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ORIGINAL RESEARCH ARTICLE

Drought Characterization Using Standardized Precipitation Index for Sustainable Crop Farming in Yola, North-East Nigeria

Ibrahim Mohammed[1], Abdulqadir Abubakar Sadiq[1] & Aisha Musa Wali[2]
[1]Department of Library Science, Adamawa State Polytechnic, Yola
[2]Department of Agricultural Technology, Adamawa State Polytechnic, Yola
Research and Development Unit, Adamawa State Polytechnic, Yola

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***Corresponding Author:**
Phone: +2347068036372
E-mail: *sadiqhsadiq6@gmail.com*

ABSTRACT

In this paper, Standardized Precipitation Index (SPI) technique was employed to assess drought characteristics in Yola, Adamawa State. Monthly rainfall data for the period of fifty (50) years (1969-2018) was obtained from Upper Benue River Basin Development Authority, Yola. The data were analyzed to characterized drought using SPI method. The result shows that within the 50 years study period, Yola experienced 20 years (40 %) of drought events. The years 1973, 1987 and 2002 were classified as extremely dry and 1971, 1974 and 2006 as severely dry respectively. Analysis of drought duration in Yola shows that the area had few cases of sporadic events and more of one year with 4 incidences (50%) prolong back to back events of two years constitute 25 % of drought duration. Decade temporal analysis shows that the fourth decade 1999-2008 recorded the highest frequency with 7 incidences. Similarly, sever and extreme drought events were recorded in 3 years (6 %) each in the area. Generally, 1969-1978 and 1999-2008 decades were characterized as mildly drought events (SPI =-0.99 to 0). Out of the 40 % of drought events 18 % occurred with mildly drought, moderately drought (-1.0 to -1.49) constituted 10 % and 6 % were of the severely dry and extremely dry conditions (-1.5 to -3.0) respectively. Implications of findings were thoroughly discussed as it affects sustainable farming in the area. Due to seasonal drought episode identified in this study, farmers are therefore recommends to early maturing crop varieties and also adopt the use of soil water conservation techniques. Government should also provide drought resistant seedlings and the establishment of a drought monitoring and mitigation centre.

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Introduction

Agricultural production is directly influenced by weather variability particularly precipitation over a short and long period of time of a given local and regional geographical area. Of all human endeavors, agriculture is perhaps the first sector for which humans recognized the strong relationship between crops and weather. Several attempts have been made both at federal and state levels to stabilized agricultural output but yield still remain variable especially in the savannah region (Binbol and Edicha, 2012). This might be attributed to spatiotemporal variability of climatic parameters most importantly the precipitation as its plays a pivotal role in agricultural production. Hence, the sustainable use of water is a priority for water scarce regions and for agriculture in particular (Ana and Luis, 2006). A reduction in precipitation with respect to the normal precipitation amount is the primary driver of drought, resulting in a successive shortage of water. Drought is a natural disaster that has considerable impacts on agriculture and economy and thus affecting lives of the population in drought-stricken area (Saeid, *et al.,* 2017). Drought impacts in various ways. The effect of drought may be direct or indirect, singular or cumulative, immediate or delayed. Droughts lead directly to poor crop yield, famine, deterioration of pasture, dead of livestock etc. The direct losses caused by drought are more complex and many. Some of them lead to changes of land use practices, abandonment of fertile lands, migration of rural population, heavy pressure on urban areas and so on. These put severe strain on the economic development of a nation, either immediately or with a time lag (Appa, 1987; Binbol and Edicha, 2012). Therefore, the understanding of drought phenomena, their identification and prediction constitute a current challenge to mitigate the drought impacts in many areas around the world (Ana *and* Luis, 2006). Different drought indices have been developed to characterize the severity, incidences and extent of drought at a local and regional scale over a short or long period. Thus, using appropriate drought indices to monitor climate and hydrological variables related with drought is extremely helpful to identify the occurrence of droughts, their onset, evolution and dissipation, so to adopt first preventive measures and, later, appropriate mitigation measures.

In Yola area documentation on the extent and consequences of some drought events has been made using different indices (For example Sadiq, *et al.,* (2020a) using Rainfall Anomaly Index (RAI), Sadiq, (2020a) using Rainfall Seasonality Index (RSI), Sadiq, (2020b) also characterized drought using Rainfall Decile Index (RDI), Sadiq, *et al.,* (2020b) using Percent of Normal Precipitation (PNP), Binbol and Edicha (2012) assessed drought characteristics in Yola, using Standardized Precipitation Index (SPI) techniques,). However, Binbol and Edicha (2012) assessed drought by the use of SPI in Yola for the past eight (8) years for a period of 75 years from 1931 – 2005 respectively. Due to the prolong duration coupled with wider gap of seasonal weather variability (from 2005-2018) of the previous study, there is ardent need for research analysis to fill in the existing gap due to dynamic variability of drought scenarios occurred in the area. Thus, therefore, this present study saddled to fill in the gap with the aim of providing updated information on characterization, severity and variation of seasonal drought in the area for sustainable farming activities in the area.

Materials and Method

Study Area

Yola is located on latitude 9^{o} 14'N and longitude 12^{o} 38'E of the Greenwich meridian. It has an

average altitude of about 185 meters above sea level. Yola lies within the Benue trough consisting of undulating flood plains. It has an area of 8,068 sq/km and a population on 3,166, 101 inhabitants for the entire state (NPC, 2006) provisional census figure. Yola lies within the Sudan savannah vegetation classification characterized by tall grasses and sparsely distributed trees mostly of economic value such as shear butter, locus bean, baobab, gum Arabic, *balanite* etc. In terms of climate classification, Yola falls under the Koppen's Aw class. That is, tropical savannah climate with distinct dry season in the low sun period. The dry season is strongly developed for about five months, beginning from October ending to late March. Rainfall is about 958.99 mm per annum with highest down pour occurring between August/September (Binbol and Zemba, 2007). Yola has an average minimum temperature of 15.2 ^{o}C and an average maximum of 39.7 ^{o}C. The hottest months are March/April with maximum temperature of 42.7 ^{o}C while the coldest months are November/December with minimum temperature of 11.11 ^{o}C (Binbol and Henry, 2009). Agriculture and cattle rearing are among the major economic activities of the people in the study area. Crops grown include Cotton, Groundnuts, Rice, Millet, Maize, Beans and Guinea corn. Cows, Sheep and Goats are reared while the river Benue is exploited for fishing and dry season cultivation (Binbol and Edicha, 2012).

Data Source

The rainfall data used in the research work were obtained from the Agro-meteorological Station of the Upper Benue River Basin Development Authority, (UBRBDA) Yola for the period of fifty (50) years (1969-2018).

Data Analysis

The data were subjected to analysis of drought characterization using Standardized Precipitation Index (SPI) formula as follows;

$$SPI = (Xik - Xi) / oI \qquad (1)$$

Where oI = standardized deviation for the ith station; Xik = rainfall for the ith station and kth observation; Xi = mean rainfall for the ith station.

The Standardized Precipitation Index (SPI) was developed by McKee et al. (1993) with the purpose of identifying and monitoring local droughts. McKee *et al.,* in (1993) defined criteria for occurrence of drought in different time scales based on SPI scores as depicted on table 1 below.

Table 1: SPI Drought Class Intervals

SPI Value	Category
<-2	Extremely Dry
-1.99 to -1.5	Severely Dry
-1.49 to -1.0	Moderately dry
-0.99 to 0	Mildly Dry
0 to 0.99	Mildly Wet
1.0 to 1.49	Moderately Wet
1.5 to 1.99	Severely Wet
>2.0	Extremely Wet

Source: McKee *et al.,* (1993).

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As they argued, if negative score of SPI is consistently observed a drought is said to have occurred, and if it reaches the value of -1 or less the drought is considered severe; accordingly, the positive sign of SPI scores means end of drought event. This index is obtained by difference of precipitation from the mean for a given time scale and then dividing it by standard deviation. Conceptually, SPI indicates the standard deviation above or below the average record.

Result

Table 2: Characterization of Drought Severity for the First Decade 1969-1978

S/N	YEARS	SPI VALUES	Drought Characterization
1	1969	2.07	Extremely Wet
2	1970	-0.63	Mildly Dry
3	1971	-1.58	Severely Dry
4	1972	-0.28	Mildly Dry
5	1973	-2.47	Extremely Dry
6	1974	-1.71	Severely Dry
7	1975	0.52	Mildly Wet
8	1976	0.99	Mildly Wet
9	1977	0.35	Mildly Wet
10	1978	1.03	Moderately Wet

Table 3: Characterization of Drought Severity for the Second Decade 1979-1988

S/N	YEARS	SPI VALUES	DROUGTH CHARACTERIZATION
1	1979	-1.24	Moderately Dry
2	1980	1.63	Severely Wet
3	1981	0.36	Mildly Wet
4	1982	0.61	Mildly Wet
5	1983	-0.24	Mildly Dry
6	1984	0.77	Mildly Wet
7	1985	0.76	Mildly Wet
8	1986	-0.05	Mildly Drought
9	1987	-2.66	Extremely Dry
10	1988	2.09	Extremely Wet

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Table 4: Characterization of Drought Severity for the Third Decade 1989-1998

S/N	Years	SPI Values	Drought Characterization
1	1989	0.90	Mildly Wet
2	1990	-0.95	Mildly Dry
3	1991	-0.51	Mildly Dry
4	1992	0.75	Mildly Wet
5	1993	0.92	Mildly Wet
6	1994	0.22	Mildly Wet
7	1995	2.06	Extremely Wet
8	1996	1.23	Moderately Wet
9	1997	0.85	Mildly Wet
10	1998	1.38	Moderately Wet

Table 5: Characterization of Drought Severity for the Fourth Decade 1999-2008

S/N	Years	SPI Values	Drought Characterization
1	1999	2.44	Extremely Wet
2	2000	0.49	Mildly Wet
3	2001	0.12	Mildly Wet
4	2002	-2.92	Extremely Dry
5	2003	-1.41	Moderately Dry
6	2004	-1.23	Moderately Dry
7	2005	-1.24	Moderately Dry
8	2006	-1.65	Severely Dry
9	2007	-0.02	Mildly Dry
10	2008	-1.13	Moderately Dry

Table 6: Characterization of Drought Severity for the Fifth Decade 2009-2018

S/N	Years	SPI Values	Drought Characterization
1	2009	1.86	Severely Wet
2	2010	1.86	Severely Wet
3	2011	-0.96	Mildly Dry
4	2012	2.11	Extremely Wet
5	2013	-0.91	Mildly Dry
6	2014	1.29	Moderately Wet
7	2015	0.86	Mildly Wet
8	2016	4.17	Extremely Dry
9	2017	0.18	Mildly Wet
10	2018	0.66	Mildly Wet

Table 7: Occurrences of Characterized Seasonal Drought

Drought Characterization	Years of Occurrences	Percent (%)
Extremely Wet	1969, 1988, 1995, 1999, 2012 and 2016	12
Severely Wet	1980, 2009 and 2010	6
Moderately Wet	1978, 1996, 1998 and 2014	8
Mildly Wet	1975, 1976, 1977, 1981, 1982,1984, 1985, 1989,1992, 1992, 1994, 1997, 2000,2001, 2015,2017 and 2018	34
Mildly Dry	1970, 1972, 1983,1986, 1990, 1991, 2007, 2011 and 2013	18
Moderately Dry	1979, 2003, 2004, 2005 and 2008	10
Severely Dry	1971, 1974 and 2006	6
Extremely Dry	1973, 1987 and 2002	6

Table 8: Drought Duration and Frequency

Drought Duration	Frequency	Percent (%)
1 Year	4 Incidences	50
2 Years	2 Incidences	25
3 Years	0 Incidence	0
4 Years	0 Incidence	0
5 Years	1 Incidence	12.5
6 Years	0 Incidence	0
7 Years	1 Incidence	12.5

Table 9: Drought Severity and Magnitude

S/n	Area	Study period	Years of Drought Incidence	SPI Class	Percent (%)	Severity
1	Yola	50	20	0 to -99	18	Mildly
				-1.0 to -1.49	10	Moderate
				-1.5 to -1.99	6	Severe
				-2.0 to -3.0	6	Extreme

Table 10: Decadal Temporal Severity Variation of Drought

Variable	1969-1978	1979-1988	1989-1998	1999-2008	2009-2018
Drought Reoccurrence	5	4	2	7	2
SPI Decadal Mean value	-0.17	0.20	0.68	-0.65	1.11
Drought Characterization	Mildly drought	Mildly wet	Mildly wet	Mildly Drought	Moderately wet

Discussion

Characterization of Drought Severity and Variation

Results for the first decade (1969-1978) are presented on Table 2. The findings revealed that an extreme drought event was occurred in 1973 with a SPI values of -2.47 having mean annual rainfall of 115.00 mm. Similar finding of Sadiq (2020b) shows that the year 1973 was marked with seasonal drought condition. In addition, severe drought episodes were characterized in 1971 and 1974 measured as -1.58 and -1.71 on the SPI magnitude scale respectively. Likewise mildly drought was occurred in 1970 and 1972 measuring of SPI values between 0.99 to 0 scales. Conversely, in the year 1969 extreme wet condition was recorded with SPI value of 2.07 with an annual rainfall amount of 154.48 mm, moderately wet event was identified in 1978 (SPI value of = 1.03) and mildly wet episode was characterized in three years under the decade of study as depicted on table 2 accordingly. However, the year 1969 with an extreme wet condition is due to high amount of rainfall recorded coupled with high runoff that led to flooding event damaging hundred hectares of farmland in the area.

For the second decade (1979-1988), the results on table 3 expressed that 1987 was characterized as extreme drought with SPI value of -2.66 with 75.41 mm of mean annual rainfall coupled with only 57 of rainy days. Due to low rainfall recorded in the year cropping system have adversely affected and also led to early drying of reservoirs and dams meant to stored water for irrigation practices. Sadiq, (2020a) also identified 1987 with an extreme drought event posed serious effect on agricultural production in the area. Similarly, 1979 was recorded with -1.24 of SPI scale moderately dry. However, using RAI method the year was characterized as very dry condition as reported by Sadiq, *et al.,* (2020a). The mildly drought was identified in 1983 and 1986 as presented on table 3 respectively. In contrast, an extreme wet was measured as 2.09 of SPI scale in 1988 which might sufficiently support the growth and development of most cereals and legumes due to high amount of mean annual rainfall of 154.78 mm and prolong duration of 74 rainy days recorded in the area. Sadiq *et al.* (2020a) also described the year as very wet using RAI method. Likewise 1980 characterized as severely wet with a recorded value of SPI = 1.63 and mildly wet event had occurred in four years out of the decade period of study. Sadiq *et al.,* (2020a) also described the year as very wet using RAI method.

The third decade (1989-1998) was characterized using SPI scale presented on table 4. The result shows that mildly drought episode was recorded in a consecutive years of 1990 and 1991 measuring -0.95 and -0.51 of SPI values correspondingly. Sadiq *et al.,* (2020a) also identified the year as moderately dry in 1991 and very dry in 1990 respectively. Conversely, 1995 was identified as extremely wet with SPI value of = 2.06 due to high amount of mean annual rainfall of 135.10 mm coupled with prolong duration of 69 rainy days while moderately wet incidence were found in 1996 and 1998, and mildly wet was found to have occurred in five years under the decade of study.

From the year 1999-2008 were considered as fourth decade, the result on table 5 shows that extreme wet condition was characterized in 1999 with SPI value of 2.44 having recorded mean annual value of 159.04 mm and 73 number of rainy days. This finding correlated with the result of Sadiq, *et al.,* (2020a) characterized the year as extremely wet in the area. Meanwhile

mildly wet event was recorded in 2000 and 2001 consecutively. In contrast, the year 2002 was described with an extreme drought episode (SPI = -2.92) with a lowest mean annual rainfall ever recorded of 82.08 mm in the area which in consequence led to reduction in crop yield per unit area. . It was also revealed that due to low rainfall and frequent dry spells in the study area, farmers suffer reduced crop yield, shortage of water and biomass for animals (Adebayo *et al*. 2012; Mohammed, *et al.,* 2013). This outcome corroborated with the findings of Sadiq, (2020b) who revealed that the year 1987 and 2002 were quantified as Much below normal with the rainfall amount not exceeded by the lowest 10% defined as Exceptional Drought (D4) classified by Gibbs, (1967) and Samuel *et al.,* (2003) respectively. Moreover, severely dry condition was characterized in 2006 with SPI scale value of -1.65. Sadiq *et al.,* (2020a) also identified extremely dry condition in 2006 due to low rainfall amount moderately dry episode were occurred in four years measuring between -1.49 to -1.0 of SPI scale and mildly dry was occurred in 2008 (-1.13 SPI) respectively.

Results of drought characterization for the period of 2009-2018 described as fifth decade were presented on table 6. The result shows that 2011 and 2013 were recorded as mildly dry with SPI value of -0.96 and -0.91 respectively. Conversely, 2012 and 2016 were classified as extremely wet measuring 2.11 and 4.17 of SPI class rating with high annual mean of 135.00 mm and 180.00 mm. These years were report to have affected by flood scenarios due to increase in rainfall amount. According to Sadiq *et al.,* (2020b) 2016 and 2012 were estimated as extremely and very wet conditions that led to exacerbated flooding in the area which damaged hundred hectares of farmlands. In addition, 2009 and 2010 were characterized as severely wet, while moderately wet in 2014 (SPI = 1.29) and mildly wet was in three years under the study decade respectively.

Drought duration and frequency

The results on table 7 and 8 shows that out of the 50 years analyzed for the study area, only four (4) drought incidences were short sporadic annual occurrences which constitutes 50 % of the nature of drought in the area. 25 % of drought occurrences were of the two years duration which referred to as back to back which occurs in only two incidences. In a related findings of Binbol and Edicha (2012) reported that 28.6 % of drought occurrence in the area was of two years duration. One incidence of drought occurred in 5 years and 7 years as long stretch periods respectively. Similarly, 20 years out of the 50 years of the study were characterized with drought events where 18 % were identified as mildly dry and severe and extreme drought condition were assessed with 6 % as presented on table 9 respectively.

Decadal Temporal Severity Variation of Drought and Its Implication on Sustainable Farming

Decadal temporal severity variation of drought is presented on table 10. The result shows that prolong drought was identified in the fourth decade (1999-2008) with 7 years reoccurrences characterized as mildly drought measuring -0.65 with a decadal mean value of SPI scale. Farmers may experience reduction in annual yield in the decade (except in 1999) due to significant decrease in rainfall amount and duration in the area. Thus, Sadiq, *et al.,* (2020a) reported that dry conditions were estimated in 15 years which mostly occurred in the recent decades (2002, 2003, 2004, 2005, 2006, 2007, 2008, 2011 and 2013) which signifies apparent climatic change of rainfall deficit and consequently affects crop growth respectively. To achieve maximum crop

yield soil water content should be adequately improve through irrigation and other agronomic practices such as mulching and water harvesting. The decade 1969-1978 was recorded with 5 years mildly drought events (-0.17 SPI value). Agronomically, the decade (1969-1978) faced with insufficient moisture content that may not support the growth and development of crops in the area. Therefore, supplemented irrigation is required to improve adequate soil moisture in most of the years in the decade. Thus, the decade was characterized with markedly seasonal with a long drier season as described by Sadiq (2020a)

The 1979-1988 was experienced 4 drought incidences described with mildly wet (SPI = 0.20) conditions in the area. Practically, the decade may have soil moisture potentials that will effectively support farming activities with little or no supplemented irrigation except otherwise in 1979 and 1987 respectively. Thus, these decades may have wet and moist soil conditions which may favor effective farming activities. Conversely, the second, third and fifth decades fall under wet conditions within the SPI range of 0.2-1.11.

Conclusion

The study adopted the use of SPI techniques in assessing drought events and severity in the area. Drought events encompassed 40 % of the study period where the year 1973, 19787 and 2002 were characterized with an extreme drought event. It therefore concludes that the area is facing growing of drought events due to climatic change which may eventually affects farming activities, grazing lands and environmental sustainability. To cope with the existing trends of drought reoccurrences and variations that will sustain the farming system in the area government at all level should be made available the improved, early maturing and drought resistant seed varieties to the small scale farmers. Drought preparedness plan and mitigation strategies should be considered by the relevant agencies in the area for sustainable farming operation.

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