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Integration of standardized precipitation index and drought severity index for assessment of drought in the Sudano-Sahelian ecological zone of Nigeria

Odewale OM[1], **Adebola AO**[2]✉

[1]Department of Remote Sensing and GIS, Federal University of Technology Akure, Ondo State.
[2]Department of Remote Sensing and GIS, Federal University of Technology Akure, Ondo State.

✉**Correspondence author:**
Department of Remote Sensing and GIS, Federal University of Technology Akure, Ondo State.
Nigeria
Email: aoadebola@futa.edu.ng; collinola@gmail.com

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ABSTRACT
Drought is a natural hazard characterized by lower than expected normal precipitation which is insufficient to meet demands of human activities and the environment. It occurs in both high and low rainfall areas and virtually all climatic regimes. A quantitative assessment of drought characteristics and their associated variability in the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria was

carried out. Monthly Rainfall data for seven selected meteorological stations were collected and used. The long term rainfall records were analyzed for drought using Standardized Precipitation Index (SPI) and Palmers Drought Severity Index (PDSI) to assess the Drought period in the SSEZ. The annual rainfall data for the period 50years (1965-2015) were collected from the Nigeria Meteorological Agency. The results of SPI and PSDI analysis revealed that there were several drought years in the study area within the study period .These were classified into mild, moderate, severe and extreme drought conditions. 20years of total drought occurrence was noted, in which the prominent extreme drought years across the zone were 1973, 1983 and 1987 proved to be more devastating due to its duration and severity. The study has provided useful information and pro- active intervention to reduce the impact of drought which will be helpful to effectively plan for a rain fed agriculture within the SSEZ of Nigeria.

Key words: Drought, Ecological, Standardized precipitation Index, Drought Severity Index, Sudano-Sahelian, climate

1. INTRODUCTION

Drought is a natural hazard characterized by lower than normal precipitation which is insufficient to meet demands of human activities and the environment. It occurs in both high and low rainfall areas and virtually all climatic regions. With reference to global climatic anomalies, drought is not a strange phenomenon on the African continent especially in the Sahel region in which the northern fringes of Nigeria lies. Many nations have experienced considerable distress arising out of drought occurrences, mass starvation (even famines) and food insecurity particularly within the developing world where economies are tied to agriculture.

The Sahelian drought of 1969 -1973 which lingered on till 1985/87 is so far the worst (Adefolalu, 1990). The climatic calamity has had tremendous socio-economic impacts on human livelihood arising from pressure on available resources in the face of a fluctuating rainfall regime (Usman, 1993). The Most serious is the occurrence of breaks (in rainfalls) during a normal planting season when wilting of emerging plants occurs. Even though subsequent rainfall may be abundant, local farmers have to reinvest in replanting for some particular crop which they can hardly afford, when unsteady or late onset occurs after peak early storms.

Drought affects river patterns, agricultural production, water supply and hydro-electric power generation. Extreme events connote climate variability and climate change and seem to become more frequent in the Sudano-Sahelian Ecological zone of Nigeria. Their environmental and socio-economic costs are often high. Problem of ecological disasters such as drought, desertification, flood and erosion have been on the increase in Nigeria, within the past four decades. The persistent drought has indeed, a number of times caused famine in Northern Nigeria, especially during the drought episode of 1972-1973, during which thousands of animals died and farm yields dropped by up to 60% (Fidelis, 2003). It is estimated that 4 billion people will live under conditions of severe water stress by the year 2025, with conditions being particularly severe in Africa, the Middle East, and South Asia (Diwan, 2002).

One undisputable cause of 'famine' in northern Nigeria is the failure of crops resulting from insufficient or untimely rainfall. This region was severely hit by droughts and famines during the Sahelian drought episode of late 1960's -1980's (Adefolalu, 1990). The entire region is primarily oriented towards subsistence and extensive agricultural practices and animal husbandry which naturally are rainfall dependent, and drought have triggered on famines in some areas with inadequate food security structure.

Disasters caused by drought are also strongly affected by such diverse factors as agriculture practices, changes in population density and the country's ability to provide alternative supplies of food, water and employment. It is a common knowledge that availability of water has been man's means of survival and at times his enemy (Adefolalu, 1990). At various places and at different times, people migrated from place to place in search of water or in the quest to run away from drought, flood and erosion. In his effort to provide a safe and comfortable environment for sustainable development, man has since then continued to intensify research in areas of drought and flood mitigation, erosion control, and water resources development for irrigation, navigation, domestic and industrial water supplies.

The aim of this study is to provide further insight into drought in Sudano-Sahelian Ecological Zone of Nigeria through the following Objective specific objectives: Compute trends in rainfall anomalies in the Sudano-Sahelian zone of Nigeria; Quantify the most dominant drought years in the Sudano-Sahelian zone; and Suggest possible pro-active intervention practices to avert drought.

Ojo (2002) observed that rainfall decline which has extended towards the equator has led to relatively persistent drought in the Sudano-Sahelian Ecological Zone of Nigeria from 1960s. Drought has however become evident since the seventies which created the global droughts of 1969-1973 (Adefolalu, 2007). According to Medugu (2007), the zone started the 20th century with a prolonged drought of 1903 culminating in that of 1911-1914. Other droughts included those of 1919; 1924; 1935 and 1951-1954. Since then, other drought episodes with considerable adverse impact on the environment and socio-economic activities are those of 1972-1973 and 1984-1985.

Drought is a natural component of climate, it need not always lead to disaster as the desertification of the drought-prone, front-line States of Nigeria now portray. It has been suggested that their impact can be managed by reducing Vulnerability and improving preparedness. As Adefolalu (1990) postulated:

DESERTIFICATION = DROUGHT + MAN

The human interaction activities that contribute to the effects of drought as factors of desertification in the northern parts of Nigeria are:

- Forest depletion through fuel wood;
- Deterioration of rangelands due to over grazing;
- Deterioration of water resources through over ambition and unco-ordinated harnessing of water.

Types of droughts

(a) Meteorological Drought

It is an expression of precipitation's departure from 'normal' over some period of time. It also connotes the degree of dryness (in comparison to some 'normal' or average amount) and the duration of the dry period. It basically originates from the deficiency of precipitation and focuses on the physical characteristics of drought (Mokhtari, 2005) rather than impacts associated with shortage of precipitation. Meteorological drought leads to a depletion of soil moisture (Legesse, 2010).

(b) Agricultural Drought

An agricultural drought is considered to have set in, when the soil moisture deficits has dropped to such a level that it adversely affects the crop yield and hence agricultural production (Panu and Sharma, 2002). Definitions of agricultural drought hover around soil moisture deficiency in relation to meteorological droughts and climatic factors and their impacts on agricultural production. Such agricultural impacts are caused by short-term precipitation shortages, temperature anomaly that caused increased evapotranspiration and soil water deficits that could adversely affect crop production (Narasimhan, 2004).

(c) Hydrological Drought

Hydrological drought is an expression of deficiencies in surface or subsurface water supply (i.e., stream flow, artificial and natural reservoirs, ground water). At various points in time the departure is dependent on the status of surface and subsurface water supplies in lakes, reservoirs, aquifers and streams because these components of the hydrological system are used for multiple and competing purposes, such as irrigation, recreation, tourism, flood control, transportation, hydroelectric power production, domestic water supply, protection of endangered species, environmental and ecosystem management and preservation. It occurs when there is a substantial deficit in surface runoff below normal conditions or when there is a depletion of ground water recharge (Okorie, 2003).

(d) Socioeconomic Drought

The socio-economic effect of meteorological, hydrological, and agricultural drought associated with the supply and demand of the society. The supply of many economic goods, such as water, forage, food grains, fish, and hydroelectric power, depends on weather. This form of drought associates the supply and demand of some economic goods with elements of meteorology, agricultural and hydrological droughts (Okorie, 2003; Legesse, 2010).

Causes of drought

Drought is a condition of extreme but short term climatic variation which results in insufficient rainfall to meet the socio-economic demands of a region in terms of water supply for domestic and industrial uses, agriculture and ecosystem. One of the earliest and most influential explanations of the cause of drought in the Sahel was that of Charney *et al.* (1977), which suggested that reductions in rainfall were the result of human activity. In what has come to be known as Charney's model, decreases in vegetation cover caused by over-grazing and deforestation lead to an increase in the reflectivity or albedo of the land surface. The essence of Charney's hypothesis is that this increase in reflectivity results in a reduction in the heating of the ground, which in turn reduces the heating of the atmosphere by the ground, resulting in a reduction in the convection that is essential for the formation of rainfall-generating clouds.

Other studies have suggested that the build-up in atmospheric dust, exacerbated by anthropogenic factors such as fire-wood exploitation, bush burning and poor farming practices, as well as, frequent sand storms, which cause changes in surface albedo may be responsible for large-scale climatic alterations in the Sahel (Ekpoh, 2007).

More recently, proactive practices of government manifested through its many drought hazard mitigation schemes (e.g. buying and storing grains in silos and introduction of drought –resistant varieties) are poor palliatives and not full response to drought problems. Drought cannot be ignored in this belt where its frequent occurrence is devastating to millions of people. The effect of rainfall variability on agricultural production, private and government ventures and the economy are costly experiences for its victims. The present study updated these studies and focused on assessment of drought in the Sudano-Sahelian Ecological Zone of Nigeria.

THE STUDY AREA

The Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria is a large Ecological Zone that occupies almost one-third of the total land mass of the country. The area lies in the north between longitudes 4^0 and 14^0E, and latitudes 10^0 and 14^0N figure 1.

Studies have shown that although, rainfall is generally experienced in the Sudano-Sahelian Ecological Zone between early June and the first ten days of September, its distribution characteristics are adequate for crop germination, establishment and development for roughly only two months between the first ten days of July and the first five days of September (Odekunle et al., 2008). Apart from its short growing season, the Ecological Zone has a persistent and severe drought tendency (Nicholson, 2001). The major drought periods with resultant farming reported in Sudano-Sahelian Ecological Zone during the twentieth century include: 1913-1914, 1931-1932, 1942-1943, 1972-1973 and 1983-1984, (Odekunle et al., 2008). The droughts have led to severe environmental consequences and human tragedy.

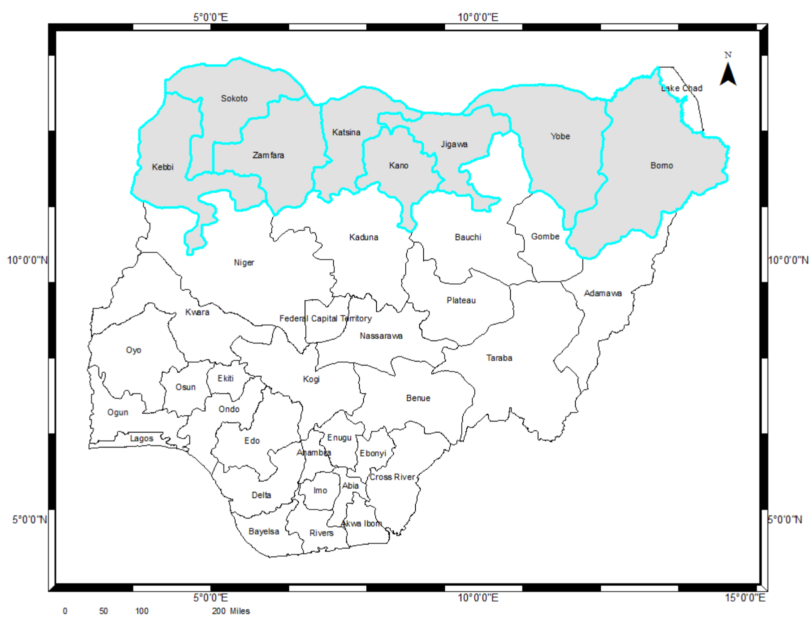

Figure 1 Map of Nigeria showing Study Area

2. METHODOLOGY

A quantitative assessment of drought characteristics and variability in the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria were analyzed for drought using Standardized Precipitation Index (SPI), and Palmers Drought Severity Index (PDSI). Several researchers have observed that PDSI has limitations among which are calibration and spatial comparability (Guttman *et al.,* 1998; Chopra, 2006). In order to solve this problem, McKee *et al.,* (1993), developed the Standardized Precipitation Index (SPI) which can be calculated at different time scales to monitor droughts and hence applicable to diverse areas of interests. Moreover, the SPI is comparable in time and space (Hayes and Svoboda, 1999).

For this study an Observed monthly rainfall data which was later processed into annual rainfall total spanning over the period of (1965-2015) for 50years was analyzed for the seven selected stations in the Sudano-Sahelian Ecological Zone of Nigeria. The data was collected from the Nigeria Meteorological Agency Lagos.

Analysis

The standardized precipitation index (SPI)

Standardized precipitation index is a relatively new drought index based on precipitation only. It is a dimensionless index whose negative values indicate drought; positive values wet conditions. According to McKee *et al.* (1993), Drought intensity, magnitude, and duration can be determined as well as the historical data based probability emerging from a specific drought (table 1). Guttman (1998) has made comparison of PDSI and SPI, and recommended SPI as a drought index, which is easy to determine and has greater spatial consistence. Moreover, it can be used in risk assessment analysis and making decisions with special ability for adjustments to time periods for which the users are interested, for example, short time periods in life cycle of crops or longer periods regarding water resources. According to Legesse (2010), SPI can be used to examine the severity and spatial patterns of drought in a given region. Besides, it offers a quick, handy and simple approach with minimal data requirements (Komuscu, 1999). It is designed to quantify the impacts of precipitation deficit on groundwater, reservoir storage, soil moisture, and stream flow for multiple time scales.

The standardized precipitation index were analyzed at various stations for the period of 50 years using the annual rainfall for various stations, the mean annual rainfall at Station and standard deviation of the annual rainfall for station to assess drought in the Sudano-Sahelian Ecological Zone of Nigeria. However, SPI is generally computed using an SPI Program. According to Murad and Saliful (2011) SPI is calculated based on the following equation:

The Standard Precipitation index is expressed as:

$$spi = \frac{(R_{ij} - \overline{r_i})}{\sigma_i}$$

$$\sigma = \sqrt{\frac{\sum_i^n (R_{ij} - \overline{r_i})^2}{N}}$$

Where SPI = Standard Precipitation index for station *i* and year *j,*

$R_{,ij}$ = annual rainfall for station *i* and year *j*

$\overline{r_i}$= the mean annual rainfall at station *i,*

σ_i = standard deviation of the annual rainfall for station *i.*

N = number of specific years for sample station.

Table 1 Drought classification for SPI value and corresponding event probabilities

SPI Values	Category	Time in Category (%) Probability
≥ +2.00	Extremely Wet	2.3
+1.50 to +1.99	Very Wet	4.4
+1.00 to +1.49	Moderately Wet	9.2
0 to 0.99	Mildly wet	34.1
0 to -0.99	Mildly dry	34.1
-1.00 to -1.49	Moderately Dry	9.2
-1.50 to -1.99	Severely Dry	4.4
≤ -2.00	Extremely Dry	2.3

(Adapted from Edwards and McKee, 1997).

As part of the advantages of SPI, it is able to produce a meaningful estimate of drought for different locations and time scales. It has been widely and largely used operationally to quantify and monitor the wet and dry conditions across different locations, in the United States, Italy, Greece, Mexico and Spain to mention a few (Dalezios et al. (2000), Bordi and Sutera (2000), and Wihilte (2003).

Palmer Drought Severity Index (PDSI)

Palmer Drought Severity Index (PDSI) is a measurement of dryness based on recent precipitation. PDSI reveal distinct period of negative and positive values with the negative value indicating occurrence of drought and the positive values show wet condition.

The index gives the normalized annual departure from the mean for the seven meteorological stations covering the Sudano-Sahelian region. A drought year occurs if palmer drought severity index is negative. The drought magnitude is the mean sum run total of the departure below the long-term mean rainfall variability index, while the palmer drought severity is defined as the run total of departure below the long-term mean rainfall variability index (table 2). Meanwhile, drought run duration equals the period of *n* years with a negative rainfall variability index (Shaw, 1993).

The mean annual values were sought by averaging annual total and the months in a year

$$\bar{r} = \frac{I}{N}\sum_{J=I}^{j=N} R_{ij}$$

Where $\bar{r}_i$= mean annual values for the base period

R_{ij} = total annual rainfall values for the year

N= number of years

Then the departure was estimated by subtraction of yearly values from the annual mean and dividing the summation of the annual mean at an interval of 30years in order to arrive at the Palmer Drought Severity Index (PDSI) moving average.

Palmer Drought Severity Index is expressed:

$$PDSI = \frac{\sum(R_{ij} - \bar{r}_i)}{\sum \bar{r}_i}$$

Where PDSI= palmer drought severity index;

$\sum(R_{ij} - \bar{r}_i)$= departure from annual mean;

$\sum \bar{r}_i$ = mean annual value for the period of 50 years.

Table 2 Palmer Drought Severity Index

SEVERITY	PSDI VALUES
Extreme drought	-4.00 and below
Severe drought	-3.00 to -3.99
Moderate drought	-2.00 to -2.99
Mild range	-1.99 to 1.99
Moderate wet	2.00 to 2.99
Very wet	3.00 to 3.99
Extremely wet	4.00 and above

(Source: Palmer,1965).

3. RESULT AND DISCUSSION

The Standardized Precipitation Index (SPI)

Standardized precipitation index was analyzed at various stations for the period of 50 years using the annual rainfall, the mean annual rainfall and standard deviation to assess drought in the Sudano-Sahelian Ecological Zone of Nigeria. 50years (1965-2015) under study were sub-divided into three climatological period of 30years (1965-1995, 1975-2005, 1985-2015) .The annual rainfall means and standard deviation were divide into three climatological periods and the 50years under study were analyzed in order to determine the moving average of drought years.

The annual rainfall means and standard deviation of 1965-1995 and 1975 – 2005, were found to be lower than the long-term mean and standard deviation of 1965-2015 and 1985-2015. This indicates that there was a decline in rainfall amount in the study area in the second and the third half of the sub-division under consideration. The decline in rainfall in this region experienced annual rainfall below the long –term average during the 1965 -1995, 1975 - 2005 periods (Table 3) and (Table 4).

The above analysis shows that in 1970s and 1980s wet years were rare and drought was the norms for most of the study area, below average rainfall affected the entire study area making the decades a universal drought decade for most of the stations under study.

The standardized precipitation index for the three climatological period of 30years sub-division from 50years under study were analyzed in order to determine the distinguish features of drought and the moving average trend in the selected stations in the

Sudano-Sahelian Ecological Zone of Nigeria. The mean annual rainfall and standard deviation analyzed were used in the standardized precipitation index to assess the drought for each station, the analyses were found to have the same trend, which shows a decline in rainfall. Drought was found to have been intensified in all the stations from 1970 to 1990.

Table 3 Mean annual rainfall (mm) for particular period at selected stations in Sudano-Sahelian Ecological Zone

Stations	1965 - 2015	1965- 1995	1975 - 2005	1985 - 2015
Kano	709.9	604.4	645.8	765.8
Nguru	668.1	578.0	693.3	777.6
Sokoto	763.0	681.9	607.8	811.3
Yelwa	828.4	710.9	786.9.6	924.8
Maiduguri	659.3	602.1	636.7	713.9
Dutse	663.8	570.8	606.7	706.6
Katsina	682.0	636.0	638.1	705.4

Table 4 Standard deviation of rainfall (mm) for particular period at selected stations in the Sudano-Sahelian Ecological Zone

Stations	1965 - 2015	1965- 1995	1975 - 2005	1985 - 2015
Kano	222.5	153.0	188.8	242.0
Nguru	216.9	155.1	193.6	198.1
Sokoto	254.6	251.6	239.2	247.7
Yelwa	235.0	222.7	249.5	196.6
Maiduguri	164.4	131.6	193.6	170.7
Dutse	163.6	98.9	140.5	185.9
Katsina	178.9	170.2	172.0	179.5

For instance, the SPI analysis for Kano reveals the magnitude, intensity of the entire drought types the analysis shows that there have been drought conditions since 1960s with 22 mild, 6 moderate and 2 extreme drought conditions in the areas. The SPI was at its peak in the year1983 and 1986 which are the most severe drought years, while the year 1996 had the smallest negative SPI value. The SPI values of -1.65 and -0.04 for the peak and smallest years respectively. The most multiple year of drought event was 1970-1989 a run of 20years.While all other years at Kano were wet years with positive values which implies no drought wet conditions were experienced (Fig. 2-6).

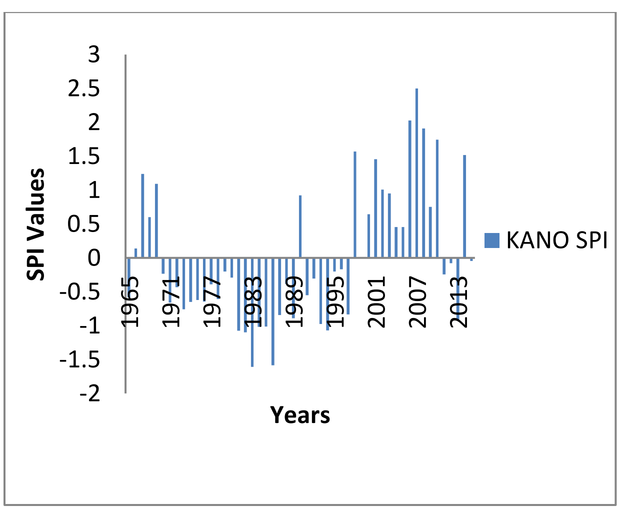

Figure 2 Standardize Precipitation Index For Kano. 1965-2015

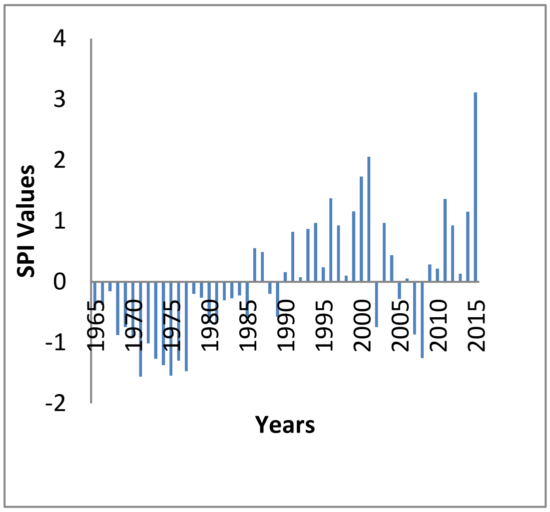

Figure 3 Standardized Precipitation Index for Nguru 1965-2015

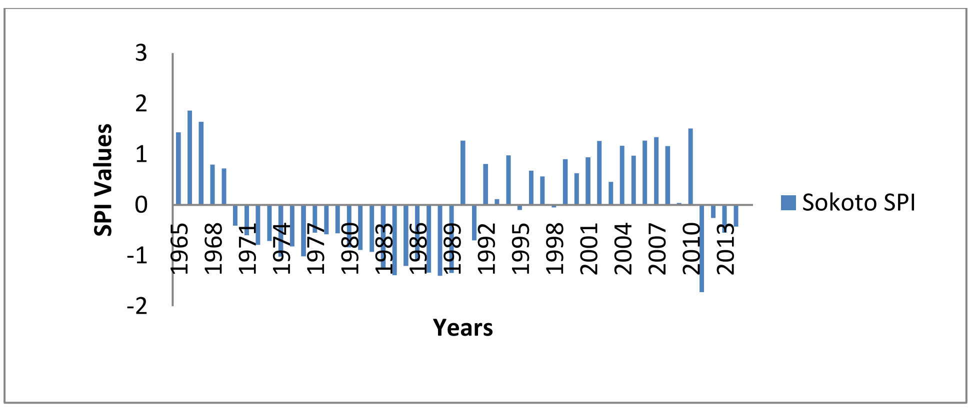

Figure 4 Standardized Precipitation Index for Sokoto 1965-2015

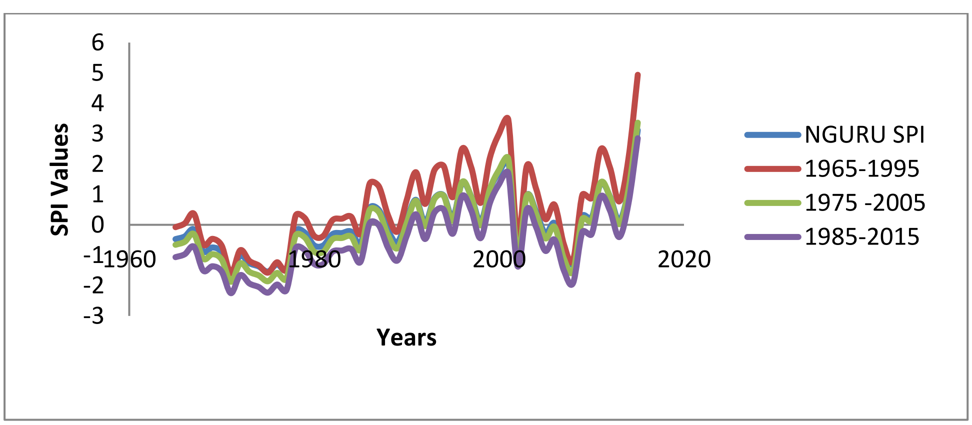

Figure 5 Standardized Precipitation Index for Nguru Showing Relationship among SPI and Moving Average Years

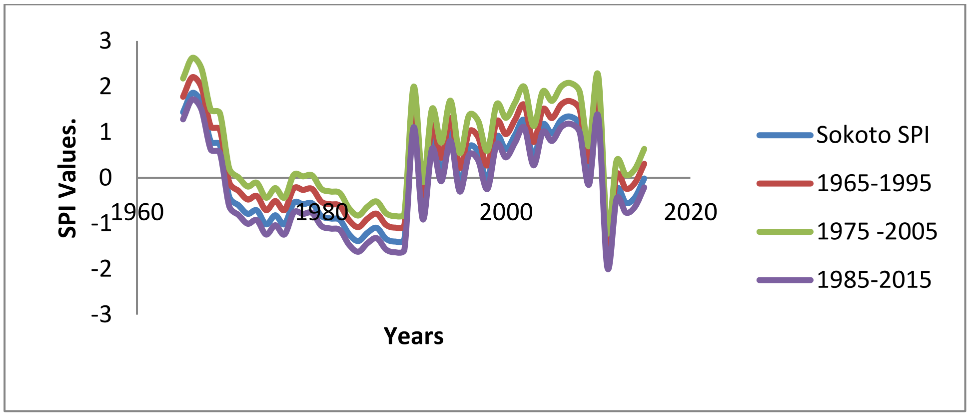

Figure 6 Standardized Precipitation Index for Sokoto Showing Relationship among SPI and Moving Average Years

The Palmer Drought Severity Index (PDSI)

For the purpose of this work the span period of 50years under study is divided into decades i.e. 1965-1974, 1975 – 1984; 1985-1994, 1995 -2004, 2005-2015. The mean annual rainfall for each of the decades was analyzed as shown in Table 5. The mean annual rainfall 1971-1980 period, 1981 to 1990 were found to be lower than the long-term mean of 1961-2010. This indicates that there was a decline in rainfall amount in the study area in the second and the third decades of the sub-period under consideration.

Table 5 Mean annual rainfall (mm) for each decades at selected stations in Sudano-Sahelian Ecological Zone

Stations	1965 - 2015	1965- 1974	1975 - 1984	1985 - 1994	1995-2005	2006-2015
Kano	718.0	806.0	593.0	518.7	662.6	1004.8
Nguru	620.4	519.8	437.1	632.1	847.4	685.8
Sokoto	799.7	1024.2	592.5	519.9	860.6	1021.1
Yelwa	834.0	963.0	594.7	552.7	984.3	1075.4
Maiduguri	655.3	745.4	534.3	523.3	765.0	707.7
Dutse	663.8	641.4	567.8	503.1	749.2	867.6
Katsina	682.0	771.5	522.1	614.3	777.9	724.0
Gusau	923.6	1155.5	873.7	812.3	770.9	1005.8

PDSI for Kano showed that there have been drought conditions since 1960s with mild drought in 1970, 1972, 1979-1980, 1988, 1995-1996. The moderate drought 1965,1971,1973-1978,1981,1984-1985,1989,1993-1994.The PDSI was at its peak in the year1983 and 1986 which are the most severe drought years, the while the year 1996 had the smallest negative PDSI value. The PDSI values of -2.00 and 0.05 for the peak and smallest years respectively (Fig. 7-10).

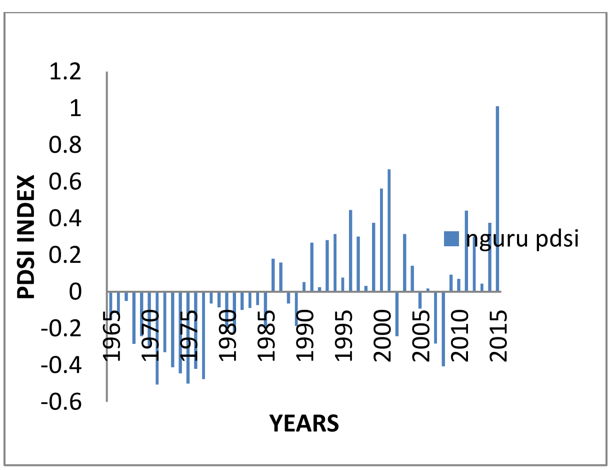

Figure 7 Palmer drought severity index for nguru 1965 -2015

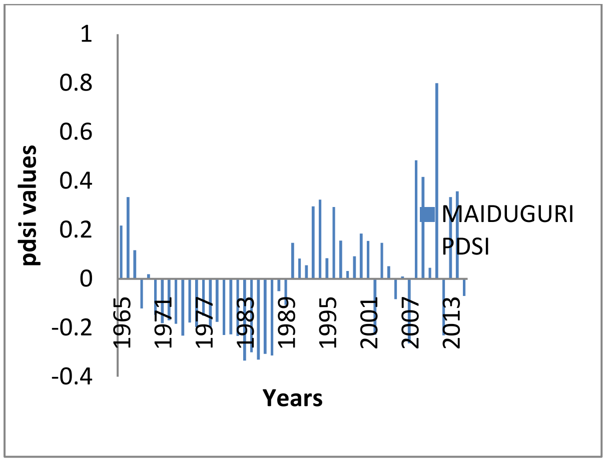

Figure 8 Palmer drought severity index for Maiduguri1965 -2015

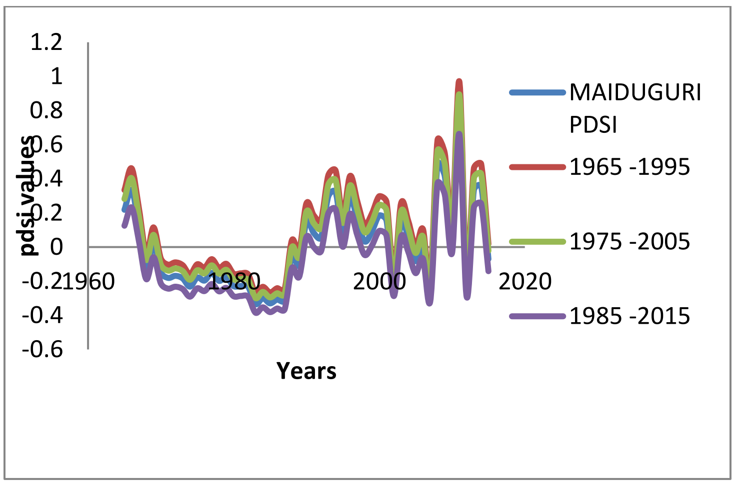

Figure 9 palmer drought severity index for Maiduguri showing the relationship among the PDSI and the moving average years

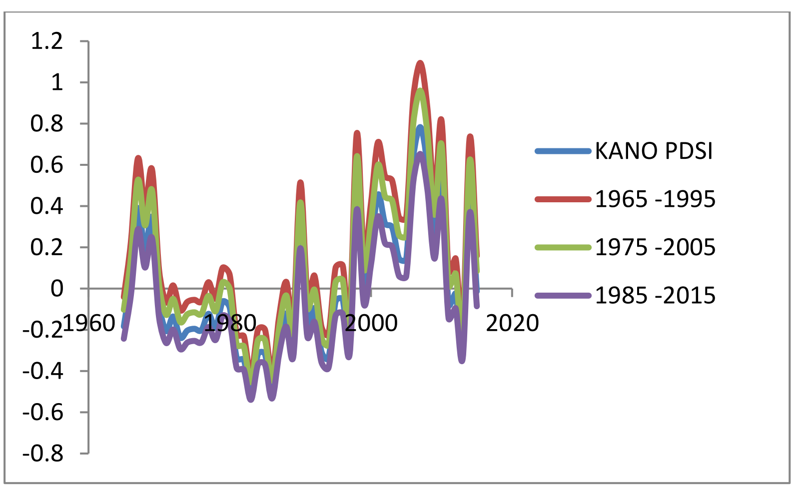

Figure 10 palmer drought severity index for kano showing the relationship among the PDSI and the moving average years

The drought years, 1972/73, 1983/84 and 1992/93 did not only experience below average annual rainfall but also experienced late onset and early cessation, which led to a drastic reduction in the length of the rainy season. Following the result of the analysis we discovered that standardized precipitation index and palmer severity index shows the same trend of dryness and wet period in zone.

4. CONCLUSION AND RECOMMENDATION

The assessment of drought in the Sudano-Sahelian Ecological Zone of Nigeria has revealed that there are two distinct trends: below normal rainfall and above normal in the area. It is evident from the study that the drought of 1972/73 in the Northern part of Nigeria actually have its toll on the climate of the Sudano-Sahelian Ecological Zone as all the stations in the region showed below normal rainfall in 1970-1980 and this trend persisted till 1980s which is even more severe than what was observed in the 1970s.

This has shown that Drought affects people more than any other natural disaster and results in serious economic, social and environmental costs. The development of effective drought monitoring, early warming and delivery systems has been a significant challenge because of the unique characteristics of drought. Strides have been made in recent years to improve the effectiveness of these systems with the increasing frequency and severity of droughts in many regions of the world and increased societal vulnerability. More emphasis is now being placed on the development of drought preparedness plans that are proactive rather than reactive and emphasize risk-based management measures.

Early warning systems can provide decision makers with timely and reliable access to information on which mitigation measures can be based. Standardized precipitation index and Palmers Drought Severity Index (PDSI) can be use to assess the drought period even if a new station with only a year of data is involved. They have good quality rainfall pattern that is very suitable for drought assessment. These indexes are therefore important parameters for planning agricultural activities, hydrology and rainfall variability.

It is shown in this study that a steady downward trend in rainfall persisted from 1970 to 1989, a period when drought became a common occurrence. The effects of the trend towards aridity in the study area can be mitigated by the formulation of drought policy, planning and decision-making processes. Such decision-making processes should involve dynamic drought analysis, prediction, preparedness and contingency planning. The plans should have the capability of balancing water demand with water supply as well as reducing drought hazard intensity and vulnerability.

There is lack of real time and early drought warning systems to manage drought in the country. Medugu (2007) called for the development of a national drought forecasting and early warning system to manage the frequent droughts in the Nigerian Sudano-Sahelian zone.

There should be establishment of functional watershed management out fits for irrigation to guard against high water loss in the zone. Rainfall harvesting is another strategy whereby rain water is collected and stored in reservoirs for irrigation farming during the dry season and domestic uses. This is recommended particularly where there is no big stream on which reservoir can be constructed.

Finally, it is suggested that, in the quest to find permanent solution to the perennial drought problems in the region, the growing of drought-resistant plants should be highly encouraged, especially on a large scale.

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