Drought risks and impact on water resources in part of northern Nigeria

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Abstract Knowledge concerning various aspects of drought and water scarcity is required to predict and to articulate strategies to minimize the effects of future events. This paper investigated drought episodes in northern Nigerian using the Standardized Precipitation Index (SPI) for monthly rainfall standardization at temporal scales of 6 and 12 months. The region has been hit by droughts with maximum severity in the 1980s. The Sahel savannah is more prone to extreme drought with great magnitudes while the Guinea and Sudan savannahs are more prone to mild to moderate drought. Hence, there is a call for people-oriented national drought policies and preparedness.

Key words drought; northern Nigeria; rainfall; standardized precipitation index (SPI); recurrence interval

INTRODUCTION

Droughts are periods of abnormally dry weather conditions when compared with a normal period at a local or regional level. Drought can occur in any hydro-climatological region and at any time of the year (Wilhite *et al*., 2000; Rossi *et al*., 1992) with severe societal consequences that span many sectors of the economy and reach well beyond the area experiencing physical drought. Drought therefore constitutes one of the most damaging societal climate-related hazards and was regarded as the most serious climatic risk in the 20th century (Obasi, 1994; Wilhite *et al*., 2000).

Losses resulting from drought phenomena amount to billions of US dollars annually. In Europe the drought of 2003 affected 19 countries, and the total costs were estimated to exceed 11.6 billion Euro (EurAqua, 2004). The Sudano-Sahelian ecological drought and famine of 1968–1974 also resulted in the death of over 200 000 people and millions of animals. The devastating effect of the drought led to the establishment of the United Nations Sudano-Sahelian Office and other international-scale special programmes on drought and desertification were initiated.

In Nigeria, since the 1970s phenomena associated with climatic anomalies have taken a severe toll on water availability, decreasing the inflows to water bodies, particularly in the Sahel. During this period of increasing desiccation and aridity, the rainfall amount decreased by 20–30% and runoff by 40–60% while Lake Chad shrunk to just 5.7% of its 1963 area, i.e. from 22 902 km^2 in 1963 to 1304 km^2 in 2000. Issues relating to hydro-climatological drought are therefore not new, especially not in the northern part of Nigeria (Adefolalu, 1986; Oladikpo, 1995).

In this study, basic drought indices were derived based on the Standard Precipitation Index (SPI) and the log-Pearson Type III probability distributions. The drought index permits the measurement of drought intensity, magnitude and severity, as well as its duration based on historical data. Such knowledge is needed for understanding various aspects of drought and water scarcity in northern Nigeria as well to predict and articulate strategies towards attaining appropriate mitigation measures and policies on drought planning and water resources management.

REGIONAL SETTING

Northern Nigeria occupies about 70% of the surface area of the country and lies between latitudes 6°27′N and 14°N, and longitudes 2°44′E and 14°42′E (Oladipo, 1995). The region includes three distinct ecological zones, namely the Guinea savannah (6°–9°N), the middle Sudan savannah, (9°–11.5°N), and the Sahel savannah (north of 11.5°N). The region, otherwise known as the sub-Saharan region constitutes the “grain basket” of Nigeria, and is a transitional zone between the

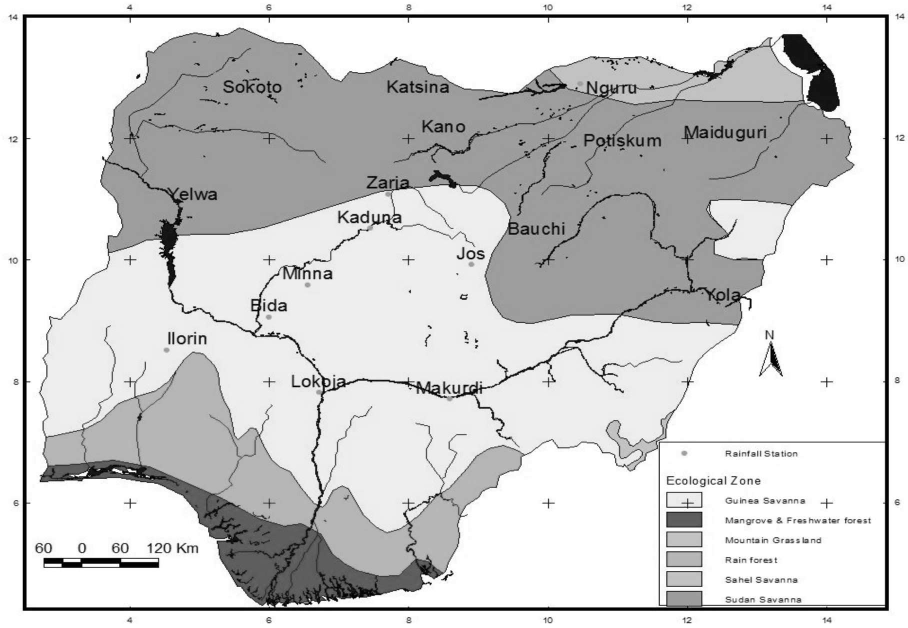

Fig. 1 Northern Nigeria.

humid areas to the south and the Sahara Desert to the north (Fig. 1). This region is characterized as an ecologically fragile zone since it is highly vulnerable to climatic and ecological anomalies (Oladikpo, 1995).

It should be noted that the region is classified as a tropical climate area and that it is dominated by the tropical maritime air mass, which brings rain from April to October, and by the dry, dusty tropical continental air mass that prevails from October to March. The region therefore has two marked seasons, the wet and dry seasons. Average annual rainfall in the region ranges from 500 to 1000 mm with rain days of between 40 and 100 per year (Adefolalu, 1986; Ojo & Oyebande, 1987). Rainfall is highly seasonal and variable in time and space, while periods of deficit rainfall impose serious limitations on the growth of viable vegetation cover. The effect of the higher and cumulative rainfall variability in the region has being identified as a resultant effect of the atmospheric systems controlling the whole region.

Northern Nigeria has been hit by several episodes of drought of indeterminable levels of severity and impact, including the Sahelian droughts of the 1960s and 1980s, associated with low rainfall (Ojo, 1986). It is therefore known to be prone to drought hazard, and most especially in the Sahel areas, since the scourge of the 1970s. The impact of the drought phenomena includes mass starvation, famine and cessation of economic activity, most especially in the rain-fed agriculture region which constitutes the main stay of the rural economy. For example, during the drought of 1972–1973, about 300 000 animals died, and farm yields dropped by about 60% resulting in famine in northern Nigeria.

METHODOLOGY

The research methodology employed in this study involves analysis of monthly rainfall data of 17 stations (Fig. 1) for the period 1945–1995 in order to derive basic drought indices. The drought definition is based on the standardized precipitation approach with an index that is linearly proportional to precipitation deficit (Guttman, 1999; Wilhite *et al.*, 2000). The log-Pearson Type III probability distribution was used to fit the drought severity, in order to estimate the return period of drought characteristics (deficit volume and duration). The estimate is useful for the analysis of past droughts and to define "design droughts" of a fixed return period.

According to Guttman (1999), first a probability density function should be established that describes the long time series record. Then the cumulative probability of the observed precipitation is calculated, and finally an inverse normal (Gaussian) distribution is applied to get the SPI. SPI values greater than 2 or less than –2 are then representative of extreme conditions.

The Standardized Precipitation Index (*SPI*) is defined as the ratio of the difference between the measured rainfall and the long term mean to the standard deviation for any month. The index is quantitatively expressed as:

$$SPI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 - d_1 W + d_2 W^2 + d_3 W^3} \quad (1)$$

where C_n and d_n are constants, $W = \sqrt{(-2\ln p)}$ is calculated for $p \leq 0.5$, and p is the exceedence probability of a given value of precipitation whose total series follows a Pearson III distribution. In this method, the positive sums of the SPI values that are continually negative over consecutive months are used to define drought episodes and to express their duration, severity and intensity (Bonaccorso *et al*., 2003). The SPI represents the standardized departure of observed precipitation data from its mean value for a specified location and time scale. The time scales used in this study are 6 and 12 months.

Drought severity (S_D) or the run sum is the arithmetic sum of the SPI deficit over a given duration, and drought magnitude (M) or the run intensity is the mean severity over the duration (D) which is quantitatively expressed as $M = S_D/D$.

The ArcView spatial analysis tool was used for the synoptic stations mean 1-month drought intensity interpolation using the inverse distance-weighted interpolation method at power 2. The method assumes that the unknown value of a point is influenced more by nearby control points than those farther away. Power 2 indicates that rate of change in values is higher near a known point and levels off away from it.

The drought frequency analysis was carried out using the log-Pearson Type III probability distribution (WMO, 2009). The distribution is quantitatively expressed for drought severity estimate as:

$$\log Q = X - (K \times S) \quad (2)$$

where Q is the expected drought severity, X is the mean logarithm of the observed drought severity values, S is the standard deviation of logarithms of the observed drought severity, and K is a factor that is a function of the skewness coefficient of the observed values and the selected non-exceedence probability.

The associated risk to the return periods is given as:

$$1 - \left(1 - \frac{1}{Tr}\right) \quad (3)$$

where Tr is the expected return period.

RESULTS AND DISCUSSION

The SPI values calculated for the distinct ecological zones within northern Nigeria, the Guinea savannah, the middle Sudan savannah and the Sahel savannah depict mild to extreme drought. In the study period, earlier years (1945–1972), especially in the Guinea savannah, witnessed mostly mild droughts, while moderate droughts characterized the 1970s. Severe to extreme droughts characterized the 1980s and moderate droughts prevailed in the 1990s (Fig. 2). Large cumulative rainfall deficits (severity) and magnitudes are witnessed more in the 1980s when compared with the early years and the 1990s. On the average, drought occurrences in the Guinea and Sudan savannahs fall between mild and moderate droughts, while the Sahel savannah experiences severe droughts using both 6 and 12 month periods to represent mean rainfall for SPI calculation.

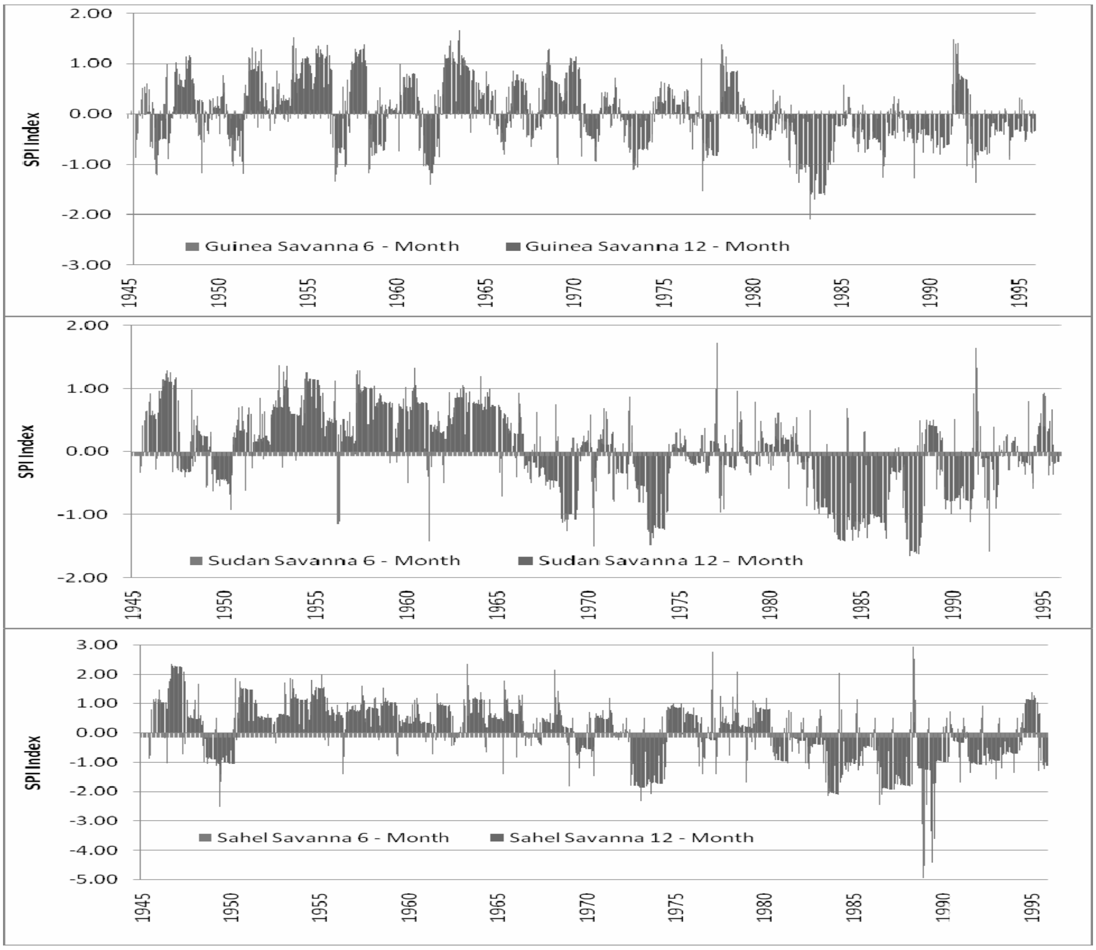

Fig. 2 SPI index of rainfall in northern Nigeria (1945–1995).

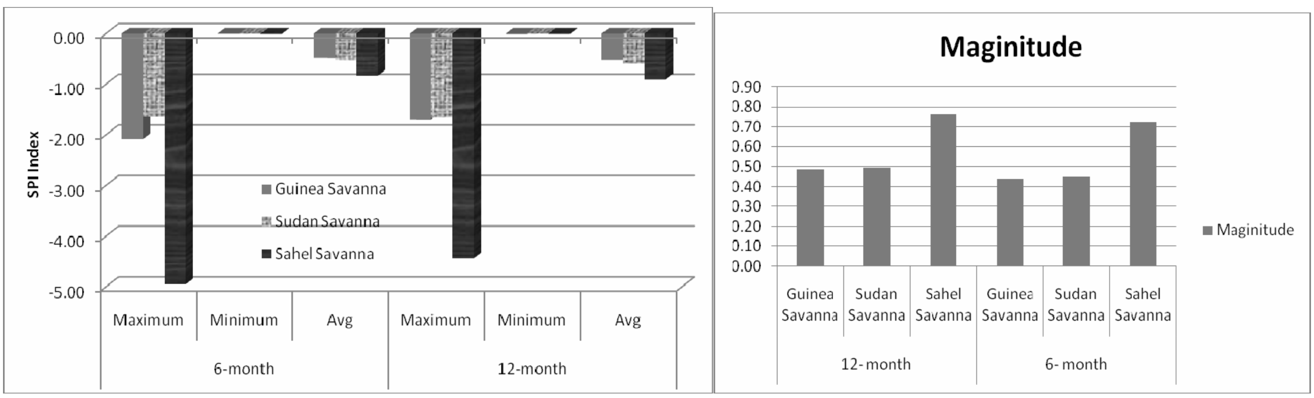

Fig 3 Drought SPI and magnitude in northern Nigeria (1945–1995).

The 12-month maximum cumulative rainfall deficiency indices of 16.62 (1983), 14.72 (1984) and 21.93 (1989) were attained in the Guinea, Sudan and Sahel savannahs, respectively. For the 6-month time scale, maximum cumulative water deficiencies were attained in 1983 (13.81), 1987 (11.18) and 1989 (15.24) in the Guinea, Sudan and Sahel savannahs, respectively. Drought magnitudes at 6-month and 12-month rainfall deficiency per month depict that average water deficiency is higher in the Sahel savannah and is about twice that which is being experienced in the Guinea savannah (Fig. 3). Extreme drought severity is therefore common around Kano,

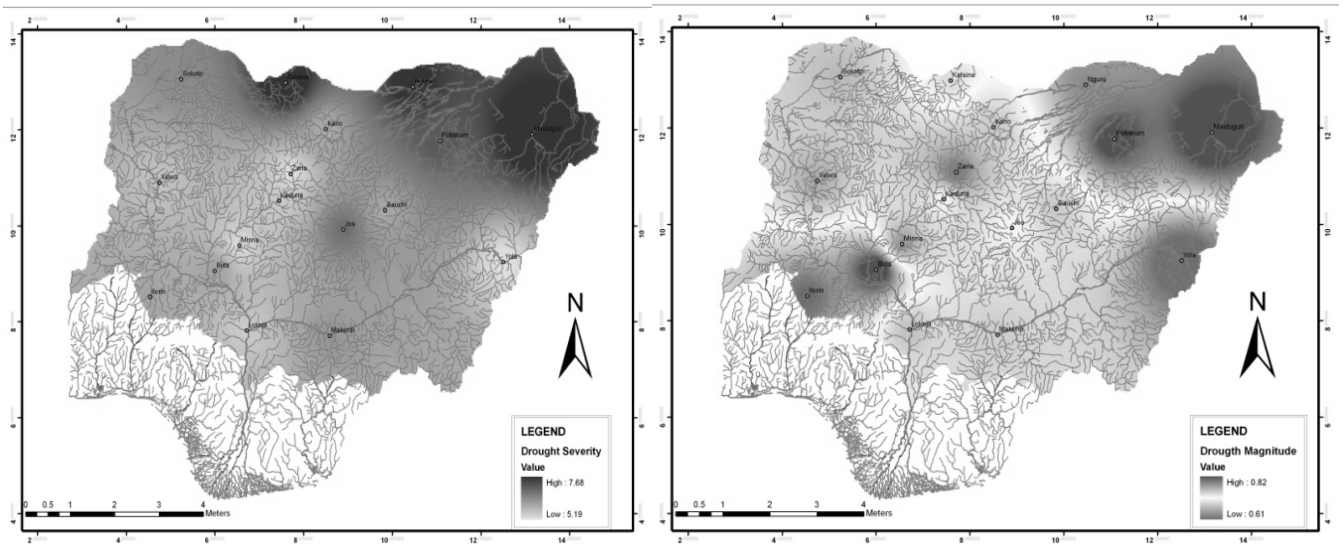

Fig. 4 12-month mean drought severity (left) and magnitude (right) in northern Nigeria (1945–1995).

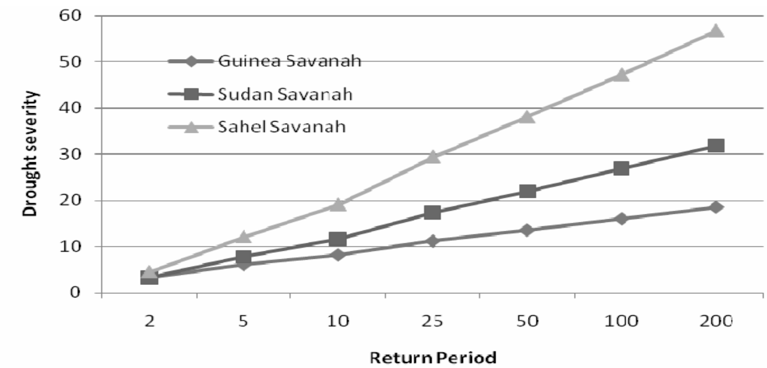

Fig. 5 12-month drought severity in northern Nigeria.

Sokoto, Nguru, Maiduguri, Potiskum, Kastina and Yelwa (Adeaga, 2002) while the 12-month drought magnitude ranges from 0.61 at Yola to –0.82 at Maiduguri with the northeastern region having the highest magnitude while regions around Yola have the lowest; in other regions magnitudes are mild with the exception of the discrepancy observed around Bida and Ilorin (Fig. 4).

From the point of view of creating provision for meeting exigencies during a drought spell, the most important parameters of concern are the longest duration and the largest severity for a desired return period of *T* years. Return period of the cumulative rainfall deficit index (drought severity) of 12-month SPI index is shown in Fig. 5.

Since drought risk is a product of a region's exposure to the natural hazard and its vulnerability to extended periods of water shortage (Wilhite *et al*., 2000), the severity of drought, most especially in the Sahel savannah, in the wave of climate change is expected to intensify the increasingly critical water situation through reduced annual average rainfall in the fragile water-stressed regions. This will negatively affect the water availability, groundwater recharge processes, and further decrease the streamflow, and cause overexploitation and utilization of available surface water. This means the region will not have sufficient water resources to maintain the current level of per capita food production in the rain-fed agricultural sector or irrigated agriculture (even at high levels of irrigation efficiency), or to meet reasonable water needs for domestic, industrial and environmental purposes.

CONCLUSION

The Standardized Precipitation Index calculated for the distinct savannah ecological zones within northern Nigeria reflects how severe to extreme droughts characterized the 1980s, while the 1990s experienced mild droughts, like the years before the 1980s. The Sahel savannah experiences severe droughts with higher average water deficiency than elsewhere. Drought intensity data also show that severe to extreme drought characterized the Sudan and Sahel savannah ecological zones. The Sahel savannah region is therefore more prone to drought risk and hazard, since future drought events may also exceed the “drought of record” and the capacity of a region to respond.

Thus, drought preparedness planning should be considered an essential component of integrated water resources management within the savannah ecological zones of northern Nigeria since the magnitude of drought impacts may increase in the future as a result of an increased frequency of occurrence of the natural event (i.e. meteorological drought) as projected by climate change scenarios. The planning should also entail the development of people-oriented national drought policies, with options for an early warning signal and regional and international cooperative plan.

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