2nd International Civil Engineering Conference (ICEC 2020)
Department of Civil Engineering
Federal University of Technology, Minna, Nigeria

Drought Vulnerability Assessment of Minna using Standardized Precipitation Index (SPI) Method

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ABSTRACT
Drought is one of the most naturally occurring menace and threat to human existence and the environment through the ages and the Standardized Precipitation Index (SPI) has become a popular measure of drought across the globe. In this study, Standardized Precipitation Index (SPI) was used for observing and describing drought based on seventy (70) year precipitation data of Minna sub-station. This is evident from the obtained results as the driest and the wettest years were observed with the SPI at a 3-month scale. 1987 was observed as the driest year with the worst drought using SPI at a 3-month scale while 2019 was observed to be the wettest year. Therefore, the present study concludes that the 3-month SPI of June represents the good indicator of any drought vulnerability assessment of any drought-prone areas.

Keywords: *Drought, Minna, Time scale, Standardized Precipitation Index*

1 INTRODUCTION

Drought is one of the most naturally occurring menace and threat to human existence and the environment through the ages; as it cut across all geographic regions (Hao et al., 2018; Eze, 2018). This climatic hazard is as old as the existence of man. It is a temporary, recurring natural disaster which originate from lack of precipitation, bringing significant economic loss (Smakhtin and Hughes, 2004). It is a multifaceted and multidimensional phenomenon and is considered by many to be the most complex but least understood natural hazards due to its multiple causing mechanisms or contributing factors operating at different temporal and spatial scales (Kiem et al., 2016; Mishra and Desai, 2005).

It is very difficult to determine when a drought begins or ends but its origin usually starts with the lack of precipitation (Mishra and Desai, 2005). Depending on its severity, it may affect agriculture and water supplies with respect to soil moisture, streams, and groundwater. In certain cases, unusual deviation of environmental variables such as evapotranspiration, high wind, low relative humidity, temperature, characteristics and duration of rain, intensity and onset may result to drought (Cook et al., 2014; Livneh & Hoerling, 2016; Luo et al., 2017). However, the role of deficient long-term precipitation records greatly contributes in all these (Vardharajula et al.,2011). Specifically, high temperature may lead to increased evaporation and reduced soil moisture, causing drought in agricultural sectors. However, drought may not be a purely natural hazard as human activities such as land use changes, overexploitation of surface water resources and reservoir operation may alter hydrologic processes and could deteriorate to drought development (Van Loon et al., 2016).

Minna, the capital city of Niger State in Northern Nigeria constitutes one of the the 'grain baskets' of Nigeria in terms of food production, producing a large proportion of the grains (e,g. maize, millet, sorghum, and wheat) (Oladipo 1993) that provide the main staple diet of Nigerians. Despite the heavy investment in agriculture by both Federal and State governments in the area of massive irrigation schemes in this region, for instance, agriculture is still largely rainfed, depending majorly on rainfall which is between the months of April and October in average. However, with rainfall in northern part of Nigeria largely seasonal and highly variable from year to year, agriculture in the region has suffered serious setbacks and this has thus led to insecurity in food supply in the region and by extension food scarcity in the entire country. Because of the large inter-annual variability of rainfall, this region has also been subjected to frequent dry spells of which has affected the farming activities in the entire region. These can sometimes result in severe and widespread droughts that are capable of imposing serious socio-economic constraints as reiterated by Lange et al (2017) and Dar et al., (2020).

2 METHODOLOGY

The study area is Minna, the capital city of Niger State located between Latitude 9° 5000^I and 9° 5625^I N and Longitude 6° 373^I and 6° 4375^I E (Figure 1). The soil type on the study area was in a textural class of gravelly sand up to the depth of 80 - 90 cm. The area is characterized with low and erratic rainfall of between 1000 to 1200 mm as total annual rainfall with peaks in July and August. Seventy years monthly precipitation data has been collected from Nigerian Meteorological Agency (NiMet) for the study area from 1950 to 2019. Variations in the annual precipitation for seventy years from 1950 to 2019 is as shown in Figure. 2.

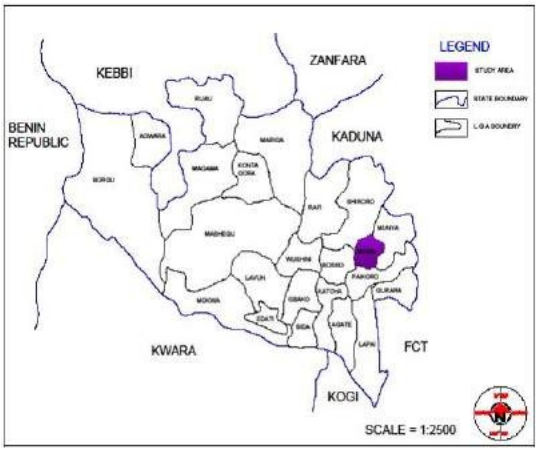

Figure 1: Map of Niger State showing the study area
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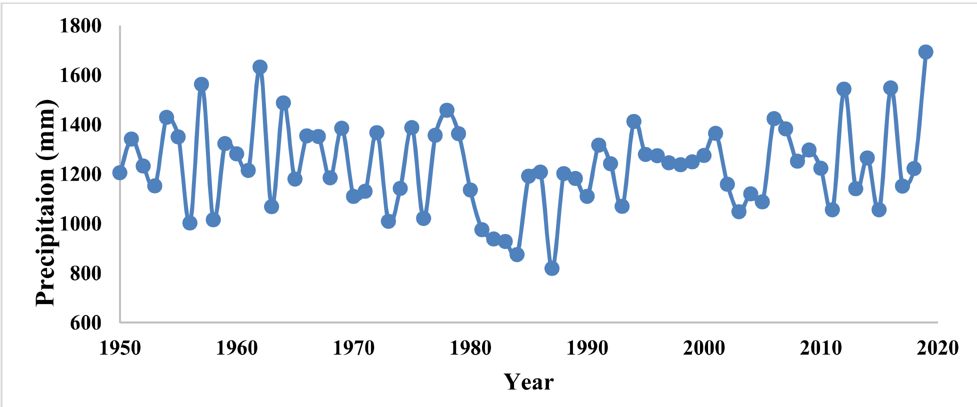

Figure 2: Annual Precipitation (mm) from 1950 to 2019 for Minna Station

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The drought events based on the precipitation obtained from Minna basin were assessed using SPI (McKee et al., 1993). This index is based on the cumulative probability of the considered precipitation as presented in equation 1:

$$G(x) = \frac{1}{\beta_{pro}^{\alpha_{pro}}\Gamma(\alpha_{pro})}\int_0^x x^{\alpha_{pro}-1}e^{-\frac{x}{\beta_{pro}}}dx \qquad 1$$

where

$$\alpha_{pro} = \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right)$$

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The 3-month SPI was calculated for Minna rainfall station using monthly rainfall data for the period of 1950–2019. SPI is categorized based on their range values as shown in table 1.

TABLE 1. CATEGORY OF STANDARDIZED PRECIPITATION INDEX (SPI) BASED ON RANGE VALUES

SPI	Range Category
+ 2 to more	Extremely wet
1.5 to 1.99	Very wet
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3 RESULTS AND DISCUSSION

Table 2 presents the results of SPI for 3-month time scale drought estimation for the study area. From the table, the drought months for consideration are June to November as months of December to May are mostly regarded as dry season months.

TABLE 2: SPI 3-HR TIME SCALE FOR STUDY AREA

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1950			-0.524	0.357	0.929	0.293	0.923	-0.570	-0.269	-0.957	-0.117	0.389
1951	0.746	0.524	0.991	0.499	-0.471	-0.965	-0.385	-0.113	0.507	1.061	1.569	1.709
1952	0.539	0.594	-0.292	-0.400	0.844	0.610	1.111	-0.975	-0.299	-0.605	0.574	0.295
1953	0.444	2.059	1.981	0.476	0.841	-0.422	0.203	-1.559	-0.632	-0.704	-0.312	0.336
1954	0.444	0.524	2.062	1.739	0.569	-0.186	-0.074	0.678	0.629	0.807	1.000	1.185
1955	0.632	0.524	-0.230	0.361	-0.544	-0.409	0.475	0.847	1.304	0.566	0.827	-0.123
1956	0.444	0.768	0.786	0.198	-1.470	-0.415	-1.383	-1.914	-1.595	-0.871	0.235	0.583
1957	1.843	1.528	-0.524	0.240	0.408	0.867	2.020	2.298	1.176	0.408	0.549	1.259
1958	2.135	0.942	0.199	0.079	0.645	0.132	-1.290	-2.129	-1.336	-0.645	-0.498	-0.334
1959	1.101	1.052	1.105	0.218	-0.664	0.186	-0.222	0.839	0.861	0.787	0.527	-1.069
1960	1.334	0.524	0.840	1.230	0.071	-0.030	0.430	0.035	0.365	-0.583	0.309	0.253
1961	1.991	1.781	0.239	-0.168	-0.670	-0.070	1.016	0.308	0.286	-0.805	0.105	-0.340
1962	0.444	0.524	-0.524	1.216	0.838	1.170	0.360	1.313	1.132	1.869	1.843	1.680
1963	1.451	0.711	-0.072	0.144	-1.533	-1.203	-0.723	0.061	-0.119	-0.468	-0.601	0.027
1964	0.444	0.524	-0.172	0.328	-0.018	-0.444	-0.474	0.077	1.973	2.031	2.270	0.213
1965	1.580	2.250	2.315	0.058	-0.539	0.375	0.631	0.068	-0.950	-0.960	-0.793	-0.162
1966	0.444	0.524	-0.524	0.212	0.067	0.763	-0.057	0.482	0.327	1.029	0.875	0.522
1967	0.444	0.524	-0.105	0.925	-0.076	0.447	-0.807	0.145	0.910	1.222	1.240	-0.534
1968	0.444	0.524	0.037	1.506	0.993	1.479	0.523	0.164	-1.140	-1.352	-1.259	-0.562
1969	0.444	0.524	0.158	0.210	0.909	0.253	1.449	0.460	0.135	-0.017	0.592	1.763
1970	0.780	0.524	0.184	-1.077	-1.931	-2.118	-1.783	-0.101	0.972	0.804	0.216	-1.398
1971	0.444	0.768	0.623	-0.873	-0.472	0.131	0.716	0.432	-0.063	-0.911	-1.024	-2.046
1972	0.444	0.524	1.410	0.339	1.358	-0.117	0.993	1.588	1.296	0.272	-1.443	-1.285
1973	0.444	0.524	-0.208	-1.024	-1.542	-1.759	-3.007	-0.813	0.170	0.730	-0.248	-1.176
1974	0.444	0.524	-0.145	-1.651	-0.901	-0.877	0.284	0.095	0.197	-0.292	-0.152	0.058
1975	0.444	1.164	1.226	1.863	1.505	0.991	0.768	-0.186	0.542	-0.199	0.583	-0.617
1976	0.444	2.353	2.218	1.163	-0.471	0.006	-0.377	-1.182	-3.352	-1.709	-1.375	1.667
1977	0.444	0.524	-0.524	-2.453	-1.119	-0.708	0.301	1.502	1.567	1.209	0.480	-0.283
1978	0.444	0.524	0.667	1.146	2.224	1.229	0.676	0.425	0.615	0.762	0.123	0.231
1979	0.688	0.524	0.431	-0.823	-0.202	-0.017	0.697	2.176	1.084	0.748	-0.892	-0.128

1980	0.821	0.524	-0.524	-2.078	0.619	0.428	0.665	-0.311	-0.937	-0.637	-0.873	0.475
1981	0.444	0.524	-0.524	-1.133	-2.243	-1.163	-0.749	-0.258	-0.658	-0.836	-0.916	-0.258
1982	0.444	0.524	0.325	0.379	-2.191	-3.994	-2.286	-0.357	0.116	-0.535	-1.279	-0.203
1983	0.444	0.524	0.287	-1.713	-1.488	-1.866	-1.643	-0.886	-0.258	-0.483	-1.120	-1.838
1984	0.444	0.524	-0.253	-0.072	-0.903	-1.112	-0.997	-1.578	-1.324	-1.831	-1.366	-0.717
1985	0.444	0.524	1.889	0.356	0.361	0.469	1.177	1.068	-0.340	-1.294	-1.861	-1.475
1986	0.444	0.524	1.229	-0.139	-0.860	-0.662	-0.182	0.646	0.490	0.227	-0.117	-0.542
1987	0.656	0.524	1.672	-0.061	-0.493	-2.023	-1.961	-1.947	-1.947	-1.582	-2.054	-0.185
1988	0.935	0.945	0.209	-0.063	-0.660	-0.668	-1.053	-0.235	0.919	0.703	0.525	-1.729
1989	0.444	0.524	0.031	1.217	0.988	1.393	0.582	0.076	-0.985	-1.238	-1.180	-0.815
1990	0.444	0.524	-0.524	0.862	1.412	0.464	-0.166	-1.818	-1.086	-0.922	-0.365	0.307
1991	0.444	0.524	-0.524	0.941	2.742	2.218	1.646	-0.027	-0.511	-1.047	-1.618	-1.869
1992	0.444	0.524	-0.393	1.525	1.692	1.264	0.235	-0.525	-0.470	-0.919	-0.512	-0.481

The SPI diagrams for different drought months (June to November) have been presented to show the pattern and trends of SPI during these years (Figures 3 to 5). The 3-month SPI for the months of August to November show the temporal dynamics of below and above normal precipitation distribution in Minna. It can be seen that during the drought years of 1976. 1982, 1984 and 1987, negative SPI values were observed in the study area and this indicates that there was rainfall deficit in these areas particularly during the drought months of June–November. In these drought years of 1976, 1982, 1984 and 1987, the spatial patterns of 3-month SPI across crucial months (June-November) shows negative SPI values, with the area having an SPI value above −3.0. Thus, the spatio-temporal evolution of the SPI clearly indicates that 1982 was the most drought-prone year taking into consideration the magnitude and extent of a negative SPI value (-3.993) which is consistent with Gore and Sinha Ray (2002). From the results, the month of June recorded this highest value of 3-month SPI across the years under study. 1973 and 1976 were also seen as having high SPI values ranging from −3.0 to −3.35, especially in the months of July, September and October. However, during the wet years of 1957, 1962, 2001 and 2019, the observed 3-month SPI values across the drought months of June-November are mostly positive, ranging from 2.00 in 1962 to 2.49 in 2016 which shows that these years were wet years which is in consonance with Figure 2.

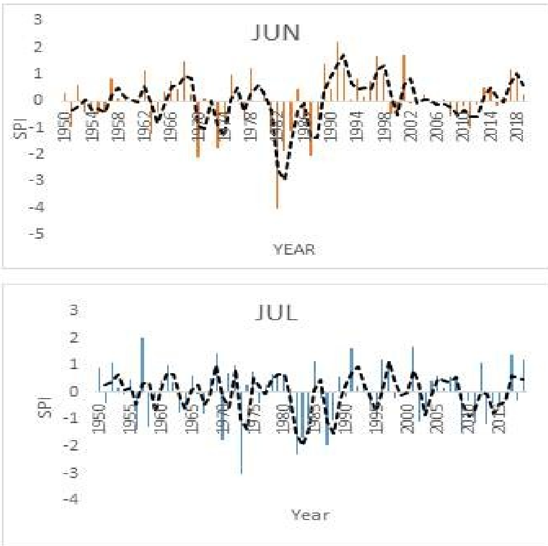

Figure 3: SPI diagrams for JUNE & JULY in the study area

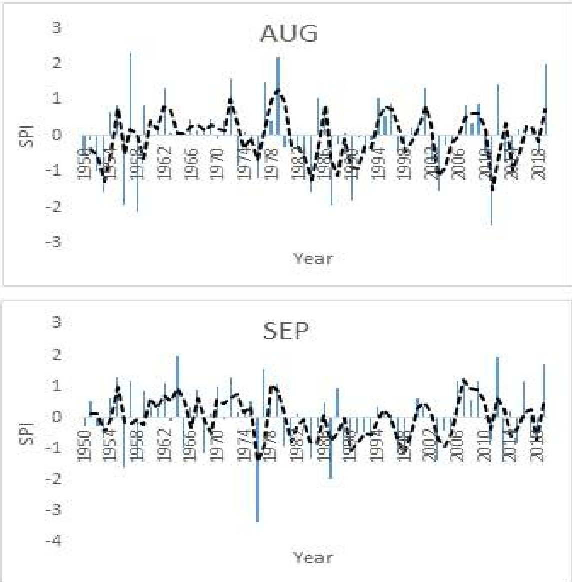

Figure 4: SPI diagrams for AUG & SEP in the study area

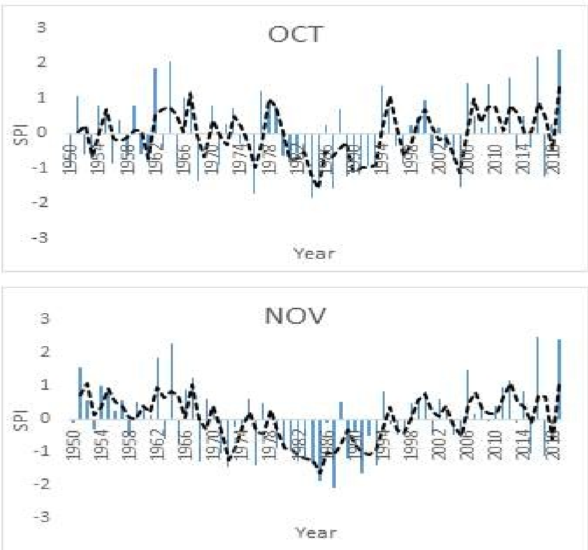

Figure 5: SPI diagrams for OCT & NOV in the study area

4 CONCLUSION

The assessment of drought vulnerability of Minna has been presented in this study using 70 years rainfall data. This study has also shown the appraisal and the usefulness of the SPI to check the variability in meteorological drought at seasonal scale in semi-arid parts of Nigeria in which Minna is found. The SPI at a 3-month time-scale was found effective in capturing seasonal drought patterns over space and time in Minna. This is evident from the obtained results as the driest and the wettest years were observed with the SPI at a 3-month scale. 1987 was observed as the driest year with the worst drought using SPI at a 3-month scale while 2019 was observed to be the wettest year. Therefore, the present study concludes that the 3-month SPI of June represents the good indicator of any drought vulnerability assessment of any drought-prone areas.

REFERENCES

Dar, M. H., Waza, S. A., Shukla, S., Zaidi, N. W., Nayak, S., Hossain, M., ... & Singh, U. S. (2020). Drought Tolerant Rice for Ensuring Food Security in Eastern India. *Sustainability*, *12*(6), 2214.

Eze, J. N. (2018). Drought occurrences and its implications on the households in Yobe state, Nigeria. *Geoenvironmental Disasters*, *5*(1), 18.

Hao, Z., Singh, V. P., & Xia, Y. (2018). Seasonal drought prediction: advances, challenges, and future prospects. *Reviews of Geophysics*, *56*(1), 108-141.

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

Kiem, A. S., Johnson, F., Westra, S., van Dijk, A., Evans, J. P., O'Donnell, A., ... & Jakob, D. (2016). Natural hazards in Australia: droughts. *Climatic Change*, *139*(1), 37-54.

Lange, B., Holman, I., & Bloomfield, J. P. (2017). A framework for a joint hydro-meteorological-social analysis of drought. *Science of the Total Environment*, *578*, 297-306.

Livneh, B., & Hoerling, M. P. (2016). The physics of drought in the US central Great Plains. *Journal of Climate*, *29*(18), 6783-6804.

Luo, L., Apps, D., Arcand, S., Xu, H., Pan, M., & Hoerling, M. (2017). Contribution of temperature and precipitation anomalies to the California drought during 2012–2015. *Geophysical Research Letters*, *44*(7), 3184-3192.

Mishra, A. K., & Desai, V. R. (2005). Drought forecasting using stochastic models. *Stochastic Environmental Research and Risk Assessment*, *19*(5), 326-339.

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

Smakhtin, V. U., & Hughes, D. A. (2004). Review, automated estimation and analyses of drought indices in South Asia (Vol. 83). Iwmi.

Van Loon, A. F., Gleeson, T., Clark, J., Van Dijk, A. I., Stahl, K., Hannaford, J., ... & Hannah, D. M. (2016). Drought in the Anthropocene. *Nature Geoscience*, *9*(2), 89.

Vardharajula, S., Zulfikar Ali, S., Grover, M., Reddy, G., & Bandi, V. (2011). Drought-tolerant plant growth promoting Bacillus spp.: effect on growth, osmolytes, and antioxidant status of maize under drought stress. *Journal of Plant Interactions*, *6*(1), 1-14.

Williams, A. P., Seager, R., Abatzoglou, J. T., Cook, B. I., Smerdon, J. E., & Cook, E. R. (2015). Contribution of anthropogenic warming to California drought during 2012–2014. *Geophysical Research Letters*, *42*(16), 6819-6828.

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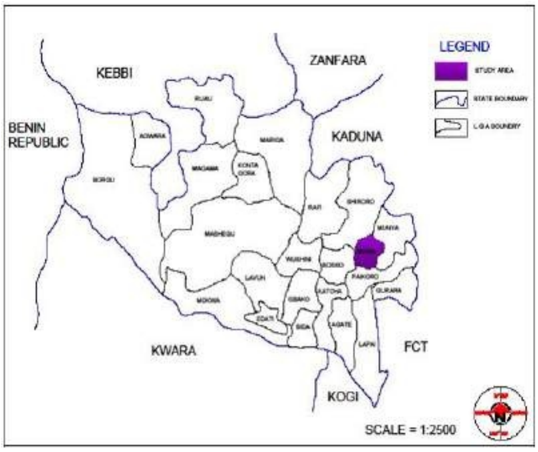

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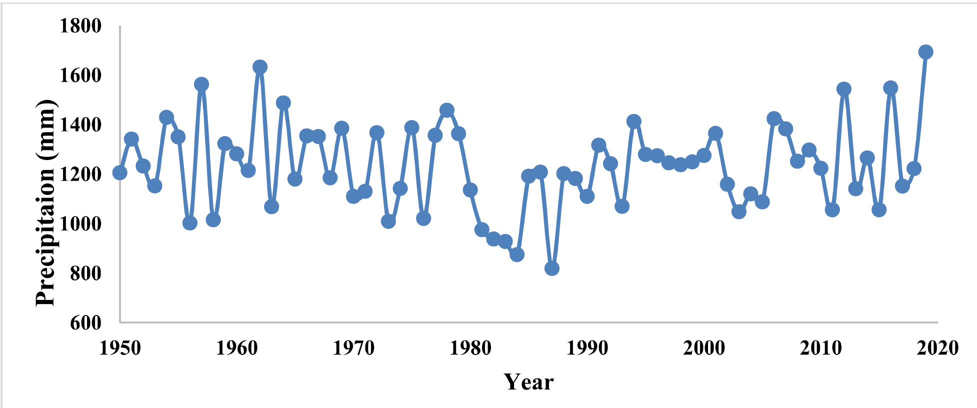

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1950			-0.524	0.357	0.929	0.293	0.923	-0.570	-0.269	-0.957	-0.117	0.389
1951	0.746	0.524	0.991	0.499	-0.471	-0.965	-0.385	-0.113	0.507	1.061	1.569	1.709
1952	0.539	0.594	-0.292	-0.400	0.844	0.610	1.111	-0.975	-0.299	-0.605	0.574	0.295
1953	0.444	2.059	1.981	0.476	0.841	-0.422	0.203	-1.559	-0.632	-0.704	-0.312	0.336
1954	0.444	0.524	2.062	1.739	0.569	-0.186	-0.074	0.678	0.629	0.807	1.000	1.185
1955	0.632	0.524	-0.230	0.361	-0.544	-0.409	0.475	0.847	1.304	0.566	0.827	-0.123
1956	0.444	0.768	0.786	0.198	-1.470	-0.415	-1.383	-1.914	-1.595	-0.871	0.235	0.583
1957	1.843	1.528	-0.524	0.240	0.408	0.867	2.020	2.298	1.176	0.408	0.549	1.259
1958	2.135	0.942	0.199	0.079	0.645	0.132	-1.290	-2.129	-1.336	-0.645	-0.498	-0.334
1959	1.101	1.052	1.105	0.218	-0.664	0.186	-0.222	0.839	0.861	0.787	0.527	-1.069
1960	1.334	0.524	0.840	1.230	0.071	-0.030	0.430	0.035	0.365	-0.583	0.309	0.253
1961	1.991	1.781	0.239	-0.168	-0.670	-0.070	1.016	0.308	0.286	-0.805	0.105	-0.340
1962	0.444	0.524	-0.524	1.216	0.838	1.170	0.360	1.313	1.132	1.869	1.843	1.680
1963	1.451	0.711	-0.072	0.144	-1.533	-1.203	-0.723	0.061	-0.119	-0.468	-0.601	0.027
1964	0.444	0.524	-0.172	0.328	-0.018	-0.444	-0.474	0.077	1.973	2.031	2.270	0.213
1965	1.580	2.250	2.315	0.058	-0.539	0.375	0.631	0.068	-0.950	-0.960	-0.793	-0.162
1966	0.444	0.524	-0.524	0.212	0.067	0.763	-0.057	0.482	0.327	1.029	0.875	0.522
1967	0.444	0.524	-0.105	0.925	-0.076	0.447	-0.807	0.145	0.910	1.222	1.240	-0.534
1968	0.444	0.524	0.037	1.506	0.993	1.479	0.523	0.164	-1.140	-1.352	-1.259	-0.562
1969	0.444	0.524	0.158	0.210	0.909	0.253	1.449	0.460	0.135	-0.017	0.592	1.763
1970	0.780	0.524	0.184	-1.077	-1.931	-2.118	-1.783	-0.101	0.972	0.804	0.216	-1.398
1971	0.444	0.768	0.623	-0.873	-0.472	0.131	0.716	0.432	-0.063	-0.911	-1.024	-2.046
1972	0.444	0.524	1.410	0.339	1.358	-0.117	0.993	1.588	1.296	0.272	-1.443	-1.285
1973	0.444	0.524	-0.208	-1.024	-1.542	-1.759	-3.007	-0.813	0.170	0.730	-0.248	-1.176
1974	0.444	0.524	-0.145	-1.651	-0.901	-0.877	0.284	0.095	0.197	-0.292	-0.152	0.058
1975	0.444	1.164	1.226	1.863	1.505	0.991	0.768	-0.186	0.542	-0.199	0.583	-0.617
1976	0.444	2.353	2.218	1.163	-0.471	0.006	-0.377	-1.182	-3.352	-1.709	-1.375	1.667
1977	0.444	0.524	-0.524	-2.453	-1.119	-0.708	0.301	1.502	1.567	1.209	0.480	-0.283
1978	0.444	0.524	0.667	1.146	2.224	1.229	0.676	0.425	0.615	0.762	0.123	0.231
1979	0.688	0.524	0.431	-0.823	-0.202	-0.017	0.697	2.176	1.084	0.748	-0.892	-0.128

1980	0.821	0.524	-0.524	-2.078	0.619	0.428	0.665	-0.311	-0.937	-0.637	-0.873	0.475
1981	0.444	0.524	-0.524	-1.133	-2.243	-1.163	-0.749	-0.258	-0.658	-0.836	-0.916	-0.258
1982	0.444	0.524	0.325	0.379	-2.191	-3.994	-2.286	-0.357	0.116	-0.535	-1.279	-0.203
1983	0.444	0.524	0.287	-1.713	-1.488	-1.866	-1.643	-0.886	-0.258	-0.483	-1.120	-1.838
1984	0.444	0.524	-0.253	-0.072	-0.903	-1.112	-0.997	-1.578	-1.324	-1.831	-1.366	-0.717
1985	0.444	0.524	1.889	0.356	0.361	0.469	1.177	1.068	-0.340	-1.294	-1.861	-1.475
1986	0.444	0.524	1.229	-0.139	-0.860	-0.662	-0.182	0.646	0.490	0.227	-0.117	-0.542
1987	0.656	0.524	1.672	-0.061	-0.493	-2.023	-1.961	-1.947	-1.947	-1.582	-2.054	-0.185
1988	0.935	0.945	0.209	-0.063	-0.660	-0.668	-1.053	-0.235	0.919	0.703	0.525	-1.729
1989	0.444	0.524	0.031	1.217	0.988	1.393	0.582	0.076	-0.985	-1.238	-1.180	-0.815
1990	0.444	0.524	-0.524	0.862	1.412	0.464	-0.166	-1.818	-1.086	-0.922	-0.365	0.307
1991	0.444	0.524	-0.524	0.941	2.742	2.218	1.646	-0.027	-0.511	-1.047	-1.618	-1.869
1992	0.444	0.524	-0.393	1.525	1.692	1.264	0.235	-0.525	-0.470	-0.919	-0.512	-0.481

The SPI diagrams for different drought months (June to November) have been presented to show the pattern and trends of SPI during these years (Figures 3 to 5). The 3-month SPI for the months of August to November show the temporal dynamics of below and above normal precipitation distribution in Minna. It can be seen that during the drought years of 1976. 1982, 1984 and 1987, negative SPI values were observed in the study area and this indicates that there was rainfall deficit in these areas particularly during the drought months of June–November. In these drought years of 1976, 1982, 1984 and 1987, the spatial patterns of 3-month SPI across crucial months (June-November) shows negative SPI values, with the area having an SPI value above −3.0. Thus, the spatio-temporal evolution of the SPI clearly indicates that 1982 was the most drought-prone year taking into consideration the magnitude and extent of a negative SPI value (-3.993) which is consistent with Gore and Sinha Ray (2002). From the results, the month of June recorded this highest value of 3-month SPI across the years under study. 1973 and 1976 were also seen as having high SPI values ranging from −3.0 to −3.35, especially in the months of July, September and October. However, during the wet years of 1957, 1962, 2001 and 2019, the observed 3-month SPI values across the drought months of June-November are mostly positive, ranging from 2.00 in 1962 to 2.49 in 2016 which shows that these years were wet years which is in consonance with Figure 2.

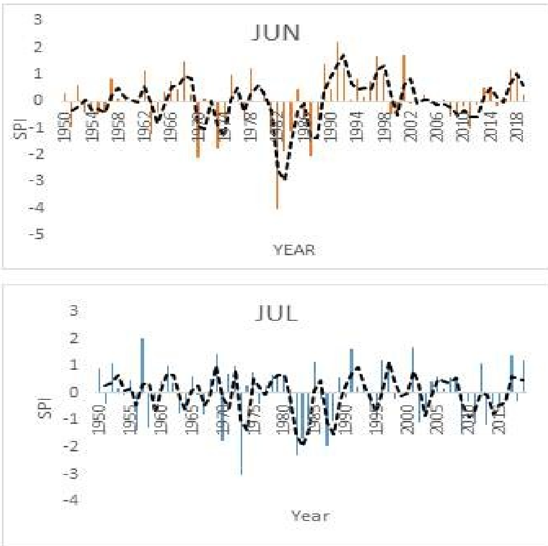

Figure 3: SPI diagrams for JUNE & JULY in the study area

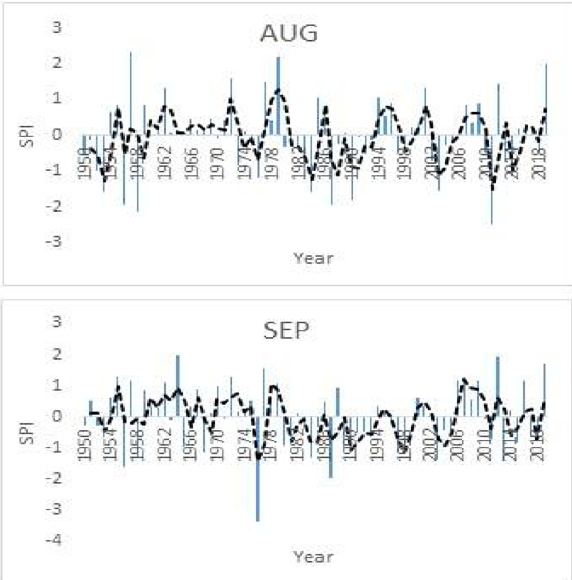

Figure 4: SPI diagrams for AUG & SEP in the study area

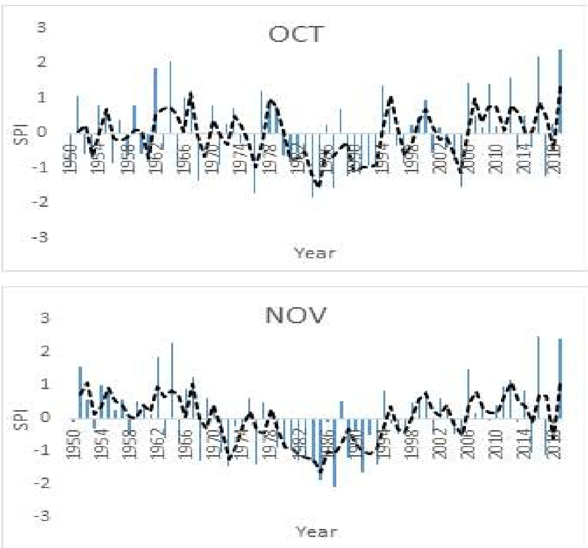

Figure 5: SPI diagrams for OCT & NOV in the study area

4 CONCLUSION

The assessment of drought vulnerability of Minna has been presented in this study using 70 years rainfall data. This study has also shown the appraisal and the usefulness of the SPI to check the variability in meteorological drought at seasonal scale in semi-arid parts of Nigeria in which Minna is found. The SPI at a 3-month time-scale was found effective in capturing seasonal drought patterns over space and time in Minna. This is evident from the obtained results as the driest and the wettest years were observed with the SPI at a 3-month scale. 1987 was observed as the driest year with the worst drought using SPI at a 3-month scale while 2019 was observed to be the wettest year. Therefore, the present study concludes that the 3-month SPI of June represents the good indicator of any drought vulnerability assessment of any drought-prone areas.

REFERENCES

Dar, M. H., Waza, S. A., Shukla, S., Zaidi, N. W., Nayak, S., Hossain, M., ... & Singh, U. S. (2020). Drought Tolerant Rice for Ensuring Food Security in Eastern India. *Sustainability*, *12*(6), 2214.

Eze, J. N. (2018). Drought occurrences and its implications on the households in Yobe state, Nigeria. *Geoenvironmental Disasters*, *5*(1), 18.

Hao, Z., Singh, V. P., & Xia, Y. (2018). Seasonal drought prediction: advances, challenges, and future prospects. *Reviews of Geophysics*, *56*(1), 108-141.

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

Kiem, A. S., Johnson, F., Westra, S., van Dijk, A., Evans, J. P., O'Donnell, A., ... & Jakob, D. (2016). Natural hazards in Australia: droughts. *Climatic Change*, *139*(1), 37-54.

Lange, B., Holman, I., & Bloomfield, J. P. (2017). A framework for a joint hydro-meteorological-social analysis of drought. *Science of the Total Environment*, *578*, 297-306.

Livneh, B., & Hoerling, M. P. (2016). The physics of drought in the US central Great Plains. *Journal of Climate*, *29*(18), 6783-6804.

Luo, L., Apps, D., Arcand, S., Xu, H., Pan, M., & Hoerling, M. (2017). Contribution of temperature and precipitation anomalies to the California drought during 2012–2015. *Geophysical Research Letters*, *44*(7), 3184-3192.

Mishra, A. K., & Desai, V. R. (2005). Drought forecasting using stochastic models. *Stochastic Environmental Research and Risk Assessment*, *19*(5), 326-339.

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

Smakhtin, V. U., & Hughes, D. A. (2004). Review, automated estimation and analyses of drought indices in South Asia (Vol. 83). Iwmi.

Van Loon, A. F., Gleeson, T., Clark, J., Van Dijk, A. I., Stahl, K., Hannaford, J., ... & Hannah, D. M. (2016). Drought in the Anthropocene. *Nature Geoscience*, *9*(2), 89.

Vardharajula, S., Zulfikar Ali, S., Grover, M., Reddy, G., & Bandi, V. (2011). Drought-tolerant plant growth promoting Bacillus spp.: effect on growth, osmolytes, and antioxidant status of maize under drought stress. *Journal of Plant Interactions*, *6*(1), 1-14.

Williams, A. P., Seager, R., Abatzoglou, J. T., Cook, B. I., Smerdon, J. E., & Cook, E. R. (2015). Contribution of anthropogenic warming to California drought during 2012–2014. *Geophysical Research Letters*, *42*(16), 6819-6828.