$ = the mean rainfall for month *n*; $\overline{R}$ = the 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 RSI classes by Walsh and Lawler (1981) are presented in Table 2.

Table 2: 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

Linear regression was used to determine the linear trends of the rainfall and temperature for the three stations. Also, changes in rainfall and temperature were calculated. The linear regression was computed as:

$y = a + bx$ eq. 4

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

$$a = \frac{\sum y - b\left(\sum x\right)}{n} \quad 5$$

$$b = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{n\left(\sum x^2\right) - \left(\sum x\right)^2} \quad 6$$

Furthermore, a 5-year moving average was calculated and plotted using Microsoft Excel 2013 in order to smoothen the time series, thereby reducing the irregular fluctuations and highlighting those that are regular. Given a set of numbers y_1, y_2, y_3, - - - y_n, a moving average of order *n* is defined by the sequence of arithmetic means:

$$\frac{y_1 + y_2 + --- + y_n}{n}, \frac{y_2 + y_3 + --- + y_n + 1}{n}, \frac{y_3 + y_4 + --- + y_n + 2}{n}, etc. \quad 7$$

The sum in the numerators of equation 7 is called moving totals of order *n*. Here the order is 5.

Cramer's test was used to determine the changes in the rainfall and temperature series (see Lawson et al. 1981 for details). The data were subdivided into non-overlapping decadal sub-periods (1961–1970, 1971–1980 through 2011–2020 for the rainfall data and 1981–1990, 1991–2000 through 2011–2020 for the temperature data). The means of the decadal sub-periods were then compared with the mean of the whole record period. In applying Cramer's test, the mean ($\overline{x}$), and the standard deviation (δ), are calculated for the total number of years for the study area, *N,* under examination. The purpose of this statistic is to measure the difference in terms of a moving *t*-statistic, between the mean **(**$\overline{x}k$**)**, for each successive n-year period and the mean ($\overline{x}$) for the entire period. The *t*-statistic is computed as:

$$t_k = \left(\frac{n(N-2)}{N - n\left(1 + \tau_k^2\right)} \right)^{1/2} \tau_k \quad 8$$

where τ_k is a standardized measure of the difference between means given as:

$$\tau_k = \frac{\bar{x}k - \bar{x}}{\delta} \quad 9$$

Where: $\bar{x}k$ is the mean of the sub-period of n-years; $\bar{x}$ and δ are the mean and standard deviation of the whole record period 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 *t*-distribution table, at 95% confidence level appropriate to a two-tailed form of test. If t_k is outside the bounds of the two-tailed probability of the Gaussian distribution, which is equal to 1.96 at 95% confidence level, a significant deviation from the mean is assumed.

Rainfall Anomaly Index (*RAI*) as developed by van Rooy (1965) was used in depicting periods of different drought intensities in the study area. This method is only based on rainfall input. The choice of this method is due to the fact that long periods of rainfall records are available in all the synoptic stations of the study area. In applying this technique, the rainfall values for the period of study were ranked in the descending order of magnitude with the highest rainfall values being ranked first and the lowest rainfall values being ranked last. The average of the ten highest rainfall values as well as that of the ten lowest rainfall values for the period of study were calculated. This technique is given by the equations:

$$RAI = 3\left[\left(p - \bar{p}\right)/\left(\bar{m} - \bar{p}\right)\right] \quad 10$$

for positive anomalies and

$$RAI = -3\left[\left(p - \bar{p}\right)/\left(\bar{x} - \bar{p}\right)\right] \quad 11$$

for negative anomalies,

where: p = the actual rainfall; $\bar{p}$ = the long-term average rainfall; $\bar{m}$ = the mean of the ten highest values of p on record, and $\bar{x}$ = the mean of the ten lowest values of p on record.

The arbitrary threshold values of +3 and – 3 have been assigned to the mean of the ten most extreme positive and negative anomalies, respectively. There are nine abnormality classes in this technique, ranging from extremely wet to extremely dry (see van Rooy 1965 for details). These nine classes were modified and seven abnormality classes, ranging from very wet to severe drought conditions, were adopted in this study (Table 3). This modified *RAI* classes were tested and found to be suitable for depicting periods of different drought intensities in the study area.

The percentages of areas affected by mild, moderate, or severe droughts for a given period in any sub-area or the whole region is determined by dividing the number of the occurrences of mild, moderate, or severe droughts by the total number of the three categories of drought intensities (mild, moderate, and severe droughts) in the three sub-areas.

Table 3: Modified *RAI* classification values

Index	Character of the weather
≥ 3.00	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
-0.99 to 0.99	Normal
-1.99 to -1.00	Mild drought
-2.99 to -2.00	Moderate drought
≤ -3.00	Severe drought

The frequencies of occurrence of mild, moderate and severe droughts were then calculated and their absolute empirical probabilities were computed as the ratio of the number of actual occurrences of mild, moderate and severe drought to the number of possible occurrences. From these absolute probability values, drought recurrence intervals (or return periods) were also obtained as their inverse (see Oladipo 1993 for details).

Results and Discussion

Normality test and relative seasonality index of the rainfall series

Based on the result of Z_1 and Z_2, the data were accepted as normal at 95% confidence level (Table 4). Therefore, no transformation was done to the data. The results of the calculated *RSI* of the rainfall series for the study area are 1.15 for Potiskum, 1.16 for Maiduguri, and 1.21 for Nguru (Table 4). The mean *RSI* for the region is 1.17. The implication of this result is that most of the effective rainfall in the region 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 SSEZ of Nigeria by Abaje (2010) where effective rainfall in this region was within 3 months or less.

Trend analysis of annual rainfall

Figure 2 shows the annual rainfall trend of the study area. In the Potiskum sub-area (Figure 2a), the highest amount of rainfall (1020.58 mm) was recorded in the year 1964 while the lowest amount (360.21 mm) was recorded in 1968. The year (1968) is often referred to as the beginning of the Catastrophic Sahelian Droughts of the 1970s (Oladipo 1993). The linear trend line of the rainfall series for the period of study (1961–2020) showed an insignificant decrease of approximately 52.2 mm at the rate of 0.87 mm year^{-1} (Figure 2a). When compared with the long-term average, it means that the annual rainfall was decreasing at a rate of 0.13% year^{-1}. The 5-year moving average was above the long-term mean from the beginning of the study period to 1967. From that point to the late 1980s, the moving average was below the long-term mean. This period corresponds with the Great Sahelian Droughts of the 1970s and the droughts of the 1980s that ravaged the region (Oladipo 1993, Abaje et al. 2013). From the beginning of the 1990s, the moving average was along the long-term mean up to the first half of the 2010s and below it afterwards. This is an indication that the Potiskum sub-area, after the droughts of the 1970s and 1980s, is experiencing a normal condition in recent years.

In the Maiduguri sub-area, the highest amount of rainfall (1076.3 mm) was recorded in the year 2007, while the lowest amount (256.0 mm) was recorded in 1983. The year (1983) was the second driest year in the history of droughts in the SSEZ of Nigeria after 1987 (Oladipo 1993, Abaje et al. 2013). The linear trend line in the sub-area (Figure 2b) showed an increase of approximately 36.6 mm at the rate of 0.61 mm year^{-1}. When this is compared with the long-term mean, it means that the annual rainfall was increasing at a rate of 0.10% year^{-1}. The 5-year moving average was below the long-term mean in the first half of the 1970s and the whole of the 1980s to the late 1990s. From the 2000s to the end of the study period, the moving average was above the long-term mean. This means that the Maiduguri sub-area is experiencing increasing wetness in recent years as a result of climate change which is in line with the findings of Odekunle et al. (2008) and Abaje (2010).

Table 4: Results for the test of normality and relative seasonality index

Statistics	Potiskum	Maiduguri	Nguru
Skewness (Rainfall (mm))	0.28	0.53	0.16
Kurtosis (Rainfall (mm))	0.44	1.26	-0.44
Skewness (Temperature (°C))	0.11	-0.63	-0.75
Kurtosis (Temperature (°C))	0.21	0.87	0.14
Relative Seasonality Index (RSI)	1.15	1.16	1.21

Source: Author’s Analysis (2022).

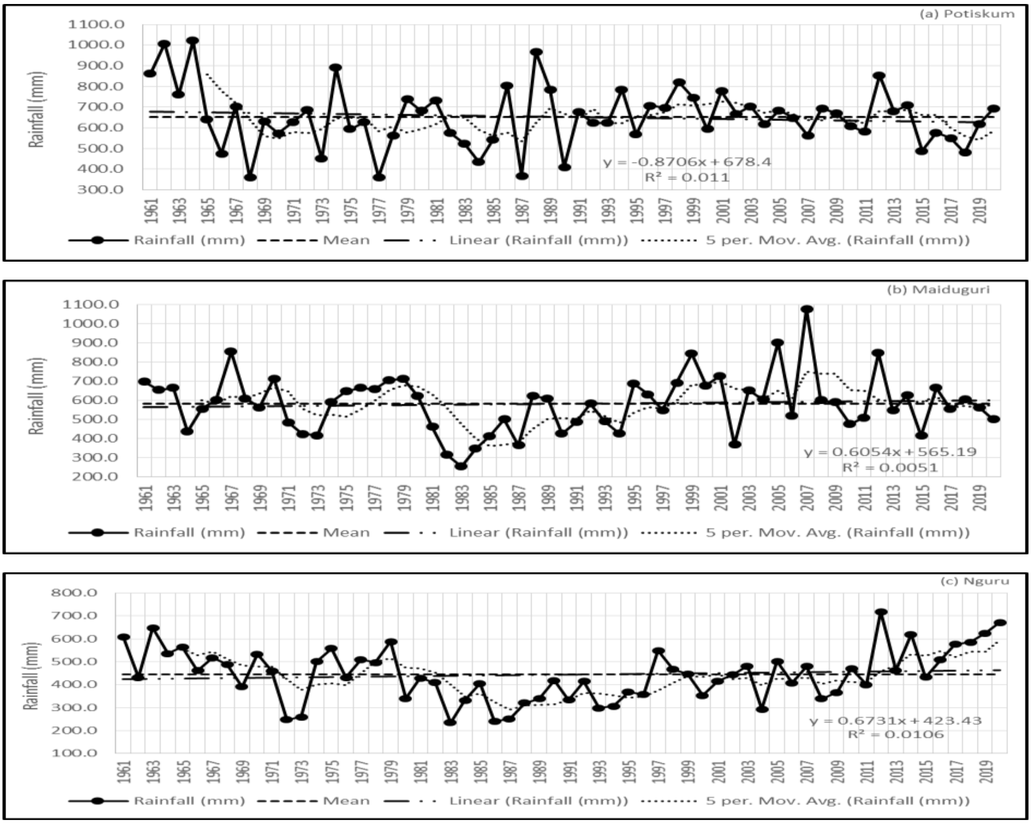

Figure 2: Trends of annual rainfall for: (a) Potiskum; (b) Maiduguri; and, (c) Nguru.

The lowest amount of rainfall (234.7 mm) in the Nguru sub-area was recorded in 1983, while the highest amount (718.3 mm) was recorded in 2012. This coincided with the 2012 flood disaster that ravaged the SSEZ of the country (NiMet 2012, Abaje et al. 2018). The linear trend line (Figure 2c) showed an increase of approximately 40.2 mm at the rate of 0.67 mm year^{-1}. When compared with the long-term mean, it means that the annual rainfall was increasing at a rate of 0.15% year^{-1}. The 5-year moving average, just like the Maiduguri sub-area, was below the long-term mean in the first half of the 1970s and above it in the late 1970s. From 1982 to 2011, the moving average was below the long-term mean and above it from 2012 to the end of the data set (2020). This is another evidence that the rainfall is increasing in recent years.

Trend analysis of average annual temperature

Figure 3 shows the graphical presentation of the average annual temperature trends of the study area. The mean temperature of the Potiskum sub-area is 27.28 °C. The highest recorded temperature of 28.39 °C was in 1992, while the lowest recorded temperature of 26.18 °C was in 1989 (Figure 3a). Estimation of changes in the average temperature for Potiskum expressed in °C for the 40 years period of the study shows an increase of approximately 0.28 °C at the rate of 0.007 °C year^{-1}.

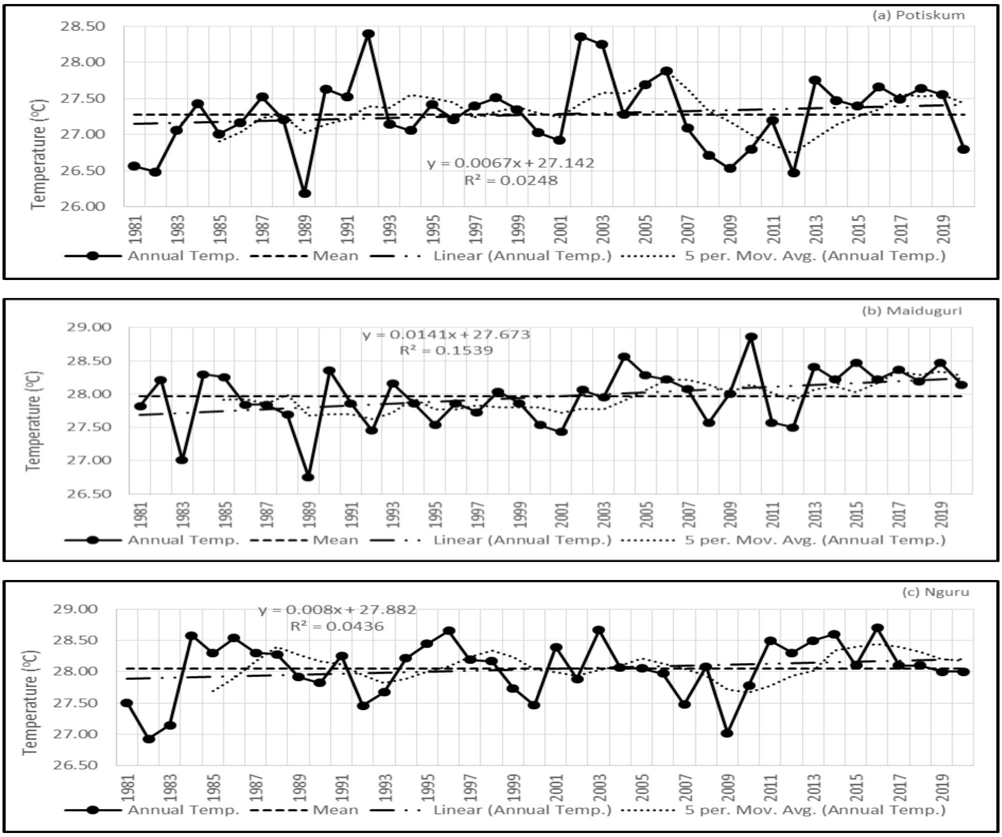

Figure 3: Trends of average temperature for: (a) Potiskum; (b) Maiduguri; and, (c) Nguru.

The linear trend lines for the period of study in Maiduguri and Nguru indicate a rise in average temperature. Estimation of changes in temperature for the 40 years period of study in Maiduguri (Figure 3b) indicates an increase of approximately 0.56 °C at the rate of 0.014 °C per year^{-1}, whereas the linear trend line for Nguru (Figure 3c) indicates an increase of about 0.32 °C for the period of study at the rate of 0.008 °C per year^{-1}. The 5-year moving average in the region revealed that the average temperature was fluctuating around the long-term mean up to around 2012. From that point to 2020 the moving average was above the long-term.

The increase in temperature as shown by the linear trend lines and also the increase in temperature in the recent decade as revealed by the 5-year moving average are the major manifestations of global warming in recent years. The rise in temperature may not be unconnected with human activities taking place in this region such as widespread use of land, destruction of nature, and combustion of fossil fuels among others (Abaje and Oladipo 2019).

Decadal sub-periods analysis of annual rainfall

The results of the decadal sub-periods analysis (Cramer's test) of the annual rainfall for the study area are presented in Table 5. The results of the Cramer's test for Potiskum revealed that all the decades were normal at $p < 0.05$. Three decades (1961–1970, 1991–2000 and 2001–2010) have positive *tk* values which is an indication of wetness in the sub-area. In the Maiduguri sub-area, the decade 1981–1990 was statistically drier (drought) at $p < 0.05$ than the long-term condition. This result is in line with the findings of Abaje et al. (2013) that it was the decade in which severe drought in the region became more extensive. Conversely, the t_k values for the last 3 decades (1991–2000, 2001–2010 and 2011–2020) were all normal at $p < 0.05$. Although they were not statistically significant, the positive *tk* values are indications that the annual rainfall has been increasing in the last 3 decades. The sub-period, 1981–1990, for Nguru was also statistically drier (drought) at $p < 0.05$ than the long-term condition. This also concurs with the findings of Abaje et al. (2013) as earlier discussed. The last sub-period for (2011–2020) for Nguru was statistically wetter at $p < 0.05$ than the long term condition which is also an indication of increasing rainfall yields in recent years.

In summary, the whole region has been experiencing increasing wetness in recent years, especially in the last 2 decades. This is in agreement with the findings of Abaje et al. (2012) and NiMet (2016, 2017, 2019 and 2021) that the northern part of the country, especially the SSEZ, is experiencing wetter conditions in recent years.

Table 5: Decadal sub-periods analysis of the annual rainfall

Sub-Period	Potiskum	Maiduguri	Nguru	Mean for the region
1961–1970	1.14	1.11	1.77	1.34
1971–1980	-0.68	0.21	-0.19	-0.22
1981–1990	-0.85	-2.43*	-2.29*	-1.86
1991–2000	0.75	0.52	-1.46	-0.06
2001–2010	0.27	1.42	-0.73	0.32
2011–2020	-0.67	0.00	2.47*	0.60

*Significant at $p < 0.05$. Source: Author's analysis (2022).

Decadal sub-periods analysis of annual average temperature

The decadal sub-period analysis (Cramer's test) of the average temperature of the study area (Table 6) showed that the temperature has been rising from the first decade (1981–1990) to the recent decade (2011–2020). Although none of the stations was statistically significant at 95% confidence level, the positive t_k values are indications that the temperature has been increasing in the region, especially in the last decade (2011–2020). This is a clear proof of the increasing warming of the Earth's atmosphere (climate change) in recent years. The result is in agreement with the reports of NiMet (2016, 2017, 2019 and 2021) in which the trend analyses revealed a higher rate of temperature increase in the northern part of the country in recent years. Also, it is in agreement with the Fifth Assessment Report of the IPCC that, in Africa, the number of warm days and warm nights has increased with a greater magnitude of changes in the last two decades (Niang et al. 2014).

Table 6: Decadal sub-periods analysis (annual average temperature)

Sub-Period	Potiskum	Maiduguri	Nguru	Mean for the region
1981–1990	-1.62	-1.23	0.49	-0.79
1991–2000	0.85	-1.36	1.18	0.22
2001–2010	0.50	1.11	0.56	0.72
2011–2020	0.44	1.47	1.68	1.20

Source: Author's analysis (2022).

Occurrence and intensity of droughts

The results of analysis of the occurrence of meteorological droughts in the study area using Rainfall Anomaly Index (*RAI*) are presented graphically in Figure 4, while the intensities and frequencies of drought occurrences (in years) are presented in Table 7. The results revealed that the region has experienced mild, moderate and severe droughts during the study period. All previously identified drought episodes in northern Nigeria by other researchers such as Oladipo (1993) and Abaje et al. (2013) were captured by this drought index. The 1960s were characterized by normal to wet conditions in the first half except mild drought that affected the Maiduguri sub-area in 1964. In 1966 and 1968, the Potiskum sub-area was affected by moderate and severe droughts, respectively. Surprisingly, Nguru at the extreme northern part of the study area was not affected by any form of drought in the 1960s.

The early 1970s featured mild to severe droughts in the region. Mild drought occupied about 11.1% of Maiduguri sub-area in 1971, moderate drought occupied 33.3% of Potiskum and Maiduguri sub-area in 1972 and 1973, while severe drought affected about 22.2% of Nguru sub-area (the extreme northern part of the study area) in 1972 and 1973. As a whole, about 67% of the region was affected by droughts between 1971 and 1973. From 1974 to 1980, the region experienced normal to very wet conditions with the exception of Potiskum that was affected by severe and mild droughts in 1977 and 1978, respectively. The well-known Great Sahelian Droughts started in the northern part of the West African Sahel in 1968 (Oladipo 1993). But from the results of the analysed data of this region, it is only the Potiskum sub-area that was affected by severe drought in 1968. This result concurs with the findings of Abaje (2010) that the Great Sahelian Droughts of 1968–1973 did not start at the same time; they started in the northern part of the West African Sahel in 1968 and by 1973 the whole Sahelian region was affected by moderate to severe droughts (Abaje et al. 2013).

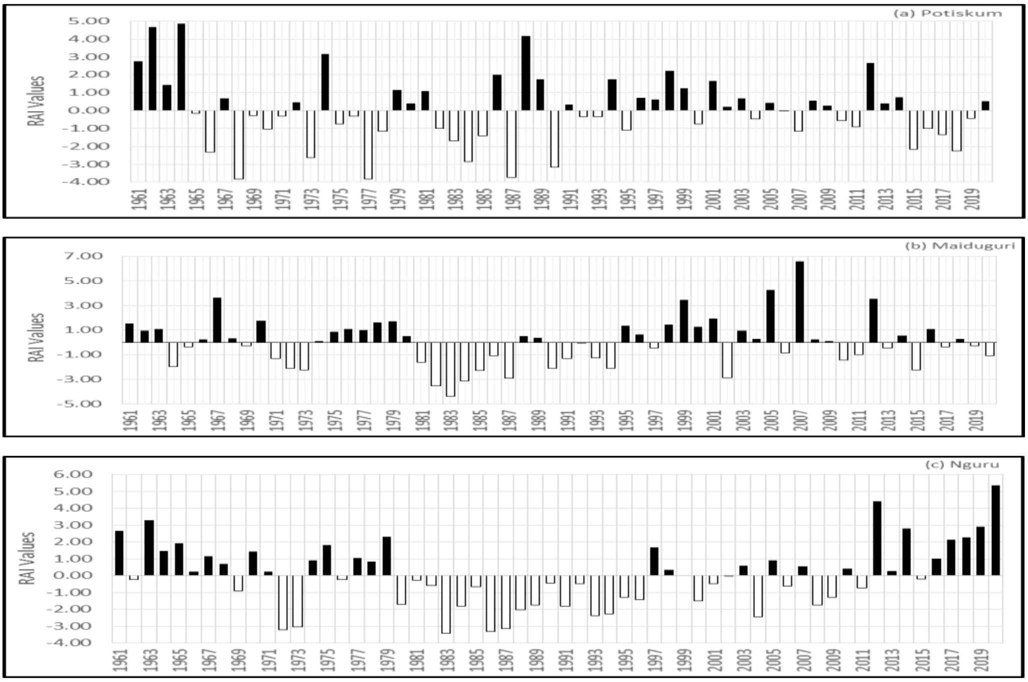

Figure 4: Rainfall Anomaly Index for: (a) Potiskum; (b) Maiduguri; and, (c) Nguru.

Table 7: Intensity and frequency of drought occurrences

Station	Intensity	Frequency
Potiskum	Mild	1970, 1978, 1982, 1983, 1985, 1995, 2007, and 2017 (**8 Years**).
	Moderate	1966, 1973, 1984, 2015, and 2018 (**5 Years**).
	Severe	1968, 1977, 1987, and 1990 (**4 Years**).
Maiduguri	Mild	1964, 1971, 1981, 1986, 1991, 1993, 2010, and 2020 (**8 Years**).
	Moderate	1972, 1973, 1985, 1987, 1990, 1994, 2002, and 2015 (**8 Years**).
	Severe	1982, 1983, and 1984 (**3 Years**).
Nguru	Mild	1980, 1984, 1989, 1991, 1995, 1996, 2000, 2008, and 2009 (**9 Years**).
	Moderate	1988, 1993, 1994, and 2004 (**4 Years**).
	Severe	1972, 1973, 1983, 1986, and 1987 (**5 Years**).

Source: Author's Analysis (2022).

The 1980s featured more widespread and severe droughts than the Great Sahelian Droughts of the 1970s. About 63.3% of the region was covered by droughts (mild to severe droughts) during this decade. The year 1987 was the driest in that decade in which 66.7% of the region was covered by severe droughts, while 33.3% was covered by moderate droughts. This is followed by the year 1983 in which 66.7% of the area was affected by severe droughts and 33.3% experienced mild droughts. This finding is in line with the works of Oladipo (1993), Abaje (2010), Abaje et al. (2013) and Ati et al. (2022) where more widespread, severe and persistent droughts were the features of the 1980s. The drought of the year 1987, in particular, was more severe than the driest year (1973) of the Catastrophic Sahelian Droughts of 1968–1973.

The first half of the 1990s was drier than the second half. In 1990, for instance, 66.7% of moderate and severe droughts affected Maiduguri and Potiskum sub-area. Amazingly, the extreme northern part of the study area (Nguru sub-area) had a normal moisture condition that year. From 1991 to 1994, the Maiduguri and Nguru sub-areas were affected by mild to moderate droughts. About 80% of the other half of the 1990s (1995–1999) was dominated by normal to very wet conditions. This corresponds with the findings of Abaje (2010), Abaje et al. (2013) and Ati et al. (2022).

In the 2000s, about 80% of the whole region generally experienced normal to very wet conditions with just some isolated mild and moderate droughts that affected about 13.3%, and 6.7% of the area, respectively. The driest years in the 2000s were 2002 and 2004. These years were affected by moderate droughts. The sub-areas affected were Maiduguri in 2002 and Nguru in 2004. This finding also concurs with the results of Abaje (2010) and Abaje et al. (2013) where about 85% of the SSEZ of the country experienced normal to very wet conditions in the 2000s. Similarly, 82% of the whole region from 2010 to 2020 witnessed normal to very wet conditions. Only isolated mild to moderate droughts were experienced in Potiskum and Maiduguri. Surprisingly, the extreme northern part of the study area (Nguru sub-area) had a normal moisture condition in that period (2010–2020).

A cross-examination of the whole study period (1961 to 2020) revealed that the year 2012 was the wettest (very wet) in the whole region. This is the year in which the country experienced the worst flooding in more than 80 years as a result of heavy rainfall (NiMet 2012). About 33 states including the study area were affected. Generally, the whole region has been experiencing increasing wetness from the middle of the 1990s to recent years. This finding concurs with that of Abaje et al. (2012) and NiMet (2016, 2017, 2019 and 2021) that the northern part of the country is now experiencing wetter conditions in recent years.

Probabilities of occurrence of droughts and recurrence intervals

The absolute probabilities of occurrence of the different drought intensities (mild, moderate and severe) and their respective recurrence intervals (or return periods) were calculated for each sub-area in the region.

The results are presented in Table 8. The values show variations among sub-areas.

The Nguru sub-area has the highest absolute probability of occurrence of mild drought (0.15) than any other sub-area in the region with a recurrence interval of 7 years, while the absolute probability of occurrence of mild drought for Maiduguri and Potiskum is 0.13 each with a recurrence interval of 8 years each. In terms of moderate drought, the Maiduguri sub-area has the highest absolute probability of occurrence (0.17) with a recurrence interval of 6 years. This is followed by the Potiskum sub-area which has a probability of 0.08 and a recurrence interval of 12 years. The Nguru sub-area is the least with absolute probability of 0.07 and a recurrence interval of 15 years. On the other hand, Nguru sub-area has the highest absolute probability of occurrence of severe drought (0.08) with a recurrence interval of 12 years. This is closely followed by the Potiskum sub-area with a probability of 0.07 and a recurrence interval of 15 years. The least is the Maiduguri sub-area in which the probability of occurrence of severe droughts is 0.05 with a recurrence interval of 20 years. On average, the probability of occurrence of mild drought is the highest (0.14) in the area with a recurrence interval of 8 years. This is followed by moderate drought with a probability of 0.11 with a recurrence interval of 11 years, and the least is severe drought with a probability of 0.07 with a recurrence interval of 16 years.

Table 8: Probabilities of occurrence of droughts and recurrence intervals (in years)

Stations	Mild drought		Moderate drought		Severe drought	
	Probability	Recurrence interval	Probability	Recurrence interval	Probability	Recurrence interval
Potiskum	0.13	8	0.08	12	0.07	15
Maiduguri	0.13	8	0.17	6	0.05	20
Nguru	0.15	7	0.07	15	0.08	12
Mean for the region	**0.14**	**8**	**0.11**	**11**	**0.07**	**16**

Source: Author's analysis (2022).

Conclusion and Recommendations

Drought occurs in virtually all the climatic zones of the world. However, it varies in terms of its magnitude, severity, duration and geographical coverage. Findings from the analyses of the linear trend lines, the 5-year moving average and decadal non-overlapping sub-periods, revealed that the region has been experiencing increasing rainfall (wetness) in the last two decades which is not unconnected with climate changes. Also, findings from the trend analyses of the observed temperature data for the period of study generally showed that the temperature has been increasing in the last decade. This is a proof of the increasing warming of the Earth's atmosphere in recent years.

The results of the study further revealed that the region has experienced mild, moderate and severe droughts during the study period. The 1980s featured more widespread and severe droughts than the Great Sahelian Droughts of 1968–1973. The year 1987 in particular was the driest in which 66.7% and 33.3% of the region was covered by severe and moderate droughts, respectively. In the 2000s and 2010 to 2020, about 80% and 82%, respectively of the whole region generally experienced normal to very wet conditions. This is clear evidence that the number of drought occurrences has been decreasing in recent years. The computed frequency of drought in the region revealed that the mean probabilities of mild, moderate, and severe droughts were 0.14 (recurrence interval of 8 years), 0.11 (recurrence interval of 11 years), and 0.07 (recurrence interval of 16 years), respectively.

This study recommends the establishment and improvement of the existing early warning systems for monitoring the occurrence of meteorological drought. This would help in providing input for determining agricultural drought. The establishment of more meteorological stations and improvement of the existing ones in order to provide accurate climatic data is also recommended. This is of paramount importance in order to develop the probability distribution of rainfall amount and timing (onset and cessation). Lastly, government policies related to agriculture and water resources development in the area should take into account the increasing rainfall (wetness) and temperature (warming) in recent years.

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Conflict of Interest

The author declares that there is no conflict of interest with respect to the research and publication of this article.

References

Abaje IB 2007 Introduction to Soils and Vegetation. 1st ed, Personal Touch Productions, Kafanchan.

Abaje IB 2010 Occurrence of droughts in the Sudano-Sahelian Zone of Nigeria M.Sc. Dissertation, Ahmadu Bello University, Zaria, Nigeria.

Abaje IB and Oladipo EO 2019 Recent changes in the temperature and rainfall conditions over Kaduna State, Nigeria. *Ghana J. Geogr.* 11(2): 127-157.

Abaje IB, Abashiya M, Onu V and Masugari DY 2017 Climate change impact and adaptation framework for rural communities in northern Nigeria. *J. Res. Nat. Dev.* 15(2): 142-150.

Abaje IB, Achiebo PJ and Matazu MB 2018 Spatio-temporal analysis of rainfall distribution in Kaduna State, Nigeria. *Ghana J. Geogr.* 10(1): 1-21.

Abaje IB, Ati OF and Iguisi EO 2012 Changing climatic scenarios and strategies for drought adaptation and mitigation in the sudano-sahelian ecological zone of Nigeria. In: Iliya MA and Dankani IM (Eds) *Climate Change and Sustainable Development in Nigeria* (pp 99–121), Crown F. Publishers, Ibadan.

Abaje IB, Ati OF, Iguisi EO and Jidauna GG 2013 Droughts in the sudano-sahelian ecological zone of Nigeria: implications for agriculture and water resources development. *Global J. Human Soc. Sci. (B): Geogr. Geo-Sci. Environ.* 13(2): 1-10.

Achugbu IC and Anugwo SC 2016 Drought trend analysis in Kano using standardized precipitation index. *FUOYE J. Eng. Technol.* 1(1): 105-110.

Ati OF, Aremu K, Olatunde AF, Abaje IB and Oladipo EO 2022 Meteorological drought and temperature in sudano-sahelian region of Nigeria under increasing global warming. In: Stuart Harris (Ed) *The Nature, Causes, Effects and Mitigation of Climate Change on the Environment*, Chapter 12, IntechOpen Book Series, London.

Ayuba HK, Maryah UM and Gwary DM 2007 Climate change impact on plant species composition in six semi-aid rangelands of northeastern Nigeria. *Nigerian Geogr. J.* 5(1): 35-42.

Brazel SW and Balling RC 1986 Temporal analysis of long-term atmospheric moisture levels in Phoenix, Arizona. *J. Clim. Appl. Meteor.* 25: 112-117.

Dai A 2013 Increasing drought under global warming in observations and models. *Nat. Clim. Change* 3(1): 52–58.

Delk J 2020 A statistical analysis of drought and its global impact a statistical analysis of drought and its global impact. M.Sc. (Civil Engineering) Thesis, Clemson University.

Eze JN 2018 Drought occurrences and its implications on the households in Yobe state, Nigeria. *Geoenvironmental Disasters* 5(18): 1-10.

Federal Republic of Nigeria (FRN) 2018 National Drought Plan. Retrieved from https://knowledge.unccd.int/sites/default/files/country_profile_documents/1%2520FINAL_NDP_Nigeria.pdf

Henchiri M, Igbawua T, Javed T, Bai Y, Zhang S, Essifi B, Ujoh F and Zhang J 2021 Meteorological drought analysis and return periods over North and West Africa and linkage with El Niño–Southern Oscillation (ENSO). *Remote Sens*. 13: 4730.

Köppen W 1936 Das geographische System der Klimate, Handbuch der Klimatologie (The Geographical System of the Climate, Handbook of Climatology). Borntraeger, Berlin, Bd. 1, Teil. C.

Lawson MP, Balling RC, Peters AJ and Rundquist DC 1981 Spatial analysis of secular temperature fluctuations. *J. Climatol.* 1: 325-332.

Niang I, Ruppel OC, Abdrabo M, Essel A, Lennard C, Padgham J, and Urquhart P 2014 Africa. *Climate Change 2014: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, United Kingdom and New York, NY.

Nigerian Meteorological Agency (NiMet) 2012 *Nigeria Climate Review Bulletin* (pp 46). Nigerian Meteorological Agency, Abuja.

Nigerian Meteorological Agency (NiMet) 2016 *Nigeria Climate Review Bulletin,* (pp 74). Nigerian Meteorological Agency, Abuja.

Nigerian Meteorological Agency (NiMet) 2017 *Climate Review Bulletin,* (pp 67). Nigerian Meteorological Agency, Abuja.

Nigerian Meteorological Agency (NiMet) 2018 *Climate Review Bulletin,* (pp 58). Nigerian Meteorological Agency, Abuja.

Nigerian Meteorological Agency (NiMet) 2019 *Climate Review Bulletin,* (pp 97). Nigerian Meteorological Agency, Abuja.

Nigerian Meteorological Agency (NiMet) 2021 *State of the Climate in Nigeria,* (pp 92). Nigerian Meteorological Agency, Abuja.

Odekunle TO 2010 An assessment of the influence of the inter-tropical discontinuity on inter-annual rainfall characteristics in Nigeria. *Geographical Research* 48(3): 314 – 326.

Odekunle TO, Andrew O and Aremu SO 2008 Towards a wetter sudano-sahelian ecological zone in twenty first century Nigeria. *Weather* 63(3): 66-70.

Oladipo EO 1993 Some aspects of the spatial characteristics of drought in northern Nigeria. *Natural Hazards* 8: 171-188.

Olatunde AF and Aremu JK 2016 Mild and moderate droughts in savanna ecological zone of Nigeria. *Adv. Soc. Sci. Res. J.* 3(4): 236-247.

Paulo AA and Pereira LS 2007 Stochastic prediction of SPI drought class transitions. *Water Resour. Manag.* 22: 1277-1296.

Sadiq AA, Umar SM and Bello MU 2020 An estimation of rainfall anomaly index and its impact on crop production in Yola and environs. *Afr. J. Environ. Nat. Sci. Res.* 3(4): 35-53.

van Rooy MP 1965 A rainfall anomaly index independent of time and space. *Notos* 14: 43-48.

Walsh RPD and Lawler DM 1981 Rainfall seasonality: description, spatial patterns and change through time. *Weather* 36: 201-208.