Spatiotemporal Analysis of Agricultural Drought Event over Niger South, Nigeria

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ABSTRACT

Drought virtually occurs in all climatic zones but its characteristics vary significantly from one region to another. Nigeria like many West African countries has been afflicted by droughts occasioned by the negative trend pattern of rainfall since 1970s. Thus, this study assessed the spatiotemporal pattern of agricultural drought event over Niger South, Nigeria. Observation datasets (1965-2015) of precipitation and temperature obtained from the Climate Research Unit (CRU_TS 4.06) were analyzed. Agricultural drought indices, namely agricultural standardized precipitation index (aSPI) and effective reconnaissance drought index (eRDI) were used to characterize the drought event over the area. The results of the study reveal that all the locations within the study area had experienced drought events ranging from mild drought to extreme drought. A very severe to extreme drought was recorded in the years 1973-1974, 1987- 1988, 2001-2002, 2011-2012 and 2015 in all the locations. A good agreement (r > 0.90) was found between the two indices. The results imply that the region had experienced droughts that are capable of attracting loss in crop and animal production. More so, the results show that the drought pattern is consistent with the popular pattern over Northern Nigeria and most parts of West Africa. The study provided a framework for agricultural drought monitoring and mitigation strategy in Niger South. Identifying drought-resistant crops as well as farming strategies that will mitigate the impact of drought in case of future occurrence has become a necessity.

Keywords: Agricultural drought, agricultural standardized precipitation index, effective reconnaissance drought index, Niger south, Nigeria

1. INTRODUCTION

Drought is one of the most globally known hazards that can have a devastating effect on agriculture, water resources and ecosystems. It is an extreme hydrological event that shows its influence steadily over time and space leaving its negative impact on lives and the environment. It occurs when there is a temporary and recurring water shortage that can range from a month to several years thereby causing hydrological imbalance and affecting land productivity (Oguntunde *et al.,* 2018; Ogunrinde *et al.,* 2019). There is no universally embraced meaning of drought because of the assortment of areas influenced by its spatial and temporal incidence (Wilhite *et al.,* 2014). It is regarded as a catastrophic event that differs from other hydrological events due to its gradual occurrence (Yue *et al.,* 2018). It is a deceptive and least understood among natural hazards which has attracted a global annual loss that ranges from 6 to 8 billion dollars and claimed the lives of many (Chen*et al.*, 2016; Vicente-serrano *et al.,* 2012; Wu *et al.,* 2016). Hence, not only agricultural materials are under the threat of drought but also human survival and social stability.

The magnitude, intensity and frequency of drought could be amplified as a result of climatic change (Animashaun *et al.*, 2023). The magnitude of drought can be specified by the degree to which precipitation, runoff or soil moisture falls below a baseline over a certain period of time, its intensity is the relationship of its magnitude to its duration, while drought severity is the level of impact resulting from the precipitation deficit (Ogunrinde *et al.*, 2019). Though a number of studies have been carried out on drought events, agricultural drought has not been very much reported for many decades and the effect is expanding in size and complexity resulting in a decrease in agricultural productivity.

In Nigeria, like many developing nations, the common means of survival for the rural population is agriculture and livestock rearing. However, agricultural production is mostly rain-fed which is naturally predisposed to unpredictable occurrences (Animashaun *et al.,* 2020). Years with adequate rainfall are marked with bountiful harvests from both crop and livestock productions while years with insufficient rainfall are noted with low crop output, starvation, hunger, and animal deaths (Eze *et al.* 2018). The impacts of drought are not uniform across the world, it is more felt in locations that frequently experience drought and in crop systems that are more susceptible to drought occurrences (e.g., rainfed agriculture).

Though there are basically four types of droughts (meteorological, hydrological, agricultural and socioeconomic), agricultural drought is of particular concern due to its great damaging effects within a short duration. Agricultural drought is a type that is characterized by a considerable reduction in the amount of water that is easily accessible for plant growth for an extended period in a specific location and thus obliterates agricultural productivity (Gidey *et al.* 2018). A number of studies on drought analysis have been conducted in Nigeria in recent times using different indices (e.g., Oguntunde *et al.*, 2018). Nevertheless, only a few considered indices that are appropriate for agricultural drought determination as well as varying cropping periods. More so, the few studies that considered cropping calendars were conducted on a nationwide scale without consideration of the heterogeneity of the areas. Thus, this study aims at the spatiotemporal analysis of agricultural drought events in Niger South, Nigeria using the agricultural standardized precipitation index (aSPI) and effective reconnaissance drought index (eRDI)

2. MATERIALS AND METHOD

2.1 Study Area

The area of study is Niger South which is located in Niger state at latitude 8°10'0''N to 9°40'0''N and longitude 4°37'50''E to 6°54'0''E (Figure 1). The area experiences two distinct seasons; a dry season which occurs from November to March, when the North-East trade winds are predominant, and a wet season which occurs from April to October, when the South-West trade winds are predominant (Sule *et al.*, 2020). Niger South records annual rainfall of about 1,600 mm while the northern part of the state records annual rainfall of about 1,200 mm.

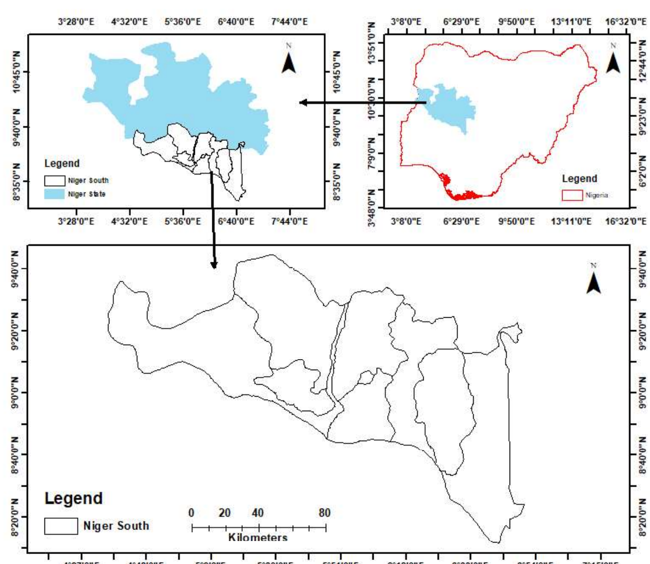

Figure 1. Map of Niger South, Nigeria

2.2 Dataset

The gridded monthly rainfall and temperatures (minimum and maximum) data used for the analysis were obtained from the Climate Research Unit (CRU_TS 4.06). The data has 0.5 by 0.5 latitude and longitude resolution and a data length of 51 years (1965-2015) was utilized. The locations of the study area for which the data was obtained are Agaie, Bida, Edati, Gbako, Lavun, Lapai and Mokwa. The choice of CRU dataset for the study was due to the non-availability of station data for the area and also due to the high correlation between the data and the available station data within the state (Animashaun *et al.*, 2020).

2.3 Agricultural Standardized Precipitation Index (aSPI)

Standardized Precipitation Index (SPI) is a widely used index. Though the index is constrained by the absence of vital components (e.g., evapotranspiration and soil moisture) related to crop growth of the crop, its simple structure and low data requirement have made it a principal choice for agricultural drought identification. Recently, Tigkas *et al.* (2017a) modified the index by substituting effective precipitation for total precipitation in the original SPI. That makes it better suited to describing agricultural drought and evaluating the effects of drought on plants. The modified version known as the Agricultural Standardized Precipitation Index (aSPI) still maintained the inherent merit of the original index as it can be used in locations with a dearth of data. For its computation, the cumulative probability distribution is transformed into a normal distribution using the following approximation (Abramovitz and Stegun 1965):

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

With the following constant values:

$c_0 = 2.515517, c_1 = 0.802853,$

$c_2 = 0.010328, d_1 = 1.43278,$

$d_2 = 0.189269, d_3 = 0.001308$

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 1.

Table 1. Classification of drought based on aSPI and eRDI values

aSPI and eRDI Value	Category	Probability of Occurrence (%)
≥ 2.00	Extreme wet	2.3
1.50 to 1.99	Severe wet	4.4
1.00 to 1.49	Moderate wet	9.2
0 to 0.99	Mildly wet	34.1
0. to -0.99	Mildly drought	34.1
-1.00 to -1.49	Moderate drought	9.2
-1.50 to -1. 99	Severe drought	4.4
≤ - 2	Extreme drought	2.3

2.4 The Effective Reconnaissance Drought Index (eRDI)

The Reconnaissance Drought Index (RDI) is another widely used index for drought analysis. Unlike SPI, RDI integrates major parameters of precipitation and potential evapotranspiration. However, to enhance its performance and improve its ability to assess agricultural drought, total precipitation was substituted with effective precipitation, which signifies more accurately the amount of water that is productively used by the crops (for details see Tigkas *et al.* 2017b). The equation below is used to compute the index's initial form (α) within a year for a reference period of *k* months:

$$a_k = \frac{\sum_{I=1}^{J=K} P_J}{\sum_{I=1}^{J=K} PET_J} \quad (2)$$

P and *PET are* precipitation and evapotranspiration respectively. In the modified form (i.e., eRDI) the *P* is substituted with *Pe* as shown in equation 3

$$a_e(k) = \frac{\sum_{I=1}^{J=K} P_{eJ}}{\sum_{I=1}^{J=K} PET_J}$$
(3)

Where *Pej* is the effective monthly precipitation of the jth month. The classification is based on Table 3 below. The crop-growing reference periods for the selected crops Table 2.

Table 2: Crops and their reference period

Crop	Season	Period (Month)
Maize	April – July	3
Soya bean	May – November	6
Cassava	April – January	9

3. RESULTS AND DISCUSSION

The drought magnitude and frequency of the Niger South were assessed at each of the six grid stations using aSPI and eRDI. The computation of the indices was done for the cropping period (3, 6 and 9 months) of some of the commonly planted crops within the area (Table 3). The results showed that over the entire period (1965-2015) Niger South has recorded a mild agricultural drought season with an average value ranging from -0.015 to -0.069. This indicates that agricultural drought has a 34.1% probability of occurrence. A mild to extreme drought was observed in all the locations during the crop-growing season. This implies that farmers in the Niger South experienced similar effects of drought events as the magnitude of agricultural drought in different areas of the Niger South is similar in space and time. This is in agreement with earlier studies which claimed that mild to severe agricultural drought had been experienced in Northern Nigeria, and comparable drought events as been witnessed across the different locations of the Niger Basin (Okpara *et al.*, 2021).

Table 3: aSPI and eRDI value at different reference period and their correlation

Location	Reference period	Average		Correlation between aSPI and eRDI
		aSPI	eRDI	
Agaie	3 months	-0.043	-0.048	0.984
	6 months	-0.016	-0.028	0.974
	9 months	-0.041	-0.049	0.985
Bida	3 months	-0.043	-0.048	0.984
	6 months	-0.015	-0.028	0.973
	9 months	-0.040	-0.049	0.985
Gbako	3 months	-0.051	-0.053	0.983
	6 months	-0.020	-0.031	0.971
	9 months	-0.043	-0.049	0.984
Lapai	3 months	-0.062	-0.053	0.974
	6 months	0.019	0.019	0.961
	9 months	-0.021	-0.025	0.975
Lavun	3 months	-0.053	-0.050	0.950
	6 months	-0.019	-0.022	0.972
	9 months	-0.041	-0.044	0.983
Mokwa	3 months	-0.069	-0.066	0.984
	6 months	-0.033	-0.037	0.973
	9 months	-0.054	-0.056	0.984

The aSPI and eRDI indices value for the entire period (1965-2015) were correlated for the 3-, 6-, and 9-month reference period in all the study locations and it showed very strong positive correlations that ranged from 0.961 to 0.985. This strength of the correlation indicated the effectiveness of the two indices in monitoring and detecting agricultural drought and each of the indices can be used.

The time series plot shows agricultural drought occurrence (severity, magnitude and frequency) in Agaie, Bida, Gbako, Lapai Lavun and Mokwa areas as presented in Figures 2 to 7 respectively.

Indicatively, the time series analysis showed that agricultural drought which ranged from mild to extreme drought has been experienced in all the study areas. In terms of frequency, only 16 years out of the study period (51 years) were free from drought events. The first decade (1965-1974) experienced a normal to mild drought in all the study areas, except for 1970-1971 and 1973-1974 which experienced a moderate and severe drought respectively. Generally, a very wet season was experienced in 1978-1979 and 1991-1992 across the locations. Furthermore, very severe to extreme droughts were recorded in 1987-1988, 2001-2002, 2011- 2012 and 2015 across all the locations.

Similarly, the study area experienced a mild drought in 1965-1966, 1967-1968, 1972-1973, 1980-1981, 1993-1994, and 1999-2000. A moderate drought in 1970-1971, 2009-2010 and 2013-2014, Lapai however, experienced a long normal to mild wet season from 1993-2010. It is worth noting that all the study areas recorded severe to extreme drought from 2011-2015. The occurrence of agricultural drought has negatively impacted agricultural production, particularly crop yield in Niger South. This conforms with the work of Eze *et al.*, (2020) which reported a low yield of maize for a location in Niger south between 2013 to 2015.

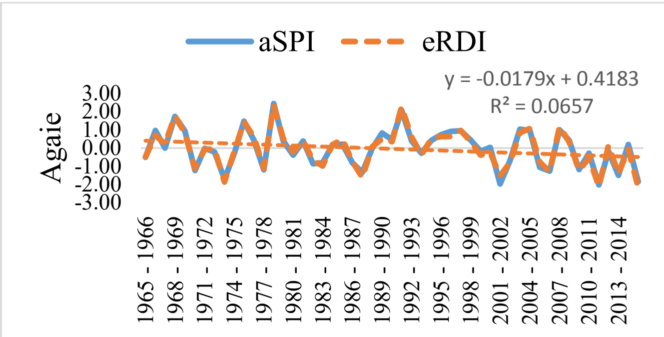

Figure 2. aSPI and eRDI of maize growing season (April-July) for Agaie.

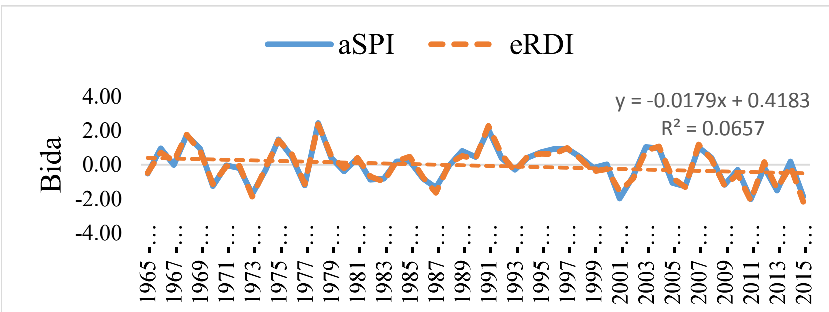

Figure 3. aSPI and eRDI of maize growing season (April-July) for Bida

The result of the analysis at Agaie (Figure 2), indicated that extreme drought was experienced in 2001-2002, 2011-2012 and 2015-2016 and a very severe to extreme drought occurred in 1987-1988, 2011-2012 and 2015. A similar level of severity has been reported for the tropical semi-arid zone of Nigeria and the frequency of the drought episodes seems to have increased (Shiru *et al.,* 2018). The occurrence of mild drought can result in a reduction of crop yield, while the occurrence of severe drought could attract total crop loss and increase the death rate of livestock (Abaje *et al.*, 2013; Animashaun *et al.*, 2020). Hence, the results obtained indicated that the State is vulnerable to drought events and liable to its impacts. This study suggests a need for an efficient drought mitigation strategy against the impact of the drought.

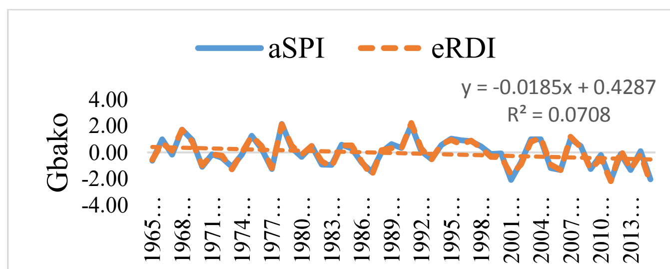

Figure 4. aSPI and eRDI of maize growing season (April-July) for Gbako

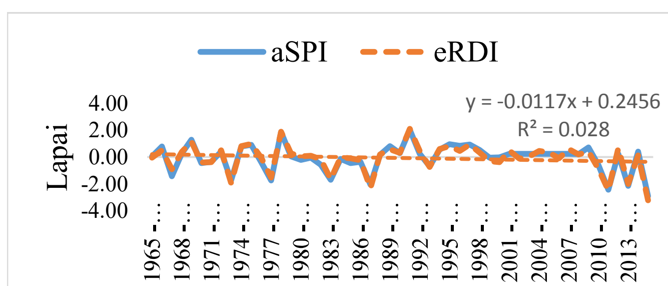

Figure 5. aSPI and eRDI of maize growing season (April-July) for Lapai

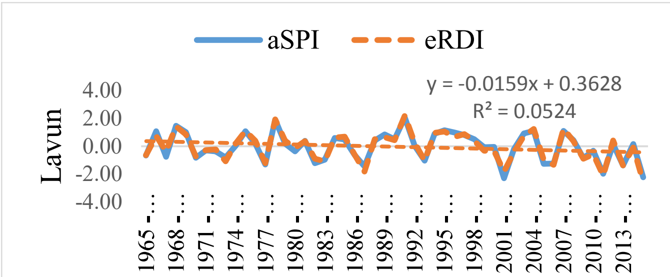

Figure **6.** aSPI and eRDI of maize growing season (April-July) for Lavun

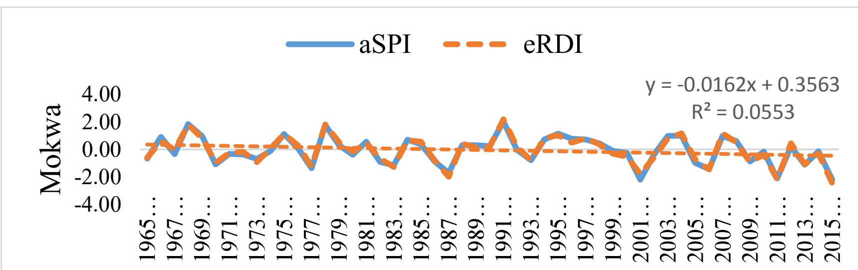

Figure 7. aSPI and eRDI of maize growing season (April-July) or Mokwa location

4. CONCLUSION

The indices (i.e., aSPI and eRDI) adopted in this study revealed that all the locations within the study area were susceptible and affected by agricultural drought episodes during the study period. A very severe to extreme drought incidence (≤ -2.0) was observed in the mid-80s, and early 2000 and between 2011-2015 across all but one location (Lapai) which received a mild wet season in 2001-2002. It was noted that the drought average value for all the locations shows a mild drought season ranging from (-0.015 to -0.066) and that agricultural drought has a high 34.1% probability of occurrence in the study area. The two indices used showed a very strong positive correlation (0.961 to 0.985) and effectiveness. The study underscores the need for proper monitoring of drought events to examine their potential impacts on agriculture and take proper measures to mitigate it.

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