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Research Article

CHARACTERIZATION OF METEOROLOGICAL DROUGHT USING RAINFALL DEFICIT INDEX FOR EFFECTIVE CROP PRODUCTION IN YOLA SOUTH LGA, ADAMAWA STATE NIGERIA

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ABSTRACT

The study aimed at characterization of meteorological drought using rainfall deficit index (RDI) for effective Crop Production in Yola South LGA, Adamawa State Nigeria. Rainfall data for the period of 50 years (1969–2018) were analyzed using RDI. The results revealed that the month of March, April, May, June, and October were characterized as severe drought episodes with <26% of mean rainfall in 34–50 years of the study period. The month of July experienced severe drought in 21 years and 16 years (33%) in September. August was characterized with normal rainfall in 17 years (34%) and no drought episodes occurred in 16 years (32%), respectively. The annual drought characterization shows that 39 years (78%) were classified with no drought where only 10% (5 years) were quantified as severe drought which mostly occurred in the first (1969–1978) and fourth (1999–2008) decades under the study. To realize effective crop production, farmers are, therefore, recommended to adjust the planting dates and also to adopt the use of early maturing crop varieties with low water use efficiency in the area.

Keywords: Characterization, Crop, Deficit, Drought, Effective Yola, Meteorological, Rainfall.

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INTRODUCTION

Agricultural production is directly related to climatic parameters most importantly rainfall (intensity variability and effectiveness) over a period of time (temporal) in a given geographical area (spatial). Rainfall prediction in different temporal and spatial scales has become one of important inputs to not only planners and policy maker but also farmers as well for management to minimize (maximize) the loss (gain) accordingly (Jagvir *et al.,* 2015). Understanding spatiotemporal rainfall patterns have been directly implicated to combating extreme poverty and hunger through agricultural enhancement and natural resource management (IPCC, 2007; Kisaka *et al.,* 2015). Thus, low rainfall below the mean average is considered as drought. In general, the drought could be clustered into meteorological drought, agricultural drought, hydrological drought, and societal/economic drought (Wilhite and Glantz, 1987). It is broadly defined as severe water shortage (Shri *et al.,* 2014). Drought is considered by many to be the most complex but least understood of all natural hazards, affecting more people than any other hazard (Hagman, 1984). It thus emerges that, understanding climatic parameters, rainfall in particular, can aid in developing optimal strategies of improving the socioeconomic well-being of smallholder farmers. This is particularly important in sub-Saharan Africa (SSA) where agricultural productivity is principally rainfed yet highly variable (Jury, 2002; Kisaka *et al.,* 2015). The drought characteristics and associated problems vary from area to area, depending on the amount of variability of available water/rainfall over a period of time. Nigeria has been recognized as country in Sub Saharan Africa which is very vulnerable to climate change (IPCC, 2007; BNRCC, 2008). This is due to the fact that majority of the countries' population engage in agriculture as their primary occupation and agriculture in the country is mainly rain fed. Food production will be adversely affected by the variability in timing and amount of rainfall and heat stress and the consequence is an increase in food shortages and many farmers could lose their sources of livelihood due to climate change. Benhin (2006); Mano and Nhemachena (2006); Seo and Mendelsohn (2006) observed that climate attributes (temperature and precipitation) affect net farm revenue and such impacts can be significantly reduced through adaptation (Mohammed *et al.,* 2013). In Adamawa State, analysis of climate data (temperature and precipitation) over 25 years (1980–2005) reveals that temperature had increased by 0.3°C and rainfall fluctuated over the years (Adebayo, 2010; Sawa and Adebayo, 2010; Audu, 2013). This leads to warmer seasons; increased frequency and intensity of weather extreme events such as drought, decline in rainfall amount by about 15–20%, increased incidence of dry spell (Adebayo, 1998; Anuforom, 2010; Mohammed *et al.,* 2013). Similarly, it was revealed that majority of the farmers (60%) in Yola South LGA, revealed that the level of the drought impact on agricultural production was high affecting crop yield, drying of dams, reservoirs, and lakes and outbreak of crops' pest and diseases (Sadiq *et al.,* 2020a). Thus, Yola is characterized by marked rainfall variability both seasonally and annually, this makes the area highly susceptible to drought (Binbol and Edicha, 2012). The yield of crops particularly in rain-fed areas depends on the rainfall pattern, which makes it important to predict the probability of occurrence of rainfall (and drought) from the past records of hydrological data using statistical analysis (Arvind *et al.*, 2017). For this reasons, in Yola South LGA, of Adamawa State Nigeria, different methods and indices have been adopted by researchers toward characterization of drought and its implication on agriculture and environment. For example, Binbol and Edicha (2012) assess drought characteristics in Yola, using standardized precipitation index techniques, Sadiq (2020b) studied the rainfall anomaly variation, Sadiq *et al.* (2020a) studied the seasonal variability of rainfall using rainfall seasonality index (RSI), Sadiq (2020b) also characterized drought using rainfall decile index, Sadiq *et al.* (2020a) studied the percent of normal precipitation (PNP). However, despite the intensive and wide researches conducted on drought characterization little or no efforts have so far been made by scholars to assess drought characterization using rainfall deficit index (RDI) Method with the aim of relating it to effective crop production in the area. Therefore, this study saddled to characterize drought in the area using RDI method for a long historical data (50 years) focusing on effective crop production for optimum yield.

METHODS

Study area

Yola is located on latitude 9° 14' N and longitude 12° 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 of 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, and Balanite. 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 5 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°C and an average maximum of 39.7°C. The hottest months are March/April with maximum temperature of 42.7°C while the coldest months are November/December with minimum temperature of 11.11°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.

Data analysis

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). The data were subjected to analysis of meteorological drought characterization using RDI formula as follows;

$RDI=[(P_i-P_m)\div P_m]\times 100$

Where P_i=Actual precipitation (mm)

P_m=Mean precipitation (mm)

For calculating monthly rainfall deficit, if the rainfall value of a given month of a year is >75% of mean seasonal rainfall then it is called the no drought year. It is further classified as moderate drought if the rainfall deficit is between 26–50% and severe drought when it is <26% of mean seasonal rainfall value as shown in Table 1, respectively.

While for calculating annual rainfall deficit, if the value of annual rainfall of year is >0.0–(−25%) of mean seasonal rainfall then it is called the no drought year. It is further classified as moderate drought if the rainfall deficit is between (−26)–(−50%) and severe drought when it is >(−50%) of mean rainfall value respectively. To achieve appropriate drought characterization in the area, calibration was made due to the spatiotemporal scale and geographical variability of the region as depicted in Table 2.

RESULTS AND DISCUSSION

Results

Table 3 calculated monthly rainfall deficit index values for the period of 50 years (1969–2018).

Table 4 calculated annual rainfall deficit index for the period of 50 years (1969–2018) using calibrated threshold reference level.

DISCUSSION

Results on monthly characterization of drought using RDI are presented in Table 3. The result shows that the month of April was characterized as severe drought conditions in all the periods (98%) under study (50 years) with an estimated deficit rainfall of <26% mean rainfall except in the years 2012 where the month (April) characterized with no drought with >75% of mean rainfall (2%), respectively. This might be attributed to the onset date of rainfall in the area which usually begins around April before it will well be established in May-June. Thus, the month of May to November constitute the wet season, while the dry season commences in November and ends in April (Adebayo, 1999; Mohammed *et al.,* 2013). However, rainfall was experienced in the month of March in the year 1971, 1975, 1980, 1984, 1985, 1987, 1992, 1993, 1995, 1996, and 2014 identified with severe drought (100%) episodes, respectively.

The trend remains almost similar in the month of May where only 3 years (1979, 1991, and 1992) were identified with no drought episodes while moderate drought occurred in 1980, 1985, and 1996 accordingly. In 2015, normal rainfall (75–50% of mean rainfall) while in the remaining years the month (May) is characterized as severe drought (85.6%). The implication of such deficit rainfall on crop production is negative in the area. The result explained that sowing in the months of April and May is not recommendable due to low rainfall below the required mean level for effective crop performance. Thus, most farmers (55%) in the area agreed that to have high impact on their productivity while the remaining 45% of them considered the impact as low to have affected their production in the study area.

For the months of June under the years of study (50 years), the results expressed that 1973, 2001, and 2012 were categorized as no drought having rainfall amount of >75% of mean rainfall, while 5 years (1976, 2000, 2015, 2016, and 2017) were characterized with normal rainfall conditions and moderate drought was assessed in 10 years while the remaining 32 years the month (June) was found with rainfall <26% of mean rainfall classified as severe drought, respectively. This finding revealed that the rainfall in the month of June still remained not effective and not well established in most seasons which may eventually affect crop germination and growth in the area. Therefore, sowing practices can be achieved at the Middle and late June most especially maize, rice, and groundnut with the aim of reducing the effects of water deficit during germination process. This result is in conformity of the findings of (WMO, 2012; Umar, 2001; Umar and Musa, 2005) revealed that the month of May and June in the Northern part of the state is characterized by drought conditions. It is important to note that the impacts of droughts can be as varied as the causes of droughts. Droughts can adversely affect agriculture and food security (WMO;5). A drought impact is an observable loss or change at a specific time (WMO, 2016). Thus, supplemented irrigation is recommendable to meet up the moisture requirement and also the use of early maturing crop varieties with low water use potentials should be adopted for optimum production in the area. The amount of soil-water available to crops depends on rainfall onset, length, and cessation which influence the success/failure of a cropping season (Ngetich *et al.,* 2014; Kisaka *et al.,* 2015).

The month of July shows a little departure of rainfall amount, where 21 years (42%) were identified to have severe drought episodes in the month (July) under the periods (50 years) of study, while 12 years were classified with normal rainfall (26–50% of mean rainfall) and moderate drought was characterized in 10 years, respectively. The years with no drought conditions in the month of July were found in the 1982, 1984, 1986, 1990, 1993, 1998, and 2007 in the area. The

Table 1: Classification of rainfall deficit index

Drought	Classification
>75%	No drought
<75–50%	Normal drought
50–26%	Moderate drought
<26%	Severe drought

Table 2: Classification of rainfall deficit index

Drought values (%)	Calibrated threshold values (%)	Intensity
0.0–(−25.0)	0.0–(−10)	No drought
−26–(−50)	(−11)–(−15)	Moderate
>(−50)	>(−15)	Severe drought

Table 3:

Years	March	April	May	June	July	August	September	October	November
1969	-	−58.18	−56.11	27.97	12.11	118.66	15.22	−59.67	-
1970	-	−97.04	−4.39	−40.48	−22.56	150.63	108.38	−94.73	-
1971	−99.48	−78.50	−46.84	41.29	67.87	135.98	48.87	−69.47	-
1972	-	−56.20	−0.04	−11.61	50.70	101.41	−13.83	−65.02	-
1973	-	−42.95	17.31	98.75	42.51	54.80	TR	−70.06	-
1974	-	−61.18	−37.77	−24.12	14.04	32.29	144.39	−67.64	-
1975	−79.86	−40.73	−34.86	−27.19	51.09	142.43	41.82	−52.89	-
1976	-	−70.72	−26.66	50.89	−29.35	61.08	−3.26	18.01	-
1977	-	-	−13.59	−74.93	4.73	27.10	81.46	−24.62	-
1978	-	6.83	−54.91	−20.64	107.18	24.59	−11.90	−51.02	-
1979	-	−88.78	113.39	−27.63	64.24	52.73	28.01	−45.05	−96.89
1980	−99.61	−56.17	38.99	14.24	65.73	59.14	−16.17	−6.13	-
1981	-	−41.74	−29.70	7.01	22.12	56.37	−7.79	−6.22	-
1982	-	−67.52	−46.73	−2.98	117.9	76.21	96.33	−73.17	-
1983	-	−76.72	0.15	23.43	63.97	73.15	0.39	−84.40	-
1984	−78.65	−28.06	13.79	−37.21	99.90	50.79	38.67	−55.09	-
1985	−55.48	−67.02	31.06	8.82	65.36	65.44	43.10	−91.09	-
1986	-	−85.15	20.79	−16.59	142.67	−8.66	−38.82	−23.35	-
1987	−93.36	−99.60	−54.11	39.90	35.92	164.81	68.81	−41.51	-
1988	-	−86.43	−11.16	8.54	30.50	20.94	101.89	−64.27	-
1989	-	−65.36	24.22	−37.06	−5.56	212.02	−41.91	−86.31	-
1990	-	−58.62	−12.49	−8.03	118.80	93.84	20.03	−68.43	-
1991	-	−55.89	76.26	−18.60	33.45	74.64	−29.41	−79.77	-
1992	−74.30	−54.22	77.93	−18.47	−2.41	60.33	111.51	−94.70	−98.05
1993	−87.87	−57.59	16.41	−9.45	78.00	42.77	51.48	−40.4	-
1994	-	−40.25	−26.70	46.58	−22.16	102.24	−19.73	−39.95	-
1995	−97.26	−72.16	−24.64	33.75	47.37	77.27	−0.96	42.56	-
1996	−98.65	−67.20	45.30	−14.35	26.76	58.37	108.44	−58.64	-
1997	-	−56.38	−50.94	−84.81	40.72	−4.54	34.04	−26.08	-
1998	-	−64.82	−58.25	−33.00	81.30	−6.30	143.10	−61.87	-
1999	-	−94.65	−11.46	−13.66	13.10	53.79	66.24	21.03	-
2000	-	−97.63	9.94	62.07	21.61	48.95	35.36	−80.44	-
2001	-	−66.44	−28.37	88.73	59.60	−21.95	47.50	−77.98	-
2002	-	−87.63	−46.27	45.38	14.03	1.52	203.71	−34.81	−99.63
2003	-	−90.72	−49.59	−7.76	27.83	77.34	63.78	−20.87	-
2004	-	−89.14	2.20	3.34	0.28	96.73	31.78	−45.13	-
2005	-	−73.71	−26.32	−9.41	63.20	106.04	14.23	−73.98	-
2006	-	−73.82	−41.53	10.09	24.31	58.14	108.47	−85.63	-
2007	-	−51.72	−60.40	−24.37	94.18	108.60	−4.92	−61.33	-
2008	-	−83.21	−0.21	−0.38	32.32	67.89	51.27	−67.89	-
2009	-	−90.0	−15.14	31.78	27.31	62.26	56.73	−73.01	-
2010	-	−78.8	−49.38	38.93	40.31	31.17	30.97	−13.97	-
2011	-	−71.85	−22.78	−0.59	−0.17	37.67	97.77	−16.15	–
2012	-	75.82	18.46	77.14	15.29	26.35	57.83	−30.26	-
2013	-	−78.34	−98.35	39.66	15.11	42.47	39.47	97.56	−57.47
2014	−92.49	−29.31	8.4	70.67	−4.49	24.34	48.92	−26.24	-
2015	-	−94.65	60.93	52.32	66.81	107.32	80.84	−52.11	−99.53
2016	-	−87.61	25.54	78.10	−25.7	49.93	15.88	−56.05	-
2017	-	−33.77	24.53	53.90	24.65	44.61	85.82	−99.67	-
2018	-	−81.50	−11.03	10.52	23.69	66.72	47.87	−56.31	-

Table 4:

S. No.	Years	Values	Years	Values	Years	Values	Years	Values	Years	Values
1	1969	19.46	1979	−11.69	1989	8.50	1999	22.99	2009	17.47
2	1970	−5.92	1980	15.34	1990	−8.99	2000	4.68	2010	17.50
3	1971	−14.86	1981	3.41	1991	−4.79	2001	1.17	2011	−9.05
4	1972	−2.70	1982	5.75	1992	7.08	2002	−27.45	2012	19.88
5	1973	−23.26	1983	−2.32	1993	8.64	2003	−13.31	2013	−8.56
6	1974	−16.11	1984	7.25	1994	2.13	2004	−11.62	2014	12.16
7	1975	4.88	1985	7.21	1995	19.40	2005	−11.72	2015	8.15
8	1976	9.36	1986	−0.50	1996	11.55	2006	−15.56	2016	39.20
9	1977	3.43	1987	−25.02	1997	7.99	2007	−019	2017	1.70
10	1978	9.74	1988	19.69	1998	12.99	2008	−10.63	2018	6.22

result further ascertains the existing of rainfall deficit in some years in the area. However, rainfalls in the month of July favor the growth and development of some crop with little supplemented irrigation for sufficient moisture content in the soil.

Furthermore, the result of monthly drought characterization in the area revealed that the month of August was characterized with severe drought conditions in the year 1986, 1987, 1988, 1997, 1998, 2001, 2002, and 2014 out of the 50 years under study in the area, while

9 years were described with moderate drought and 16 years (34%) experienced no drought in the month (August) with >75% of mean rainfall, respectively. Month of August was considered as the month with the highest amount of rainfall received than any other months in 50 years of study. Vegetative crop growth and development mostly occurred in the month of August due to high soil moisture content which adequately supports plant growth as influenced by high amount of rainfall respectively. Conversely, Sadiq *et al.* (2020a) revealed that the months of July-August were assessed to have more reoccurrences of drought scenario in the area by about 55% of the farmers while 45% perceived to have occurs mostly in the months of May-June, respectively.

Severe drought condition was found to hard occur in the month of September in 16 (33%) years while moderate drought in 13 years and no drought episodes had occurred in 12 years and normal rainfall condition was identified in 8 years as depicted in Table 2, respectively. In September, most cereals are at the flowering stage, a stage that required adequate soil water content and most essential for optimum production. However, most of the drought scenarios in the area occurred seasonally in the month of September when most crops such as rice and maize are in ardent need of water for flowering and other physio-biochemical processes, which in consequence caused great economic lost of farm produce. Thus, most farmers perceived negative impact of agricultural production in the area (Sadiq *et al.,* 2020a). It is important to note that the impacts of droughts can vary with time trends, places, and severity. A drought impact is an observable loss or change at a specific time (WMO, 2016).

However, in the year 2019 and 2020 drought occurred in the month of August in the study, respectively. Sadiq *et al.* (2020a) and Adebayo *et al.* (2012a) reported that annual rainfall is decreasing, onset date of rain is increasing (delayed onset), cessation date of rains is decreasing (early cessation), while length of rainy season is reducing in the area. Therefore, to realize optimum yield supplemented irrigation should be made timely before the apparent wilting of crops beyond the recovery stage. The month of October was also characterized as severe drought in all the years except in 1995 identified as normal rainfall and 2013 as no drought as depicted on Table 3, respectively. However, this might be attributed to the fact that the October is month of which cessation of rainfall occurs. It usually occurred in form of drought before it manifested to the cessation leading to the establishment of dry season. This episode posed a serious vulnerability on crop production in the area. Thus, it is a known fact that the complexity of drought lies in the fact that it cannot easily be predicted because it develops slowly, and it is usually noticed when it has already been present for weeks or months (Sadiq *et al.* 2020a).

Annual characterization of drought

The results on annual drought characterization are presented in Table 4. The results described that no drought condition occurred in 39 years (78%) out of the 50 years under study, while 12% of the years were characterized as moderate drought and severe drought episodes happened in only 5 years (10%), respectively. These findings revealed that the area is still resistant to drought infestation despite the climatic changes experienced in the region. However, agricultural activities are seriously affected with insufficient of rainfall most especially the cessation of rainfall during flowering stage of crop in recent years. A continuous basis of drought leads to reduce availability of fodder, decline in agricultural production and livestock wealth, besides causing misery to people inhabiting these areas (Shri *et al.,* 2014).

For the decades' analysis, the result shows that in the first decade of the study (1969–1978) 7 years (70%) were characterized with no drought episodes while only 1 year (1971) as moderate and 2 years severe drought, respectively. From 1979 to 1988 (second decade), 80% of the years were also described with no drought conditions while moderate occurred in 1979 and severe drought episode occurred in 1987. The year 1987 was rated as the second utmost severe drought condition after 2002 in more than five decades (1969–2018) with low amount of annual rainfall of 678.7 mm. Similar finding of Sadiq (2020b) 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 and Maher (1967) and Samuel *et al.* (2003), respectively.

During the third decade, (1989–1999) all the year experienced no drought episodes while between 1999 and 2009 no drought and moderate drought each occurred in 4 years (40% each) and severely in 2 years (2002 and 2006), respectively. The decade was considered with the highest reoccurrence of drought than any other decades under the study. Similarly, Sadiq *et al.* (2020a) also reported drought condition using percent normal in the area where they found out 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. 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*. 2012b; Mohammed *et al.,* 2013).

The last decade from 2008 to 2018 no drought condition had occurred in the area. The third and fifth decades (1989–1998 and 2009–2018) were the decades with no drought episodes due to an increase in the rainfall amount experienced. However, according to Sadiq (2020b) 2016 and 2012 were estimated as extremely and very wet conditions using rainfall anomaly index method (RAI) which led to exacerbated flooding in the area which damaged hundred hectares of farmlands.

CONCLUSION

Successful crop production is directly linked with the availability of water resources for either irrigated or rain-fed farming. In Yola south LGA, of Adamawa Sate most of the farmers participated in rainfed farming which is associated with climatic challenge due to the incidences of drought that led to low or poor crop performances. However, several studies have been made to quantified and characterized the drought condition in the area using different indices. Present study characterized drought by the use of RDI in relation to effective crop production in the area. The findings revealed that the months April, May, June, and October were identified with insufficient of rainfall amount characterized as severe drought (32–50%). The month of August was characterized with no drought for 16 years (32%) and normal rainfall for 17 years (34%) out of the 50 years under study. Effective crop growth and development can be achieved maximally from the month of July, August, and September, respectively. The annual droughts characterization shows that about 39 years (78%) were characterized with no drought, 12% as moderate drought and 5 years (10%) as severe drought. There is need for the farmers to adjust planting dates in the area (middle June) to combat the insufficient of soil moisture for effective germination and to avoid crop failure due to late onset and early cessation of rains. In addition, the use of early maturing crops with low water use efficiency should be adopted to realize sustainable food production in the area.

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