ASSESSMENT OF DROUGHT VULNERABILITY IN NORTHER NIGERIA

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ABSTRACT

Drought is one of the most devastating hazards and widespread natural menace. Several studies have employed precipitation-based indices for drought appraisal in different geographical locations. In this study, the standardized precipitation evapotranspiration index (SPEI) was applied to assess the severity of drought in some parts of northern Nigeria (Bauchi and Gombe substations). The SPEI was calculated from fifteen-year precipitation and temperature data at 3- and 6-month time scale. The study observed that mild drought has been ever present in the area of study at short- and long-term accumulation periods. The year 2019 was observed to be the driest year. The study concludes that SPEI-3 and SPEI-6 showed the ability to quantify drought.

Keyword: SPEI, Drought, Evapotranspiration, Northern Nigeria

1. INTRODUCTION

Drought is one of the most costly and widespread hazards which cut across all hydro-climatological region and at any time of the year (Wilhite et al., 2000) bearing with it, severe societal consequences that span various sectors of the economy. While much of the other hazardous phenomena like flood, pollution and earthquake are distinct events, drought is a creeping phenomenon as it is more gradual, slowly affecting an area and tightening its grip (Mishra and Desai, 2005). It gradually increases in severity and tend to persist over a long period of time even after it has stopped (Yue *et al.* 2018).

Mishra and Desai (2005) opines that the multidimensional and multifaceted nature of drought makes it difficult to arrive at a unique definition of drought, however, based on the nature of water deficit, studies from Zulfiqar *et al.* (1992), Okorie (2003), Sepulcre-Canto *et al.* (2012), Abaje et al (2013), and Achugbu and Anugwo (2016) amongst others, broadly classifies droughts into four: (a)meteorological drought which is defined as a shortage or lack of precipitation, (b) the agricultural drought which is related to the period of inadequate water to meet crop water requirement (c) hydrological drought occurs when the water reserves available in surface and ground water sources fall below a locally significant threshold and (d) socio-economic drought which is related to failure of water resources systems to meet the water demands and therefore, associating droughts with supply of and demand for an economic good, in this case, water. In all these categories, drought can be said to occur as a result of significant rainfall deficit or lack of it for a fairly long period of time resulting to hydrological imbalances and affects the land productive system (Eze, 2018).

Drought has been identified as an integral part of Sudano-Sahel ecological zone (SSEZ) of Africa in which Northern Nigeria is part of since the 1960s (Adeniyi and Uzoma, 2016; Chibueze, 2016). The result of this menace according to Eze (2018) includes but not limited to impoverished household, livestock mortality, low crop yield and increased desertification. Consequently, the situation is being worsened by increase in human population, overgrazing, over-cultivation and high poverty rate (Abaje et al, 2013)

However, studies on the evaluation of drought impact have been undertaken in Northern Nigeria (Adeaga, 2011; Abaje *et al.*, 2013; Chibueze, 2016; Achugbu and Anugwo, 2016; Adeniyi and Uzoma, 2016; Achugbu and Balogun, 2017). The studies concentrated on the use of precipitation-based drought indices like standardized precipitation index (SPI) and drought severity index (DSI), hence, taking only account of precipitation as the only parameter for assessment. According to Narendra *et al.* (2019) precipitation-based indices give a wrong conceptualization of drought because it is based on the assumption that droughts are controlled by the temporal variability in precipitation only while other variables like temperature, evapotranspiration (E_T) and relative humidity remain stationary. Therefore, a key limitation for the precipitation-based index is that it cannot be used to evaluate future climatic scenario since parameters like temperature and evaporation are negligible. The standardized precipitation evapotranspiration index (SPEI) developed by Vicente-Serrano et al (2010) is considered as an alternative to SPI because it takes into account variability in temperature for the calculation of potential evapotranspiration (PET). The SPEI combines the effect of PET with multi-temporal nature of SPI (Potopova et al., 2015).

Therefore, the seasonal and inter-annual climatic variability in rainfall and temperature in this present global warming scenario calls for a suitable technique for drought assessment based on relevant data (Abaje et al., 2013). Against this background, the research seeks to assess the temporal variability of droughts in some parts of Northern Nigeria using standardized precipitation evapotranspiration Index (SPEI).

2. METHODOLOGY

The Sudan-Sahel ecological zone (SSEZ) in northern Nigeria lies between the latitude 10^o N-14.00^o N and longitude 2.73^o E-14^o E (Adeniyi and Uzoma, 2016). It extends from the Sokoto plains in the west to the Chad Basins in the east. Ferruginous tropical soils which are heavily weathered and markedly laterized covers more than half of the region (Oladipo, 1993; FRN, 2000).

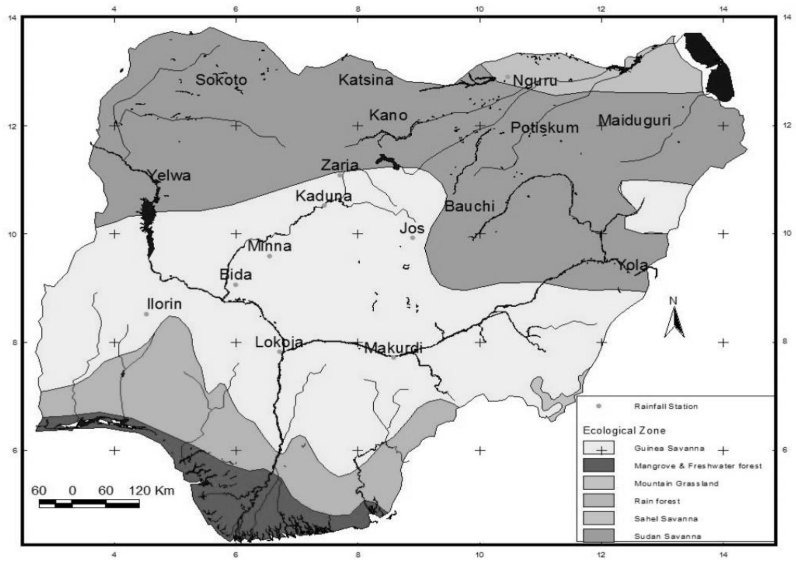

Figure 1: Map of Nigeria showing the study area. Source: Adeaga (2011)

The vegetation is the Savanna type consisting of Sudan and Sahel with the density of trees and other plants decreasing as one move northwards (Abaje, 2007). The region’s climate is dominated by two distinct seasons; dry season with northeast winds (October–April) and wet season (May-September) with strong southwest winds (Achugbu and Balogun, 2018). The average annual rainfall ranges between 300mm to 1500mm with peaks in July and August (Olatunde, 2013). For the purpose of this study, analysis of drought is narrowed down to two selected stations within the zone: Bauchi and Gombe, which are located in the north Eastern part of Nigeria. Fifteen years monthly precipitation, relative humidity and maximum and minimum temperature data has been collected for the study area from 2006 to 2020. Variations in the annual precipitation for fifteen years from 1950 to 2019 are shown in Figure 2 and Figure 3.

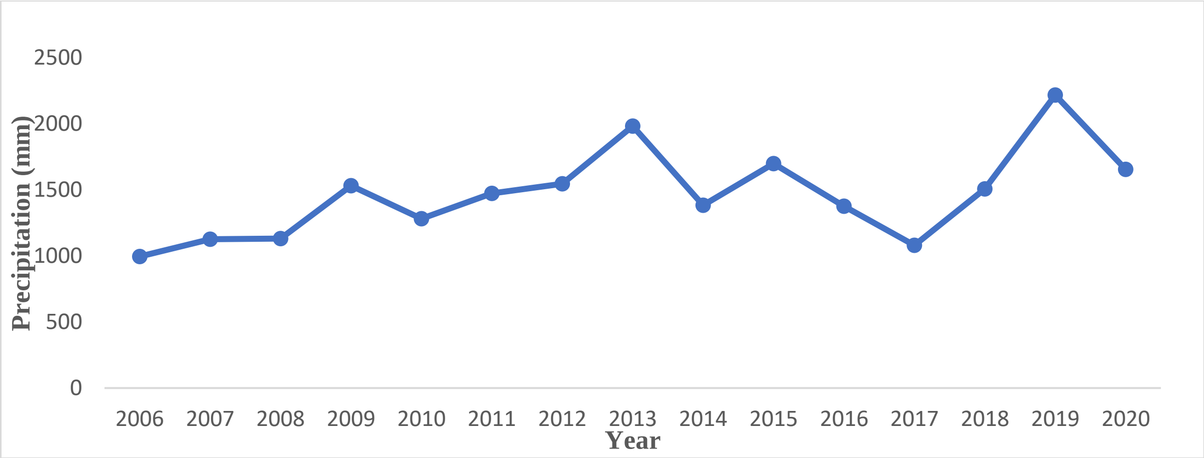

Figure 2: Annual Precipitation (mm) from 2006 to 2020 for Bauchi Station

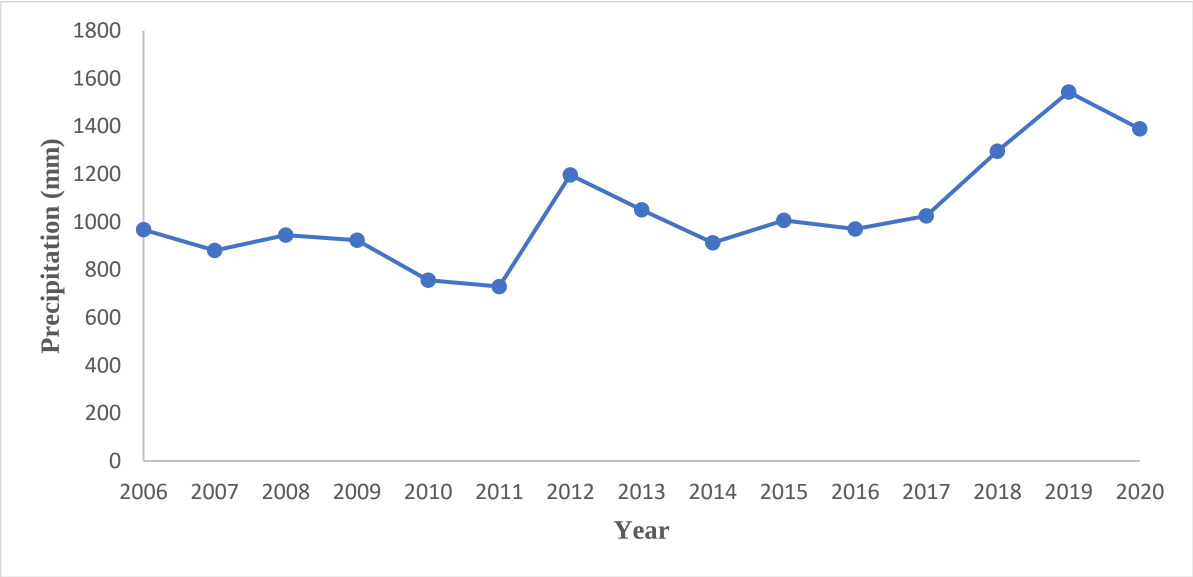

Figure 3: Annual Precipitation (mm) from 2006 to 2020 for Gombe Station

2.1 Standardized Precipitation Evapotranspiration Index (SPEI)

In this study, the SPEI was used to evaluate the drought events based on simple climatic water balance, that is, the difference between precipitation and potential evapotranspiration for each day. In line with Vicente-Serrano *et al.* (2010), the calculated daily D_i were aggregated at different time scales of 3 and 6 month following the same procedure as SPI.

$$D_i = P_i - PET_i \qquad (1)$$

Where, D_i is the difference between precipitation and potential evapotranspiration, P_i is the daily precipitation, and PET_i is the daily potential evapotranspiration.

The three-parameter log-logistic distribution was used to standardize the D series to get the SPEI. The log-logistic probability density function was used to fit the sequence as follows:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-y}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-y}{\alpha}\right)^{\beta}\right]^{-2} \quad (2)$$

where α, β and γ are scale, shape and origin parameters of the Log-logistic distribution respectively, for the D values in the range (γ> D<∞).

Thus, the probability distribution function of the D series, according to the log-logistic distribution, is given by:

$$F(x) = \left[1+\left(\frac{\alpha}{x-y}\right)^{\beta}\right]^{-1} \quad (3)$$

The SPEI was then obtained as a standardized value of F(x) using the classical approximation of Abramowitz and Stegun (1965) as given by Vicente-Serrano *et al.* (2010);

$$\text{SPEI} = W - \frac{C_0+C_1\text{W}+C_2W^2}{1+d_1W+d_2W^2+d_3W^3}, \quad (4)$$

where, W = √-2ln(P) for P ≤ 0.5, and P is the probability of exceeding a determined D value and P = 1 – F(x); when P > 0.5, P = 1 – P. the constants are C_0 = 2.515517, C_1= 0.802853, C_2 = 0.010328, d_1 =1.432788, d_2 =0.189269 and d_3 =0.001308

For ease of computation and elimination of error, all calculations were done using Microsoft Excel

Table 1. Standardized Precipitation Evapotranspiration Index Drought classification

SPI numerical range	Drought Conditions
Greater than 2.0	Extremely wet
1.5 - 1.99	Very wet
1.0 - 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Very dry
Less than -2.0	Extremely dry

Source: Faye et al. (2019)

2.2 Estimation of Potential Evapotranspiration (PET)

The PET in this study was estimated on temperature based empirical model developed by Duru (1984); the Blaney-Morin Nigeria (BMN). Blaney Morin Nigeria (BMN) takes into account the wide variability of relative humidity in Nigeria and the role it plays in evapotranspiration process (Idike, 2005). The PET estimate was obtained using the following formula:

$$\mathrm{PET} = Ƥ\frac{(0.45t+8)(H-R^{m})}{100} \tag{5}$$

where, PET = Potential evapotranspiration (mm/day), Ƥ = ratio of maximum sunshine hours for the period of interest to the annual maximum, t = average temperature (◦C), R = relative humidity (%), H and m are empirical constants given as 520 and 1.31 respectively.

3. RESULTS AND DISCUSSION

Tables 2 to 4 present the results of SPEI-3 and SPEI-6 for Bauchi and SPEI-3 and SPEI-6 for Gombe. From the tables, the drought months investigated are June to November as these are months which fall within the rainy season in Nigeria. The temporal variability of droughts was analysed for both 3-month and 6-month timescales. A higher negative value of SPEI suggests more severe drought, and persitence of negative value in the consecutive year for a given time scale depicts the persistence of drought. In this study, the SPEI diagrams (Figures 4 to 7) for drought months under investigation have been presented to show the pattern and trends in the years of study.

The drought analysis based on SPEI-3 in Bauchi indicates a near normal condition through the study period (2006 to 2020) (see table 2). This is illustrated in Figure 4 in which the month of June witnessed 7 consective years of mild drought between 2008 and 2014, July month also reveals 13 mild drought years except in 2012 and 2013 in which moderate droughts were observed. The result also showed severe drought years in August; 2013 and 2019. SPEI-3 September potrays 3 mild droughts, 10 moderately drought and 2 severe drought (2013 and 2019) were observed. Twelve drought years were observed in August and September more than other months.

Analysis of the variations of droughts years as illustrated in Figure 7 depict the spatial extent of SPEI as it reveals similarity between droughts events in both sub-stations (Gombe and Bauchi). Twelve mild wet years and 3 mild droughts years were observed in June. August years reveals mild and moderates droughts at the beginning of the first six and at the end of the last three years of the study period. SPEI-6 of September showed that the last three consecutive years were moderately dry while 2006 to 2012 were are slightly dry.

Generally, the results from this work shows that both the temporal variations of rainfall and temperature of Bauchi and Gombe are characteristically similar. a findings in this work agrees with the judgement of Abaje et al (2012a)

Table 2: SPEI-3 for Bauchi Sub-station

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
2006			1.0217	0.8607	0.19	-0.1883	-0.6968	-0.827	-0.7578	-0.371	0.04	0.643
2007	0.83	0.833	0.8472	0.7126	0.63	0.1103	-0.3706	-1.145	-1.1914	-0.858	0.096	0.814
2008	0.826	0.833	0.8504	0.8118	0.44	-0.3813	-0.7686	-1.176	-0.8303	-0.538	0.36	0.621
2009	0.84	0.845	0.8597	0.1465	0.03	-0.4429	-0.5485	-1.01	-1.1326	-1.089	-0.47	0.085
2010	0.837	0.843	0.8582	0.6522	0.32	-0.132	-0.7308	-0.607	-1.0325	-0.786	-0.781	0.179
2011	0.834	0.835	0.8509	0.8358	0.47	-0.0726	-0.3488	-1.184	-1.3647	-1.291	-0.422	0.338
2012	0.828	0.829	0.8419	0.7653	0.06	-0.2082	-1.0883	-1.205	-1.3961	-0.826	-0.309	0.765
2013	0.827	0.829	0.8437	0.7045	0.42	-0.3702	-1.2167	-1.703	-1.5853	-1.189	0.08	0.314
2014	0.844	0.748	0.7375	0.3537	0.04	-0.4636	-0.916	-1.147	-1.1264	-0.653	0.002	0.778
2015	0.839	0.837	0.7562	0.7587	0.69	0.1933	-0.8211	-1.485	-1.6135	-1.249	-0.257	0.596
2016	0.842	0.842	0.7934	0.6671	0.17	-0.1483	-0.7591	-1.171	-1.2683	-0.901	-0.038	0.829
2017	0.84	0.841	0.8529	0.8602	0.45	0.0661	-0.4165	-0.966	-0.9671	-0.798	0.11	0.511
2018	0.838	0.841	0.8499	0.8377	0.22	-0.3339	-0.7711	-1.326	-1.2762	-1.097	0.021	0.551
2019	0.84	0.839	0.8576	0.5173	0.14	-0.442	-1.0974	-1.603	-1.5938	-1.464	-0.692	-0.1
2020	0.836	0.836	0.752	0.7405	0.36	-0.1139	-0.8767	-1.352	-1.4525	-1.161	-0.374	0.509

TABLE 3: SPEI-6 for Bauchi Sub-station

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
2006						0.2952	0.0039	-0.2948	-0.46138	-0.50179	-0.343	-0.105
2007	0.0248	0.451	0.7814	0.8071	0.768	0.4975	-0.012	-0.459	-0.62355	-0.60141	-0.587	-0.466
2008	-0.144	0.4838	0.8646	0.8524	0.6745	0.0238	-0.069	-0.5294	-0.58847	-0.62149	-0.549	-0.173
2009	-0.1	0.6356	0.7758	0.5155	0.3044	-0.02	-0.103	-0.5634	-0.81587	-0.82615	-0.742	-0.578
2010	-0.359	-0.0458	0.4871	0.7814	0.6116	0.2045	-0.081	-0.0858	-0.63255	-0.726	-0.662	-0.467
2011	-0.078	-0.0742	0.5381	0.8673	0.6868	0.3897	0.0433	-0.5317	-0.82472	-0.90129	-0.845	-0.734
2012	-0.565	-0.0138	0.6223	0.8313	0.4594	0.1463	-0.374	-0.6491	-0.94564	-0.94505	-0.822	-0.687
2013	-0.115	0.07	0.8384	0.8022	0.6598	0.03	-0.513	-1.072	-1.15059	-1.19727	-1.163	-0.963
2014	-0.457	0.3034	0.565	0.6314	0.2793	-0.073	-0.319	-0.6671	-0.81913	-0.76202	-0.613	-0.408
2015	0.0361	0.4298	0.8043	0.8334	0.7998	0.5077	-0.129	-0.7952	-1.01245	-1.04395	-1.035	-0.949
2016	-0.519	0.1115	0.7342	0.7906	0.5319	0.1712	-0.1	-0.589	-0.82229	-0.80409	-0.71	-0.542
2017	-0.18	0.2618	0.8729	0.8812	0.6828	0.3333	0.0002	-0.3354	-0.51682	-0.58367	-0.502	-0.322
2018	-0.088	0.3567	0.716	0.8699	0.5546	0.0588	-0.065	-0.7227	-0.88534	-0.92545	-0.824	-0.604
2019	-0.366	0.2995	0.7398	0.7151	0.5127	-0.02	-0.439	-1.0101	-1.17647	-1.29984	-1.254	-1.095
2020	-0.749	0.0022	0.1874	0.8235	0.6313	0.1798	-0.183	-0.7175	-0.96973	-1.01254	-0.957	-0.791

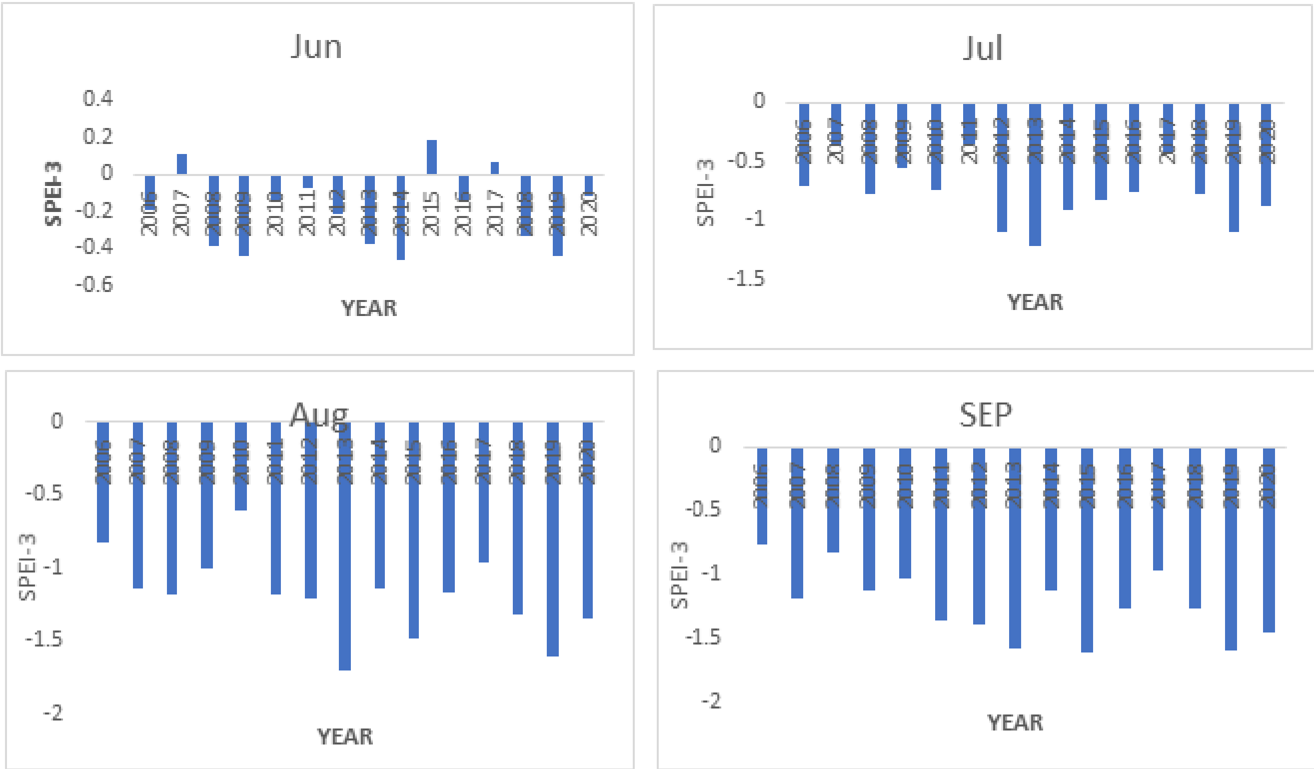

Figure 4: BAUCHI SPEI-3 diagram for JUN, JUL, AUG, SEP

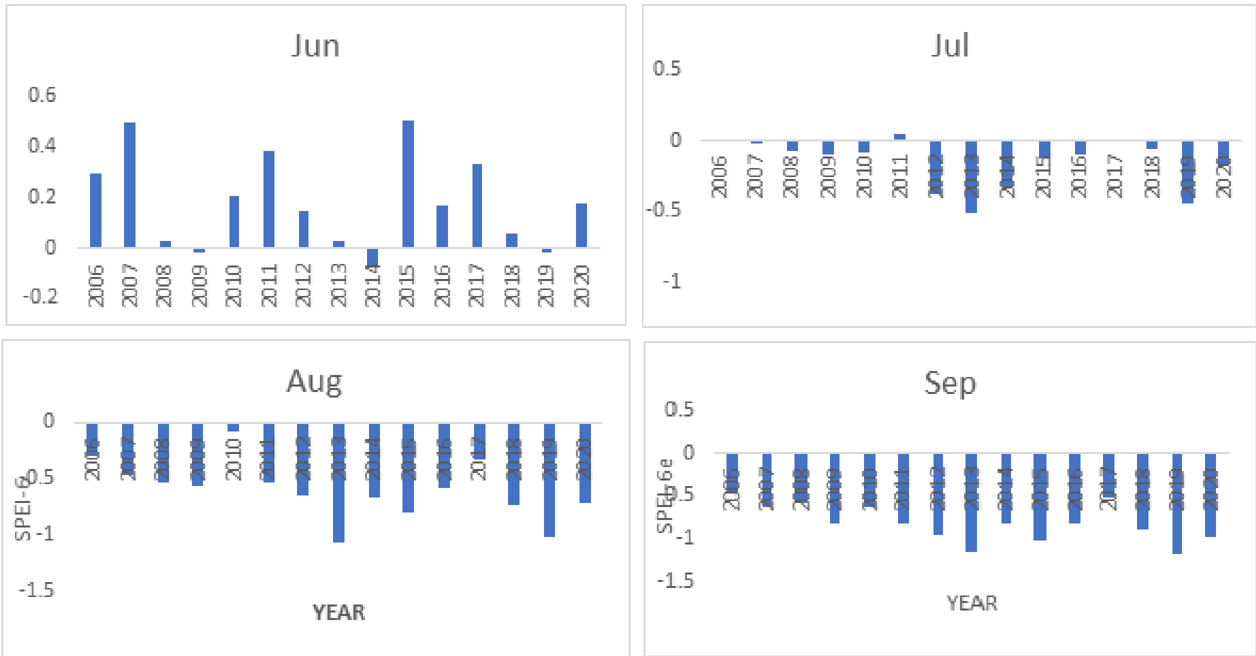

Figure 5: BAUCHI SPEI-6 diagram for JUN, JUL, AUG, SEP

The SPEI-3 for Gombe stations demostrates that Gombe suffered from 32 droughts episodes. Table 4 depicts January through to June and subsequently November to December as normal months. The drought analysis based on 3-months time scale for SPEI-3 (June) points to 10 mild drought years and 5 mild wet years. SPEI-

3 (July) demostrate 11 mild droughts, 3 moderate droughts and 1 severe drought in 2019. In this study, SPEI-3 reflects the similar spatio-temporal characteristics in Gombe as well as Bauchi (Figure 4 and 6) as the drought severity levels observed in both sub-stations have occurrence of frequent mild drought conditions, occasional moderate droughts as well as flashes of severe drought in the August and November months. This by implication means both states are prone insuffcent rainfall which can be a danger to agricultural development. This findings agree with Achugbu and Balogun (2017)

The multiscalar nature of SPEI like the SPI could also be asscoaited with seasonal to medium term trends in precipiatation as impacts stream flows, reservoir levels (WMO, 2012). Figure 5 shows that Bauchi experienced 12 years of mild wet and 3 years of mild droughts episodes (see SPEI-6 June). Like SPEI-3, the SPEI-6 (July) shows persistence of mild drought in 13 years. A glance at SPEI-6 August shows negative values. Although, the values are not extreme case of drought severity but the continued negative value indicate a likelihood of crop stress resulting from inadequte water to meet soil moisture. The mild drought years were further revealed in Figure 5 which reveals 7 consective years of mild drought (2006 to 2012) but 12 drought years in total for SPEI-6 September. Moderate droughts were also observed in between years (2013, 2015 and 2019).

Table 4: SPEI-3 for Gombe sub-station

Year	*jan*	*feb*	*mar*	*apr*	*may*	*jun*	*jul*	*aug*	*sep*	*oct*	*Nov*	*dec*
2006			1.082	0.922	0.477	0.052	-0.621	-0.986	-1.275	-1.0116	-0.46	0.6142
2007	0.8782	0.883	0.9	0.752	0.3877	-0.0089	-0.7734	-1.172	-1.179	-0.621	0.089	0.855
2008	0.8579	0.883	0.901	0.741	0.0522	-0.1911	-0.4684	-0.939	-1.089	-1.0223	-0.2	0.4363
2009	0.8861	0.89	0.908	0.689	-0.0896	-0.3812	-0.7224	-0.892	-0.92	-0.763	-0.1	0.3653
2010	0.8831	0.891	0.899	0.59	0.3816	0.044	-0.4176	-0.805	-0.752	-0.5837	0.028	0.2284
2011	0.8847	0.884	0.906	0.613	0.4621	0.0354	-0.2828	-0.845	-0.918	-0.627	-0.06	0.5203
2012	0.8858	0.887	0.902	0.835	0.4375	-0.3186	-1.1076	-1.519	-1.467	-0.996	0.01	0.6922
2013	0.8812	0.885	0.872	0.723	0.5112	0.0971	-0.3397	-1.433	-1.374	-1.2632	0.058	0.5017
2014	0.8833	0.885	0.902	0.716	0.0308	-0.1309	-0.7131	-0.781	-1.142	-0.7576	-0.33	0.7053
2015	0.8818	0.889	0.85	0.858	0.6432	0.0658	-0.3828	-1	-1.299	-1.206	-0.63	0.2277
2016	0.8849	0.886	0.788	0.284	0.0847	-0.4843	-0.6	-1.085	-1.067	-0.8301	-0.07	0.8261
2017	0.8854	0.885	0.898	0.685	0.0591	-0.5291	-1.0101	-1.052	-1.125	-0.6905	-0.11	0.6946
2018	0.8821	0.886	0.9	0.903	0.0963	-0.1066	-0.7833	-1.313	-1.648	-1.4187	-0.63	0.7355
2019	0.8824	0.883	0.895	0.831	0.2101	-0.9542	-1.5044	-1.675	-1.326	-1.1157	-0.52	-0.101
2020	0.8796	0.879	0.705	0.519	0.0282	-0.5451	-1.2729	-1.458	-1.538	-1.0743	-0.4	0.5038

Table 5: SPEI-6 for Gombe sub-station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006						0.497	0.113	-0.321	-0.756	-0.808	-0.723	-0.549
2007	-0.23	-0.006	0.7898	0.847	0.667	0.312	-0.06	-0.509	-0.696	-0.668	-0.592	-0.399
2008	0.094	0.5032	0.9068	0.833	0.482	0.1928	-0.06	-0.414	-0.69	-0.75	-0.586	-0.422
2009	-0.24	0.1826	0.7031	0.82	0.401	0.0621	-0.04	-0.427	-0.647	-0.714	-0.514	-0.299
2010	-0.01	0.2524	0.6618	0.77	0.667	0.3451	-0.07	-0.202	-0.364	-0.462	-0.407	-0.212
2011	-0.1	0.3297	0.5909	0.783	0.706	0.4816	0.026	-0.208	-0.404	-0.423	-0.383	-0.251
2012	0.098	0.4156	0.7436	0.89	0.694	0.1049	-0.33	-0.83	-1.024	-1.042	-0.978	-0.725
2013	-0.22	0.3185	0.8158	0.835	0.732	0.3676	0.027	-0.728	-0.827	-0.871	-0.832	-0.671
2014	-0.48	0.486	0.734	0.832	0.47	0.2335	-0.02	-0.303	-0.708	-0.706	-0.537	-0.399
2015	-0.01	0.0926	0.812	0.899	0.799	0.4764	0.044	-0.287	-0.708	-0.843	-0.805	-0.665
2016	-0.42	0.0957	0.5408	0.612	0.365	-0.054	-0.08	-0.592	-0.786	-0.69	-0.568	-0.299
2017	-0.07	0.4104	0.8919	0.818	0.349	-0.052	-0.28	-0.575	-0.843	-0.839	-0.633	-0.387
2018	0.046	0.2428	0.8295	0.921	0.509	0.2488	-0.03	-0.712	-1.123	-1.143	-1.012	-0.91
2019	-0.64	0.0917	0.8473	0.887	0.571	-0.177	-0.74	-1.033	-1.152	-1.335	-1.253	-0.843
2020	-0.33	-0.052	0.1792	0.733	0.327	0.1031	-0.57	-0.919	-1.149	-1.175	-1.042	-0.836

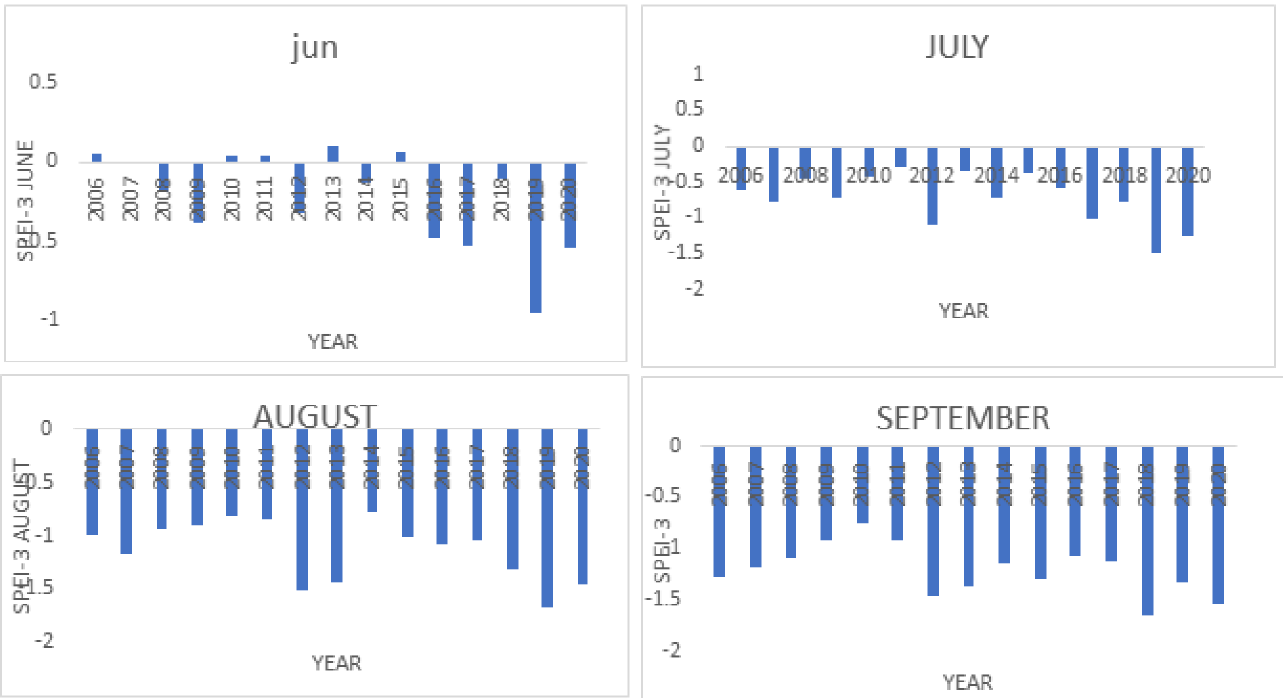

Figure 6: GOMBE SPEI-3 diagram for JUN, JUL, AUG, SEP

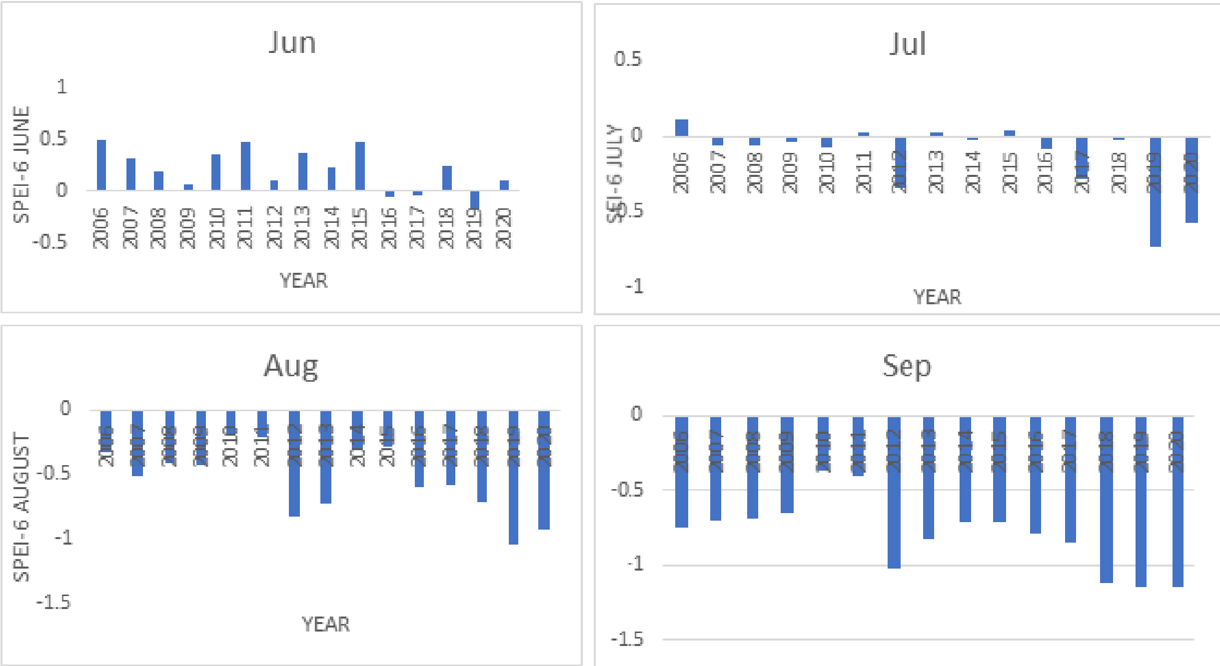

Figure 7: GOMBE SPEI-6 diagram for JUN, JUL, AUG, SEP

4.0 CONCLUSION

This study was undertaken to evaluate the severity of droughts in some selected parts of northern Nigeria which falls within the Sudan-Sahel belt. Temporal variability of both meteorological and agricultural droughts at seasonal scale were also investigated and results showed that mild droughts were the most dominant drought category in the area of study with constant presence. The years 2012, 2013, 2015 and 2019 qualified as the most drought prone years by SPEI-3 and SPEI-6. However there was no record of extreme drought conditions except flashes of severe droughts which was observed in 2019 that also happened to be the driest year. The study furtrher showed a similar temporal variation of both stations under study as the drought spatio-temporal characteristics have a similar trend. It can be concluded that better judegement of the drought ocurrence and its impact on agriculture and water resources can be obtained using both the SPEI-3 and SPEI-6.

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