

# Chapter 26

## Spatio-Temporal Variation of Drought Severity in the Sudano-Sahelian Region of Nigeria: Implications for Policies on Water Management

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**Abstract** The African Ministerial Council on Science and Technology agreed that drought is one of the major environmental problems that is afflicting the African continent, with its consequent negative impacts on the socioeconomic development of the affected areas. It is within this context that this study assessed the spatio-temporal variation of drought severity in the Sudano-Sahelian region (SSR) of Nigeria, which is highly vulnerable to drought. The study analysed spatio-temporal variation of drought severity in the region between 1961 and 2006 using the Standardized Precipitation Index (SPI) and Principal Component Analysis (PCA). It was established that most of the extreme droughts of the highest magnitude were recorded around the 1970s and 1990s and that there were indications that this would continue in the future. Results also identified sub-regions characterized by a different level of drought risks in the region. The study concluded by making appropriate policy recommendations for effective water management for the region.

**Keywords** Sudano-Sahelian region · Drought severity · Nigeria · Water · Policies · SPI · PCA

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## Background

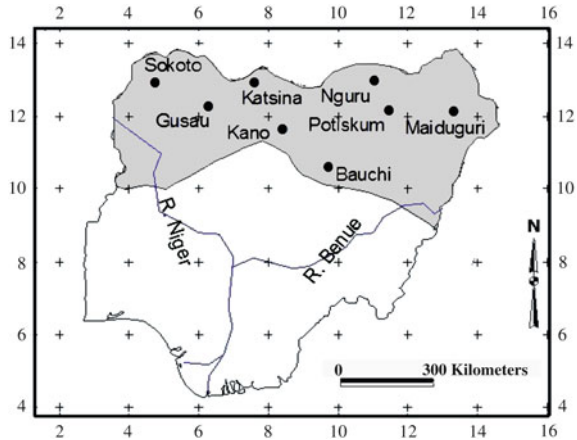
Over the years, people living in the arid and semi-arid lands have been in a continuous struggle with extreme events such as droughts and a wide range of other natural hazards. Many of these events could be of short duration, high intensity and with great impacts. It is against this backdrop that the African Ministerial Council on Science and Technology concluded that drought is one of the major environmental problems that is afflicting the African continent, with its consequent negative impacts on the socioeconomic development of the affected areas. Major scientific research activities have even linked global warming with extreme weather patterns such as droughts. It is usually difficult to define drought because the meaningful threshold of significant moisture deficiency is a function of the water use being impacted (National Academy of Sciences (NAP) 1986). As a matter of fact, there is no universal definition of drought. Wilhite and Glantz (1985) reviewed more than 150 definitions of drought. A critical assessment of these definitions showed that drought is unique to a region. For the purpose of this study, however, drought is considered as an interval of time, generally months or years in duration, during which the actual moisture supply at a given place is consistently less than the climatically expected or climatically appropriate moisture supply (Palmer 1965). Meanwhile, drought severity as it relates to public water systems is necessarily a function of human actions and/or inactions as well as the magnitude and duration of the individual hydrologic event (National Academy of Sciences (NAP) 1986). In view of this, it has been advocated that more effective research activities and abatement measures be directed toward the challenges of water management during drought events.

Droughts represent a problem of long-term common concerns in the Sudano-Sahelian region (SSR) of Nigeria. Drought severity during the 1960s and 1970s (popularly called Sahelian desiccation) has caused a wide range of impacts across the SSR of Nigeria (Nicholson et al. 2000). These impacts generated widespread scarcity of potable water as well as depleted supplies for irrigation, industry and domestic uses. One of the sectors of the economy that was severely affected was the agricultural sector, where there was significant reduction in livestock population. For instance, the drought impact during that period resulted in the loss of millions of metric tonnes of millet and sorghum worth millions of US dollars (Oladipo 1995). The aftermath of the effects of these droughts is also seen in biological productivity, as well as the regenerative capacity of the ecological systems, migration of active labour force and consequent reinforcement of rural poverty (Watts 1983; Anyadike 1987). In relation to rural poverty, the rural poor in the SSR, constituting the majority of the population, are the most vulnerable because they have few assets to call upon in order to cope with extreme events such as prolonged droughts (Thomas 2008). Meanwhile, vulnerability has been defined as the degree to which production and livelihood systems are susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC 2001). To buttress the level of exposure of this

region to the risk of extreme events, (UN-HABITAT 2006) has estimated that there are 199 million slum-dwellers in sub-Saharan Africa (SSR inclusive) with little or nothing to cope with the impacts of extreme events. In addition to the problem of poverty, the rural poor in this region also depend on the quality and functioning of the agro-ecosystems that they live in through the provision of goods and services such as food, water, fodder, fuelwood, and other materials. Therefore, any disruption in these ecosystems ultimately affects their survival. Another source of concern in this region is the high increase in population. Dynamic increase in population at the rate of 3.5% in sub-Saharan Africa, as compared to the global rate of 1.7%, has led to a lot of pressure on land and other natural resources (Naginder and Kundzewicz 1997). Consequently, it becomes imperative to provide for this ever increasing number of people. Meanwhile, this increase also poses danger to already over-stressed water infrastructures in the region. Moreover, the ability of governments and international relief agencies to deal with droughts in the region is also constrained by the absence of reliable data, information networks, professional and institutional capacities. In addition to this, (Naginder and Kundzewicz 1997) have reported that hydrological networks and observing stations in this region are in decline and the databases to assess drought and desertification risks and reduce their impacts in Africa are not adequate. Meanwhile, it is interesting to note that even though drought also hits the developed countries, it does not kill them. This has been made possible because of their ability to cope and implement efficient strategies such as sharp water-price rises, bans on watering lawns or car washes, etc. during drought episodes. Unfortunately, such strategies are difficult to implement in the SSR because of inadequate structures, institutions, legislation, markets, awareness and education (Naginder and Kundzewicz 1997). Glantz (1976) also corroborated this fact on the situation of Sahelian desiccation where he stated that even a six-month forecast of weather would not have been sufficient to avert the drought impacts in the region, due to the lack of institutional and human capabilities to manage the problems.

Today, the world's drylands are facing a greater water crisis, and droughts of lesser magnitude are now resulting in greater impacts. Even regions with normal precipitation are not left out of the challenges of water shortages, which are now widespread in both developing and developed nations (Wilhite 2005). Studies have shown that most of the strategies related to development (in most drylands), such as irrigation, improved land use, urban and rural water supply, range and livestock management, agricultural extension, energy (fuelwood), and community development, are inherently and intrinsically related to water (Naginder and Kundzewicz 1997). Drought management usually poses a serious challenge to water resources and usage. Although droughts predominate in arid and semi-arid regions of the world, their frequency and severity in the SSR regions have been on the increase. Scientists have shown that many of the world's arid and semi-arid lands would face increasing temperatures with climate change (Hulme 2001) and, more importantly, disruptions in their hydrological cycles, resulting in less and more erratic rainfall that could exacerbate the already critical state of water scarcity and conflicts over water allocation and usage (Thomas 2008). For instance, studies

**Fig. 1** Map of Nigeria, showing the Sudano-Sahelian ecological zone of Nigeria



have shown that an increase in temperature in this region could mean that recharge would be much reduced and that groundwater exploited would not be replaced at the same rate. Issues such as public health and economic development have brought improved water access to the global scene and attracted the attentions of policy-makers, water professionals, international bodies and non-governmental organizations. In view of these, the United Nation's Millennium Development Goals (MDGs) related to water and sanitation access are now on the agendas of many governments and NGOs (World Water Assessment Program (WWAP) 2006). It is apparent, therefore, that any strategy that resolves the water problem has the capability of solving many other challenges in the region and subsequently, action plans for other issues can easily be determined and effective policy successfully implemented. It is therefore important to assess spatio-temporal variation of droughts in the region in order to evaluate and anticipate drought risk and implement effective water management policies. The ability to determine the onset of droughts and map their severity will be a significant development in mitigating the negative effects of drought, combating desertification and ultimately promoting economic development in the advent of global warming. It is within this context that this study intends to assess the spatio-temporal variation in the SSR of Nigeria which is highly vulnerable to drought and climate change impacts, and suggests appropriate policies for effective and efficient water management strategies.

## Study Area

### *Location and Size*

The area chosen for this study is the SSR of Nigeria which lies roughly between Longitude 4° and 15° E and latitudes 11° and 13° N and comprises most of Borno,

Yobe, Kano, Zamfara, Katsina, Kaduna, Jigawa, Kebbi, and Sokoto states (Fig. 1). It occupies approximately 26,159 km<sup>2</sup>.

## *Climate*

In the SSR of Nigeria, rains fall mostly from June to September with the rest of the year virtually dry. The mean annual rainfall is between 1,016 mm in the wettest part (southernmost part of Sokoto state), less than 508 mm or less in the driest part (northern part of Borno state) (Ojanuga 1987) of the region with coefficients of variation ranging from 15 to 30% (Sivakumar 1989). Low annual rainfall is not necessarily as critical a constraint in crop production; rather it is the irregular occurrence of rainfall (Sivakumar and Wallace 1991). There is a 10% probability of receiving rainfall of 50 mm and 400 mm annually at the northern and southern border, respectively (Breman and De Wit 1983). The mean annual temperature is between 26°C and 28°C (Ojanuga 1987).

Variability in rainfall has been identified as a normal part of the climate of the SSR of Nigeria. An average departure of 20–40% from the annual mean rainfall has been estimated (Janowiak 1988). Mortimore (2000) identified the key source of this variation (and of drought) to be the seasonal rainfall. D'Amato and Lebel (1998) and Chappell and Agnew (2008) have recognized the importance of the number of storm events, rather than the amount of rain, to be more responsible for much of the rainfall variation in the region. This led to the conclusion that the migrations of the Intertropical Discontinuity (ITD)—the mechanism that brings rain to the SSR of Nigeria (Omotosho 1990)—are not the primary causes of the droughts. In other words, they were of the opinion that drought is the result of dynamic conditions in the weather system. Another study by Nicholson (1985) and Ba et al. (1995) also concluded that drought in the Sahel is apparently more clearly linked to reduced convective activity. The Nigerian climate is classified on a world scale as Af, Aw, and BS (Trewartha 1968). Af, Aw, and BS are Tropical wet, Tropical wet-and-dry, and Semi-arid climates, respectively (Trewartha 1968; Ojo 1987). The SSR could be classified under BS. The most obvious climatic feature of this category is that potential evaporation and transpiration exceed precipitation. The tropical desert climate is influenced by upper air stability and subsidence, which is the result of the presence of the subtropical high pressure zone. Relative humidity is normally low, averaging 10–30% in interior locations. Although the northward migration of the ITD and its associated winds appears to be the most popularly accepted of the factors known to promote rainfall in the SSR of Nigeria, precipitation is very low in quantity and very infrequent in distribution, both temporally and spatially (Adedokun 1978; Lamb 1982). However, there are opposing views that believe that rainfall deficit could be experienced even when there is sufficient incursion by the mT air mass. For instance, Nicholson and Chervin (1983) and Odekunle (2010) established that major rainfall fluctuations in the SSR appear to be primarily linked to factors modifying the intensity and

frequency of disturbances. However, the other opinions (Winstanley 1973; Kraus 1977) ascertained that the inter-annual variability observed is significantly generated by the shift in the mean positions of the ITD. In the same light, Adedokun (1978) has explained the effect of strong cold-water upwelling in the Gulf of Guinea, which could bring about a strong Walker circulation, which in turn strengthens the mT air mass, and push the ITD significantly further north of the equator, resulting in heavy precipitation in the SSR of Nigeria. The opposite trend has also been noted when there is weak cold-water upwelling, which brings about a weak Walker circulation. This phenomenon is usually associated with a weak mT air mass and limited ITD incursion into the SSR region, consequently bringing about limited precipitation in the SSR of Nigeria (Adedokun 1978). There are some opinions that SSR precipitation in general, and Nigeria in particular, is also modulated, to some extent, by the complex feedback mechanisms mainly due to deforestation/land-cover change (Brovkin 2002; Zeng 2003; Brooks 2004).

## Methodology

### *Data Collection*

The climate data required for this study includes monthly and annual rainfall totals. Data on these parameters was collected over a uniform period of time for all the rainfall stations in the SSR of Nigeria. These locations include Sokoto, Kano, Katsina, Nguru, Maiduguri, Bauchi, Gusau, and Potiskum (Fig. 1). The data was sourced from the archives of the Nigerian Meteorological Services, Oshodi, Lagos. The length of the data spanned a period of 45 years (1961–2006).

### *Data Analysis*

A consistent framework for the description of drought is essential for any study of this magnitude. This study adopted the climatology definition of drought and used the six-month Standard Precipitation Index (SPI) to determine the drought severity index. A number of other different indices of drought have been developed to quantify drought, each with its own strengths and weaknesses. Some of them are Palmer Drought Severity Index (PDSI—Palmer 1965), Deciles (Gibbs and Maher 1967), Crop Moisture Index (CMI—Palmer 1968), Food and Agriculture Organization (FAO) Water Satisfaction Index (WSI—Frere and Popov 1979), Surface Water Supply Index (SWSI—Shafer and Dezman 1982), Agro-Hydro Potential (AHP—Petrasovits 1990), Vegetation Condition Index (Kogan 1990), Index of Moisture Adequacy (IMA—Sastri 1993), Vegetation Condition Index (Kogan 1990), and Soil Moisture Deficit Index (Narasimhan and Srinivasan 2005). Two of

**Table 1** Classification of drought intensity using SPI

SPI Values	Drought intensity
2 and more	Extreme wet
1.5–1.99	Very wet
1–1.49	Moderately wet
–0.99–0.99	Near normal
–1––1.49	Moderate drought
–1.5––1.99	Severe drought
–2 and less	Extreme drought

Source McKee et al. (1993)

the most commonly used are PDSI and SPI. There are several other methods which can be used in drought analysis. SPI is a drought monitoring index developed by McKee et al. (1993) to quantify precipitation deficit for multiple timescales. The index uses long-term precipitation record for a desired period of time which will be fitted to a probability distribution. If a particular rainfall event gives a low probability on the cumulative probability function, then this is indicative of a likely drought event. The classification system shown below in Table 1 is used to define drought intensities resulting from SPI values.

### *Determination of Spatial Variation of Drought Severity*

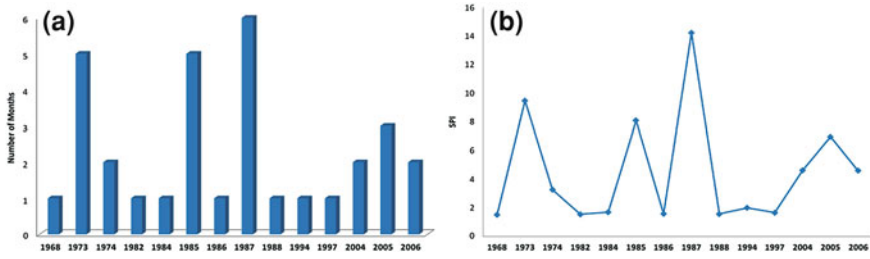
Another technique which can be used to identify spatially homogeneous drought regions is Principal Components Analysis (PCA) (Peter 1990). Studies such as those of Dyer (1975), Barring (1987) and Ehrendorfer (1987) have already established that PCA can be used to identify clusters of stations or spatial units that behave similarly with respect to a particular climatic variable. This study employed PCA to analyse spatial variation of drought severity in the region. The variable used is the drought severity magnitude in the period of 1961–2006. The values of drought magnitude are better than that of the raw SPI values because SPI values only give the probability of occurrence of a determined SPI value, which will be the same for the different areas represented by the PCA (Dracup et al. 1980). As a result of this, the index cannot be used for estimating the spatial differences in drought risk. However, the temporal patterns of drought can differ due to the temporal succession of SPI values. The loadings generated by the PCA can be mapped to show the spatial pattern of the characteristic under investigation (Peter 1990). The study used the rotated component matrix because the un-rotated one does not give physically interpretable patterns when dealing with meteorological or climatological data (Richman 1981, 1986). Thus, the principal components clusters of climatic divisions that behave similarly with respect to the various drought types or magnitude were identified and mapped (Peter 1990).

## Discussion of Results

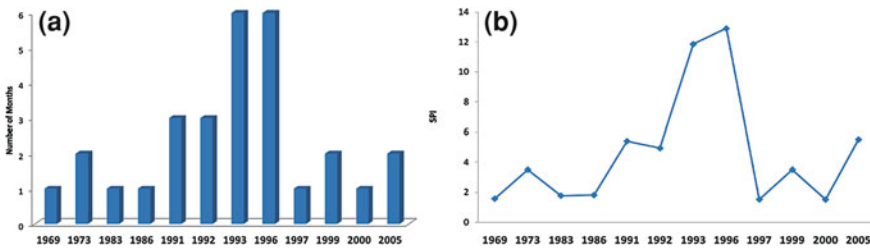
### *Assessment of Drought Severity in the SSR of Nigeria Between 1961 and 2006*

The evaluation of drought severity in the SSR of Nigeria showed that most of the drought severity with the highest magnitude occurred between the 1970s and 1990s. It was also observed that the individual rainfall stations under examination experienced severe drought of highest magnitude at different periods during the years under study. For instance, Sokoto station experienced its highest magnitude of severe drought during 1987; severe drought of high magnitude was experienced in Katsina in 1996; that of Kano was in 1973; Nguru was in 1991; Maiduguri was in 1983; severe drought of high magnitude was experienced in Bauchi in 1985; Gusau was in 1984; while that of Potiskum was in 1982 (see Figs. 2, 3, 4, 5, 6, 7, 8, and 9). Observation of the duration of the drought severity showed that there is an increase in the occurrence of drought severity in 1973, the 1980s and 2000s. In Sokoto, 1987 recorded the longest duration of drought severity (Fig. 2a). Further insight into the analysis showed that there was a persistent drought severity for six months during this year. This is followed by 1973 and 1985, which experienced drought severity for a period of five months each, respectively. These periods coincided with the periods when West African Sahel experienced most of the extreme droughts. It was observed that this region experienced decline in rainfall of more than 20% (Hulme et al. 2001). These same periods also saw the death of hundreds of thousands of people and millions of animals (Glantz 1976, 1996). This particular change in climate in the region has since been referred to as Sahelian desiccation (Hulme 2001; Chappell and Agnew 2008). Some explanation could be adduced to explain this phenomenon. Recent studies have established that the Sahelian desiccation is a product of long-term climate variability driven by changes in patterns of global sea surface temperature (Giannini et al. 2003). Giannini et al. (2003), argued that dry conditions in the Sahel occur during periods in which the southern hemisphere oceans and northern Indian Ocean are warmer than the remaining northern hemisphere oceans, and that it is a shift to such a pattern of global temperature distributions that is responsible for the turn towards aridity in the Sahel from the late 1960s. Giannini et al. (2003) identify SSTs as the principal driver of Sahelian rainfall variability, which they model successfully for the period between 1930 and 2000 using only SST forcing. The model also represents land–atmosphere interaction via moisture feedbacks. They identify warming in the Indian Ocean as “the proximate cause for the negative rainfall trend observed in the Sahel from the late 1960s to the 1980s”, which, they suggest, in combination with a more intermittently warmer than average eastern equatorial Atlantic, reduced the land–ocean temperature contrast that is crucial in monsoon dynamics, causing the deep convection associated with monsoon rainfall to migrate southwards (Brooks 2004).

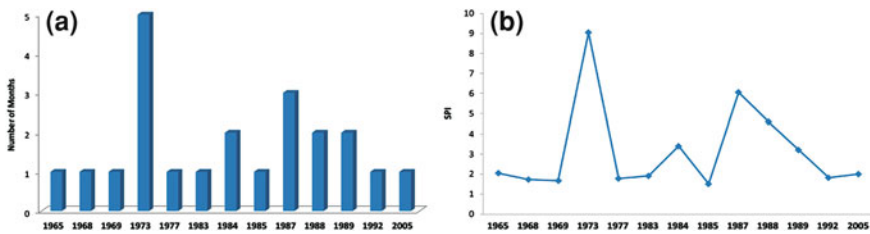




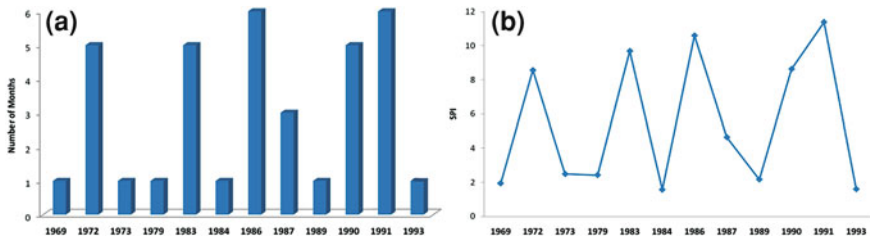
**Fig. 2** a duration of drought severity in Sokoto between 1961 and 2006 b Magnitude of drought severity in Sokoto between 1961 and 2006



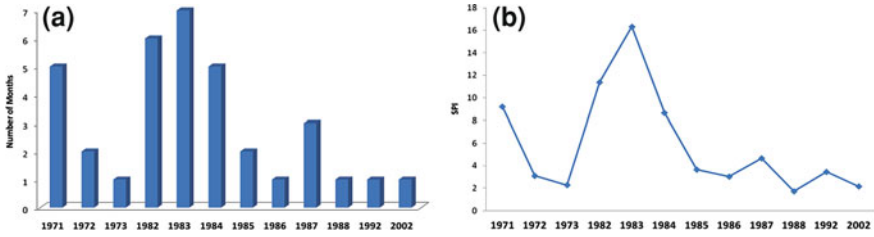
**Fig. 3** a Duration of drought severity in Katsina between 1961 and 2006 b Magnitude of drought severity in Katsina between 1961 and 2006



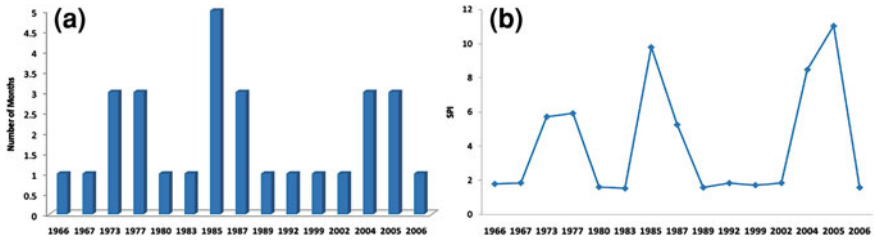
**Fig. 4** a Duration of drought severity in Kano between 1961 and 2006 b Magnitude of drought severity in Kano between 1961 and 2006



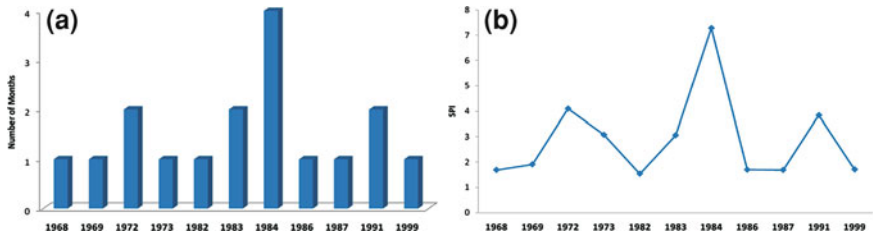
**Fig. 5** a Duration of drought severity in Nguru between 1961 and 2006 b Magnitude of drought severity in Nguru between 1961 and 2006



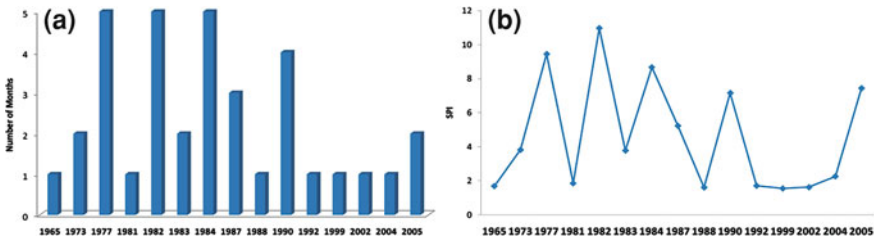
**Fig. 6** a Duration of drought severity in Maiduguri between 1961 and 2006 b Magnitude of drought severity in Maiduguri between 1961 and 2006



**Fig. 7** a Duration of drought severity in Bauchi between 1961 and 2006 b Magnitude of drought severity in Bauchi between 1961 and 2006



**Fig. 8** a Duration of drought severity in Gusau between 1961 and 2006 b Magnitude of drought severity in Gusau between 1961 and 2006



**Fig. 9** a Duration of drought severity in Potiskum between 1961 and 2006 b Magnitude of drought severity in Potiskum between 1961 and 2006

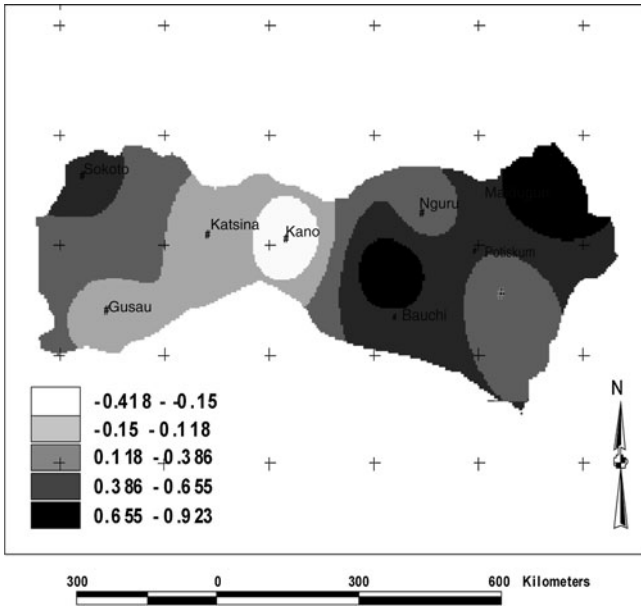


Fig. 10 Spatial distribution of rotated correlation matrix of PCA (component one)

***Spatial Variation of Drought Severity in the Sudano-Sahelian Region of Nigeria***

The analysis of PCA generated three main components. These components explained 73.63% of the total variance. The first component explained 34.43% of total variance, and represented mainly the drought evolution of the eastern region of the study area (Fig. 10). The second component (22.93% of total variance) mainly represented the western region of the study area (Fig. 11). The third component (16.27% of total variance) could be attributed to both the western and eastern parts of the study area (Fig. 12). The first two aforementioned patterns showed distinct spatial distribution, while the last one overlapped between the first two components. The implication of these results is that the areas with higher magnitude on the maps are those regions with higher drought risk.

The analysis of the spatial variation of drought severity indicated that rainfall-producing mechanisms in the different rainfall stations analysed could be as a result of local factors. For instance, analysis of the components one (which explained 34.43% of the variation in the drought magnitude) established that the area towards the eastern part of the SSR was homogeneous. This is because the map clearly showed that this section of SSR was highly coherent. Another important feature of this map was that this area was also susceptible to high drought risk. The same pattern could also be seen in the western part of the region. In all, the analysis of the spatial variation revealed that three zones could be

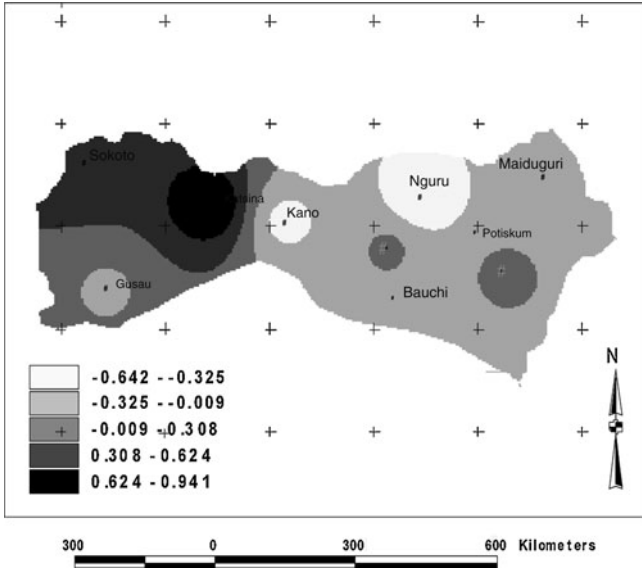


Fig. 11 Spatial distribution of rotated correlation matrix of PCA(component two)

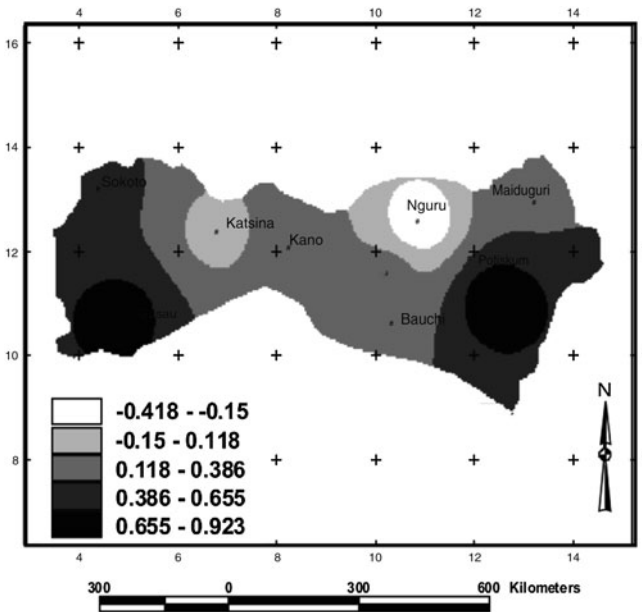


Fig. 12 Spatial distribution of rotated correlation matrix of PCA(component three)

delineated in the SSR in terms of drought risk and that areas to the extreme west and eastern section of the region were the areas which were most vulnerable. The factor which could explain the spatial variation of drought severity is the feedback mechanism associated with interactions between the atmosphere and the land surface in the mobilization and transport of dust (MacLeod 1976). The region under study is the largest source of atmospheric dust in the country. Atmospheric dust can affect the vertical temperature profile of the local atmosphere, affecting its stability and ability to support the convection necessary for rainfall generation. For instance, where dust is present as an elevated layer, cooling near the Earth's surface due to reduced incoming solar radiation can combine with heating in the dust layer due to absorption on outgoing longwave radiation, reducing the vertical temperature gradient, thus increasing atmospheric stability and inhibiting convection (Brooks 2004).

## **Conclusion and Policy Recommendations**

### ***Conclusion***

This study examined drought severity in the SSR of Nigeria between 1961 and 2006. Drought severity was assessed in terms of temporal and spatial variations. It was observed that there is the tendency for drought severity for Katsina, Nguru, Bauchi, and Gusau to increase, while that of Sokoto, Kano, Maiduguri and Potiskum indicated a decrease in the nearest future. As a result of this, policy-makers both at the federal and state levels should be aware of this and put appropriate policies in place to cope with droughts in such areas. Within this context, people living around Katsina, Nguru, Bauchi, and Gusau are particularly vulnerable to the impact of drought, especially the local farmers. This is based on the fact that drought severity showed a tendency to increase in the future.

This study also established that even though the SSR is categorized as an ecological zone, the region is different in terms of exposure to drought risk. This is coming on the heel of findings from the spatial analysis of the drought magnitude. The spatial analysis revealed that the region could be divided into three sub-regions, where the extreme western and eastern sections of SSR have the highest level of exposure to drought risk. The implication of this revelation is that the policy-makers should be wary of sharing interventions equally to the region whenever there is drought occurrence. They should be aware that the region is not homogeneous in terms of drought risk.

### ***Policy Recommendations***

Drought severity analysis is an important study in semi-arid West Africa because of the risk of droughts and the constraint it imposes on the local populace. In a

rain-fed agricultural region of SSR in Nigeria, an efficient water management system is very important. Looking at the fact that drought risks vary greatly in this region, it is imperative that research activities and policies are focused on building and strengthening capacity around local initiatives. These policies should be in line with those promulgated by the African Conference on Water Resources, as well as the results of the focused research activities at the local levels. Pertaining to water resources, communities should carry out water resources assessment both at the state and local levels for effective policy implementation. These assessments should be supported by both the international bodies and non-governmental associations. Any policy that would be implemented must involve all the stakeholders in the community: local and private sectors, and governments. More importantly, all legislations regarding water resources management should be enforced at all levels.

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