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AN ASSESSMENT OF TEMPORAL VARIABILIY OF DROUGHT IN KATSINA USING STANDARDIZED PRECIPITATION INDEX

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ABSTRACT

Drought is a recurrent phenomenon in the Nigeria's arid zone especially in the last few decades. In this study, temporal variation of drought in Katsina from 1922 to 2013 was investigated. Standardized Precipitation Index (SPI) was used to determine the temporal dimensions of drought based on frequency and severity of drought events at 3 and 6-month time steps. The study found that the period of study is cheered by drought and non-drought events. 3-month SPI reveals 48 drought occurrences throughout the period, out of which 4 were severe and 3 were extreme. For the period 1922 to 1970, only 1 extreme drought occurred, but between 1971 and 1998, 4 severe and 2 extreme droughts occurred, while neither severe nor extreme one is recorded from 1999 to 2013. Under this scenario, the severe and extreme drought events have severities of 1 in 23 and 1 in 31 years respectively. 6-month SPI also reveals 48 drought occurrences out of which 3 are severe and 4 are extreme. In this context, only 1 occurrence of extreme drought is recorded from 1922 to 1970, but from 1971 to 1998, 3 severe and 3 extreme droughts are recorded. Under this scenario, severe and extreme droughts have severities of 1 in 30 and 1 in 23 years respectively. It is recommended that even though some sort of respite from drought is being experienced in the area recently, a watchful eye should be kept on drought and coping and mitigation measures always put in place.

KEYWORDS: Drought Severity, SPI, ITCZ

INTRODUCTION

Drought is a complex natural phenomenon which adversely affects the lives of people, economies and the environment.Based on certain characteristics such as severity, duration, spatial extent, loss of life, economic loss, social effect and long term impact, drought ranks first among all natural hazards (Bryant, 1991). Political, economic and social conditions of people are among the most important factors that determine the risk and vulnerability to drought.

Definition of drought is as varied as the disciplines involved in its studies (Wilhite and Glantz, 1985). However, it has been suggested that drought results from a deficiency of precipitation from expected or normal that when this deficiency is extended over a season or longer period of time, it becomes insufficient to meet the demands for human activities (Wilhite, 2011). In Nigeria, it is an inherent characteristic of the savanna region (Oladipo, 1993a) which is highly variable in both space and time (Oladipo, 1993b). The severe and prolonged droughts of the 1970s and 1980s alone are clear evidences of this region's vulnerability to this insidious phenomenon.

Standardized precipitation index (SPI) was developed by McKee *et al.* (1993) and can be calculated at different time scales to monitor droughts in the different usable water resources. McKee *et al* (1993) and Edwards and McKee (1997) recommend using at least 30 years of high-quality data to compute SPI. (Agnew and Chappell, 1999) found out that more than 40 years of data are required to compute SPI in the Sahel that was independent of the base averaging period. Guttman (1999) recommends at least 50 years of data to compute SPI values especially for time periods smaller than 12 months and a longer record to compute multiyear SPI values. In addition, Wu *et al* (2005) conclude that the longer the length of record used in the SPI calculation, the more reliable the SPI values will be. Nevertheless, Ntale and Gan (2003) found minimal variations in the SPI computed as they increased the length of calibration period from 62 to 97 years. Thus, for East African data, increasing the calibration period does not lead to significant changes in the level of drought severity.

SPI is widely accepted and used throughout the world in both research and operational models because it is normalized or standardized to location and time (Wu *et al*., 2007). In addition, the Inter-regional Workshop on Indices and Early Warning Systems for Drought (held at University of Nebraska – Lincoln, USA, from 8 to 11 December, 2009) jointly sponsored by the School of Natural Resources (SNR) of the University of Nebraska, the United States National Drought Mitigation Centre (NDMC), the World Meteorological Organisation (WMO), the United States National Oceanic and Atmospheric Administration (NOAA), the United States Department of Agriculture (USDA) and the United Nations Convention to Combat Desertification (UNCCD). This workshop with members representing 22 countries across the globe approved the Lincoln Declaration on Drought Indices. The declaration recommended that SPI be used by all National Meteorological and Hydrological Services (NMHSs) around the world to characterize meteorological droughts, in addition to other drought indices that were used in their service. And this declaration was adopted as a resolution that endorsed the recommendation by the Sixteenth World Meteorological Congress in June 2011 (WMO, 2012).

SPI has been used to assess drought in different parts of the world including Nigeria (Akeh*et al*., 2000; Mortimore, 2000). In this study, SPI was used to characterize droughts in Katsina at 3 and 6 month time scales for the period 1922-2013.

THE STUDY AREA

Katsina is located on latitude 12°36'N and longitude 7°18'E with an average elevation of 506 metres in the extreme north-central end of Nigeria. This is well within the Nigeria's arid or Sahel zone, which has been identified as areas north of latitude 12°N (Adefolalu, 1988). It has tropical continental (semi-arid) climate, with distinct wet (May to September) and dry (November to March) seasons. Summer temperatures reach 42°C during the day (March to April), while during the harmattan (cool) period (December to January) minimum temperatures can be as low as 11°C. Oscillation of Inter Tropical Convergence zone (ITCZ) is the mechanism that controls rainy and dry seasons in this area. Its northward incursion brings about rainy season while its southward retreat brings dry season and incursion of harmattan dust.

METHODOLOGY

Data

Monthly rainfall data for Katsina town from 1922-2013 were collected from the headquarters of Katsina State Ministry of Agriculture and Natural Resources at Katsina.

SPI Calculation

Calculating SPI values requires monthly rainfall data to be fitted to gamma distribution whose probability density function is defined as

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad (1)$$

Where $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter and $x > 0$ is the amount of rainfall. $\Gamma(\alpha)$ defines the gamma function which is defined as

$$\Gamma(\alpha) = \lim_{n\to\infty} \prod_{v=0}^{n-1} \frac{n! n^{y-1}}{y+v} \equiv \int_0^\infty y^{\alpha-1} e^{-y}\, dy \quad (2)$$

Fitting the distribution to data requires α and β to be estimated. Edwards and McKee (1997) suggest estimating these parameters using the approximation of Thom (1958) for maximum likelihood

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (3)$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \quad (4)$$

where for *n* observations

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad (5)$$

Integrating the probability density function with respect to *x* and inserting the estimates of α and β yields an expression for the cumulative probability G(x) of an observed amount of rainfall occurring for a given month and time scale:

$$G(x) = \int_0^x g(x)\, dx = \frac{1}{\hat{\beta}^{\hat{\alpha}} \Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}} e^{-x/\hat{\beta}} dx \quad (6)$$

Substituting *t* for $x/\hat{\beta}$ reduces equation (6) to

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})} \int_0^x t^{\hat{\alpha}-1} e^{-1} dt \quad (7)$$

which is the incomplete gamma function. Since the gamma distribution is undefined for $x = 0$ and $q = P(x = 0) > 0$ where $P(x = 0)$ is the probability of zero precipitation. Thus, Edwards and McKee (1997) suggest that the actual probability of non-exceedence$H(x)$ should be given as

$$H(x) = q + (1- q)\, G(x) \quad (8)$$

Where q is the probability of $x = 0$. If m is the number of zeros in a sample of size n, then q is estimated as

$$q = \frac{m}{n} \quad (9)$$

The cumulative probability *H(x)*, is then transformed to the standard normal random variable *z* with mean zero and variance of one, and *z* is the SPI. Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation.

However, in order to simplify the computation of SPI, the United States National Drought Mitigation Centre developed a program which can run in both Windows and NIX environments, that computes SPI from monthly precipitation data at required time scales. The latest SPI program (SPI_SL_6.exe) for Windows/PC is used in this study and was downloaded free of charge at: http://drought.unl.edu/MonitoringTools/DownladableSPIProgram.aspx. The program is capable of calculating SPI at different time scales such as 1, 3, 6, 9, 12 and 24 months. It has been used to assess drought by researchers in different parts of the world, for instance; San Pedro River basin, Arizona, USA (Polyakov*et al*., 2010), Ethiopia (Belayneh and Adamowski, 2012) and Italy (Kumar *et al*., 2013). The WMO produced a useful user guide for this program (WMO, 2012). Table 1 is the SPI value table used to define drought intensities resulting from the SPI.

Table 1: Drought Classification by SPI Value

SPI Value	Category
≥ 2.00	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
≤ -2.0	Extreme drought

RESULTS AND DISCUSSIONS

3-Month SPI

In this study, the 3-month SPI compares the June-July-August rainfall total for each year with the totals of these months for all the years in the study period. After calculating 3-month SPI for the study period, average for every year was also calculated, plotted and presented in Figure 1. From Figure1, it is clear that even though drought is a recurring phenomenon in the study area, its frequency and intensity vary temporally. For instance, from 1922 up to 1970 (53% of the study period), there were 16 drought occurrences out of which 14 were mild, 1 severe, 1 extreme and no moderate one. In contrast to this, there were 16 occurrences of droughts from 1971 to 1998 (29% of the study period) out of which 10 were mild, 4 were severe and 2 were extreme. As for the period 1999 to 2013, there were 7 occurrences of mild droughts only. This indicates a sort of respite from the menace of drought in the area.

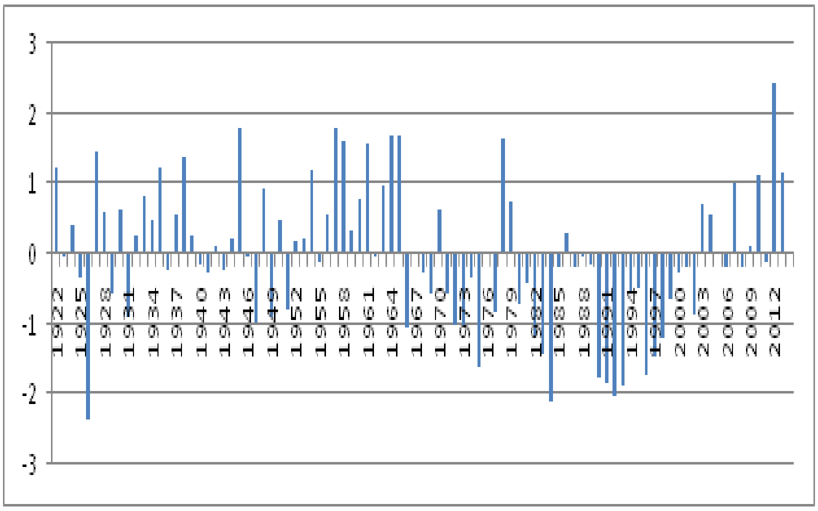

Figure 1: 3-Month SPI for the Period 1922-2013

6-Month SPI

The 6-month SPI compares the rainfall total for May to October period for each year with all the rainfall total for the same months in the study period. Here also after calculating the 6-month SPI, average for each year was calculated and presented in Figure 2. It can be seen from Figure2 that from 1922 to 1970 (53%), there were 17 drought events. Out of these, 13 were mild, 3 were moderate and one was extreme. But for the period 1971 to 1988 (29% of the study period), there were 25 drought events out of which 14 were mild, 5 were moderate, 3 were severe and 3 were extreme. There is culmination of drought in the whole of Nigeria’s arid zone in 1983 to 1984 as indicated by Mortimore (1989). Therefore, Figure 2 portrays a good picture of seasonal trend in rainfall in the study area. This is because the 6 -month period corresponds with the rainy season in the study area even though much of the rainfall is concentrated in June to August period.

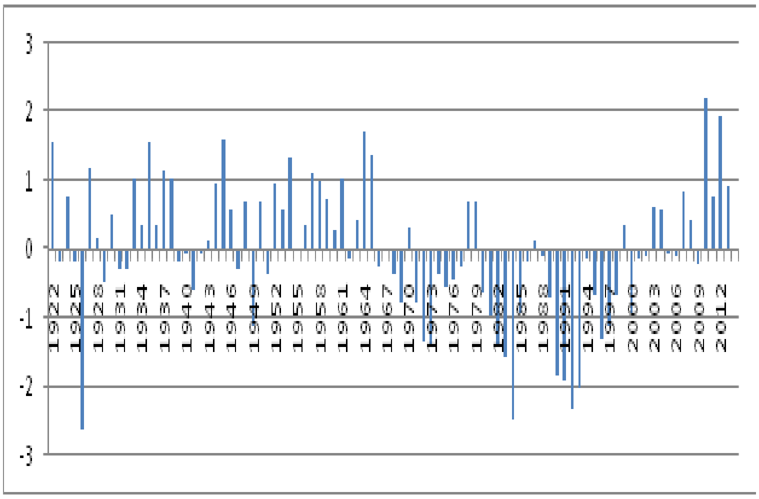

Figure 2: 6-Month SPI for the Period 1922-2013

Both figure 1 and 2 indicate decrease in rainfall in the area especially from mid 1960s up to late 1990s. For this period, Agnew and Chappell (1999) concluded that no matter what statistical averaging period is used, the downward trend manifests itself in long-term rainfall series. However the period that follows, there is evidence of increase in rainfall as revealed by Ati *et al* (2007).

Probability of Occurrence

Probability of occurrence of each category of drought in the study area is presented in Tables 2 and 3. From these tables, it is clear that more than half the study period (52%) is occupied by drought events of varying intensities. Mild droughts have the highest probabilities of 35.8% (3-month SPI) and 38% (6-month SPI) with severity of 1 in 2.78 years and 1 in 2.6 years. However, extreme drought events have the lowest probabilities of 3.2% (3-month SPI) and 4.3% (6-month SPI). This has serious implications for water resource management and agricultural production which is the mainstay of the economy of most of the populace.

Table 2: Probability of Occurrence (3-Month SPI)

SPI	Category	Number of Times in 92 Years	Probability	Severity of Event
0 to -0.99	Mild drought	33	35.8%	1 in 2.78 years
-1.00 to -1.49	Moderate drought	8	8.6%	1 in 11.5 years
-1.50 to -1.99	Severe drought	4	4.3%	1 in 23 years
≤ -2.00	Extreme drought	3	3.2%	1 in 30.67 years
	Total	**48**	**51.9%**	

Table 3: Probability of Occurrence (6-Month SPI)

SPI	Category	Number of Times in 92 Years	Probability	Severity of Event
0 to -0.99	Mild drought	35	38%	1 in 2.6 years
-1.00 to -1.49	Moderate drought	6	6.5%	1 in 15.3 years
-1.50 to -1.99	Severe drought	3	3.2%	1 in 30 years
≤ -2.00	Extreme drought	4	4.3%	1 in 23 years
	Total	**48**	**52%**	

CONCLUSIONS

The assessment shows that drought severity and frequency of occurrence vary in the study area. Out of the study period, 1922 to 1998 experiences more frequent and severe drought events than the periods that both precede and succeed it. In addition, 3-month SPI could be more relevant to crop production in the area (as this is the most critical period for growth and grain filling of most of the crops grown in the area). And 6-month SPI could be more relevant to water resource management (stream flow and reservoir levels). Recently, the area has also been experiencing a sort of respite from moderate to extreme droughts which is good for agricultural production and water resource management.

It is highly recommended that both the people and government of the area should not be deceived by the recent respite from drought, rather mitigation measures should be in place and drought always expected as it can occur any year without the slightest warning.

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