JOURNAL OF METEOROLOGY AND CLIMATE SCIENCE
J. Met & Clim. Sci. 19(1): 43-59 (June, 2021)

N.Met.S
Ngerian Meteorological Society

Characterization of Drought in Kaduna River Basin, Kaduna, Nigeria

Olufemi Sunday Durowoju[1,2*], Temi E. Ologunorisa[1] and Ademola Akinbobola[1]

[1]Department of Meteorology and Climate Science, Federal University of Technology, P.M.B 704. Akure, Nigeria
[2]Department of Geography, Osun State University, Osogbo, P. M.B. 4494, Nigeria
[*]**Corresponding Author E-mail Address:** olufemi.durowoju@uniosun.edu.ng

Abstract: *This study examined the characteristics of meteorological, agricultural and hydrological droughts, and their implications on agricultural planning and water resources management in Kaduna River Basin. To establish the extent of climate variability and drought, archival temperature, rainfall and streamflow data between 1990 and 2018 were sourced from Nigerian Meteorological Agency (NIMET), Nigeria Hydrological Services Agency (NIHSA), Kaduna State Water Board and Shiroro Hydro-Electric Power Station for ten hydrometeorological stations. Three drought indices (RDI, ASPI and SDI) were employed for the study and GIS technique was used to examine the spatial dimension of the droughts. Pearson Correlation Coefficient Analysis was used to examine the relationship among the three indices. The results of the study reveals the base year of 1998/1999 as common year of drought onset for the three drought types. The result also shows that moderate and mild droughts have the highest occurrence accounting for about 80% across the three indices. The result of the base year of 2006/2007 shows severity of meteorological, agricultural and hydrological droughts having -1.63, -1.76 and -1.5 drought intensities respectively. In conclusion, this study showed there exists strong relationship among the drought types examined and also recommends adoption of improved crop varieties such as drought-resistant crops, early maturing crops enables farmers cope with rainfall variability, particularly drought occurrences.*

Keywords: Agricultural, Drought, Hydrological, Kaduna, Meteorological

INTRODUCTION

Insufficient rainfall amounts in the northern Nigeria have been of great concern for most water resource managers, agricultural planners, government officials and other related stakeholders. Droughts are recurring climatic events, which often lead to significant water shortages, economic losses and adverse social consequences (Stahle *et al*., 2000). Dai (2011) classified drought into four main categories of meteorological or climatological drought, which is described as atmospheric conditions resulting to reduction or absence of rainfall; hydrological drought, which occurs due to depletion of streamflow and groundwater level; agricultural drought, regarded as the condition where plants and crop yields are significantly reduced due to frequent low rainfall events or excessive evapotranspiration conditions and socioeconomic drought that is principally the adverse impact of the above three drought types (Hettinger, 2013).

Wilhite and Glantz (1985) argued that drought is one of the costliest natural hazards with widespread impacts on water supply, agriculture, energy production, ecosystem, and society. It was reported that drought related disasters cause economic loss of \$6–\$8 billion annually (Pei *et al.,* 2019). Drought is a recurrent event in many parts of Africa, after the drought episodes of the early 1970s that ravaged the Sahel region. It was revealed that there was about 40% decline in annual rainfall total in West Africa, from the year 1968–1990 as against the condition between 1931 and 1960 (Dai et al., 2004). Countries of Southern Africa such as Malawi, Mozambique, Zambia and Zimbabwe are currently facing starvation among other challenges imposed by drought (GDACS, 2020).

In recent years, several scholars have examined some basic drought characteristics such as duration, onset, cessation, severity and intensity (Chen and Sun, 2015; Zhai et al., 2017; Ahmed et al., 2018; Tigkas et al., 2019). However, some vital drought characteristics are left unexamined such as magnitude, frequency, area extent and return period of drought events.

Studies at global scale had analyzed and established various links between two different types of drought such as the link between meteorological and hydrological droughts (Vicente-Serrano and López-Moreno, 2005; Dai, 2011; Haslinger et al., 2014; Li et al., 2020) as well as meteorological and agricultural droughts (Dami et al., 2010; Huang et al., 2015), and agricultural and hydrological droughts (Van Loon, 2015).

In Nigeria, extant studies on drought have focused more on meteorological drought and many of these studies indicated that some indices were found to be more effective than the other (Abaje et al., 2013; Aremu and Olatunde, 2013; Omonijo and Okogbue, 2014; Oloruntade et al., 2017; Shiru, et al., 2018). Most of the studies employed Rainfall Anomaly Index (RAI), Bhalme and Mooley Drought Index (BMDI) and the Palmer Drought Index (PDI) in their analyses and it was revealed that precipitation is the most important climatic element to monitor meteorological. Similarly, studies have engaged Standardized Rainfall Index (SRI) and Standardized Precipitation Index (SPI) and established that most of the extreme drought with highest magnitudes recorded in 1970s and 1990s in Sudano-Sahelian region were to a large extent linked to variability in the amount and distribution of rainfall and number of rain days observed in the region (Abaje *et al,* 2013; Adeogun *et al.,* 2014). Achugbu and Anugwo (2016) equally examined drought trend in the northern part of the country using SPI and Mann-Kendall test, it was reported that some cities-Ilorin, Minna, Makurdi, Jos and Kaduna reveal significant upward trends especially in August, September and October. Ogunjo et al. (2019a) reported a significant positive trend in SPI over Nigeria due to climate change while a study showed that drought in certain locations within Nigeria is multi-fractal (Ogunjo, 2021).

Despite all these studies and some others, only few have linked agricultural drought episodes to famines (Abaje et al., 2013; Shiru et al., 2018; Eze, 2018; Eze, 2020) while there is dearth of studies on hydrological drought characteristics in Nigerian river basins. It is against this backdrop that this study is aimed at characterizing meteorological, agricultural and hydrological drought with their implications on water resources and agricultural planning in a Kaduna River Basin (KRB).

MATERIALS AND METHODS

Description of the Study Area

The study area is the Kaduna River Basin (KRB) located between latitudes, 8º45ˈ15ˈˈN and 11º40ˈ5ˈˈN and longitudes 5º25ˈ48ˈˈE and 8º45ˈ36ˈˈE in the savanna ecological zone of Nigeria. KRB has two segments of upstream and downstream and a total catchment area of approximately 65,878km² with its headwater near the north-eastern edge of the Jos Plateau at Sherri Hills. The prevailing climate over the basin is described as tropical continental climate (Aw) characterized by a well-defined wet and dry season with seasonality in rainfall and temperature distributions (Koppen, 1928). The mean annual rainfall can be as high as 2000 mm in wet years and as low as 500 mm in drought years but with a long term average of 1000 mm and average annual temperature of 27.48˚C (NiMET, 2019).

Data Collection and Analysis

To establish the extent of climate variability and drought in the study area over the last twenty-eight years (1990-2018) archival temperature, rainfall and streamflow data were sourced from Nigerian Meteorological Agency (NIMET), Nigeria Hydrological Services Agency (NIHSA), Kaduna State Water Board and Shiroro Hydro-Electric Power Station for ten hydrometeorological. The monthly rainfall, temperature and streamflow data obtained were converted to annual data and rearranged in hydrological years (i.e. October-September). Drought Indices Calculator (DrinC by Tigkas *et al,* (2015) was used to calculate Potential Evapotranspiration (PET), Reconnaissance Drought Index (RDI), Agricultural Standardised Precipitation Index (ASPI) and Streamflow Drought Index (SDI). RDI, ASPI and SDI were engaged to analyse meteorological, agricultural and hydrological droughts respectively.

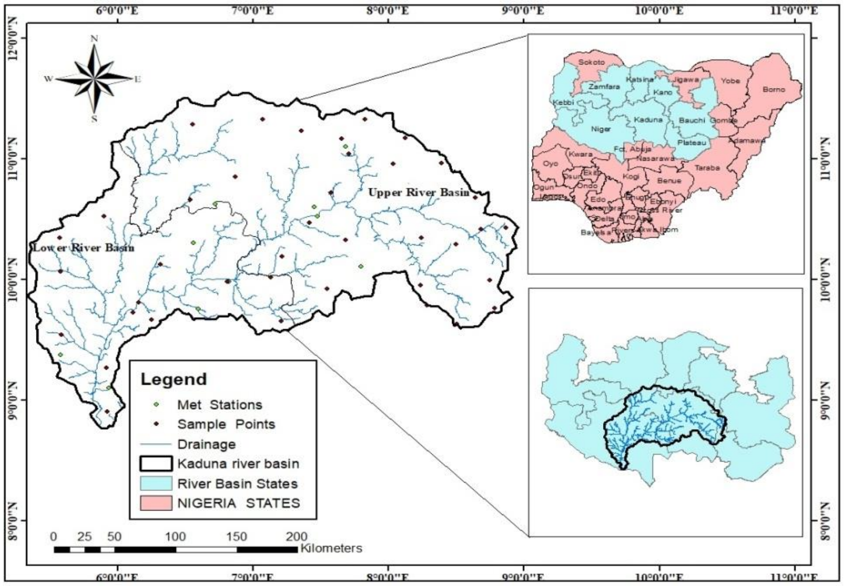

Figure 1: The Kaduna River Basin Source: Authors' Fieldwork, 2020

Pearson Correlation Coefficient Analysis was used to examine the relationship among the three indices while GIS technique was employed to analyse the spatial extent of drought. RDI was employed to analyse meteorological drought characteristics. The index is based on the ratio between precipitation and potential evapotranspiration. RDI has been successfully applied in several studies (Tsakiris and Vangelis, 2005; Tsakiris *et al*., 2007; Asadi Zarch *et al*., 2011). The initial value (a_k) of RDI is usually calculated for the *i*-th year in a time basis of k consecutive months as follows:

$$a_k = \frac{\sum_{j=1}^{j=k} P_j}{\sum_{j=1}^{j=k} PET_j} \quad (1)$$

where P_j and PET_j are the precipitation and potential evapotranspiration of the *j*-th month of the hydrological year. *k* is calculated as a general indicator of meteorological drought where *j* are the periods of 3, 6, 9 and 12 months.

For the study, lognormal distribution was applied to give standardized RDI (RDIst) as expressed in equation (2):

$$RDI_{st}(k) = \frac{y_k - \bar{y}_k}{\hat{\sigma}_k} \quad (2)$$

where y_k is the $\ln a_k$, $\bar{y}_k$ is arithmetic mean and $\hat{\sigma}_k$ is standard deviation.

Drought severity can be categorised in *mild*, *moderate, severe* and *extreme* classes, with corresponding boundary values of RDIst (-0.5 to -0.99), (-1.0 to -1.49), (-1.50 to -2.0) and (< -2.0), respectively.

ASPI is the most recent index developed by Tigkas et al., (2019) in assessing agricultural drought characteristics. The main aspect of ASPI is the substitution of the precipitation (*P*) with the effective precipitation (P_e), which indirectly incorporates the concept of water balance that is missing from the original index. The study adopts 12 months analysis for ASPI.

$$ASPI = t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}, 0.5 < H(x) \leq 1.0 \quad (3)$$

The classification of drought magnitude is based on the probability of occurrence of each drought event, as represented by the corresponding ASPI value, using the thresholds provided in Table 2.

Table 2: Drought Classification based on ASPI values

SPI Value	Category
≥ 2.00	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0 to 0.99	Near normal (mildly wet)
0 to -0.99	Near normal (mildly drought)
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
≤ -2.00	Extreme drought

Source: Tigkas et al., 2019

SDI was developed in 2009 by Nalbantis and Tsakiris to monitor and identify drought events such as drought severity, drought onset and cessation, its duration and frequency of drought occurrence. It is assumed that a time series of monthly streamflow volumes $Q_{i,j}$ is available where i denotes the hydrological year and j the month within that hydrological year (j= 1 for October and j = 12 for September). Based on this series, we obtained.

$$SDI_{i,k} = \frac{V_{i,k} - \bar{V}_k}{s_k} \quad i = 1,2, \dots, \quad k = 1,2,3,4 \qquad (4)$$

Where $\bar{V}_k$ and S_k are respectively the mean and the standard deviation of cumulative streamflow volumes of reference period k. In this definition, the truncation level is $\bar{V}_k$. Five states are recognised (Table 3).

Table 3: States of Hydrological Drought with the aid of SDI

State	Description	Criterion
0	Non-drought	SDI > 0.0
1	Mild drought	-1.0 < SDI < 0.0
2	Moderate drought	-1.5 < SDI < -1.0
3	Severe drought	-2.0 < SDI < -1.5
4	Extreme drought	SDI < -2.0

Source: Nalbantis and Tsakiris, 2009

Magnitude-frequency of drought also interest hydrologists and agricultural planners. They are interested in the frequency of drought severity and average time period within which most severe drought in a series or intensity can be expected to occur. The method of recurrence interval used in this study has been employed in many studies (Ologunorisa, 2006; Durowoju *et al*, 2017) to predict recurrence of climate extreme.

Relationship among the three indices was examined by Pearson Correlation at 99% confidence level (α = 0.01 significant level) while Kriging interpolation technique was applied to estimate spatially drought occurrence (Wambua et al., 2015). In achieving a meaningful spatial distribution of the droughts, the study considered five different years within the period of the research at seven years interval starting from 1990 to 2018 (i.e. 1990, 1997, 2004, 2011 and 2018).

RESULTS AND DISCUSSION

Meteorological Drought Characteristics

Results of RDI_{st} for lower and upper KRB showed similar pattern as presented in Figure 2. Analyses reveal that several drought events have occurred in the basin. Drought duration (D_d) for instance, shows a slight variation at the upstream compared to lowerstream. Three distinct D_d were observed in both locations but the longest D_d was observed in the downstream. The stretch started in 2005/2006 till 2017/2018 (13 hydrological years) while the shortest duration occurs in 2001/2002. Upstream revealed two similar D_d periods in the series while the third D_d only spans for 4 years. Generally, RDI results reveal 16 years and 15 years of drought incidents in upstream and lowerstream respectively. On drought onset (ti) and cessation (te), result from downstream shows early stage of drought in 1998/99 while the result at the upstream varies slightly as there are three main D_d in the series. Impliedly, there exists three ti and te in the period understudy (Figure 2).

Drought severity (S_d) and drought intensity (I_d) were equally examined in both locations and findings reveal that lowerstream has the highest and longest S_d summing up to -8.33 from 2005/06 to 2017/18 while the highest S_d at the upstream summed up to -6.23 from 2012/13 to 2017/18 (Figure 2). The study further shows the most severe drought by category, occurs during 2017/18 at the lowerstream with the highest I_d of -1.50. RDI further detects two moderate drought incidents during 2016/17 and 2012/13 and twelve mild drought incidents at different periods. Meanwhile, the lowest I_d at the lowerstream was recorded in 2008/09 with RDI value of -0.09. 2006/07 and 2017/18 appear as the most severe drought years at the upstream with I_d values of -1.63 and -1.51 respectively. Moderate and mild droughts occur most at the upstream with four episodes of moderate drought while mild drought incidents recorded ten episodes.

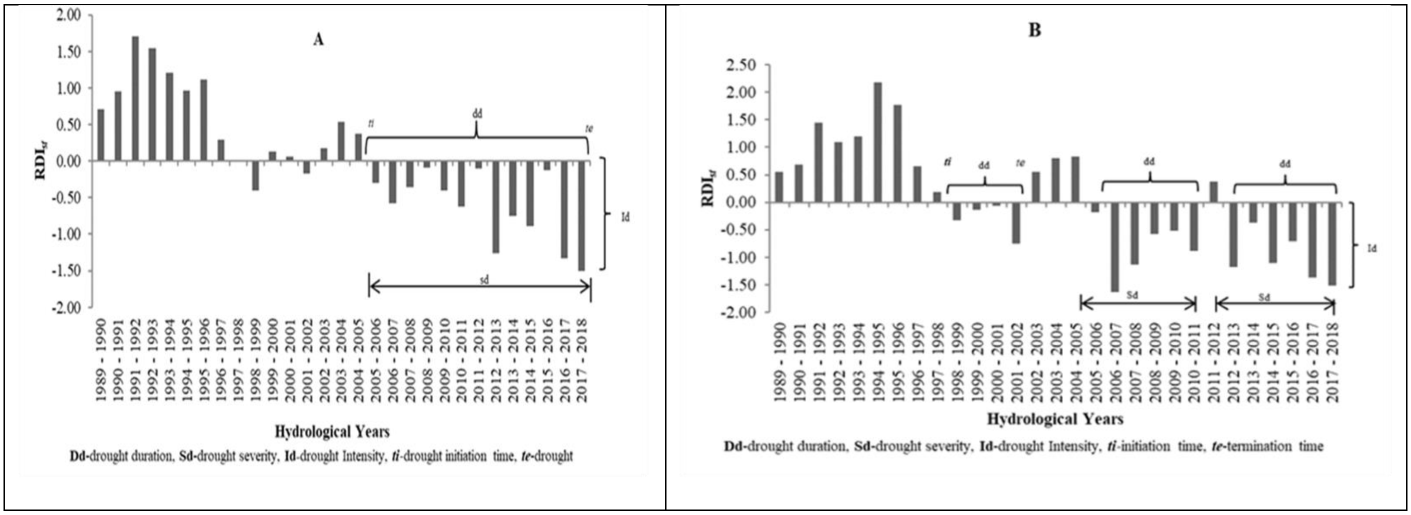

Figure 2: Reconnaissance Drought Index for ***A.*** Lower KRB ***B.*** Upper KRB
Source: Authors' Computation, 2021

The magnitude-frequency and recurrence interval for each drought event at different time durations are presented in Tables 4 and 5 for lowerstream and upstream respectively. Analyses of results for drought occurrence reveal that the occurrence probability of drought incidents is lower in the upstream than in lowerstream particularly for the identified severe droughts. The occurrence probabilities of severe drought incident during 2017/18 at the upstream and lowerstream are 11.76% and 6.25% with recurrence intervals of 8.5 and 16 years respectively.

Table 4: Magnitude-Frequency of RDI_{st} for Lower KRB

Year	RDI_{st} Value	RDI Category	Rank (m)	Recurrence Interval (Years)	Exceedance Probability	Frequency
2017/2018	-1.50	Severe Drought	1	16.00	0.06	6.25
2016/2017	-1.34	Moderate Drought	2	8.00	0.13	12.50
2012/2013	-1.26	Moderate Drought	3	5.33	0.19	18.75
2014/2015	-0.89	Mild Drought	4	4.00	0.25	25.00
2013/2014	-0.75	Mild Drought	5	3.20	0.31	31.25
2010/2011	-0.62	Mild Drought	6	2.67	0.38	37.50
2006/2007	-0.58	Mild Drought	7	2.29	0.44	43.75
2009/2010	-0.41	Mild Drought	8.5	1.88	0.53	53.13
1998/1999	-0.41	Mild Drought	8.5	1.88	0.53	53.13
2007/2008	-0.35	Mild Drought	10	1.60	0.63	62.50
2005/2006	-0.30	Mild Drought	11	1.45	0.69	68.75
2001/2002	-0.18	Mild Drought	12	1.33	0.75	75.00
2015/2016	-0.13	Mild Drought	13	1.23	0.81	81.25
2011/2012	-0.10	Mild Drought	14	1.14	0.88	87.50
2008/2009	-0.09	Mild Drought	15	1.07	0.94	93.75

Table 5: Magnitude-Frequency of RDI_{st} for Upper KRB

Year	RDI_{st} Value	Drought Category	Rank (m)	Recurrence Interval (Years)	Exceedance Probability	Frequency
2006 - 2007	-1.63	Severe Drought	1	17.00	0.06	5.88
2017 - 2018	-1.51	Severe Drought	2	8.50	0.12	11.76
2016 - 2017	-1.37	Moderate Drought	3	5.67	0.18	17.65
2012 - 2013	-1.18	Moderate Drought	4	4.25	0.24	23.53
2007 - 2008	-1.13	Moderate Drought	5	3.40	0.29	29.41
2014 - 2015	-1.10	Moderate Drought	6	2.83	0.35	35.29
2010 - 2011	-0.89	Mild Drought	7	2.43	0.41	41.18
2001 - 2002	-0.75	Mild Drought	8	2.13	0.47	47.06
2015 - 2016	-0.70	Mild Drought	9	1.89	0.53	52.94
2008 - 2009	-0.58	Mild Drought	10	1.70	0.59	58.82
2009 - 2010	-0.51	Mild Drought	11	1.55	0.65	64.71
2013 - 2014	-0.37	Mild Drought	12	1.42	0.71	70.59
1998 - 1999	-0.33	Mild Drought	13	1.31	0.76	76.47
2005 - 2006	-0.19	Mild Drought	14	1.21	0.82	82.35
1999 - 2000	-0.13	Mild Drought	15	1.13	0.88	88.24
2000 - 2001	-0.06	Mild Drought	16	1.06	0.94	94.12

Areal extent is one of the most essential drought characteristics this study considered. The results of spatial distribution of RDI_{st} are presented in Figures 3a to 3e and Table 6.

Table 6: Spatial Extent of RDI

Categories	Spatial Extent of RDI in %					Spatial Extent of RDI in Km²				
	1990	**1997**	**2004**	**2011**	**2018**	**1990**	**1997**	**2004**	**2011**	**2018**
Severe drought	0.32	3.45	8.78	0.71	19.82	213.98	2275.82	5783.54	470.75	13054.25
Moderate drought	4.31	10.30	42.70	9.62	56.18	2836.74	6787.72	28132.12	6339.90	37010.70
Mild drought	15.87	23.29	33.92	63.11	17.10	10457.45	15342.32	22344.00	41574.57	11262.94
Mildly wet	61.37	51.28	14.22	23.28	6.75	40428.28	33782.66	9367.68	15333.11	4444.65
Moderately wet	18.13	11.67	0.38	3.28	0.16	11941.55	7689.49	250.66	2159.66	105.46
Total	**100**	**100**	**100**	**100**	**100**	**65878**	**65878**	**65878**	**65878**	**65878**

Source: Authors' Computation

Results from spatial distribution of RDI values show that in the 1990, severe drought is insignificant occupying 213.98km² (0.32%) while moderate and mild drought covered few areas of the basin with 2,836.74km² and 10,457.45km² respectively. An indication that year 1990 is wetter than the condition in 1997 where areas covered by severe drought begins to expand covering 2,275.82km² (3.45%) as seen in the northern part and areas close to the mouth of the basin before draining into River Niger (Table 6). In 2004, there was a significant reduction in mildly wet areas of KRB by 37.06% with coverage of 9,367.68km² while moderate and mild droughts cover more significant areas in 2004 than 1997 with area cover of 28,132.12km² and 22,344km². The changes could be attributed to reduction in rainfall amount and increase in potential evapotranspiration. In 2011, rainfall amount across Nigeria were reported to be much (The Punch Newspaper, 24th July 2011, p.14; Durowoju *et al*, 2017) and this could have been responsible for the significant decrease in the areas covered by severe drought by 8.07%. Result of 2018 is quite different, as moderate drought covered 56.18% of the area with 37,010.70km² and severe drought covers 13,054.25km², an increase of 19.11%.

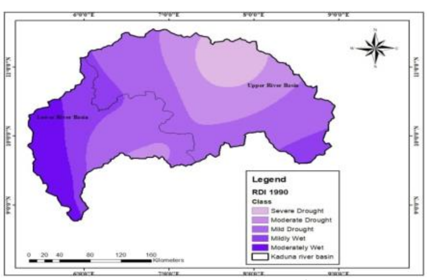

Figure 3a: Spatial Extent of RDI_{st} for 1990

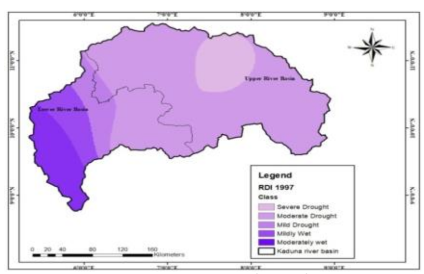

Figure 3b: Spatial Extent of RDI_{st} for 1997

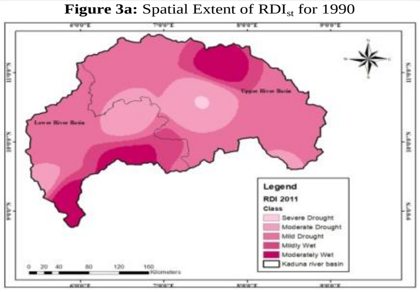

Figure 3c: Spatial Extent of RDI_{st} for 2004

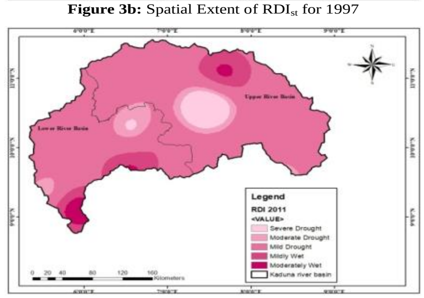

Figure 3d: Spatial Extent of RDI_{st} for 2011

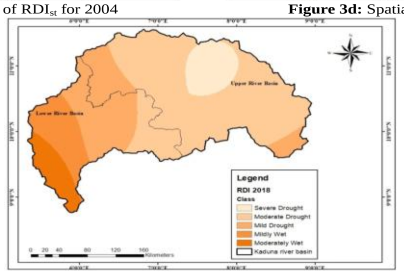

Figure 3e: Spatial Extent of RDI_{st} for 2018

Agricultural Drought Characteristics

Result showed that 1998/99 is the onset of dry spell in both locations but cease immediately in lowerstream unlike upstream whose dry spells continue until it ceased in 2001/02. After three years of consecutive wet periods, another drought episode begins in 2005/06 and ceased in 2010/11 in both locations. Results on D_d revealed there are three longest D_d of 6 years each in both locations with the upstream having two longest D_d while the longest D_d at the lowerstream is from 2005/06 to 2010/11. A total of 16 years of drought incidents occur at the upstream while the lowerstream has 14 years of drought episodes. At the upstream, the shortest and first D_d are four years while two shortest durations were identified in lowerstream (Figure 4).

Results show that highest and longest S_d occur more at the upstream with the highest summing up to -5.46 from 2012/13 to 2017/18 while the lowest S_d at upstream recorded -1.78 from 1998/99 to 2001/02 (Figure 4). At the lowerstream, the highest S_d recorded is from 2012/13 to 2014/15 with -3.13 S_d value while the lowest S_d value recorded -0.42 between 2000/01 and 2001/02 (Figure 4). The study further reveals highest I_d at the lowerstream in 2016/17 with -1.28 while the lowest I_d occurred in 1998/99. At the upstream, the highest I_d occurred in 2006/07 with -1.76 while lowest I_d occurred in 2005/06 with -0.08 (Figure 4). From the analysis, ASPI detects severe drought in 2006/07 at the upstream. Generally, mildly drought incidents were revealed to be more than other categories with nine episodes at the lowerstream and eleven incidents at upstream. ASPI equally recorded some noticeable wet episodes in the basin.

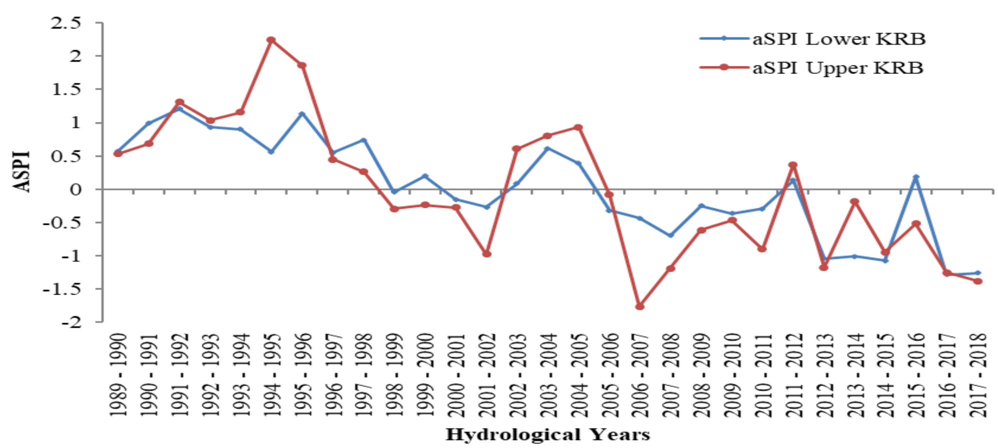

Figure 4: Temporal Analysis of Agricultural Standardised Precipitation Index (ASPI)

Magnitude-frequency of agricultural drought presented in Tables 7 and 8 showed that the severe drought of 2006/07 at the upstream has recurrence interval of 17 years with occurrence probability of 5.88% (Table 8). The moderate drought of 2016/17 at the lowerstream depicts recurrence intervals of 15 years occurrence probabilities of 6.67% while the moderate drought of 2017/18 at upstream reveals recurrence intervals of 8.5 years and occurrence probability of 11.76%. Mildly droughts which are the most occurred drought events in both locations have varying recurrence intervals and occurrence probabilities. The result implies that the higher the severity, the higher the recurrence interval and the lower the probability of occurrence.

Table 7: Magnitude-Frequency of ASPI for Lower KRB

Year	ASPI Value	Drought Category	Rank(m)	Recurrence Interval (Years)	Exceedance Probability	Frequency
2016 - 2017	-1.28	Moderate Drought	1	15.00	0.07	6.67
2017 - 2018	-1.26	Moderate Drought	2	7.50	0.13	13.33
2014 - 2015	-1.07	Moderate Drought	3	5.00	0.20	20.00
2012 - 2013	-1.04	Moderate Drought	4	3.75	0.27	26.67
2013 - 2014	-1.01	Moderate Drought	5	3.00	0.33	33.33
2007 - 2008	-0.70	Mildly Drought	6	2.50	0.40	40.00
2006 - 2007	-0.43	Mildly Drought	7	2.14	0.47	46.67
2009 - 2010	-0.36	Mildly Drought	8	1.88	0.53	53.33
2005 - 2006	-0.32	Mildly Drought	9	1.67	0.60	60.00
2010 - 2011	-0.30	Mildly Drought	10	1.50	0.67	66.67
2001 - 2002	-0.27	Mildly Drought	11	1.36	0.73	73.33
2008 - 2009	-0.25	Mildly Drought	12	1.25	0.80	80.00
2000 - 2001	-0.15	Mildly Drought	13	1.15	0.87	86.67
1998 - 1999	-0.04	Mildly Drought	14	1.07	0.93	93.33

Table 8: Magnitude-Frequency of ASPI for Upper KRB

Year	ASPI Value	Drought Category	Rank (m)	Recurrence Interval (Years)	Exceedence Probability	Frequency
2006 - 2007	-1.76	Severe Drought	1	17.00	0.06	5.88
2017 - 2018	-1.38	Moderate Drought	2	8.50	0.12	11.76
2016 - 2017	-1.25	Moderate Drought	3	5.67	0.18	17.65
2007 - 2008	-1.19	Moderate Drought	4	4.25	0.24	23.53
2012 - 2013	-1.18	Moderate Drought	5	3.40	0.29	29.41
2001 - 2002	-0.98	Mildly Drought	6	2.83	0.35	35.29
2014 - 2015	-0.95	Mildly Drought	7	2.43	0.41	41.18
2010 - 2011	-0.90	Mildly Drought	8	2.13	0.47	47.06
2008 - 2009	-0.61	Mildly Drought	9	1.89	0.53	52.94
2015 - 2016	-0.52	Mildly Drought	10	1.70	0.59	58.82
2009 - 2010	-0.47	Mildly Drought	11	1.55	0.65	64.71
1998 - 1999	-0.30	Mildly Drought	12	1.42	0.71	70.59
2000 - 2001	-0.27	Mildly Drought	13	1.31	0.76	76.47
1999 - 2000	-0.23	Mildly Drought	14	1.21	0.82	82.35
2013 - 2014	-0.19	Mildly Drought	15	1.13	0.88	88.24
2005 - 2006	-0.08	Mildly Drought	16	1.06	0.94	94.12

Results presented in Table 9 shows that mildly wet occupies most of the areas in the basin in 1990 occupying 27,562.04km² (41.84%). Study reveals that more than 70% of the basin area is wet during 1990 while severe, moderate and mild drought account for more than 20% of the basin area. Impliedly, the early stage is considerably wet and adequate for farming especially area largely characterized with guinea savannah.

Analysis of results in 1997 presents a slight difference in the spatial distribution of ASPI values. Severe drought shows an increase of 0.55% as compared to result in 1990 with coverage of 1,138.67km² (1.73%). In 2004, there is a significant reduction in mildly wet areas by 17.64 % just as it was revealed for RDI with coverage of 16,484.02km² while moderate and mild droughts increase by 20.6% and 10.38% respectively with coverage of 18,762.88km² and 20,470.15km². The changes from 1997 to 2004 could be as a result of reduction in effective rainfall amount which plants utilize for their optimal growth (Tigkas et al., 2019).

Table 9: Spatial Extent of ASPI

Categories	Spatial Extent of ASPI (%)					Spatial Extent of ASPI km²				
	1990	**1997**	**2004**	**2011**	**2018**	**1990**	**1997**	**2004**	**2011**	**2018**
Severe drought	1.18	1.73	5.42	0.89	21.23	779.50	1138.67	3568.86	588.44	13988.05
Moderate drought	6.34	7.88	28.48	16.35	49.07	4177.17	5188.99	18762.88	10769.24	32326.16
Mild drought	13.58	20.69	31.07	51.84	18.71	8944.32	13628.89	20470.15	34152.57	12323.66
Mildly Wet	41.84	42.66	25.02	23.04	10.06	27562.04	28104.60	16484.02	15178.76	6624.18
Moderately wet	30.38	20.58	9.44	6.40	0.82	20011.60	13557.14	6219.15	4213.86	538.00
Severely wet	6.68	6.47	0.57	1.48	0.12	4403.38	4259.70	372.94	975.13	77.95
Total	**100**	**100**	**100**	**100**	**100**	**65878**	**65878**	**65878**	**65878**	**65878**

Source: Authors' Computation

There is a significant change in 2011, as severe and moderate droughts drop from 5.42% and 28.48% to 0.89% and 16.35% respectively. 2018 reveals some significant changes especially to moderate and severe droughts (Figure 5e and Table 9). The spatial extents of moderate and severe droughts are more than 70% of the basin area.

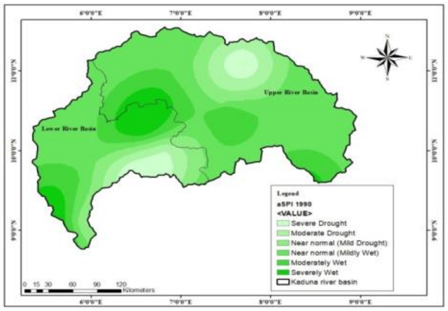

Figure 5a: Spatial Extent of ASPI for 1990

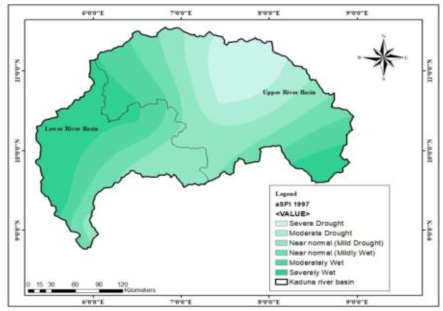

Figure 5b: Spatial Extent of ASPI for 1997

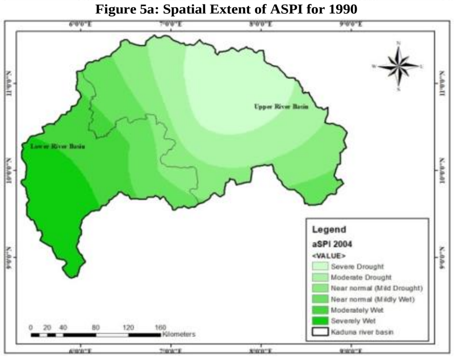

Figure 5c: Spatial Extent of ASPI for 2004

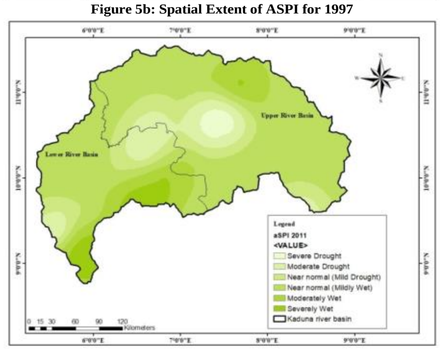

Figure 5d: Spatial Extent of ASPI for 2011

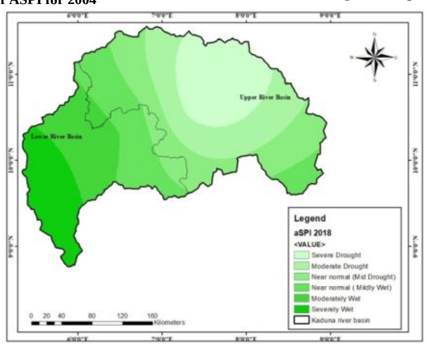

Figure 5e: Spatial Extent of ASPI for 2018

Hydrological Drought Characteristics

At the lowerstream, result shows 1996/97 as the *ti* of hydrological drought and 1998/99 as *te*. The longest D_d at the lowerstream was initiated in 2005/06 and terminates in 2017/18. Scenario at upstream does not appear to be significantly different from the lowerstream as 1998/99 was revealed as the first *ti* and ceased in 2001/02 (Figure 6). SDI results futher reveal different D_d in both locations. Lowerstream recorded 17 hydrological drought years while the upstream has 16 hydrological drought years. Basically, there are two major D_d at the lowerstream with the longest D_d of 13 years and the shortest D_d of 3 years. While the upstream recorded three distinct D_d, the first duration is 4 years while the second and third D_d have the same period length of 6 years each.

Results on S_d basically show two different periods at the lowerstream and three distinct periods at the upstream. Findings reveal that highest and longest S_d was recorded at the lowerstream from 2005/06 to 2017/18 with -8.98 S_d value while the lowest (-0.31) occurred from 1996/97 to 1998/99. The highest at the upstream summed up to -6.11 from 2005/06 to 2010/11 while the lowest was recorded from 1998/99 to 2001/02 with -1.75 (Figure 6). The study further shows that highest I_d at the lowerstream occurred in 2010/11 with -1.31 while the lowest I_d was recorded in 1998/99 with -0.06. At the upstream, the highest I_d occurred in 2007/08 with -1.52 while the lowest I_d occurred in 1999/2000 with -0.02 (Figure 6a).

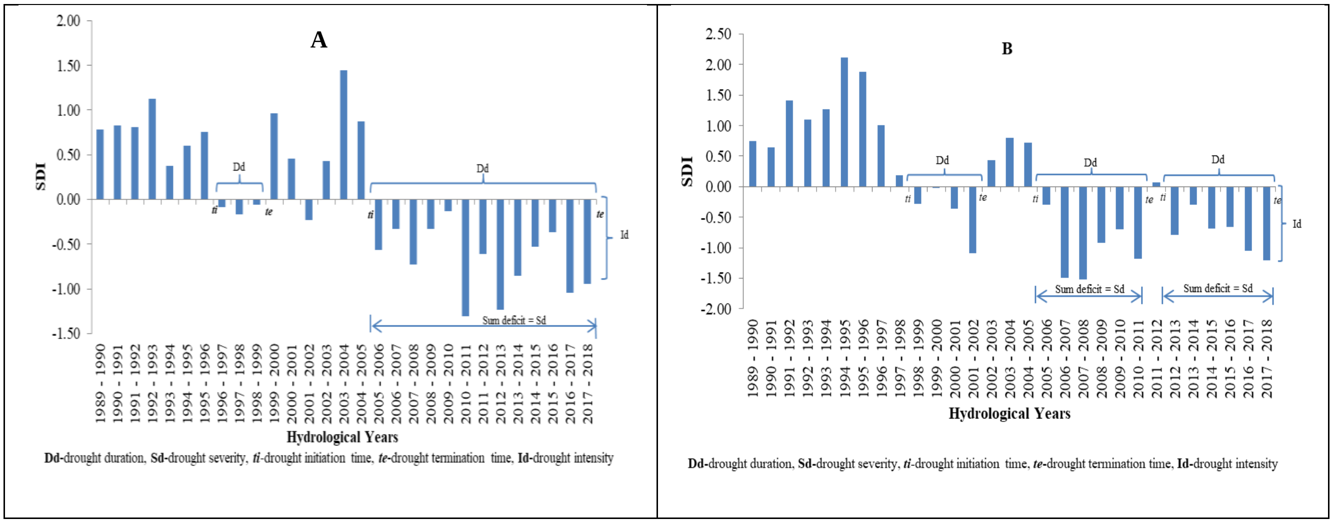

Figure 6: Standardised Drought Index (SDI) *A*. Lower KRB *B*. Upper KRB

Results from magnitude-frequency of hydrological drought shows that the most severe hydrological droughts of upstream captured in 2007/08 and 2006/07 have recurrence intervals of 17 and 8.5 years with occurrence probabilities of 5.88% and 11.76% respectively while the three moderate droughts identified at the lowerstream during 2010/11, 2012/13 and 2016/17 would reoccur in 18, 9 and 6 years with 5.56%, 11.11% and 16.67% respectively.

Table 10: Magnitude-Frequency of SDI for Lower KRB

Year	SDI Value	Drought Category	Rank (m)	Recurrence Interval (Years)	Exceedance Probability	Frequency
2010 - 2011	-1.31	Moderate Drought	1	18.00	0.06	5.56
2012 - 2013	-1.24	Moderate Drought	2	9.00	0.11	11.11
2016 - 2017	-1.04	Moderate Drought	3	6.00	0.17	16.67
2017 - 2018	-0.94	Mild Drought	4	4.50	0.22	22.22
2013 - 2014	-0.86	Mild Drought	5	3.60	0.28	27.78
2007 - 2008	-0.73	Mild Drought	6	3.00	0.33	33.33
2011 - 2012	-0.61	Mild Drought	7	2.57	0.39	38.89
2005 - 2006	-0.57	Mild Drought	8	2.25	0.44	44.44
2014 - 2015	-0.53	Mild Drought	9	2.00	0.50	50.00
2015 - 2016	-0.37	Mild Drought	10	1.80	0.56	55.56
2006 - 2007	-0.33	Mild Drought	11.5	1.57	0.64	63.89
2008 - 2009	-0.33	Mild Drought	11.5	1.57	0.64	63.89
2001 - 2002	-0.23	Mild Drought	13	1.38	0.72	72.22
1997 - 1998	-0.17	Mild Drought	14	1.29	0.78	77.78
2009 - 2010	-0.13	Mild Drought	15	1.20	0.83	83.33
1996 - 1997	-0.08	Mild Drought	16	1.13	0.89	88.89
1998 - 1999	-0.06	Mild Drought	17	1.06	0.94	94.44

Table 11: Magnitude-Frequency of SDI for Upper KRB

Year	SDI Value	Drought Category	Rank (m)	Recurrence Interval (Years)	Exceedance Probability	Frequency
2007 - 2008	-1.52	Severe Drought	1	17.00	0.06	5.88
2006 - 2007	-1.50	Severe Drought	2	8.50	0.12	11.76
2017 - 2018	-1.21	Moderate Drought	3	5.67	0.18	17.65
2010 - 2011	-1.19	Moderate Drought	4	4.25	0.24	23.53
2001 - 2002	-1.09	Moderate Drought	5	3.40	0.29	29.41
2016 - 2017	-1.05	Moderate Drought	6	2.83	0.35	35.29
2008 - 2009	-0.92	Mild Drought	7	2.43	0.41	41.18
2012 - 2013	-0.80	Mild Drought	8	2.13	0.47	47.06
2009 - 2010	-0.70	Mild Drought	9	1.89	0.53	52.94
2014 - 2015	-0.69	Mild Drought	10	1.70	0.59	58.82
2015 - 2016	-0.66	Mild Drought	11	1.55	0.65	64.71
2000 - 2001	-0.36	Mild Drought	12	1.42	0.71	70.59
2013 - 2014	-0.30	Mild Drought	13	1.31	0.76	76.47
2005 - 2006	-0.29	Mild Drought	14	1.21	0.82	82.35
1998 - 1999	-0.28	Mild Drought	15	1.13	0.88	88.24
1999 - 2000	-0.02	Mild Drought	16	1.06	0.94	94.12

Table 12: Spatial Extent of SDI

Categories	Spatial Extent of SDI (%)					Spatial Extent of SDI (Km²)				
	1990	**1997**	**2004**	**2011**	**2018**	**1990**	**1997**	**2004**	**2011**	**2018**
Severe drought	4.89	3.19	12.37	12.20	15.93	3220.38	2104.64	8149.54	8034.91	10495.67
Moderate drought	15.06	21.38	73.95	72.50	64.11	9922.51	14085.96	48715.36	47761.62	42231.79
Mild drought	63.43	62.47	12.12	13.10	18.33	41788.56	41155.76	7986.00	8627.94	12074.53
Non drought	16.62	12.95	1.56	2.21	1.63	10946.55	8531.64	1027.10	1453.53	1076.01
Total	**100**	**100**	**100**	**100**	**100**	**65878**	**65878**	**65878**	**65878**	**65878**

Source: Authors' Computation

In 2004, there was significant increase in coverage of moderate and severe droughts of 73.95% and 12.37% respectively while mild drought reveals a significant decrease in spatial extent from 62.47% to 12.12% (Table 12 and Figure 7c). This could be attributed to reduction in rainfall amount which is the major input and increased pressure on the rivers in the basin (Time et al., 2018; Eze, 2020). This revelation corroborates with the results of RDI and ASPI during year 2004. Analysis in 2011 shows that the basin is wetter than 2004 which has a direct impact on River Kaduna and its tributaries as the volume of water increases in the basin. In 2018, moderate and mild drought covers 82.44% with a slight decrease in moderate drought from 72.50% to 64.11%. A general observation in the spatial extent of SDI reveals that the volume of water in rivers in the basin keeps fluctuating with early years wetter than the latter years.

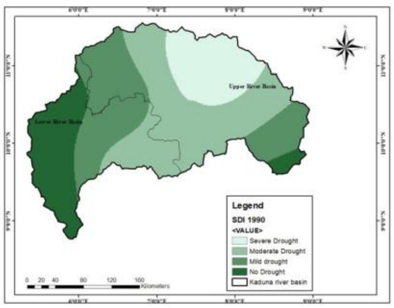

Figure 7a: Spatial Extent of SDI for 1990

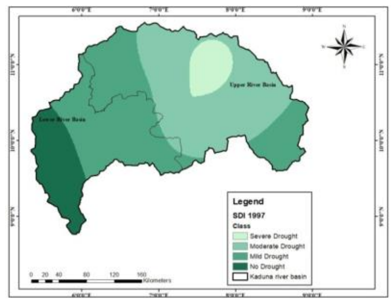

Figure 7b: Spatial Extent of SDI for 1997

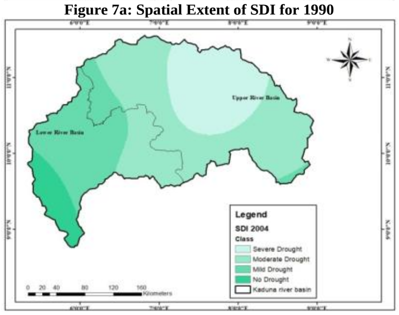

Figure 7c: Spatial Extent of SDI for 2004

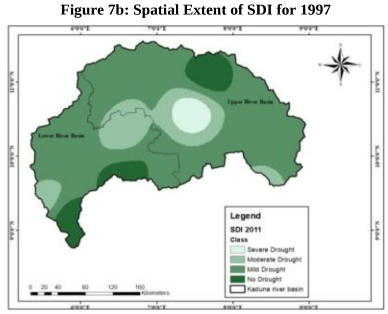

Figure 7d: Spatial Extent of SDI for 2011

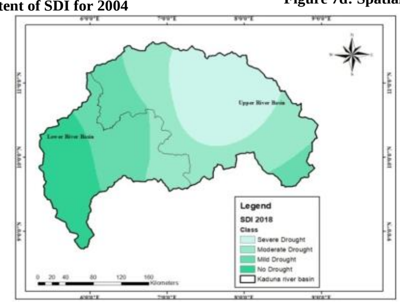

Figure 7e: Spatial Extent of SDI for 2018

Correlation Analysis among RDI, aSPI and SDI

This study reveals high level of significant relationship across the three indices (RDI_{st}, aSPI and SDI).

Table 13: Pearson Correlation Coefficients among RDI_{st}, ASPI and SDI

		RDI_{st} value	API value	SDI value
RDI_{st} value	Pearson Correlation	1	.938**	.825**
	Sig. (1-tailed)		.000	.000
	N	29	29	29
aSPI value	Pearson Correlation	.938**	1	.788**
	Sig. (1-tailed)	.000		.000
	N	29	29	29
SDI value	Pearson Correlation	.825**	.788**	1
	Sig. (1-tailed)	.000	.000	
	N	29	29	29

**. Correlation is significant at the 0.01 level (1-tailed)

The result established the fact that there exists strong connection among meteorological, agricultural and hydrological drought just as some studies have established. (Haslinger *et al.,* 2014; Tigkas *et al,* 2015; Sun *et al.*, 2017; Zhang *et al.,* 2018). The result implies that the impact of rainfall and potential evapotranspiration which are the major components of RDI is directly felt on aSPI which uses effective precipitation as its main parameter and this further reveals great impact on SDI (Sun et al., 2017; Zhang et al., 2018).

Implications of Drought on Water Resources and Agricultural Planning

From the findings, drought characteristics of the three drought types have their impact on agricultural planning and in management of water resources. Considering drought duration (*Dd*), the results imply that those years with longer *Dd* have direct impact on agricultural products (Nath et al., 2017; Eze and Shittu, 2018; Eze, 2020) and water resources (Nath et al., 2017). *Dd* impacts negatively across all stages of agricultural planning chain including land preparation, sowing, crop growth and management, harvesting, storage, transport and marketing, which equally undermines food security (Ezihe et al., 2017; Eze, 2018, 2020). Similarly, *Dd* has indirect consequence on the water balance of the basin as precipitation is being substituted with effective precipitation (Tigkas et al*.,* 2019). The longer the *Dd*, the more the vegetation are affected because of inadequate water available for plant growth (Oladipo, 1993; Bolton and Friedl, 2013) and more consequences are felt on crop productions and other vital agricultural support systems such as rivers, rangelands and wetlands that provide means of livelihood to farmers (Eze, 2018, 2020).

Dd has a greater implication on water resource in the basin especially when such basin experiences longer *Dd* (Van Lanen et al., 2016; Samaniego et al., 2018). The impacts result from a deficiency of water in surface or subsurface components of the hydrologic system. It was equally observed that the longer the *Dd*, the longer it takes the basin to recuperate from drought. The implication of *Dd* on water resource as presented in this study corroborates with the study by Samaniego et al., (2018) which reveal that soil moisture is usually the first component of the hydrologic system to be affected. As *Dd* continues, other components are affected (López-Moreno et al., 2004; Samaniego et al., 2018). Hence, the impacts of drought gradually spread from the agricultural sector to other sectors and finally a shortage of stored water becomes noticeable. This revelation aligns with the general theory on the response of the hydrological resources to precipitation deficits of different duration and intensity on longer time scales (López-Moreno et al., 2004; Vicente-Serrano and López-Moreno, 2005). In comparison, upstream has the longest *Dd* than lowerstream and by implication, there is more shortage of water for crops over time at the upstream than the lowerstream resulting into heavy irrigation at the upstream as against moderate irrigation in the lowerstream. The situation at the upstream is an indication there is higher rate of evapotranspiration than the downstream (Tuttolomondo et al., 2016).

Onset (*ti*) and cessation (*te*) of drought play crucial role in agricultural planning as it helps farmers and stakeholders in proper and adequate planning. It also helps in determining the kind of crop to plant in a particular season of the year as various crops have their own water requirements to grow and thrive (Ndamani and Watanabe, 2015; Tiamiyu et al., 2018; Eze, 2020). Eze (2020), states that the most immediate consequence of drought *ti* is the reduction in the farm output. Drought onset and cessation equally help the hydrologists in proper management of water resource. The *ti* alerts all relevant stakeholders in the basin for adequate planning as reduction in the streamflow sets in (Van Lanen et al., 2016). As revealed in the study, upstream is drier and by implication, water resource at the upstream is not adequately serving the users as against the situation in the lowerstream. The onset of drought has a direct effect on energy supply by Shiroro Dam Authority and indirect impact on fish farming (Abayomi et al., 2015; Ewugi and Usman, 2016; Okafor et al., 2017).

Results on drought severity (S_d) and intensity (I_d) equally contributed to the impact on agricultural planning and water resources. It is evident that moderate and mild drought have the highest occurrence in the study area. Impliedly, those years which experience successive drought just like 2005/06, 2006/07, 2007/08, 2008/09 and 2009/10 with continuous pressure on the limited water supplies as a result of increase in water demand would make water-resources management more difficult in the future (Shiau et al., 2001; Lweendo et al., 2017). It was further reveal that S_d and I_d have an indirect impact on the socio-economic activities of the basin dwellers (Tiamiyu et al., 2018; Eze, 2020). For example, those into fishing, catch more fishes during moderate and mild drought periods which boost their daily income unlike those farmers that depend largely on irrigation farming system. Mildly drought implies that little irrigated water is required to support the optimal growth of some crops whose water requirements are not necessarily much such as onions, soyabeans, beans, groundnuts e.t.c. (Nath et al., 2017). It is noteworthy that most of the onions available in the country are mostly grown in the study area and by implication, those years with severe and moderate droughts lead to shortage in the production which indirectly determine the cost and decrease in labour (socio-economic drought) (Nath et al., 2017; Eze, 2020). During periods of high drought severity and intensity, few farmers especially the wealthy among them, prefer to increase the number of labour where intensive irrigation is required or go more mechanized by acquiring or rent more equipment to meet up with yearly production while many farmers often sell cattle, goats, sheep, camels and donkeys used as draft animals to generate income during intense drought (Shittu et al., 2017; Eze 2018).

The role of magnitude-frequency of drought on implication for water resource management cannot be over emphasized (Shiau et al., 2001; López-Moreno et al., 2004; Lweendo et al., 2017). Highest severe drought of magnitude -1.52 during 2007/2008 was predicted to have 17 years of recurrence interval with 5.88% probability of occurrence. This implies that for such magnitude to reoccur, it will take 17 years more i.e. 2024/2025 to have similar drought incident. The study revealed that the higher the magnitude, the higher the recurrence interval but the lower the probability of occurrence and vice versa. This helps farmers, water resource personnel, industrialists and hydrologists to predict drought occurrence accurately and plan adequately when need arises. Spatial extent of drought showed that few areas like the northern parts of the basin in which severe drought are prominent, cultivate crops with low water requirements. The thriving crops in those areas are heavily irrigated compare to areas at the lowerstream where crops with much water requirements like rice are mostly grown and thrive successfully especially in waterlog areas (Ndamani and Watanabe, 2015; Eze and Shittu, 2018; Eze, 2020). All these predictions help the stakeholders in water resource management to predict drought occurrence accurately for proper planning and prudent use of the resource.

CONCLUSION

This study has attempted an assessment of drought characteristics in Kaduna River Basin, which unarguably is the economic nerve centre of the country. The study reveals that meteorological, agricultural and hydrological drought characteristics have almost similar outcomes despite different input (data). Onset and cessation of the three droughts at lower and upstreams show quite a short period but a moderately continuous episode at the later years of the study. Incidentally, drought durations (dd) in both locations reveals three episodes across all the drought types with fluctuating pattern in the late 20th century but moderately longer duration in the early 21st century. Drought severity and intensity appear low across the three indices in the early years but quite higher at later years. Moderate and mild droughts own the highest occurrence accounting for more than 80% of all categories across all the indices used in this study. Spatial distribution of drought indices values equally shows that moderate and mild droughts have the largest coverage mostly mapped at the middle of the basin while few severe droughts are recorded at the northern part. The study has established the existence of strong relationship among meteorological, agricultural and hydrological droughts.

RECOMMENDATIONS

In order to mitigate the impact of droughts on water resources and agricultural planning and achieve agricultural sustainability, the study recommends (i) adoption of improved crop varieties such as drought-resistant crops, early maturing crops enables farmers cope with rainfall variability, particularly drought occurrences. (ii) Provision of irrigation facilities such as tube-well by the government or organisation will help farmers that are dependent on rainfall to cultivate and harvest crops during shortfall in rainfall amount.

REFERENCES

Abaje, I., Ati, O. F., Iguisi, E. O., & Jidauna, G. G. (2013). Droughts in the Sudano-Sahelian ecological zone of Nigeria: implications for agriculture and water resources development. *Global Journal of Human Social Science, Geography, Geosciences & Environmental*, *13*(2), 1–10.

Abayomi, K. I., Murtala, A. I., & Babatunde, O. (2015). Trend Analysis of Hydro-meteorological Data for River Kaduna at Shiroro Dam Site , Niger State Nigeria. *Journal of Scientific Research & Reports*, *8*(5), 1–12.

Achugbu, I. C. and Anugwo, S. C. (2016). Drought Trend Analysis in Kano using Standardized Precipitation Index. *FUOYE Journal of Engineering and Technology*. 1(1). 105-110.

Adeogun, B. K., Nwude, M.O., Mohammad, Y. S., and Adie, D.B. (2014) Evaluation of Suitable Standardized Precipitation Index Time Scales for Meteorological, Agricultural and Hydrological Drought Analyses. *FUTA Journal of Research in Sciences*, 2:140-149.

Ahmed, K., Shahid, S., & Nawaz, N. (2018). Impacts of climate variability and change on seasonal drought characteristics of Pakistan. *Atmospheric Research*, *214*, 364–374.

Aremu, K. J. and Olatunde A. F. (2013). Drought Trends in Areas above Latitude 8°N of Nigeria. *Journal of Environment and Earth Science* 3(8)111-119.

Asadi Zarch, M.A., Malekinezhad, H., Mobin, M.H., Dastorani, M.T. and Kousari, M.R. (2011). Drought Monitoring by Reconnaissance Drought Index (RDI) in Iran. *Water Resour Manage* 25(13)**,** 3485-3504. https://doi.org/10.1007/s11269-011-9867-1

Bolton, D. K. and Friedl, M. A. (2013). Agricultural and Forest Meteorology Forecasting crop yield using remotely sensed vegetation indices and crop phenology metrics. *Agricultural and Forest Meteorology*, *173*, 74–84.

Chen, H., and Sun, J. (2015). Changes in drought characteristics over china using the standardized precipitation evapotranspiration index. *Journal of Climate*, *28*(13), 5430–5447.

Dai, A. (2011). Drought under global warming: A review. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(1), 45–65.

Dai, A., Lamb, P. J., Trenberth, K. E., Hulme, M., Jones, P. D., & Xie, P. (2004). The recent Sahel drought is real. *International Journal of Climatology*, *24*(11), 1323–1331.

Dami, A., Adesina, F. A., & Adeoye, N. O. (2010). The impact of drought and desertification in the Lake Chad basin region. *Journal of Environmental Issues and Agriculture in Developing Countries*, *2*(2 & 3), 92–102.

Durowoju, O. S. and Olusola, A. O. and Anibaba, B. W. (2017). Relationship between Extreme Daily Rainfall and Maximum Daily River Discharge within Lagos Metropolis. *Ethiopia Journal of Environmental Studies and Management.*10(14): 492–504.

Ewugi, M. S., & Usman, M. (2016). Analysis of Shiroro Hydro Electricity Dam (SHED) Community ' s Happiness : A Focus on the Physical Environment Using Probit Model. *Mediterranean Journal of Social Sciences*, *7*(5), 404–411.

Eze, J. N. (2018). Drought occurrences and its implications on the households in Yobe state , Nigeria, *1914*. Geoenvironmental Disasters.

Eze, J. N. (2020). Assessment of drought occurrences and its implications on agriculture in Niger State, Nigeria, (January).

Ezihe, J. A. C., Agbugba, I. K., & Idang, C. (2017). Effect of climatic change and variability on groundnut (Arachis hypogea, L.) production in Nigeria. *Bulgarian Journal of Agricultural Science*, *23*(6), 906–914.

GDACS. (2020). Global Disaster Alert and Coordination System.

Haslinger, K., Koffler, D., Schoner, W. and Laaha, G. (2014), Exploring the Link between Meteorological Drought and Streamflow: Effects of Climate Catchment Interaction. *Water Resource. Res.*, 50, 2468-2487

Hettinger, S. L. (2013). *The United States. Twentieth-Century Organ Music.*

Huang, S., Huang, Q., Chang, J., Leng, G., and Xing, L. (2015). The response of agricultural drought to meteorological drought and the influencing factors: A case study in the Wei River Basin, China. *Agricultural Water Management*, *159*,45–54.

Koppen, W. (1928). *Climate Map De Earth*. Justus Perthes, Gotha.

Li, Q., He, P., He, Y., Han, X., Zeng, T., Lu, G., & Wang, H. (2020). Investigation to the relation between meteorological drought and hydrological drought in the upper Shaying River Basin using wavelet analysis. *Atmospheric Research*, *234*, 104743

López-Moreno, J. I., Beguería, S., & García-Ruiz, J. M. (2004). Storage Regimes of the Yesa Reservoir , Upper Aragon River Basin , Central Spanish Pyrenees. *Environmental Management*, *34*(4), 508–515.

Lweendo, M. K., Lu, B., Wang, M., Zhang, H., & Xu, W. (2017). Characterization of droughts in humid subtropical region, upper kafue river basin (Southern Africa). *Water (Switzerland)*, *9*(4), 242.

Nalbantis, I. and Tsakiris, G. (2009). Assessment of Hydrological Drought Revisited. *Water Resources Management*, 23, 881-897.

Nath, R., Nath, D., Li, Q., Chen, W., & Cui, X. (2017). Impact of Drought on Agriculture in the Indo-Gangetic Plain , India, *34*(March), 335–346.

Ndamani, F. & Watanabe, T. (2015). Influences of rainfall on crop production and suggestions for adaptation. *International Journal of Agricultural Sciences*, *5*(1), 367–447

NiMET. (2019). *Archive of Nigeria Meteorological Agency.*

Ogunjo, S., Ife-Adediran, O., Owoola, E., Fuwape, I., (2019a). Quantification of Historical Drought Conditions over different Climatic Zones of Nigeria. *Acta Geophysica* 67, 879-889.

Ogunjo, S.T., (2021). Multifractal Properties of Meteorological Drought at different Time Scales in a Tropical Location. *Fluctuation and Noise Letters* 20, 2150007.

Okafor, G.C., Jimoh, O.D. and Larbi, K.I. (2017) Detecting Changes in Hydro-Climatic Variables during the Last Four Decades (1975-2014) on Downstream Kaduna River Catchment, Nigeria. *Atmospheric and Climate Sciences*, 7, 161-175.

Oladipo, E. O. (1993). Some aspects of the spatial characteristics of drought in northern Nigeria. *Natural Hazards*, *8*(2), 171–188.

Ologunorisa, E. T. (2006). The Changing Rainfall Pattern and Its Implication for Flood Frequency in Makurdi, Northern Nigeria. *Journal of Applied Science Environmental. Management.* 10(3).: 97-102

Oloruntade, A. J., Mohammad, T. A., Ghazali, A. H., & Wayayok, A. (2017). Analysis of meteorological and hydrological droughts in the Niger-South Basin, Nigeria. *Global and Planetary Change*, *155*, 225–233.

Omonijo, T. O. and Okogbue, E. C. (2014). Trend Analysis of Drought in the Guinea and Sudano-Sahelian Climatic Zones of Northern Nigeria (1907-2006).*Atmospheric and Climate Sciences.* 4: 483-507. http://dx.doi.org/10.4236/acs.2014.44045.

Pei, W., Fu, Q., Liu, D., Li, T., Cheng, K. and Cui, S., (2019). A Novel Method for Agricultural Drought Risk Assessment. *Water Resources Management* 33(6): 2033-2047.

Samaniego, L., Thober, S., Kumar, R., Wanders, N., Rakovec, O., Pan, M., Zink, M., et al. (2018). Anthropogenic warming exacerbates European soil moisture droughts. *Nature Climate Change*, *8*(5), 421–426. Springer US. Retrieved from http://dx.doi.org/10.1038/s41558-018-0138-5

Shiau, B. J., Shen, H. W., & ASCE, M. (2001). Recurrence Analysis of Hydrological Droughts of Differing Severity. *Journal of Water Resources Planning and Management*, *127*, 30– 40.

Shiru, M. S., Shahid, S., Alias, N., & Chung, E. S. (2018). Trend analysis of droughts during crop growing seasons of Nigeria. *Sustainability (Switzerland)*, *10*(3), 1–13.

Shittu A M, Fapojuwo O E, Senjobi B A, Tiamiyu S A, O., & A E, Eze J N, Akerele D, U. U. B. (2017). *Incentivising Adoption of Climate-smart Practices in Cereals Production in Nigeria: Socio-cultural and Economic Diagnosis.*

Stahle, D. W., Cleaveland, M. K. and Blanton, M. D. (2000). Tree-Ring Data Document 16th Century Megadrought over North America. *America Geography Union,* 81(12): 121-125.

Sun P., Zhang Q., Wen Q., Singh V. P. and Shi P. (2017). Multisource Data-based Integrated Agricultural Drought Monitoring in the Huai River basin, China. *Journal of Geophysical Research: Atmospheres*, *122*, 10,751–10,772. https://doi.org/10.1002/2017JD027186

Tiamiyu, S. A.; Ugalahi, U. B.; Eze, J. N. and Shittu, M. A. (2018). Adoption of Climate Smart agricultural practices and farmers' willingness to accept incentives in Nigeria. *International Journal of Agricultural and Environmental Research*, *4*(4), 198–205.

Tigkas D., Vangelis H., Tsakiris G., (2015). DrinC: a software for drought analysis based on drought indices. Earth Science Informatics, 8(3):697-709. doi:10.1007/s12145-014 0178-y

Tigkas, D., Vangelis, H. and Tsakiris, G. (2019). Drought Characterisation based on an Agriculture-oriented Standardized Precipitation Index. *Theoretical and Applied Climatology*, 135:1435–1447. https://doi.org/10.1007/s00704-018-2451-3.

Time, A., Garrido, M., & Acevedo, E. (2018). Water relations and growth response to drought stress of prosopis tamarugo phil. A review. *Journal of Soil Science and Plant Nutrition*, *18*(2), 329–343.

Tsakiris, G. and Vangelis, H. (2005). Establishing a Drought Index Incorporating Evapotranspiration. *European Water.* 9/10. 3-11.

Tsakiris, G., Pangalou, D. and Vangelis, H (2007). Regional Drought Assessment Based on the Reconnaissance Drought Index (RDI). *Water Resource Management.* 21(50:821–833 DOI 10.1007/s11269-006-9105-4. Springer.

Tuttolomondo, T., Leto, C., Bella, S. La, Leone, R., Virga, G., & Licata, M. (2016). Water balance and pollutant removal efficiency when considering evapotranspiration in a pilot-scale horizontal subsurface flow constructed wetland in Western Sicily (Italy). *Ecological Engineering*, *87*, 295-304.

Van Lanen, H. A. J., Laaha, G., Kingston, D. G., Gauster, T., Ionita, M., Vidal, J. P., Vlnas, R., et al. (2016). Hydrology needed to Manage Droughts: The 2015 European Case. *Hydrological Processes*, *30*(17), 3097–3104.

Van Loon, A. F. (2015). Hydrological drought explained. *Wiley Interdisciplinary Reviews: Water*, *2*(4), 359–392.

Vicente-Serrano, S. M., & López-Moreno, J. I. (2005). Hydrological response to different time scales of climatological drought: An evaluation of the Standardized Precipitation Index in a mountainous Mediterranean basin. *Hydrology and Earth System Sciences*, *9*(5),523- 533.

Wilhite, D.A. and Glantz, M.H. (1985). Understanding the Drought Phenomenon: The Role of Definitions. *Water International* 10(3):111–120.

Zhai, J., Huang, J., Su, B., Cao, L., Wang, Y., Jiang, T., & Fischer, T. (2017). Intensity–area–duration analysis of droughts in China 1960–2013. *Climate Dynamics*, *48*(1–2), 151–168. Springer Berlin Heidelberg.

Zhang Q., Li, Q., Singh V. P., Shi P., Huang Q. and Sun P. (2018). Nonparametric Integrated Agrometeorological Drought Monitoring: Model Development and Application. *Journal of Geophysical Research: Atmospheres,* 123(1), 73-88. doi.org/10.1002/2017JD027448

