AN ASSESSMENT OF SPATIO-TEMPORAL VARIABILIY OF DROUGHT IN THE SEMI-ARID ZONE OF NIGERIA USING STANDARDIZED PRECIPITATION INDEX

By

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ABSTRACT

Drought is a recurrent phenomenon in Nigeria's semi-arid zone especially in the last few decades. In this study, spatio-temporal variation of drought in this zone from 1976 to 2013 is investigated. Standardized Precipitation Index (SPI) is used to determine both the spatial and temporal dimensions of drought based on frequency and severity of drought events at 6-month time step. The study found that in the study area, the first two decades of the study period (1976-1985 and 1986-1995) are chequered by drought and non-drought events. During the decade that followed (1996-2005), drought events were also recorded but to a lesser degree. The latest period (2006-2013) is almost free from drought events except for a moderate drought at Sokoto. Near normal condition, which is a situation whereby rainfall is slightly above or below normal, is recently becoming prevalent in the area. This is a clear indication that a significant shift towards a wetter condition is being experienced in the area. Nevertheless, 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 it, and its coping and mitigation measures always put in place.

Keywords: Drought, Standardized precipitation index, Semi-arid, 6-month SPI

INTRODUCTION

Drought occurs in almost every part of the world and 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, all points of view seem to agree that drought is a condition of insufficient moisture caused by a deficit in precipitation over some time period (McKee, Doesken and Kliest, 1993). It has also 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, is 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.

Several drought indices have been developed based on either rainfall data alone or rainfall data along with one or more additional meteorological parameters. However, research have shown that indices based solely on rainfall data have the advantage of performing better in comparison to more complex hydrological ones (Oladipo, 1985). Drought indices are very important for monitoring droughts continuously in time and space. This is because drought early warning systems are based primarily on the information that the indices provide (Svoboda *et al*., 2002).

Standardized precipitation index (SPI) is one of the latest drought indices developed. It was developed by McKee *et al.* (1993) and can be calculated at different time scales to monitor droughts in the different usable water resources (ground water, reservoir storage, soil moisture, snowpack and stream flow). McKee *et al* (1993) and Edwards and McKee (1997) recommended using at least 30 years of high-quality data to compute SPI. Agnew and Chappell (1999) found that more than 40 years of data are required to compute SPI in the Sahel that was independent of the base averaging period. Another study 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 (Guttman, 1999). In addition, Wu, Hayes, Wilhite and Svoboda (2005) conclude that the longer the length of record used in the SPI calculation, the more reliable the SPI values will be. Nevertheless, for East Africa, 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, Svoboda, Hayes, Wilhite and Wen, 2007). It has been used to assess drought in different parts of the world, for instance; Turkey (Komuscu, 1999; Sonmez, Komuscu, Erkan and Turgu, 2005), USA (Hayes, Svoboda, Wilhite and Vanyarko, 1999), Spain (Lana, Serra and Burgueno, 2001), Hungary (Szalai and Szinell, 2000), Argentina (Zanvettor and Ravelo, 2000) Europe (Lloyd-Hughes and Saunders, 2002) and Sahel region (Agnew and Chappell, 1999).

In Nigeria, Akeh, Nnoli, Gbuyiro, Ikehua and Ogunbo (2000) and Mortimore (2000) mentioned that they used SPI to characterize drought. However, in reality what they used was not SPI but Standardized/Normalized Rainfall Anomaly. This is because the rainfall data used was not normalized using either Gamma distribution (McKee et al., 1993) or Pearson Type III distribution (Guttman, 1999). Fitting rainfall data to one of these distributions is a necessary step in SPI computation. Such a mistake or oversight by researchers using SPI has been discussed in detail in Hayes (2000).

In order to avoid this type of mistake and others that arise in the course of lengthy computations involved in fitting the data to one of the probability density functions (such as Gamma and Pearson Type III distributions), the United States National Drought Mitigation Centre (NDMC) developed an SPI program. This program computes SPI values from monthly precipitation data at different time steps. It has been used to assess drought by researchers in different parts of the world, for instance; San Pedro River basin, Arizona, USA (Polyakov, Nearing, Stone, Hamerlynk, Nichols, Holifield

Collins and Scott, 2010), Jamaica (Richards, Maramootoo and Trotman, 2010) Ethiopia (Belayneh and Adamowski, 2012) and Italy (Kumar, Bindi, Gisci and Maracchi, 2013). In this study, this program is used to investigate drought variability in Nigeria's semi-arid zone for the period 1976-2013. The study aimed to address the multi-facet aspects of drought such as frequency of occurrence, intensity, spatial and temporal variability.

STUDY AREA

Nigeria's semi-arid zone is located at the extreme northern part of Nigeria, roughly from latitude 12^{o}00'N on the western frontier to latitude 10^{o}30'N on the eastern frontier (Mortimore, 2009). This area cuts across nine states namely; Kebbi, Sokoto, Zamfara, Katsina, Kano, Jigawa, Bauchi, Yobe and Borno as shown in Figure 1. The study area covers a total area of about 163,000 km^2. Climate of the area is tropical continental (Aw) type characterised by wet (June – September) and dry (October – May) seasons respectively. Most of the region's rainfall is the result of the northward penetration of the West African Monsoon in the boreal summer as a result of generation of lines of organised convective disturbances often referred to as squall lines (Rowell and Milford, 1993). The area is made up of undulating plains found within both the low lying areas such as Sokoto and Chad basins and the High plains of northern Nigeria. Vegetation of the area ranges from Sudan to Sahel savanna types. The major occupation of the populace is cultivation of cereal crops (through both rain fed and irrigation agriculture) and rearing of animals such as cattle, sheep and goats.

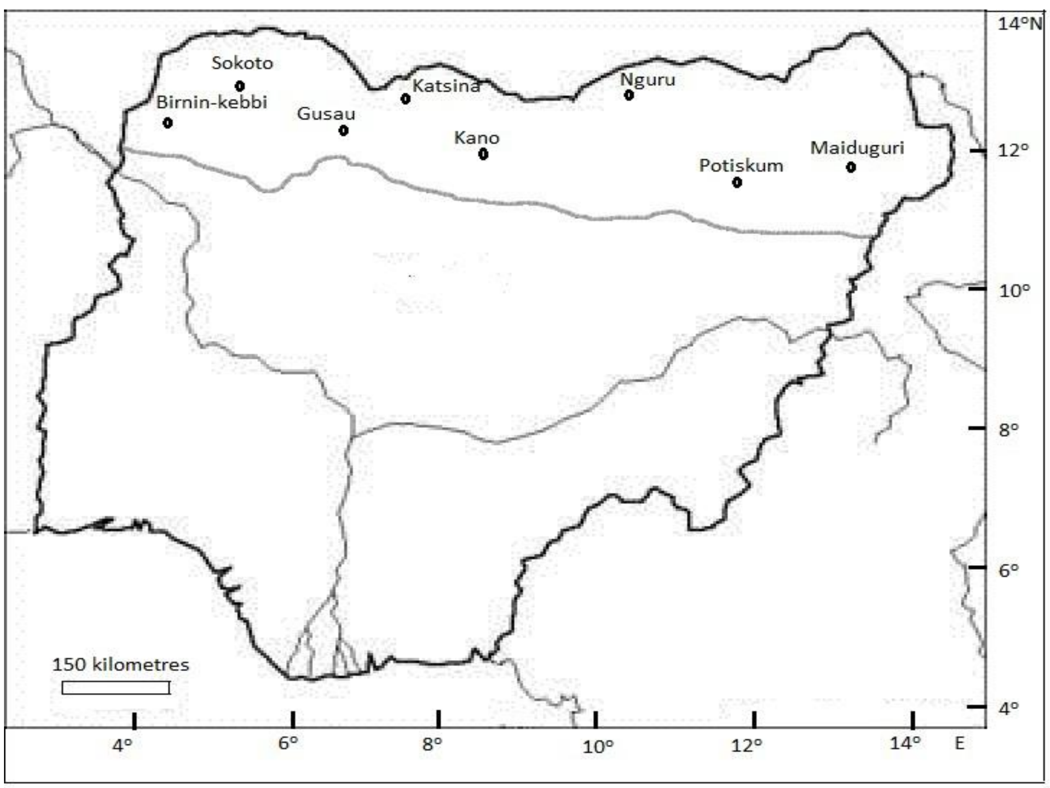


Fig. 1: Nigeria showing the study area

MATERIALS AND METHODS

Data

Monthly rainfall data from eight synoptic stations spread across the study area were collected from the Nigerian Meteorological Agency. The stations are; Birnin Kebbi, Sokoto, Gusau, Katsina, Kano, Nguru, Potiskum and Maiduguri.

SPI calculation

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

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

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

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

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

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

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

where for n observations

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

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:

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

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

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

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) suggested that the actual probability of non-exceedence $H(x)$ should be given as

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

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

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

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, NDMC simplified this cumbersome process by developing a program which can run in both Windows and UNIX (a computer operating system) environments. This program 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 it can be 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. In this study, 6 month (May to October) time step has been used because this is the time when sufficient or insufficient rainfall matters to various water using activities in the study area. The World Meteorological Organisation (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

Source: McKee *et al* (1993)

RESULTS AND DISCUSSION

6-Month SPI

In this study, the 6-month SPI for each station compares the May-October rainfall total for each year with the totals of these months for all the years in the study period for that station. After calculating 6-month SPI for each station, average for every year is also calculated, plotted and presented in

Figure 2. From this figure, it is clear that even though drought is a recurring phenomenon in the study area, its frequency and intensity vary spatially and temporally. For instance, drought events have higher frequencies of occurrences in the mid-1970s up to mid-1990. This fact has been buttressed by Mortimore (2009) that there is culmination of drought in the whole of Nigeria's arid zone in 1983 and 1984. As for the period 2006 to 2013, only Sokoto experienced a moderate drought event in 2009. This indicates a sort of respite from the menace of drought in the area. Therefore, the last part of Figure 2 in all the stations portrays a good picture of seasonal trend in rainfall in the study area. This is because there is an increase in rainfall within the 6 months under study.

Decadal Analysis of Drought based on 6-month SPI

The study period is divided into four sub-periods; 1976-1985, 1986-1995, 1996-2005 and 2006-2013. Result of analysis of occurrence of different categories of drought events in these periods is presented in table 2. From this table, results are discussed based on drought categories:

Moderate drought

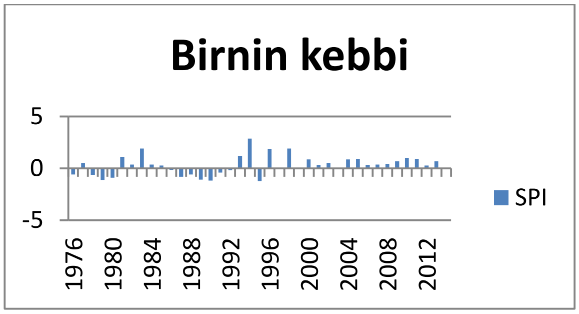
For the period 1976-1985, Kano has the highest frequency (40%) of occurrence of moderate drought followed by Potiskum and Maiduguri (each with 20%). For 1986-1995, Maiduguri is ranked first (40% of the period), Nguru and Birnin-Kebbi are ranked second each with 30%. These are followed by Katsina and Kano each with 20% of the period dominated by moderate drought events. For 1996-2005, only Gusau experienced a 10% occurrence, while for 2006-2013 only Sokoto experienced a similar occurrence.

Severe drought

For the period 1976-1985, each of Katsina, Kano, Nguru and Maiduguri recorded a 10% occurrence of severe drought respectively. During the period 1986-1995, there is an increase in the frequency of this category of drought especially in Sokoto, Katsina and Kano, where 20% of the period experienced severe drought. For 1996-2005, only Gusau experienced this type of drought for 20% of the period, while Nguru and Potiskum experienced it for 10% of the period. During the period 2006-2013 no severe drought was experienced in the study area.

Extreme drought

Extreme drought has only 10% frequency of occurrence in Sokoto (1976-1985), Kano and potiskum (1986-1995) and Maiduguri (1996-2005). During the latest period (2006-2013), no extreme drought event was experienced in the study area. This result indicates more frequent occurrences of various categories of drought in the area especially from mid 1970s up to mid-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.



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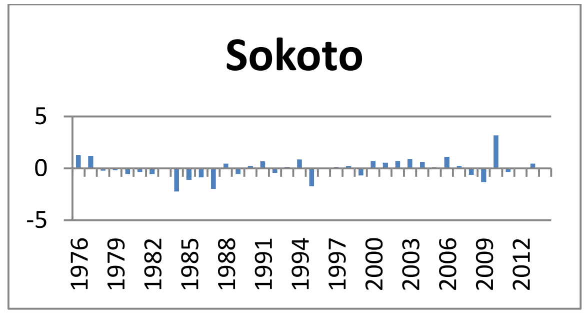

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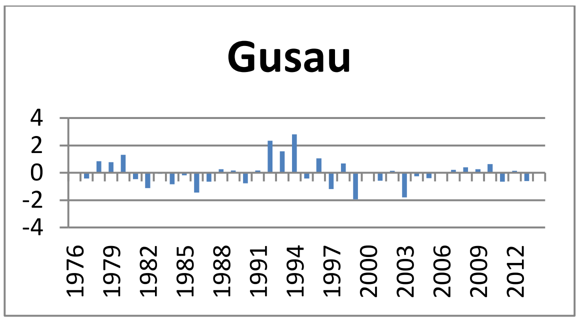

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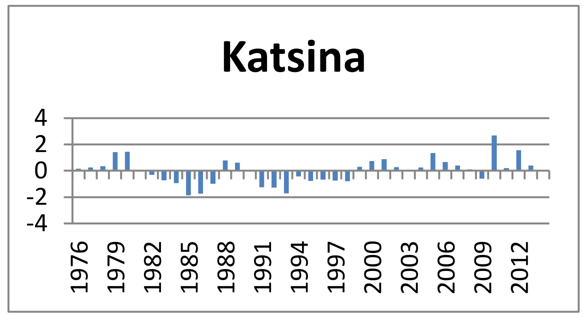

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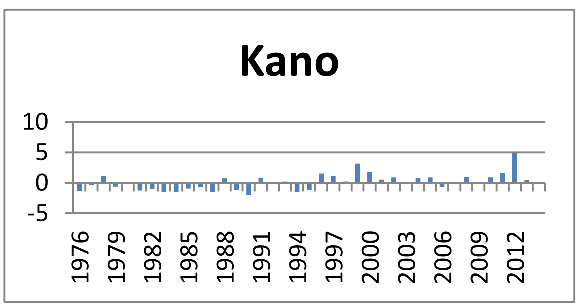

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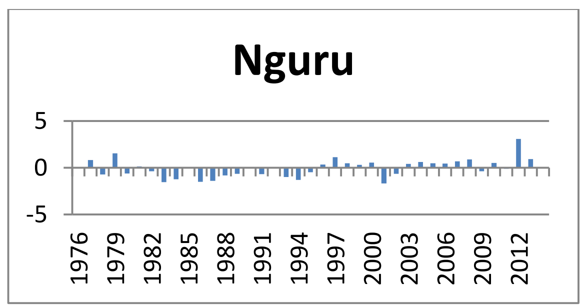

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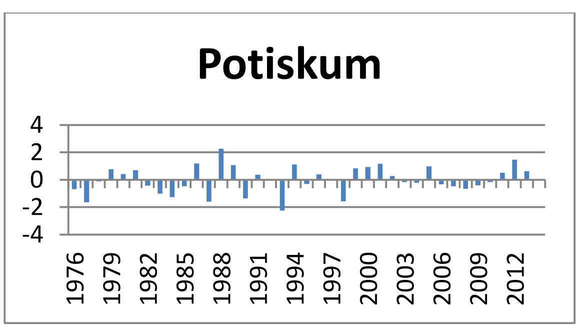

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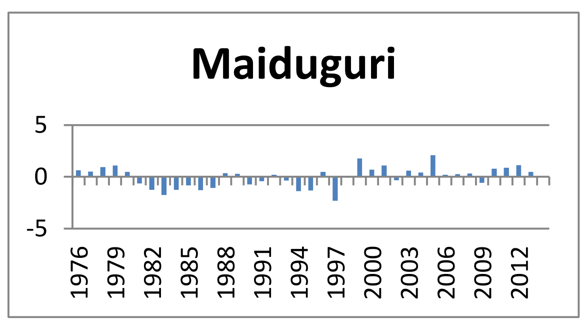

(h)

Figures 2 a-h: 6-month SPI for the period 1976-2013

Table 2: Decadal distribution of drought events in the study area for the period 1976-2013

SPI category	Period	Birnin Kebbi	Sokoto	Gusau	Katsina	Kano	Nguru	Potiskum	Maiduguri
		%	%	%	%	%	%	%	%
Extremely wet	a	-	-	-	-	-	-	-	-
	b	10	-	20	-	-	-	10	-
	c	-	-	-	-	10	-	-	10
	d	-	12.5	-	12.5	12.5	12.5	-	-
Very wet	a	10	-	-	-	-	10	10	-
	b	10	-	10	-	-	-	-	-
	c	10	-	-	-	20	-	-	10
	d	-	-	-	12.5	12.5	-	-	-
Moderately wet	a	10	20	10	20	10	-	-	10
	b	-	-	-	-	-	-	30	-
	c	-	-	10	10	10	10	10	10
	d	12.5	12.5	-	-	-	-	10	10
Near normal	a	70	60	80	70	40	70	70	60
	b	50	80	60	60	50	70	30	60
	c	90	100	60	90	60	80	80	60
	d	87.5	62.5	100	75	75	70	87.5	87.5
Moderate drought	a	10	10	10	-	40	10	20	20
	b	30	-	10	20	20	30	10	40
	c	-	-	10	-	-	-	-	-
	d	-	12.5	-	-	-	-	-	-
Severe drought	a	-	-	-	10	10	10	-	10
	b	-	20	-	20	20	-	10	-
	c	-	-	20	-	-	10	10	-
	d	-	-	-	-	-	-	-	-
Extreme drought	a	-	10	-	-	-	-	-	-
	b	-	-	-	-	10	-	10	-
	c	-	-	-	-	-	-	-	10
	d	-	-	-	-	-	-	-	-

(a=1976-1985, b=1986-1995, c=1996-2005, d=2006-2013)

The near normal condition reveals that there is a significant shift toward a wetter condition in the area recently. This is because there is an increase in the percentage of occurrence of near normal condition almost throughout the study area especially when the period 1976-1985 is compared with 2006-2013 period. It is clear that there is an increase from 70% to 87.5% in Birnin Kebbi, 80% to 100% in Gusau, 60% to 62.5% in Sokoto, 70% to 75% in Katsina, 40% to 75% in Kano, 70% to 87.5% in Potiskum and 60% to 87.5% in Maiduguri. This result corroborates the findings of Ati, Iguisi and Afolayan (2007) which reveals an increase in wet condition in the area. The year 2003 marked a turning point in terms of the shift towards a wetter condition in the area and the whole of the African Sahel region (Brooks, 2004; UK Meteorological Office, 2004).

CONCLUSION

The assessment shows that drought severity and frequency of occurrence vary in the study area both spatially and temporally. Out of the study period, 1976-1985 and 1986-1995 experience more frequent and severe drought events than the period that succeed it. Apart from agricultural planning, 6-month SPI is also 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.

Notwithstanding the recent respite from drought, coping and mitigation measures should always be in place since drought can occur any year without the slightest warning.

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