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Assessment of severity of drought in some northern Nigeria states using Drought Severity Index (DSI_5)

[1]Adeniyi, M. O. and [2]Uzoma, E. K.

[1]Department of Physics, University of Ibadan, Ibadan, Nigeria
[2]Department of Physics, Hezekiah University, Umudi, Nigeria

*Corresponding author: uzomaechefulachik@gmail.com

Abstract

Drought in various part of the northern Nigeria has been a regular occurrence over the years and has become a subject of concern to many researchers. This research considered a five-month initiation and termination sequence in the monthly precipitation data analysis of fifteen selected stations between 1960 and 2012 with the aim of identifying (i) years of drought (ii) the occurrence of major drought events and (iii) the dominant drought intensity in the region. The data were first subjected to a non-parametric test for homogeneity and thereafter, a drought severity index based on five-month (DSI5) cumulative precipitation anomalies was used to identify the years of drought and to estimate the drought severity of the years. The results revealed that mild drought was dominant within the region having an average percentage occurrence of 43.61% with18.63% wetness. The 1960s was the wettest decade while the extreme drought events were observed in 1970s but with much prevalence in 1973 and 1977 and particularly persistent in the 1980s when considered on the decadal scale. Years of mild droughts were more frequent at Maiduguri, Bauchi, Sokoto, Kano and Zaria stations. Drastic approaches on how to possibly reduce the hazardous effects of drought occurrences in the region include adequate agricultural extension services to educate farmers on the implications of the dominant drought intensity and the ways to ameliorate its effects.

Keywords: *Drought severity index; Precipitation anomalies; Surface-water; Northern Nigeria*

INTRODUCTION

Drought events in various part of the northern Nigeria have been a regular occurrence over the years and have become a subject of concern to many researchers. The slow-onset, insidious and creeping devastating nature of the drought phenomenon makes it imperative for a regular study update to ascertain the current state of the hydrological content of a drought-prone area such as the study area. According to Kalu (1987), Adefolalu (1986), and Kamara (1986), the persistence of drought in parts of northern Nigeria during the 1970s, 1980s, and 1990s has been attributed to the prevalence of a stagnated anti-cyclonic circulation of the tropical atmosphere over areas which normally should be exposed to the rising arm of the tropical Hardley Cell circulation by mid-summer. The review of the definitions of drought by Wilhite and Glantz (1985) and Dracup *et al.* (1980) suggests that drought is a condition of insufficient moisture caused by a deficit in precipitation over some time period. It is a cumulative departure from normal or expected precipitation, that is, the climatological mean. This cumulative precipitation deficit may be made manifest in the reduced stream flows, reservoir level or increased depth to the ground water table after several months. It should be noted that drought occurs in both high and low rainfall areas, dry and humid regions but most often, drought monitors and analysts associate drought only with arid, semi-arid and sub-humid areas with little or no attention to high rainfall areas. Factors considerable in the analysis of drought events include severity which is generally expressed by a drought index, time of onset and duration of the drought, areal extent and its frequency of occurrence (Aremu and Olatunde, 2012).

Drought events in the northern Nigeria have been investigated by many researchers. All pointed out various degrees of intensity ranging from invisible to extreme (Adefolalu, 1986; Aremu and Olatunde, 2012; Shuaibu and Oladipo, 1993). The general problem of drought risk assessment has led to the development of several drought severity indices (DSIs) which are based on precipitation (Maracchi, 2000). The two most commonly used of these indices are the standardized precipitation index (SPI) (Mckee *et al.* 1993) which transforms monthly precipitation time series into a standardized normal distribution and the drought severity index (DSI) which uses accumulated monthly precipitation anomalies concept of Bryant *et al.* (1992). Shuaibu and Oladipo (1993), using Bhalme and Mooley Drought Index observed that the region is rarely covered by large-scale droughts as a whole with distinct spatial differences dominating the wet and dry years. Quite a number of the studies have been based on the use of data intensive indices requiring the evaluation of local hydrological constants or evapo-transpiration whose accurate measurement proves a lot complicated. The DSI was used by Phillips and McGregor (1998) in an analysis of drought risk in southwest England. The same has been used to examine UK water resource drought (Fowler and Kilsby, 2002, 2004) and changes projected by the PRUDENCE models on a European scale (Blenkinsop and Fowler, 2007). Mawdsley *et al.* (1994) recommend the use of this type of index as it requires little rainfall data and can be easily interpreted by users. Oladipo (1985) concluded that simple indices that require rainfall as the input perform comparatively well when compared to some more complicated indices. This study aims at identifying years of drought in each of the stations, major drought events that have occurred and dominant drought intensity in the region using Drought Severity Index (DSI) that uses monthly accumulated precipitation deficit, thereby validating the method in this part of the world where it is yet to be done.

MATERIALS AND METHODS

The study area

Northern Nigeria lies on the latitude (6.45-14.00°N) and longitude (2.73-14.70°E) (Fig. 1). It produces most of the country's grains and tuber crops. Cotton, groundnut and sugar cane are also largely produced from the region. Farming is mostly irrigation-process dependent. Rainfall in the area is seasonal with a high variability from year to year. The region is characterized by frequent dry spells causing severe and widespread drought. The area is as well endowed with some economic minerals such as limestone, columbite, tin and cassiterrite.

The Sudan-Sahel ecological zone of West Africa of which the northern Nigeria is largely composed is characterized by frequent severe drought events as a result of false onset, late or delayed onset and early cessation of the summer rains combined with a large-scale pattern of the atmospheric circulation (Houndenou and Hernandez, 1998). The region's climatic composition is drastically influenced by the Sahelian climatic anomalies and atmospheric circulation pattern coupled with dry and dusty tropical continental (cT) air mass originating from Sahara desert and warm, tropical-maritime (mT) air mass originating from the Atlantic Ocean (Adefolalu, 1986).

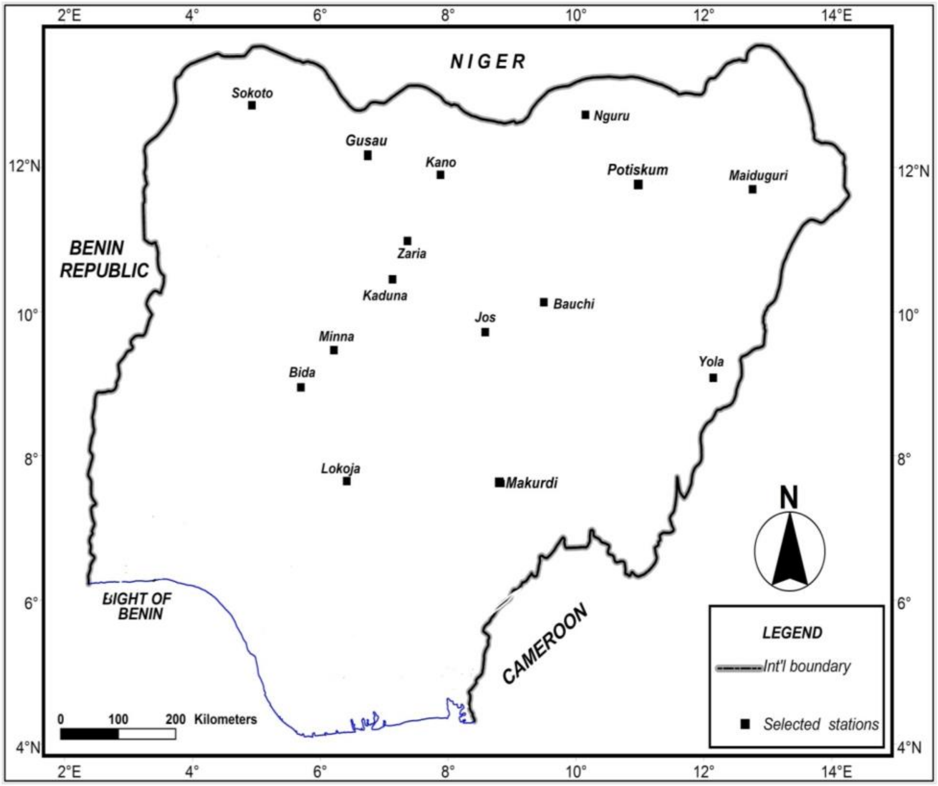

Fig. 1: The map showing the locations of the stations used in this study

Datasets

The University of East Anglia Climate Research Unit (CRU) monthly precipitation time series 3.1 gridded (0.5 x 0.5) data over Nigeria from 1958 to 2009 was obtained from the BADC website. Monthly precipitation data were also obtained from the archives of the Nigerian Meteorological Agency (NIMET) Oshodi, Lagos covering fifteen selected drought northern stations between 1960 and 2012 while the mean annual precipitation (MAP) 1961-1990 of the stations was used for the analyses.

Data analyses

Homogeneity test

The non- parametric Kruskal-Wallis (1952) (H) test which is equivalent to the parametric one way ANOVA test was used to test for homogeneity in the monthly precipitation data from 1960-2012. The monthly station precipitation data were divided into six groups 1960-1968, 1969-1977, 1978-1986, 1987-1995, 1996-2004, 2005-2012. Five of the groups are 9-year monthly data while the last group is an 8-year monthly data since the Kruskal-Wallis (1952) test statistics does not require equal sample size. In the formulation of the H statistic, all the data points from the 6 groups are jointly ranked, treating the samples as just one large sample. The sums of the ranks of the *k* samples are then used to compute the distribution. The Kruskal-Wallis (1952) test statistic is given by:

$$H = \frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{T_i^2}{n_i} - 3(n+1) \quad (1)$$

Where T_i = rank sum for the *i*th sample and n = total number of data points in all the groups.

The null and alternative hypotheses set for the test statistic are:

Null hypothesis (H_0): there is no significant difference between the *k* distributions,

Alternative hypothesis (H_a): at least one of the k distributions is different.

The Kruskal-Wallis (1952) test statistic H approximates to the Chi square distribution very closely, so calculated H is compared with the Chi tabulations for the (k-1) degrees of freedom, where k is the number of sample groups under consideration. The null hypothesis is rejected if the H value is greater than the critical Chi square value at the level of significance of interest (α = 5%).

Drought Severity Index (DSI_5)

The drought severity index (DSI) which uses accumulated monthly precipitation anomalies concept of Bryant *et al.* (1992) was used to develop the drought severity index in this study; the index values standardized and the drought categorized using the modified SPI classification (Table1).

Table 1. Modified Standardized Precipitation Index (MSPI)

MSPI Values	Categories
DSI = 0	Wetness (non drought)
0 < DSI ≤ 0.99	Mild drought
0.99 < DSI ≤ 1.49	Moderate drought
1.49 < DSI ≤ 1.99	Severe drought
DSI ≥ 2	Extreme drought

The precipitation anomaly with respect to the 1961-1990 mean is the only input to the drought severity index. The DSI_5 uses a five-monthly initiation and termination rule appropriate for the description of rainfall behaviour of the study area. Taking the precipitation anomaly in month t as X_t. If X_t is negative and the precipitation in the preceding 5-month period i.e. X_{t-1}, X_{t-2}, X_{t-3}, X_{t-4}, X_{t-5} is also lower than its mean, then a drought sequence is initiated in month t, assigning DSI_5 a positive value proportional to the precipitation deficit in month t. If the month t+1is then considered and the precipitation deficits in months t and t+1 are –X and –Y mm respectively, then DSI_5 for month t+1 equals X+Y if the mean monthly precipitation total for the preceding 5months has not been exceeded. If the precipitation anomaly is positive in month t+1 then the drought sequence can continue provided the five-monthly mean total has not been exceeded with DSI_5 = X-Y. Termination of a drought occurs when the monthly mean total has been exceeded and DSI_5 is assigned a value of zero. To make comparison between sites and regions, the DSI values are then standardized by dividing the absolute deficit by the station's mean-annual precipitation which is then multiplied by -100. The final index value expresses the accumulated deficit as a percentage of mean-annual precipitation.

Hovmoller diagram

The Hovmoller diagram is used to monitor the evolution of meteorological variable with time either over the latitude or longitude. In this investigation it is used to display the time evolution of August precipitation over Northern Nigeria from 1958 to 2009 using gridded CRU TS 3.1 monthly precipitation data.

Standardized anomaly of precipitation

Standardized anomaly of precipitation based on the mean of May-September precipitation of each year and 1961 to 1990 climatology and standard deviation. The standardized anomaly (A_s) is given by

$$A_s = \frac{P_{ms} - P_{c\lim}}{\sigma_{c\lim}} \tag{2}$$

whereP_{ms} = yearly mean of May to September precipitation,
P_{clim} = 1961-1990 mean of yearly mean of May to September precipitation and
σ_{clim} = standard deviation of the yearly mean of May to September precipitation from 1961-1990.

RESULTS AND DISCUSSION

Results of homogeneity test for station precipitation

At 5 degrees of freedom, since there are six groups α = 0.05 has the critical Chi square value of 11.070,at 0.01 level the critical Chi square value =15.086 and at 0.005 level the critical value =16.750.

The monthly station precipitation data is highly positively skewed with skewness ranging from 0.77 to 2.22 and the values of z score of skewness are far greater than 2 standard error (SE) (z score of skewness ranges from 7.95 to 22.94 while SE =0.097) and it is also measured at one month interval. These allow for the application of the non-parametric H test.This test is applicable in detection of significant difference between more than two groups of data especially when the data is not normally distributed. The Kruskal-Wallis (1952) test is only applicable when the dependent variable is measured at the ordinal or interval/ratio level. The calculated test statistic (H) ranges from 0.379 to 4.768, all the H values are less than the critical values at 5%, 1 % and 0.5 % level therefore the results are not significant and also the p for the test statistic H ranges from 0.445 to 0.978 ($p > 0.05$) which shows that there is no significant difference in the 5 (9-year) and 1 (8 year) monthly precipitation groups. The monthly precipitation data is therefore homogeneous over the years from 1960 to 2012. No post hoc test was carried out since there is no significant difference between the 6 groups.The homogeneity of the data shows that the data is stationary over the years and contains no systematic artificial changes (Leanda and Buishand, 2004). This makes the data fit for various climate variability analysis and simulations.

Results of DSI_5 analysis

Various degrees of drought, ranging from mild to extreme with a considerable proportion of wetness occurred in the study region as shown in Table 2.

Table 2: Number of years and percentage (%) occurrence of various degrees of drought in each of the stations

S/N	Stations	No. of years and % of occurrence				
		Extreme	**Severe**	**Moderate**	**Mild**	**Wetness**
1.	Maiduguri	11(20.75)	3(5.66)	4(7.55)	28(52.83)	7(13.21)
2.	Bauchi	1(1.92)	4(7.69)	10(19.23)	28(53.85)	9(17.81)
3.	Jos	8(15.38)	3(5.77)	13(25)	20(38.46)	8(15.38)
4.	Kano	4(8)	5(10)	6(12)	26(52)	9(18)
5.	Minna	6(11.32)	7(13.21)	4(7.55)	23(43.40)	13(24.53)
6.	Nguru	13(24.53)	6(11.32)	6(11.32)	25(47.17)	3(5.66)
7.	Sokoto	7(13.21)	4(7.55)	8(15.09)	28(52.83)	6(11.32)
8.	Gusau	10(19.61)	3(5.88)	10(19.61)	16(31.37)	12(23.53)
9.	Zaria	8(15.38)	0(0)	6(11.54)	26(50)	12(23.08)
10.	Potiskum	7(13.46)	2(3.85)	11(21.15)	23(44.23)	9(17.31)
11.	Makurdi	10(19.23)	3(5.77)	5(9.62)	20(38.46)	14(26.92)
12.	Yola	6(12.24)	5(10.20)	10(20.41)	20(40.86)	8(16.33)
13.	Lokoja	9(17.31)	4(7.69)	12(23.08)	13(25)	14(26.92)
14.	Kaduna	10(19.23)	5(9.62)	9(17.31)	19(36.54)	9(17.31)
15.	Bida	10(18.87)	1(1.89)	5(9.43)	25(47.17)	12(22.64)

Mild drought was the dominant drought intensity in almost all the stations which is similar to the finding of Aremu and Olatunde (2012) except for Lokoja which had 14 years of wetness against 13 years of mild drought. An average of 43.61% of mild drought occurred in the region (Fig. 2). Moderate, severe and extreme drought intensities occurred at an average of 15.33%, 7.07% and 15.36% respectively. The region witnessed an average of 23 years of mild drought and 10 years of wetness within the period of investigation. Extreme and moderate droughts occurred 8 years each while there were 4 years of severe drought. No severe drought occurred in Zaria within this period while extreme drought had more years of occurrence in Maiduguri and Nguru which was why a very low mean annual precipitation was observed in both locations. The predominance of mild drought intensity in the region may not be unconnected with the reasonable average percentage (18.63%) of non-drought or wet years which was higher than those of severe and extreme degrees of intensities. The 1973, 1977and most years within 1980-89 decade were captured by almost all the stations as years of extreme drought. This is possibly due to the tele-connections of Sahelian drought with El Nino Southern Oscillation (ENSO) – a phenomenon that is associated with periodic fluctuation in the intensity of the inter-tropical atmospheric and oceanic circulations that is usually coincident with an anomalous warming of the Eastern Tropical Pacific Ocean (Nicholson, 1989, 1993; Foland *et al.*, 1986; Akonga, 2001) whose severe effects swept across most part of the world including West Africa during these periods, causing food shortage and death of livestock. The average percentage (15.36%) of extreme drought should not be considered insignificant and negligible as these years of extreme drought and periods of extended dryness, when coupled with other climatic factors, such as extreme wind events or unsustainable agricultural and development patterns, can as well result in land degradation and, if not rapidly checked, can increase desert land areas or desertification in the study region. The aggregate impact of drought can be quite negative on the country's economy. For example, GDP fell by 4 to 6 per cent in Nigeria in 1984 (World Meteorological Organization, 2006) possibly consequent upon the devastating influence of ENSO within that period.

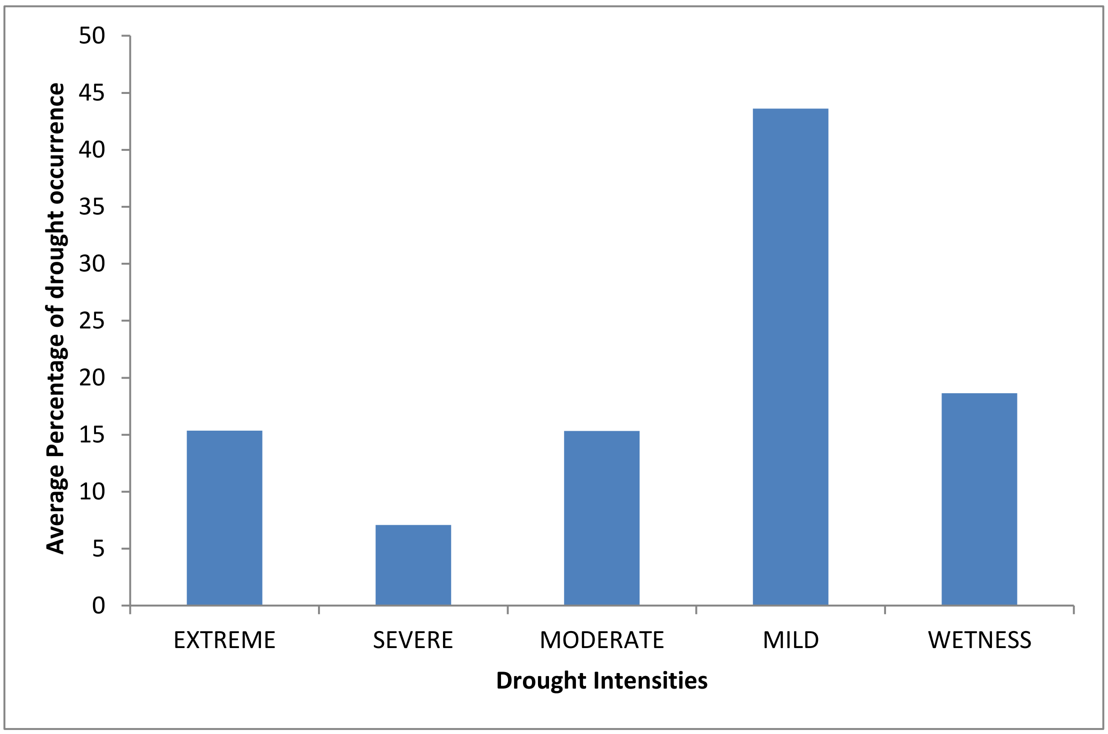

Figure 2: Average percentage occurrence of the various degrees of drought in the study region

Spatio-temporal variations of drought intensity

In northern Nigeria peak rainfall usually occurs in August, so gridded August rainfall from 1958 to 2009 was plotted over the entire northern Nigeria latitudes at 10.25 ^{0}E to visualize the latitudinal and annual propagation of drought (Fig. 3).Between 1958 and 2009, the wettest decade is the 60s. Towards the end of the 60s drought with reduced mean precipitation spread down to below 12 ^{0} N latitude and covered almost all the years with the exception of 1978. Maximum spatial and temporal spread occurs in the 1980s and the reduction in mean precipitation reached 9 ^{0}N (hot spot <100 mm). The hotspot shifted upward to ~12^{0}N in the 90s revealing reduced drought intensity. Drought reduced greatly in the 2000s with increase in mean precipitation. This corroborates the results of the DSI_5 which singles out the drought occurrences in the 80s as the major drought events in the past few decades from the 1960s to the 2000s. Severe and extreme drought has the highest spatial and temporal coverage in the 80s followed by the 70s which reduced from the 90s to the 2000s. Oguntunde *et al.* (2011) also reported based on the rainfall variability index and trend analyses that the 80s and 50s were the driest and wettest decade respectively from 1901 to 2000.

The averaged standard anomaly of May-September precipitation over the 15 northern stations (Fig. 4) also supports the results of the DSI_5 with occurrence of drought events increasing from the 60s to the80s and reducing from the 90s to the 2000s.

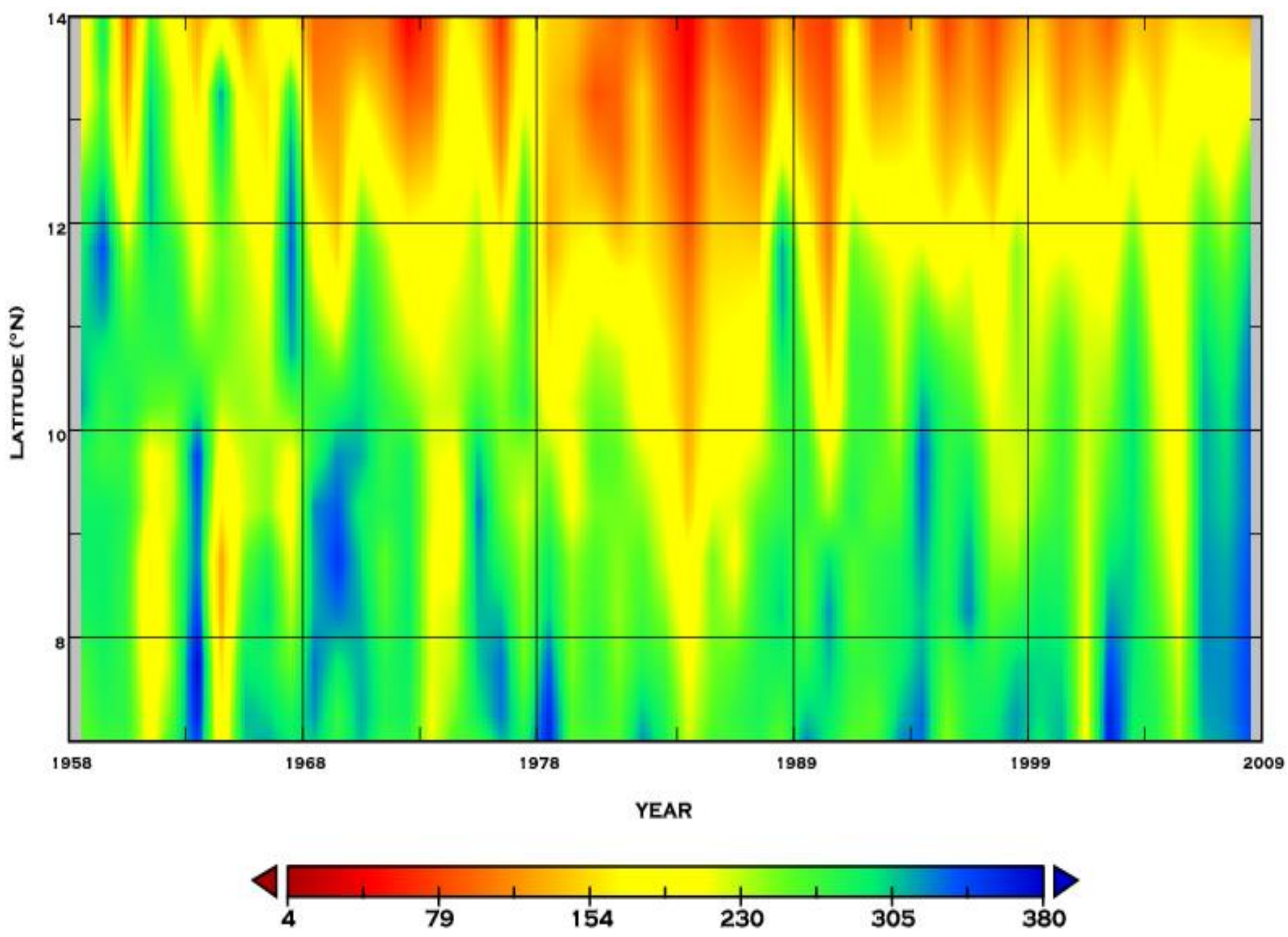

Figure 3: Hovmoller diagram of August precipitation at 10.25^{0}E over the Northern Latitudes of Nigeria

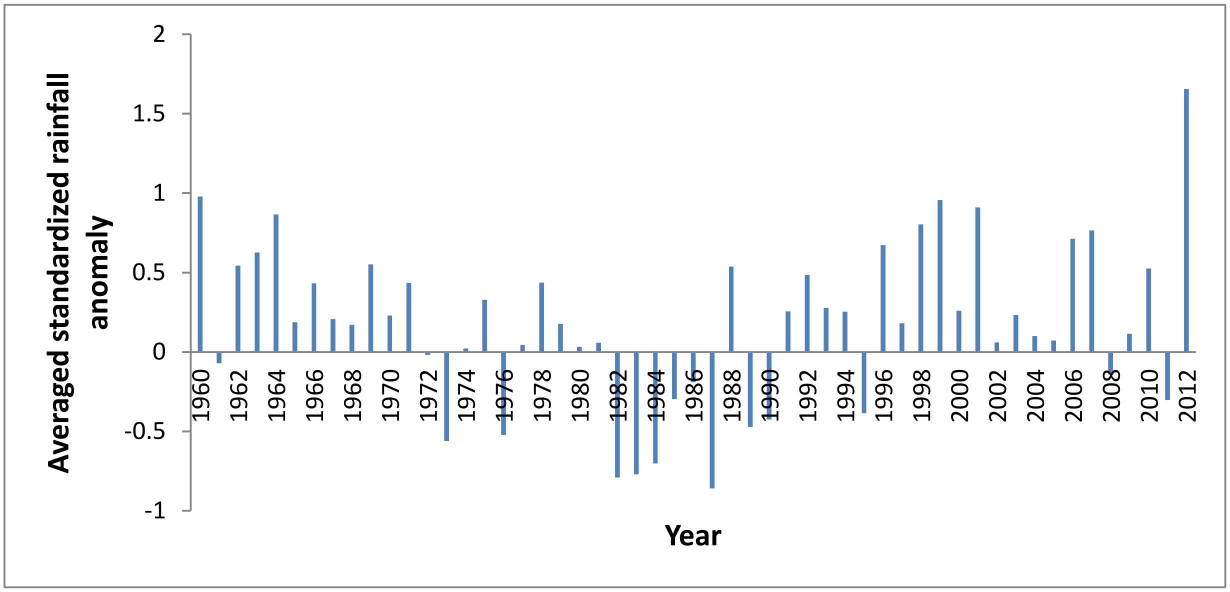

Figure 4: Averaged standardized anomaly of May-September precipitation over 15 northern stations

CONCLUSION AND RECOMMENDATIONS

Of all the investigated drought intensities, mild drought was more prevalent at 43.61% average occurrence. Severe and extreme droughts have the highest spatial and temporal coverage in the 80s followed by the 70s which reduced from the 90s to the 2000s. On the average, 23 years of mild drought and 10 years of wetness occurred in the study area while extreme and moderate droughts occurred for 8years each and severe for 4 years. The creeping and insidious nature of drought can be very dangerous and in the long run can wreak a great havoc on farm activities in the area due to the farmers' ignorance of its existence. Droughts development in some climatic regimes can be rapid with a minimum of two to three months to become established and can persist for months or years once it begins. Therefore proper proactive measures need to be put in place to forestall the effects of any sudden change possibly occasioned by the influence of constant Sahel and Sahara climatic anomalies in the region.

A drought monitoring and early warning system should be designed to identify climate and water supply trends and to detect the emergence of any change of drought intensity of the area for mitigation measures and preparedness plans to be put in place. Farmers in the region being the major agricultural food producing area of the country should be educated adequately on the implication of the dominant low intensity drought in the area through proper agricultural extension services. Farmers can as well be encouraged to plant more of drought-resistant crops and adopt more appropriate irrigation system of farming.

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