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The Spatial Pattern of Drought and its Severity in Borno State Nigeria

Babalola, A. and Ogunkunle B. T

babalola.ayo@unilorin.edu.ng or babaayo547@gmail.com

Department of Surveying and Geo-informatics, University of Ilorin, Ilorin, Nigeria

Tel: 07063988323 or 08179290547

Abstract: The purpose of this study is to present the pattern of rainfall distribution and drought analysis in Borno state. The study was carried out using Geographic Information Systems (GIS) approach and drought indices. Rainfall data from 1998-2017 was used to analyze the drought conditions and the Standard Precipitation Index (SPI) method was used to compute the drought indices. In order to identify the drought years and the extent of annual rainfall deficit, the annual rainfall departure analysis was applied. Thiessen polygon was used to present the drought severity maps (2000, 2004, 2006, 2009, 2011 and 2013), of the study area where the maximum SPI value occurred in 2011 and 2013. Mild and moderate droughts occurred in the central portion of the study area. Severe and extreme droughts were mostly found in the northern and some southern parts of the state.

Keywords: GIS, SPI, Rainfall, Precipitation, Thiessen polygon

Introduction

Drought is seen as one of the natural occurring disasters which give rise to a prolong effect on the environment. It also affects the social and the economic wellbeing of the society where this occurs. It is understood to be the shortage of water or the lack of rainfall amount over a long period of time. Drought issue is critical and should be addressed in order to avoid the devastating consequence associated with it particularly the effects of low precipitation. Close to eighty (80) countries around the globe that fall within the arid and semi arid zones experience frequent spells of drought (Kaushik and Kaushik, 2012). Dunama, et al. (2016) observed that the level of drought in Borno state is life-threatening and that the situation is further compounded by the Sahara desert that is encroaching fast on farmlands. It is therefore important to carryout studies to monitor drought for planning and management purposes and to also mitigate its impact. Ramyal et al. (2017) presented the analysis of drought and groundwater recharge at Hassan district of Karnataka, India. The drought conditions of the district were assessed using rainfall data

and groundwater level data for twenty one years. The meteorological drought analysis was carried out using rainfall departure (RD) and the standardized precipitation index (SPI) methods. The hydrological drought analysis was carried out using standardized groundwater level index (SGI). McKee et al. (1993) proposed the Standardized Precipitation Index (SPI) in order to quantify the precipitation deficit for multiple time scales. Another method that has received wide application for drought monitoring is the Normalized Difference Vegetation Index (NDVI) (Nagarajan 2003).

Herbst et al. (1996) presented a method for evaluating droughts using monthly precipitation. The technique determines the duration and intensity of droughts as well as the month of their onset and termination period. Wilhelmi et al. (2002) applied the spatial and Geographical Information Systems-based assessment of agricultural drought vulnerability in the state of Nebraska, USA. Remote sensing and GIS approaches have also been applied in the study of meteorological, hydrological and agricultural droughts monitoring. Zengchao et al. (2017) presented the general concept below for developing drought indicators to

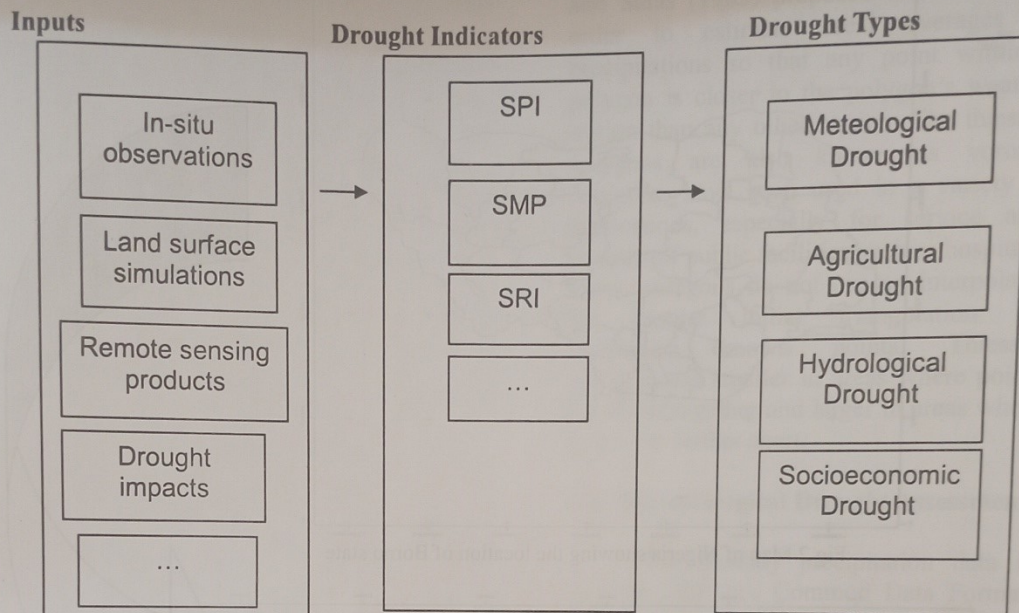


Fig. 1 General concept for developing drought indicators to monitor different drought types with various inputs (Zengchao et al. 2017).

Drought prone area is one in which the probability of a drought year is greater than 20 percent, while a chronic drought prone area is one in which the probability of a drought year is greater than 40 per cent. A drought year occurred when less than 75

percent of the "Normal" rainfall was received (Singh, 2003) or if the amount of rainfall at a particular period or year falls short of the normal with less evaporation, drought condition is said to have occurred.

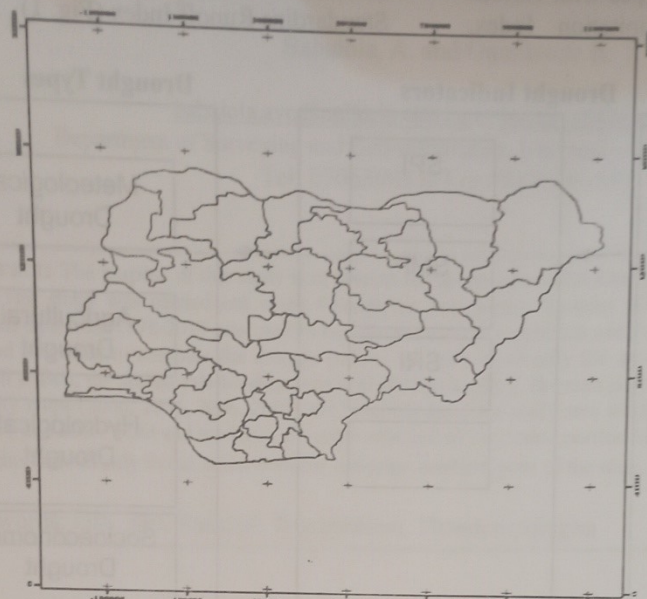


Fig.2 Map of Nigeria showing the location of Borno state

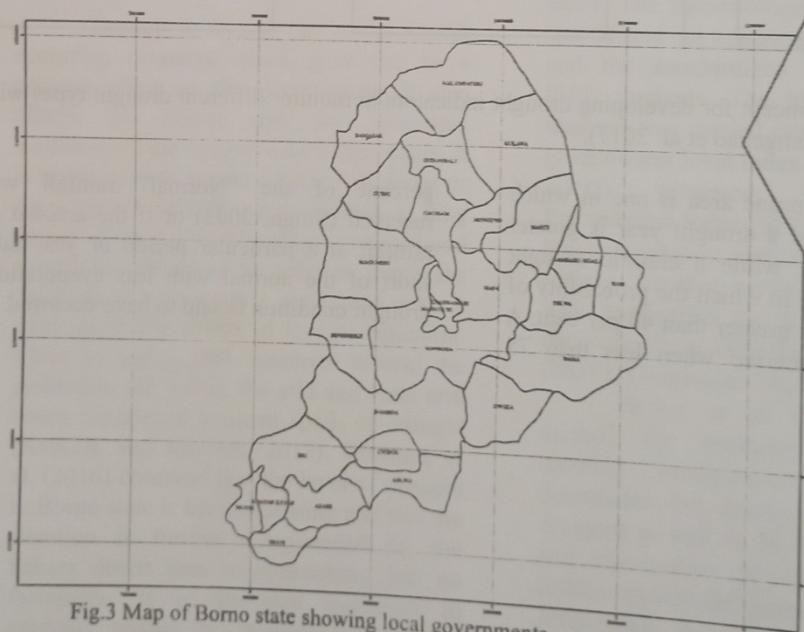


Fig.3 Map of Borno state showing local governments

Environmental Issues

Borno state is located about 130KM west of Damaturu, the administrative capital of Yobe state in North-east of Nigeria. The state lies between latitude $11^{\circ} 30' N$ and longitude $13^{\circ} 00' E$, it shares boundaries with the republic of Niger to the North, Cameroun to the East and Chad to the North-east. In Nigeria, the state shares boundaries with Adamawa state to the South and Gombe state to the West. The state occupies about 70, 898 Km^2 land area with a population density of about 4, 098,391 according to the 2006 population estimate. The area is characterized by wet season in the months of May to August and dry season in the months of January to April and September to December. The topography is gently undulating towards the Southern and southeastern parts of the state which is predominantly hilly while the major part is flat and plain. The altitude is about 775m above sea-level with an average temperature of about $21.4^{\circ}C$. The mean annual precipitation is around 215mm.

Materials and Methods

The monthly precipitation data from the Network Common Data Format (NetCDF) between 1998 and 2017 for the study area were extracted and used in this example. The software used for data processing is Arc GIS 10.2 and the computer in-built Microsoft excel. The normal rainfall for the twenty seven local government areas of Borno state was computed. The Indian meteorological drought assessment methodology has been applied here as used in various studies for drought analysis and the standard precipitation index (SPI). The thiessen polygon was developed using the ARC GIS 10.2 application. The thiessen polygons assume that any point within a

polygon is closer to the polygon's known point than any other known point. Tabios and Salas (1985) proposed this method in order to estimate areal averages of precipitations so that any point within a polygon is closer to the polygon's weather station than any other station. The thiessen polygons are also known as voronoi polygons, have been used in a variety of applications, especially for service area analysis of public facilities such as hospitals. These polygons do not use an interpolator but require initial triangulation for connecting known points. Thiessen polygons are smaller in areas where points are closer together and larger in areas where points are further apart.

IMD Meteorological Drought Assessment

The monthly precipitation data in NetCDF (Network Common Data Format) was extracted. The extracted data was exported in to Microsoft Excel and the sorted data was imported back to the Arc GIS 10.2 environment to develop thiessen network. Normal rainfall has been calculated for Abadam, Mobbar, Guzamala, Kukawa, Gubio, Nganzai, Monguno, Marte, Ngala, Kala/Balge, Dikwa, Mafa, Jere, Maiduguri, Magumeri, Kaga, Konduga, Bama, Gwoza, Damboa, Biu, Chibok, Askira/Uba, Hawul, Shani, Kwaya Kusar, Bayo as 341.1mm, 394.4mm, 446.1mm, 442.8mm, 546.1mm, 556.7mm, 503.9mm, 574.5mm, 552.4mm, 595.3mm, 616mm, 635.3mm, 647.5mm, 647.5mm, 586.2mm, 610.8mm, 688.3mm, 686.3mm, 826.6mm, 767.7mm, 922.6mm, 865.8mm, 906.6mm, 959mm, 924.3mm, 907.2mm, and 814.5mm respectively. The highest rainfall recorded at Hawul as 959mm and lowest is 341.1mm at Abadam.

Table 1: Yearly rainfall distribution in Borno State

YEAR	A	B	C	D	E	F	G	H	I	J	K	L	M
1998	359.59	363	489.8	539.9	486.46	530.8	584.2	645.8	549.5	586.2	649.2	727	737
1999	491.89	421.8	592.1	675	739.82	775.3	616.6	774.1	647.3	722.6	779.3	715.7	793.1
2000	213.47	261.3	409	314.1	435.07	484.1	399.3	478.8	489.8	607.7	519.3	497.9	514.2
2001	239.04	328.4	360.2	493.1	527.66	584.9	531	584.7	639.7	645.9	535.8	780.1	732.1
2002	247.56	238.4	310.7	313.7	408.43	434.2	373.6	495.5	571.9	704.6	543.9	801.8	599.5
2003	399.48	496.4	567.7	549.2	643.43	654.7	638.4	839.1	800.5	779.8	747	770.8	591
2004	242.01	302.4	327	319	496.98	438.1	323.3	417.1	442.4	529	456.3	556.3	562.3
2005	366.44	463.7	514.4	468.3	571.89	487.5	517.3	470	496.2	605.6	463	605.9	586.2
2006	306.02	386.3	394.9	390.8	511.05	546.8	452.8	523.4	555.9	655.9	569.5	478	458.6
2007	530.03	539.1	506.5	500	684	788.1	767.4	792.1	690.5	602	854.5	771.1	773.7
2008	252.34	457.9	354.3	354.7	577.98	553.4	582.5	824.7	617.5	600.7	1089	1011	994.8
2009	281.97	270.7	293.5	351	429.92	472.5	420.2	450.9	513.1	400.5	592.9	516.1	541.4
2010	469.85	468.3	854.9	889.6	801.14	928.9	793.2	759.7	656	678.6	759.8	649.2	870.4
2011	250.4	315.4	276	222.4	395.08	332	315.3	366.1	379.1	508.2	353.3	382.1	441.2
2012	578.43	596.2	656.6	569.6	792.98	617.2	571.2	596.6	610.4	558.3	612	695.6	797.5
2013	294.57	425.5	380.2	374.6	441.53	403.4	392.2	390	351.7	377.6	435	504.2	458.3
2014	294.45	381	348.6	336.7	392.07	412.1	349.7	358.1	470.4	609.5	408.9	434.3	473.4
2015	308	324.8	326.4	351.8	449.71	483.4	422.2	491.3	450.4	510	553.5	505.1	552.8
2016	369.92	420.2	502.8	478.8	612.22	623.3	558.2	646	591.2	740	788.8	727.8	793.2
2017	326.01	427.3	457.3	364	524.42	582.5	470	586.2	524.5	483.6	608.5	575.4	679.2
Normal Rainfall	341.07	394.4	446.1	442.8	546.09	556.7	503.9	574.5	552.4	595.3	616	635.3	647.5

YEAR	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AB
1998	737	589.8	628.1	838.8	802.8	796.61	834.2	819	978.6	929.6	906	960.4	753.9	703.4
1999	793.1	829.42	743	772.8	667.1	812.24	734.9	858.9	798.3	798.6	929.3	837.4	880.3	734.1
2000	514.2	500.36	597.6	560.9	554	631.56	721.6	823.3	688.4	709.2	921.7	936.6	855.6	737.4
2001	732.1	611.04	654.4	784.4	804	938.12	684.3	1039	942.1	1093	1128	1057	930.7	762.5
2002	599.5	477.17	524.7	747.9	682	652.6	772.3	1159	1028	1153	1049	855	919.3	846.7
2003	591	569.3	563.9	764.2	744.9	1081.8	823.7	1099	1050	1072	1093	953.5	947.2	959
2004	562.3	587.22	713.3	695.7	610	1019.6	1065	1142	1164	1134	1230	1153	1225	944.8
2005	586.2	577.86	622.9	602.8	644.4	707.15	690.2	746.9	747.5	776.5	873.9	886.4	944.6	987.3
2006	458.6	602.34	661.2	670.5	569.6	1135.1	1082	1253	1324	1393	1268	1235	986.5	1078
2007	773.7	698.29	748.2	784.1	853.4	801.33	767.4	953.9	815.4	786.4	975.9	1010	1103	944.1
2008	994.8	576.37	587.4	928.7	933.9	946.95	851.3	1054	935	915.8	1154	1044	1027	700.8
2009	541.4	413.86	480.2	572.1	604.6	940.87	664.9	862.5	699.5	682.5	767.3	835.2	856	681
2010	870.4	800.07	723.8	681.5	837.1	1018.9	643.9	841.3	803.6	960.2	871.1	833.4	862.5	808.4
2011	441.2	392.09	369.7	447.1	398	620.58	584.6	531.3	721.2	700	684.9	646.2	546.1	492.5
2012	797.5	821.39	828.4	748.9	694.8	857.43	882.8	988	990.2	1036	942.8	988.9	865.6	836.5
2013	458.3	422.01	503.7	486.6	596.1	552.41	547.8	723.7	661.7	753.1	681.1	635.1	710	623.5
2014	473.4	451.71	494.7	518.5	619.8	582.26	693	815.3	692.5	805.8	807.7	869.4	811.4	707.2
2015	552.8	507.9	625.4	613.8	558.6	815.05	761.8	790.7	650.3	661.7	881	784.5	820.9	719.3
2016	793.2	662.83	518.8	914.5	855	928.72	796.5	1058	852.5	968.4	1109	982.8	1004	1088
2017	679.2	633.57	625.9	633.3	695.8	692.55	751.1	891.8	772.4	803.9	906.9	982.8	1093	935.4
Normal Rainfall	647.5	586.23	610.8	688.3	686.3	826.59	767.7	922.6	865.8	906.6	959	924.3	907.2	814.5

The meteorological drought assessment (IMD Irrigation Commission report, 1982) on the basis of percentage deviation of rainfall from the mean rainfall was carried out using the percentage deviation given by the following equation(1)

$$MD_t = \frac{P_{act} - P_{mean}}{P_{mean}} \times 100 \quad (1)$$

Where:

MD_t = Percentage of meteorological deviation

P_{act} = Actual rainfall in the time period 't',

P_{mean} = Long term mean rainfall

The percentage deviation of rainfall and the category of drought assessment used by IMD are as given in the Table.2.

Table 2: Percentage of deviation and Category of drought assessment

	Percentage Deviation (MD_t)	Class	Category
1	>0	M0	No drought
2	0 to -25	M1	Mild
3	-25 to -50	M2	Moderate

The Standardized Precipitation Index (SPI), developed by McKee et al. (1993), quantifies precipitation deficit for multiple time scales. The SPI relies on a long-term precipitation record for a desired region (McKee et al., 1993). Positive SPI values indicates greater than mean precipitation, while negative values indicate less than mean precipitation. Because the SPI is standardized, wetter and drier climates can be represented in the same way.

The classification system shown in Table 3 (McKee et al., 1993) is used to define the strength of the precipitation anomaly. The SPI value of -1 is commonly used as threshold for drought event definition (Cancelliere et al., 2005). The duration of the drought event is defined by its beginning and end, while its severity is

the accumulated SPI values for the duration of the event and its intensity is measured as the drought severity divided by the drought duration. Based on SPI values, three drought classes were considered: non drought ($SPI \geq 0$), mild drought ($-1 < SPI < 0$), moderate drought ($-1.5 < SPI \leq -1$) and severe or extreme drought ($SPI \leq -1.5$).

Moreira et al. (2008) extended the work of Paulo et al. (2005) using the same drought classification and 3-D log linear models to predict drought class transitions one month ahead, given the drought class for the last two months, which also allows for extending the prediction to two months ahead. The quasi-association model adequately fitted their data (14 sites in southern Portugal).

Table 3: Classification of SPI values

SPI Values	Drought Category
0 to -0.99	Mild Drought
-1 to -1.49	Moderate Drought
-1.5 to -1.99	Severe Drought
≤ -2	Extreme Drought

$$SPI = \frac{(X - X_m)}{\sigma} \quad (2)$$

Where $\sigma = \sqrt{\frac{\sum(X - X_m)^2}{N-1}}$ X = Precipitation of the Station, X_m = Mean Precipitation = Standard deviation

Results and Discussion

In the year 2000, there was a moderate drought in the Northern part and three local government areas in the Southern part of the state while mild drought was recorded in many parts of the states. In 2011, extreme drought was recorded in four local government areas, severe drought in seven local government areas, moderate drought in eleven local governments and five local government areas experienced mild drought. In the year 2013, extreme drought was recorded for two local governments, severe drought was recorded for five local governments, moderate drought was recorded for nine local governments and mild drought was recorded for eleven local government areas. From the study drought severity maps were produced for Borno state, Nigeria. As indicated by the monthly precipitation data used as input to SPI calculation. The output from the SPI was also used as input to the ArcGIS to generate drought severity maps for the state for each year. The Maps shown in Fig. 4 and Fig. 5 are for the years of 2000, 2002, 2004, 2006 and 2009, 2011, 2013 and 2014 respectively. The spatial distribution of the drought categories over the study area were obtained by assigning each local government area of influence (thiessen polygon) Fig.3 shows drought occurrences

at different categories and time-steps over the study area. The drought occurrences were calculated based on percentage occurrence of each event mild and moderate droughts (Fig. 4) occur in the northern portion of the study area (Abadam and Mobbar) in the year 2000 and in Monguno, Ngala, and Marte in 2004. Again moderate and mild drought situation were also recorded in the year 2002 and 2006 over Gwoza, Gubio and Mafa, Maiduguri and Mafa respectively. The severe and extreme droughts (Fig. 5) occur in Kala/Balge in 2009 and Hawul, Konduga, Damboa, Gwoza in 2013, while extreme drought conditions were observed in Shani, and in 2011 extreme drought condition occurred in Bama, Kaga, Biu, and Kwaya Kusar, and severe condition was reached in Konduga, Mafa, Monguno, Ngala and Magumeri respectively. It was also observed that substantial part of the study area is suffered one form of drought or the other in the years 2000, 2002, 2004, 2006, 2009, 2011, 2013, and 2014. Fig. 6 and Fig. 7 present the meteorological drought analysis using the rainfall departure and GIS approach for the years of 1998, 2000, 2004 and 2008. The figures shows the annual drought severity maps for the years indicated to represent the no drought and drought affected.

Table 4: Illustration of drought severity using SPI Drought Assessment Approach

Table 4: Illustration of drought severity using SPI Drought Assessment Approach														
YEAR	A	B	C	D	E	F	G	H	I	J	K	L	M	
1998	0.18	-0.33	0.3	0.63	-0.5	-0.18	0.587	0.46	-0	-0.09	0.19	0.59	0.57	
1999	1.44	0.29	1.01	1.52	1.5	1.5	0.825	1.28	0.87	1.2	0.92	0.52	0.93	
2000	-1.22	-1.4	-0.26	-0.8	-0.9	-0.5	-0.77	-0.61	-0.6	0.12	-0.5	-0.88	-0.85	
2001	-0.97	-0.69	-0.6	0.33	-0.1	0.19	0.198	0.07	0.8	0.47	-0.5	0.93	0.54	
2002	-0.89	-1.64	-0.94	-0.8	-1.1	-0.84	-0.95	-0.5	0.18	1.03	-0.4	1.07	-0.31	
2003	0.56	1.07	0.84	0.7	0.75	0.67	0.984	1.69	2.27	1.73	0.74	0.87	-0.36	
2004	-0.95	-0.97	-0.83	-0.8	-0.4	-0.81	-1.32	-1.01	-1	-0.62	-0.9	-0.51	-0.54	
2005	0.24	0.73	0.47	0.17	0.2	-0.47	0.098	-0.67	-0.5	0.1	-0.9	-0.19	-0.39	
2006	-0.33	-0.08	-0.36	-0.3	-0.3	-0.07	-0.37	-0.33	0.03	0.57	-0.3	-1.01	-1.21	
2007	1.8	1.52	0.42	0.37	1.07	1.58	1.928	1.39	1.27	0.06	1.35	0.87	0.81	
2008	-0.85	0.67	-0.64	-0.6	0.25	-0.02	0.575	1.6	0.6	0.05	2.67	2.41	2.22	
2009	-0.56	-1.3	-1.06	-0.6	-0.9	-0.58	-0.61	-0.79	-0.4	-1.83	-0.1	-0.76	-0.68	
2010	1.23	0.78	2.84	2.92	1.97	2.55	2.117	1.18	0.95	0.78	0.81	0.09	1.42	
2011	-0.87	-0.83	-1.18	-1.4	-1.2	-1.54	-1.38	-1.33	-1.6	-0.82	-1.5	-1.62	-1.32	
2012	2.27	2.12	1.46	0.83	1.91	0.41	0.492	0.14	0.53	-0.35	-0	0.39	0.96	
2013	-0.44	0.33	-0.46	-0.4	-0.8	-1.05	-0.82	-1.18	-1.8	-2.04	-1	-0.84	-1.21	
2014	-0.45	-0.14	-0.68	-0.7	-1.2	-0.99	-1.13	-1.38	-0.8	0.13	-1.2	-1.29	-1.11	
2015	-0.32	-0.73	-0.83	-0.6	-0.7	-0.5	-0.6	-0.53	-0.9	-0.8	-0.4	-0.84	-0.6	
2016	0.28	0.27	0.39	0.24	0.51	0.46	0.397	0.46	0.36	1.36	0.98	0.59	0.93	
2017	-0.14	0.35	0.08	-0.5	-0.2	0.18	-0.25	0.07	-0.3	-1.05	-0	-0.38	0.2	
YEAR	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AB
1998	0.57	0.03	0.16	1.12	0.89	-0.17	0.49	-0.59	0.62	0.12	-0.32	0.24	-1.02	-0.16
1999	0.93	1.87	1.2	0.63	-0.15	-0.08	-0.2	-0.36	-0.4	-0.6	-0.18	-0.6	-0.18	-0.12
2000	-0.9	-0.66	-0.1	-0.9	-1.01	-1.13	-0.3	-0.56	-1	-1	-0.22	0.08	-0.34	-0.11
2001	0.54	0.19	0.4	0.71	0.89	0.646	-0.6	0.661	0.42	0.96	1.018	0.9	0.157	-0.08
2002	-0.3	-0.84	-0.8	0.44	-0.03	-1.01	0.03	1.346	0.89	1.27	0.542	-0.5	0.081	0.05
2003	-0.4	-0.13	-0.4	0.56	0.45	1.479	0.41	1.005	1.01	0.86	0.806	0.2	0.267	0.21
2004	-0.5	0.01	0.93	0.05	-0.58	1.118	2.21	1.247	1.64	1.17	1.626	1.55	2.122	0.19
2005	-0.4	-0.06	0.11	-0.6	-0.32	-0.69	-0.6	-1	-0.6	-0.7	-0.51	-0.3	0.25	0.25
2006	-1.2	0.12	0.46	-0.1	-0.89	1.788	2.33	1.88	2.52	2.51	1.859	2.11	0.529	0.39
2007	0.81	0.86	1.25	0.71	1.27	-0.15	-0	0.178	-0.3	-0.6	0.102	0.58	1.306	0.19
2008	2.22	-0.08	-0.2	1.79	1.88	0.698	0.62	0.749	0.38	0.05	1.175	0.81	0.798	-0.17
2009	-0.7	-1.33	-1.2	-0.9	-0.62	0.662	-0.8	-0.34	-0.9	-1.2	-1.15	-0.6	-0.34	-0.2
2010	1.42	1.65	1.02	-0.1	1.15	1.115	-0.9	-0.46	-0.3	0.28	-0.53	-0.6	-0.3	-0.01
2011	-1.3	-1.5	-2.2	-1.8	-2.19	-1.19	-1.4	-2.23	-0.8	-1.1	-1.65	-1.9	-2.41	-0.47
2012	0.96	1.81	1.97	0.45	0.06	0.179	0.85	0.373	0.68	0.67	-0.1	0.44	-0.28	0.03
2013	-1.2	-1.27	-1	-1.5	-0.69	-1.59	-1.6	-1.13	-1.1	-0.8	-1.67	-2	-1.32	-0.28
2014	-1.1	-1.04	-1.1	-1.3	-0.51	-1.42	-0.6	-0.61	-1	-0.5	-0.91	-0.4	-0.64	-0.16
2015	-0.6	-0.6	0.13	-0.6	-0.97	-0.07	-0	-0.75	-1.2	-1.3	-0.47	-0.9	-0.58	-0.14
2016	0.93	0.59	-0.8	1.68	1.28	0.592	0.21	0.772	-0.1	0.32	0.899	0.4	0.647	0.4
2017	0.2	0.36	0.14	-0.4	0.07	-0.78	-0.1	-0.17	-0.5	-0.5	-0.31	0.4	1.242	0.18

Table 5: Illustration of drought severity using Rainfall Departure Approach

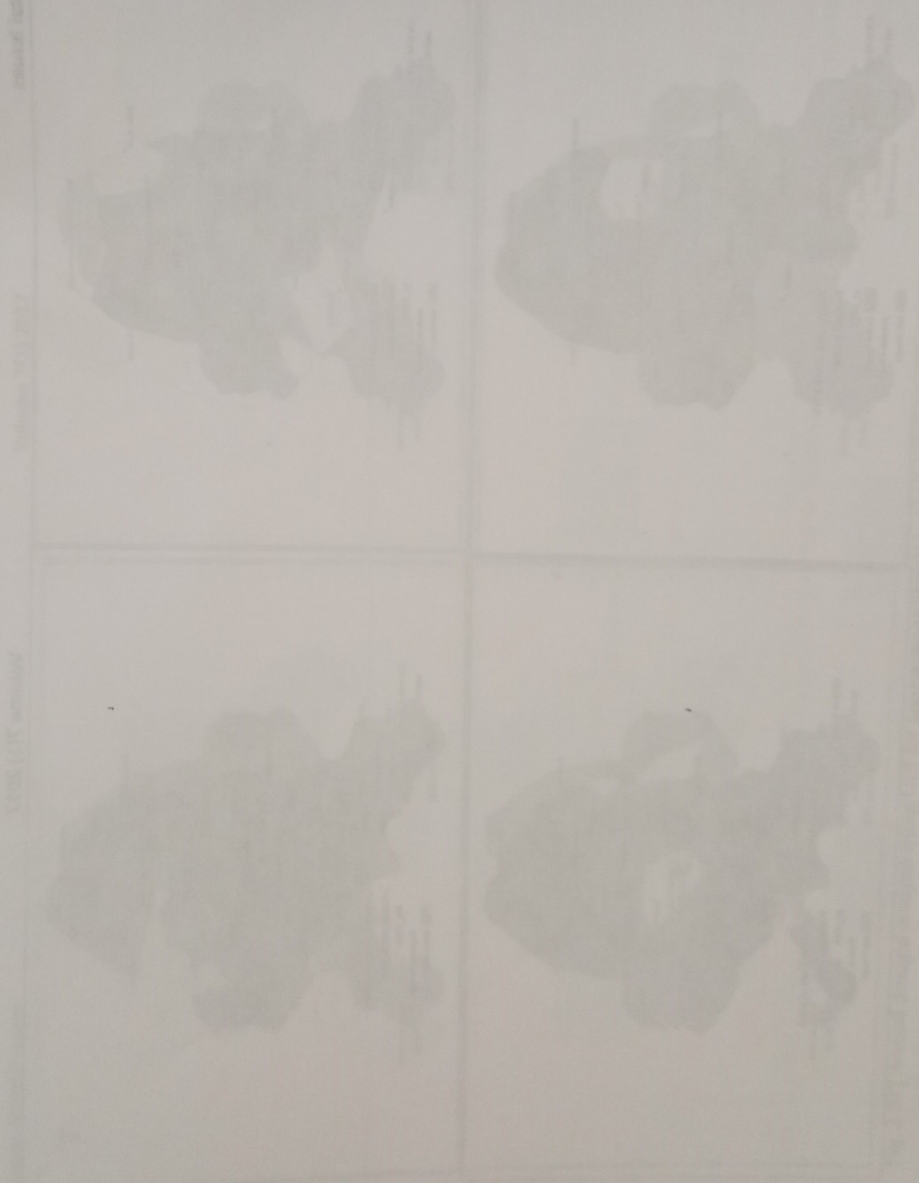
Table 5: Illustration of drought severity using Rainfall Dependent											J	K	L	M
YEAR	A	B	C	D	E	F	G	H	I					
1998	5.43	-8	9.78	21.9	-10.9	-4.6	15.9	12.4	-0.52	-1.53	5.4	14.4	13.8	
1999	44.2	6.94	32.7	52.4	35.48	39.3	22.4	34.7	17.2	21.38	27	12.7	22.5	
2000	-37	-34	-8.3	-29.1	-20.3	-13	-21	-16.7	-11.3	2.077	-16	-22	-21	
2001	-30	-17	-19	11.4	-3.37	5.07	5.38	1.78	15.8	8.491	-13	22.8	13.1	
2002	-27	-40	-30	-29.2	-25.2	-22	-26	-13.8	3.54	18.35	-12	26.2	-7.4	
2003	17.1	25.9	27.3	24	17.82	17.6	26.7	46	44.9	30.98	21	21.3	-8.7	
2004	-29	-23	-27	-28	-8.99	-21	-36	-27.4	-19.9	-11.1	-26	-12	-13	
2005	7.44	17.6	15.3	5.74	4.724	-12	2.65	-18.2	-10.2	1.73	-25	-4.6	-9.5	
2006	-10	-2.1	-11	-11.7	-6.42	-1.8	-10	-8.89	0.63	10.18	-7.5	-25	-29	
2007	55.4	36.7	13.5	12.9	25.25	41.6	52.3	37.9	25	1.122	39	21.4	19.5	
2008	-26	16.1	-21	-19.9	5.839	-0.6	15.6	43.6	11.8	0.897	77	59.2	53.6	
2009	-17	-31	-34	-20.7	-21.3	-15	-17	-21.5	-7.12	-32.7	-3.7	-19	-16	
2010	37.8	18.7	91.6	101	46.7	66.9	57.4	32.2	18.7	13.99	23	2.2	34.4	
2011	-27	-20	-38	-49.8	-27.7	-40	-37	-36.3	-31.4	-14.6	-43	-40	-32	
2012	69.6	51.2	47.2	28.6	45.21	10.9	13.3	3.85	10.5	-6.21	-0.6	9.49	23.2	
2013	-14	7.89	-15	-15.4	-19.1	-28	-22	-32.1	-36.3	-36.6	-29	-21	-29	
2014	-14	-3.4	-22	-24	-28.2	-26	-31	-37.7	-14.8	2.391	-34	-32	-27	
2015	-9.7	-18	-27	-20.5	-17.6	-13	-16	-14.5	-18.5	-14.3	-10	-20	-15	
2016	8.46	6.53	12.7	8.13	12.11	12	10.8	12.4	7.02	24.3	28	14.6	22.5	
2017	-4.4	8.33	2.5	-17.8	-3.97	4.64	-6.7	2.04	-5.05	-18.8	-1.2	-9.4	4.89	
YEAR	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AB
1998	13.8	0.6	2.84	-3.6	8.7	-11.2	13	2.54	-5.5	3.9	-17	-14	-17	-13.6
1999	22.5	41	21.7	-1.7	-4	-6.9	-7.8	-12	-3.1	-9	-3	-9.9	-3	-9.86
2000	-21	-15	-2.2	-24	-6	-10.8	-20.5	-22	-3.9	1.3	-6	-9.5	-5.7	-9.46
2001	13.1	4.2	7.14	13	-11	12.59	8.81	20.5	17.6	14	2.6	-6.4	2.59	-6.38
2002	-7.4	-19	-14	-21	0.6	25.65	18.7	27.1	9.39	-8	1.3	3.96	1.34	3.96
2003	-8.7	-2.9	-7.7	31	7.3	19.16	21.3	18.3	14	3.2	4.4	17.7	4.42	17.7
2004	-13	0.2	16.8	23	39	23.76	34.5	25.1	28.2	25	35	16	35.1	16
2005	-9.5	-1.4	1.98	-14	-10	-19	-13.7	-14	-8.9	-4	4.1	21.2	4.13	21.2
2006	-29	2.7	8.26	37	41	35.82	52.9	53.6	32.2	34	8.7	32.3	8.75	32.3
2007	19.5	19	22.5	-3.1	-0	3.394	-5.82	-13	1.76	9.2	22	15.9	21.6	15.9
2008	53.6	-1.7	-3.8	15	11	14.26	8	1.02	20.4	13	13	-14	13.2	-14
2009	-16	-29	-21	14	-13	-6.51	-19.2	-25	-20	-10	-6	-16	-5.6	-16.4
2010	34.4	36	18.5	23	-16	-8.81	-7.18	5.91	-9.2	-10	-5	-0.7	-4.9	-0.74
2011	-32	-33	-39	-25	-24	-42.4	-16.7	-23	-29	-30	-40	-40	-40	-39.5
2012	23.2	40	35.6	3.7	15	7.098	14.4	14.3	-1.7	7	-5	2.7	-4.6	2.7
2013	-29	-28	-18	-33	-29	-21.6	-23.6	-17	-29	-31	-22	-23	-22	-23.5
2014	-27	-23	-19	-30	-10	-11.6	-20	-11	-16	-6	-11	-13	-11	-13.2
2015	-15	-13	2.4	-1.4	-1	-14.3	-24.9	-27	-8.1	-15	-10	-12	-9.5	-11.7
2016	22.5	13	-15	12	3.8	14.71	-1.53	6.81	15.6	6.3	11	33.6	10.7	33.6
2017	4.89	8.1	2.48	-16	-2	-3.33	-10.8	-11	-5.4	6.3	21	14.8	20.5	14.8

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Key: Local Governments in Borno State represented by alphabets (Tables 4 and 5).

Abadam (A), Mobbar (B), Guzamala (C), Kukawa (D), Gubio (E), Nganzai (F), Monguno (G), Marte (H), Ngala (I), Kala/Balge (J), Dikwa (K), Mafa (L), Jere (M), Maiduguri (N), Magumeri (O), Kaga (P), Konduga (Q), Bama (R), Gwoza (S), Damboa (T), Biu (U), Chibok (V), Askira/Uba (W), Hawul (X), Shani (Y), Kwaya Kusar (Z), Bayo (Ab)



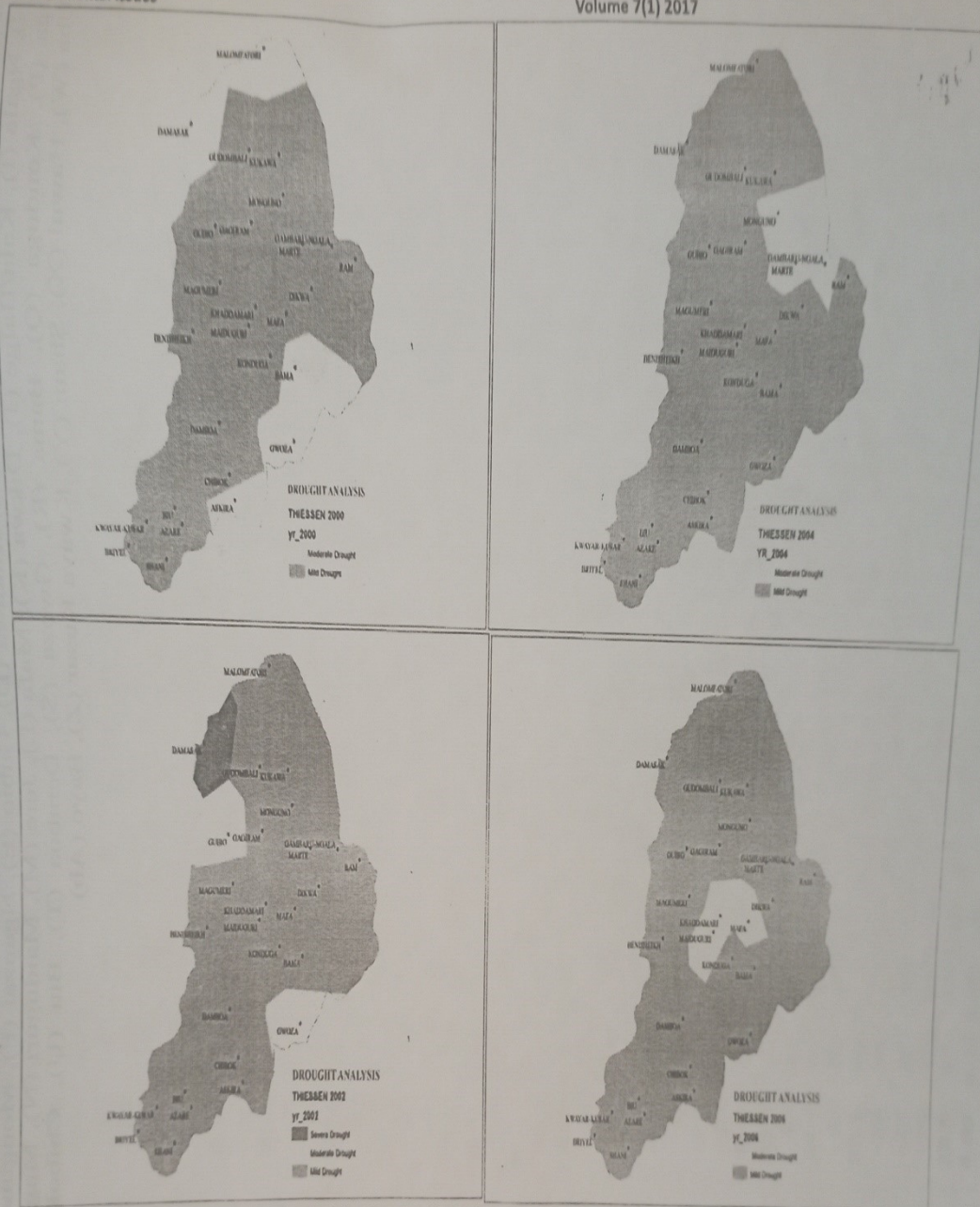


Fig.4 SPI Annual drought analysis using GIS for the years 2000, 2002, 2004 & 2006

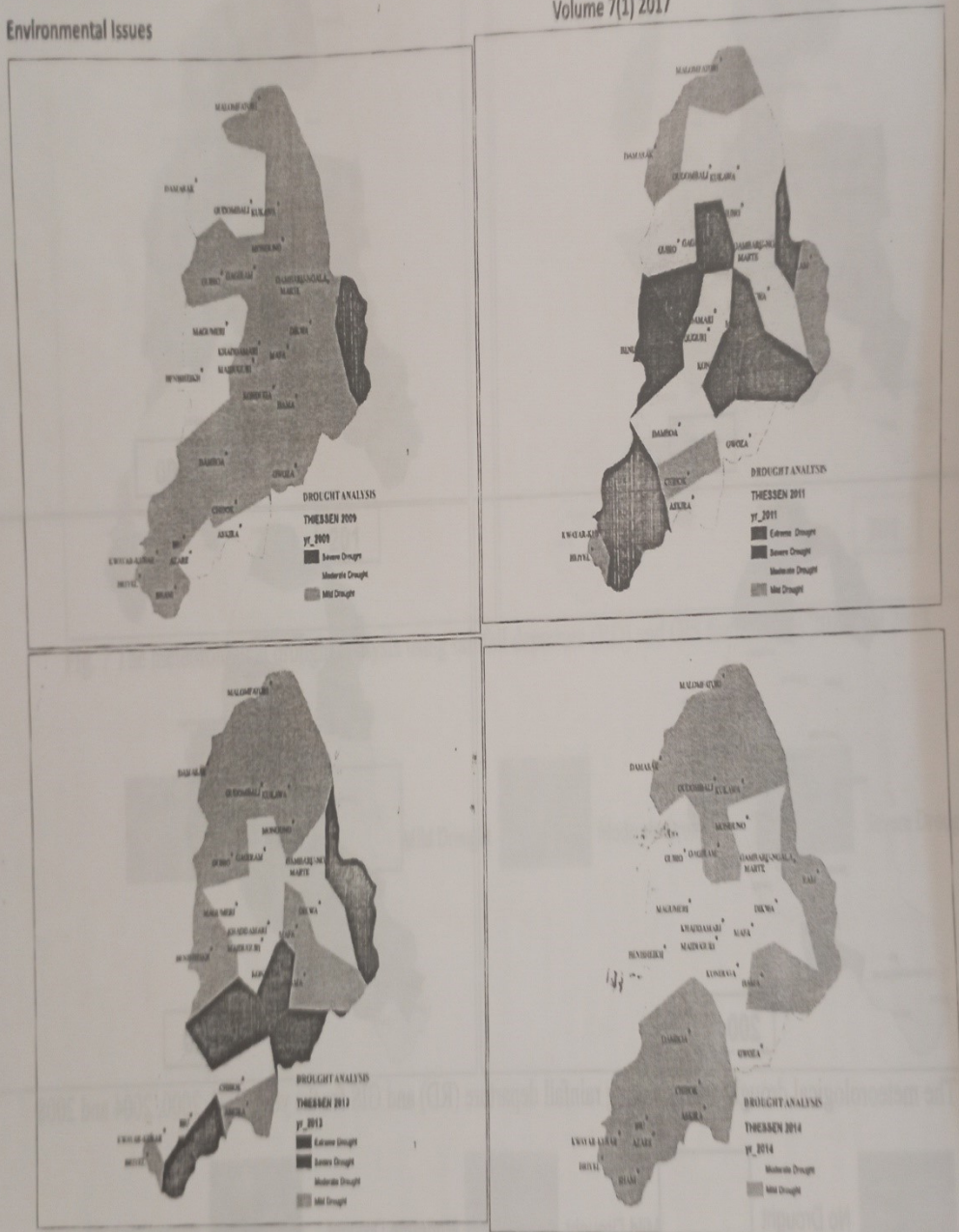


Fig. 5 SPI Annual drought analysis using GIS for the years 2009, 2011, 2013 & 2014

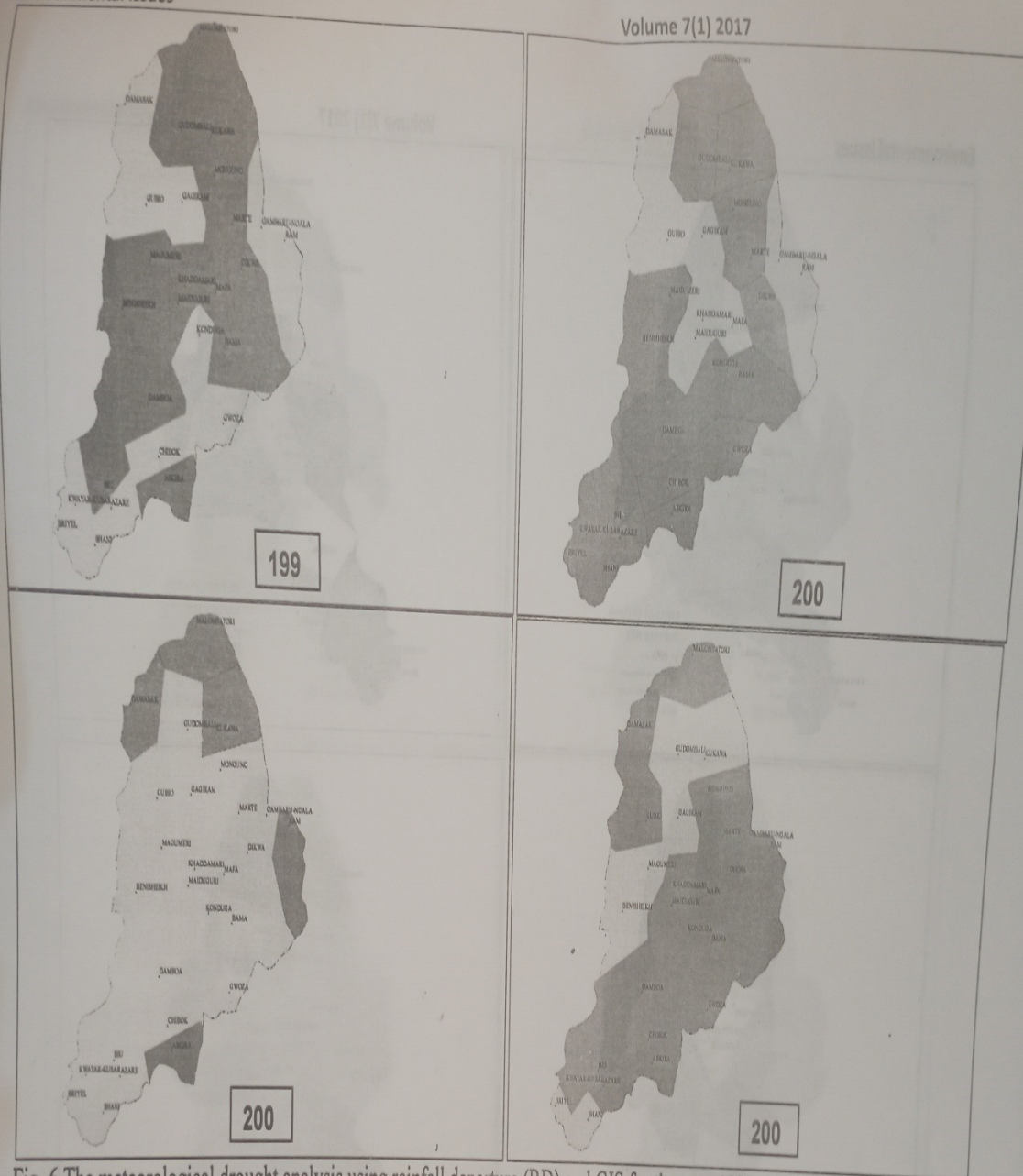
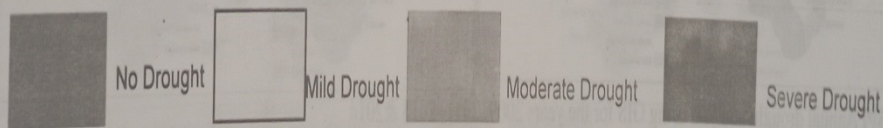


Fig. 6 The meteorological drought analysis using rainfall departure (RD) and GIS for the years 1998, 2000, 2004 and 2008



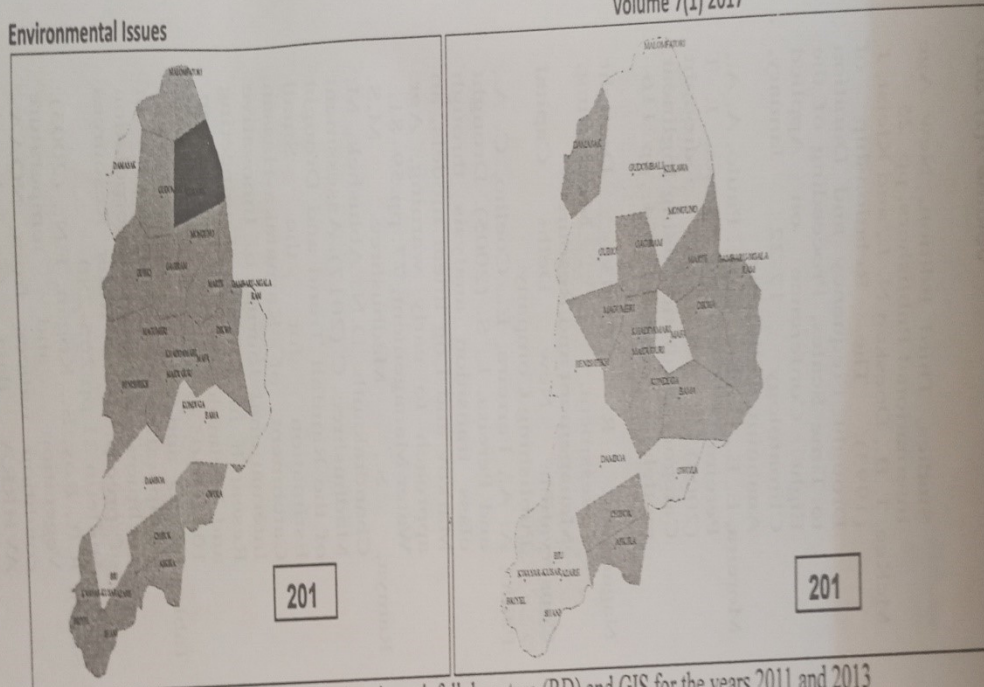
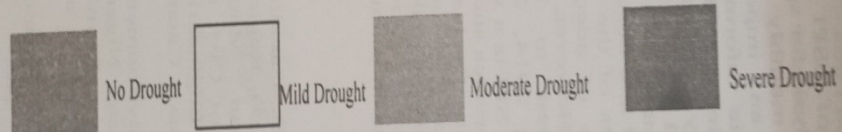


Fig. 7 The meteorological drought analysis using rainfall departure (RD) and GIS for the years 2011 and 2013



Conclusion

The application of SPI and meteorological drought analysis for spatial distribution considering monthly and yearly rainfall data is an important endeavour. The geographic information systems approach was applied in order to generate the drought severity maps for the different years and all the local government areas of the state. The SPI values were also determined and observed to be negative in most parts of the state which implied the absence of adequate rainfall in Borno state. However, the precipitation trend appeared to have improved when comparing 2014, 2015 with 2016. It was found that SPI is a valid indicator of drought characteristics such as severity and spatial extent. Evaluating precipitation conditions and drought occurrence would assist decision makers, Environmentalist, Water resource managers and Agriculturalists in planning drought mitigation measures.

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