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DROUGHT TREND ANALYSIS AND IMPLICATIONS FOR WATER RESOURCE MANAGEMENT IN THE SUDANO SAHELIAN ZONE OF NIGERIA

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Abstract
Drought is a prolonged period of shortage of precipitation which has adverse effect on various sectors of water resources like Agriculture and water supply. Rainfall is known to be major indices of drought. The 1970s and 1980s droughts in the Sudano Sahelian Ecological Zone of Nigeria had devastating consequences on the region. It is imperative to study the drought trend in the region so as to plan a sustainable water resources management in the region. The Standardized Precipitation Index using rainfall variability was used to analyze drought occurrence in the zone. The result revealed that there is an increasing trend in drought occurrence from 1970s to 1980s. The severity was found to be more in 1980s. The study further suggests inter-basin transfer of water, rainfall harvesting, and irrigation improvements among others as measures to mitigate the effect of drought in this zone.

Keywords: Drought, Trend, Management, Precipitation, Mitigation.

Introduction

Precipitation is the primary factor controlling the impact of occurrence and persistence of drought along with other variables such as evapotranspiration (Ita, 2005). Usually quantitative indices are used to identify the emergence of drought conditions over the years several indices have been developed and adopted to measure dry or wet spells and their intensity. Among these indicators, the Percent of Normal, Deciles, Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI) and Surface Water Supply Index (SWSI) are the ones that are used most commonly. It has been found that indices based solely on precipitation data performed well when compared with more complex hydrological indices Oladipo (1993).

Nevertheless, most of the drought indices lack elements for addressing the multi-temporal nature of the effects of rainfall deficiency and usually are computed for a certain time interval (monthly and seasonally).On the other hand, it is known that the impact of rainfall deficiency on water resources varies on temporal scales.
While soil moisture respond to precipitation anomalies on relatively short time

steps, most other water storage such as groundwater, stream flow and reservoir storage, reflect longer- term precipitation anomalies. McKee et al. (1993) developed the Standardized Precipitation Index (SPI) to quantify the precipitation defect for multiple time-steps, which reflect the impact of precipitation deficiency on the availability of the different water supplies. Therefore the different time-steps (1, 3, 6 and 12months) for which the index is computed address the various types of drought; the shortest season for agricultural and meteorological drought, the longer season for hydrological drought. Cuttman (1998) concluded that the SPI is better able to show how drought in one region compares to drought in another region. Also analysis of extreme drought event showed that the SPI provided a better spatial standardization than the PDSI(Ita et. al., 2005)

Another virtue of the SPI is that drought initiation and termination are implicitly part of the index. Given the advantages of the index standardization, the SPI has been largely used operationally to monitor climatic conditions across different locations (Ojoye, 2012)

Besides its advantages, practical applications of the SPI revealed some disadvantages. It is assumed that a suitable theoretical probability distribution can be found to model the raw precipitation data prior to standardization (Hughes, 2003) .Another limitation of the SPI emerges from the standardization process of the index itself. Drought measured by the SPI can occur with same frequency at all locations when considered over a long time period.A third problem is that misleading large positive or negative SPI values may result when the index is applied at short time steps to regions of low seasonal precipitation.

The SPI is calculated by taking the difference of the precipitation from mean and dividing by the standard deviation. This appears to be a modification of a drought index developed by Hastenrath (1984).It provides a means of quantifying the precipitation deficit for multiple time scales (3, 6, 12, 24 and 48 months).SPI is not normally distributed (an adjustment is made to make it so) because precipitation at time scales shorter than 12 months is not so and its use enables the depiction of wetter or drier conditions in the same way.

The wide variety of disciplines affected by drought, its diverse geographical and temporal distribution, and the many scales drought operates on make it difficult to develop both a definition to describe drought and an index to measure it. Many quantitative measures of drought have been developed. Their usage depends on the discipline affected, the region being considered, and the particular application involved. Several indices are useful for describing the many scales of the drought. One thing that is common to all types of drought is the fact that they originate from a deficiency of precipitation resulting from an unusual weather pattern. If the weather pattern lasts a short time (say, a few weeks or a couple of months), the drought is considered short-term, if the weather or atmospheric circulation pattern becomes entrenched and the precipitation deficits last for several months to several years, the drought is considered to be a long-term drought. It is possible for a region to experience a long-term circulation pattern that produces drought, and to have short-term changes in this long-term pattern that result in short-term wet spells. Likewise, it is possible for a long-term wet circulation pattern to be interrupted by short-term weather spells that result in short-term drought. This study is aimed at analyzing drought trend in the Sudano Sahelian Zone of Nigeria so as to see its implications on water resources in the zone.

The Palmer Z Index measures short-term drought on a monthly scale. The Palmer Crop Moisture Index (CMI) measures short-term drought on a weekly scale and is used to quantify drought's impacts on agriculture during the growing season. The Palmer Drought Severity Index (PDSI) (known operationally as the Palmer Drought Index (PDI)) attempts to measure the duration and intensity of the long-term drought-inducing circulation patterns. Long-term drought is cumulative, so the intensity of drought during the current month is dependent on the current weather patterns plus the cumulative patterns of previous months. Since weather patterns can change almost literally overnight from a long-term drought pattern to a long-term wet pattern.

The hydrological impacts of drought (e.g., reservoir levels, groundwater levels, etc.) take longer to develop and it takes longer to recover from them. The Palmer Hydrological Drought Index (PHDI), another long-term drought index, was developed to quantify these hydrological effects. The PHDI responds more slowly to changing conditions than the PDSI (PDI).

The Study Area

The Sudano-Sahelian Ecological Zone is located in northern Nigeria between latitude 10°N and14°N and longitude 4°E and 14°Eand lies immediately to the south of Sahara desert. As shown in Figure 1. The climate of the zone is savannah type with alternating wet and dry seasons. The rainfall in this region is less than 1000mm per annum in only about five months in the year, especially between May and October (Odjugo, 2007) Rainfall in this zone is highly variable and the onset of the rain is erratic. The rainfall intensity is very high between the months of July and August. There is intra- zonal difference in the amount of rainfall received by the zone. The southern part receives more rain and is less variable compared to the northern section.

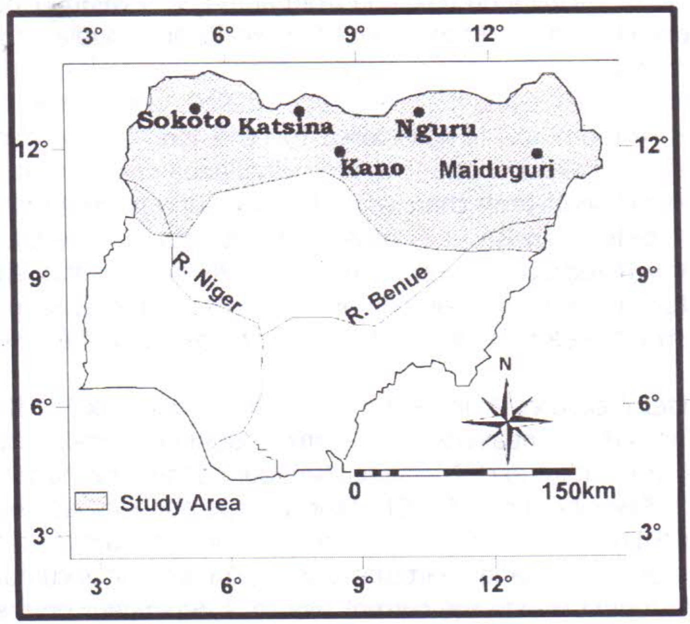

Figure 1 : Map of Nigeria showing the Sudano-Sahelian Ecological Zone. Source: Adapted from Odekunle, et al., (2008)

The study covers eight stations (Gusau, Kano, Katsina, Dutse, Maiduguri, Nguru, Sokoto, and Yelwa) north of latitude 10°N. All the eight stations have two distinct dry and wet seasons. The dry season covers a period of about seven (7) to eight (8) months from October to April/May, while the wet season is between four(4) and five(5) months from May to September. It can also be seen that rainfall has been erratic over the area and this has serious implications on water resources management. The annual rainfall varied from 400mm to 1200mm (Ojoye, 2012)

Methodology

Observed daily rainfall data were acquired for the period 1949-2009 totaling a period of 60 years for eight stations in the Sudano-Sahelian Nigeria. These stations include: Kano, Nguru, Sokoto, Yelwa, Dutse, Maiduguri, Katsina and Gusau. The short rainfall season in the Sudano Sahelian Ecological Zone of Nigeria is from June to September with a peak rainfall in the month of August. The rainy season decreases from about five months in the south (Sudan region) to three months in the extreme north (Sahel region), while mean annual rainfall in the region ranges from <500 mm in the extreme north, to about 1200 mm in the south. About 65% of the mean annual rainfall occurs in July and August which are the wettest months; while in most of the region about 32-40% of the mean annual rainfall occurs in June and July Table 1. In order to fully understand the drought occurrence and its implication for the Sudano-Sahelian Ecological Zone of Nigeria, the nation's grain-producing region, monthly rainfall series from 7 synoptic stations covering the region were analysed for the period 1960-2010. The Standardized Precipitation Index was used to identify the trend in drought in the zone. The SPI is calculated by taking the difference of the precipitation from mean and dividing by the standard deviation and appears to be a modification of a drought index developed by Ita, et.al.. (2005). It provides a means of quantifying the precipitation deficit for multiple time scales (3,6,12,24 and 48 months).SPI is not normally distributed(an adjustment is made to make it so) because precipitation at time scales shorter than 12 months is not so and its use enables the depiction of wetter or drier conditions in the same way.

A drought event occurs any time that the SPI is continuously negative and reaches intensity where the SPI is -1.0 or less. The event ends when the SPI becomes positive. Thus, the beginning, the end, the intensity and magnitude of accumulation of each drought can be determined. The standardization of the percentages of persistence of a drought event anywhere also enables the SPI to determine its rarity and the probability of the precipitation necessary to end it. The formula used is given as

$$\frac{1}{N}\sum \frac{(Xa - Xm)}{\delta} ------------equation\ 1$$

Where

X_a = Total annual rainfall for a particular year

X_b = Mean annual rainfall for a base period of 30 years

δ = Standard deviation

N = Number of years when data are available

Results and Discussion

The results obtained by plotting the Standardized anomaly Index with the years under considerations were revealed in Figures 2 to 8.

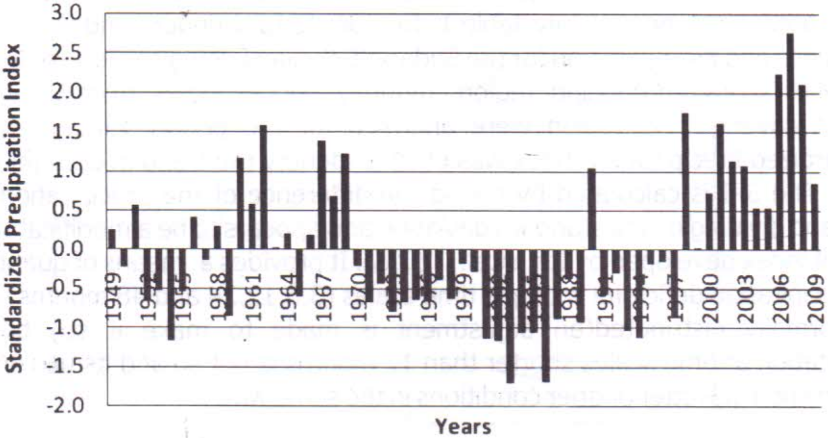

Figure 2: Standardized Precipitation Index for Kano

The Standardized Anomaly Index for Kano from 1949 to 2009 was displayed in Figure 2. The Figure reveals that two distinct seasons are observable; lower than normal rainfall which was observable in many years between 1950 to 1959 and 1970 to 1988 while above normal rainfall was observed from 1998 to 2009. It was also observed that the 1980 drought was more severe than the 1970s considering the negative values of the index. This implies that more artificial means of water supply in the zone are expected to reduce the adverse effect that may be caused by the drought for sustainable water resource management.

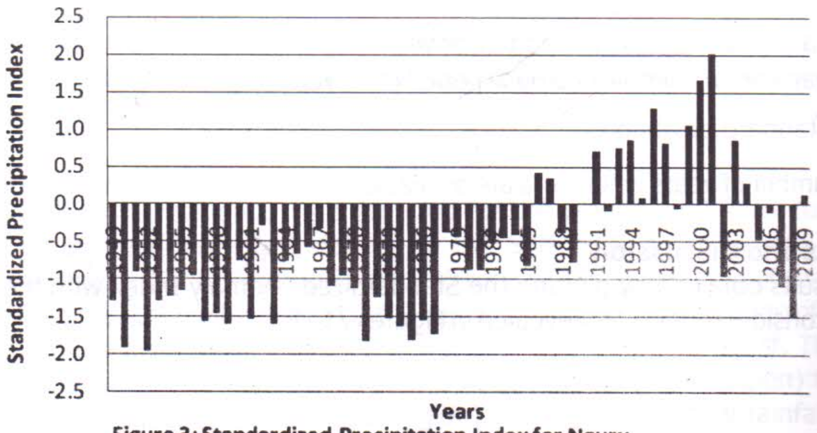

Figure 3: Standardized Precipitation Index for Nguru

The Standardized Precipitation Index for Nguru between 1949 to 2009 was as shown in Figure 3. The Figure shows that about 75% of the years under consideration reveals a lower than normal rainfall an indication that drought years are more than wet years at the station. This was observable from 1949 to 1988. The severity of the drought episodes was found to be more than the wet episodes. This will have a great impact and implications for water resources in the zone.

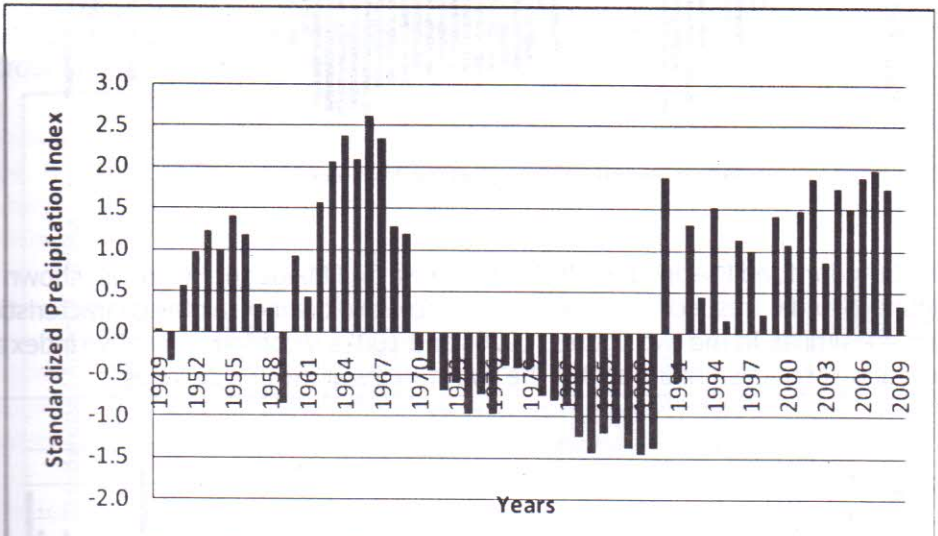

Figure 4: Standardized Preciipitation Index for Sokoto

Figure 4 shows two distinct periods; lower than normal and more than normal rainfall. The drought years was found between 1970 to 1990 with more severity in the 1980s. These two decades was widely reported in literatures as decades with high

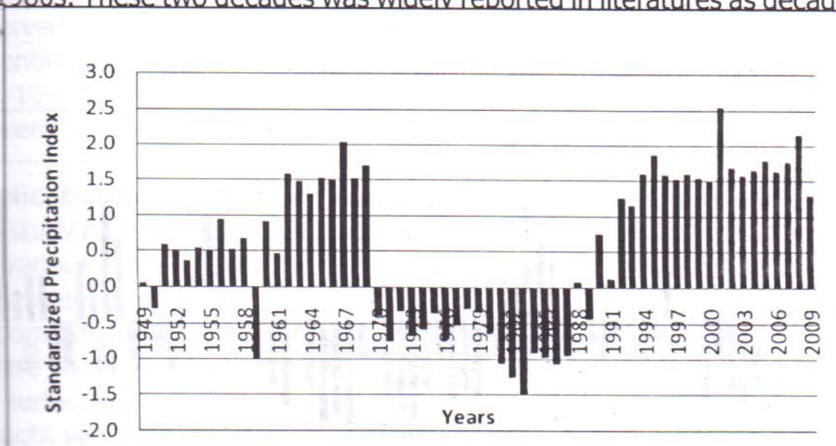

Figure 5: Standardized Anomally Index for Yelwa

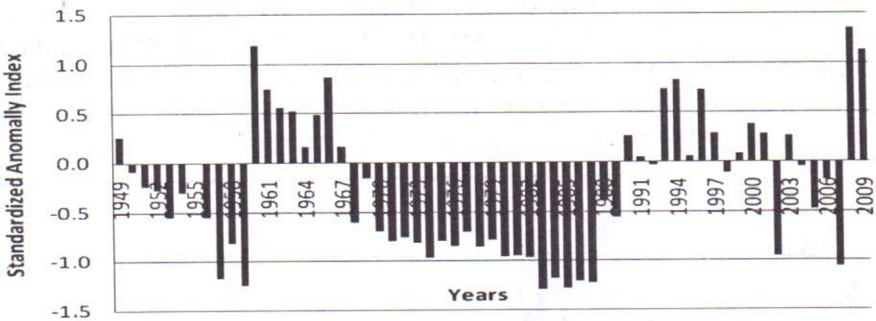

Figure 6: Standardized Anomally Index for Maiduguri

The Standardized Precipitation Index for Yelwa and Maiduguri were as shown in Figures 5 and 6 respectively. The figures show two distinct rainfall characteristics that are similar. In the two figures, 1970s and 1980s recorded a negative index an indication of persistent drought in the two stations at the two decades.

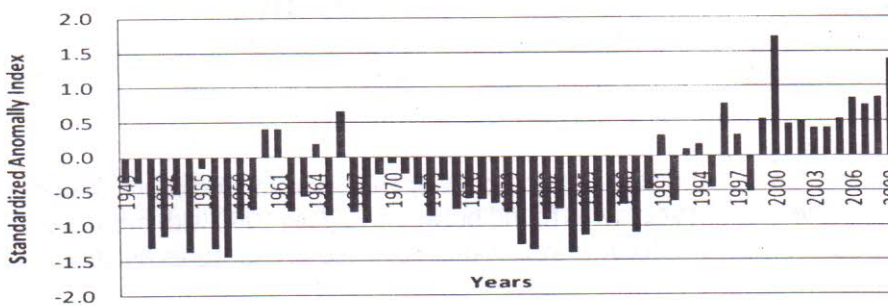

Figure 7: Standardized Anomally Index for Dutse

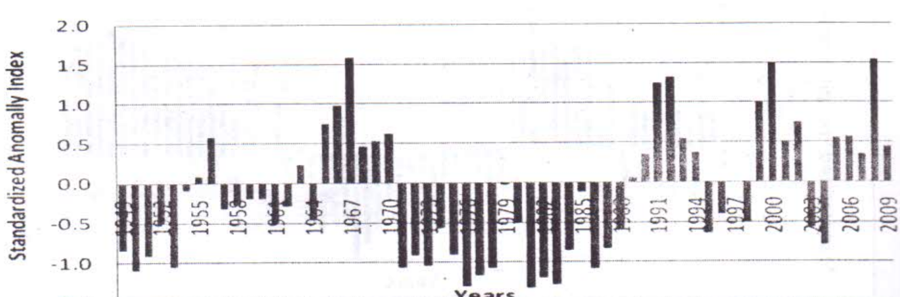

Figure 8: Standardized Anomally index for Katsina

The Standardized Precipitation Index for Dutse and Katsina are as shown in Figures 7 and 8. The Figures shows two distinct features in the rainfall events; a lower than average rainfall values (a negative Precipitation Index) observed between 1949 and 1990 for Dutse which signify drought years. It was observed from Figure 6 that 48 years of the 60 years under consideration are drought years, a condition that has negative implications for water resources in the zone. An alternating dry and wet years were observable in Katsina with lower than average rainfall more frequent between 1970 and 1988, the years that have records of drought episodes in the zone.

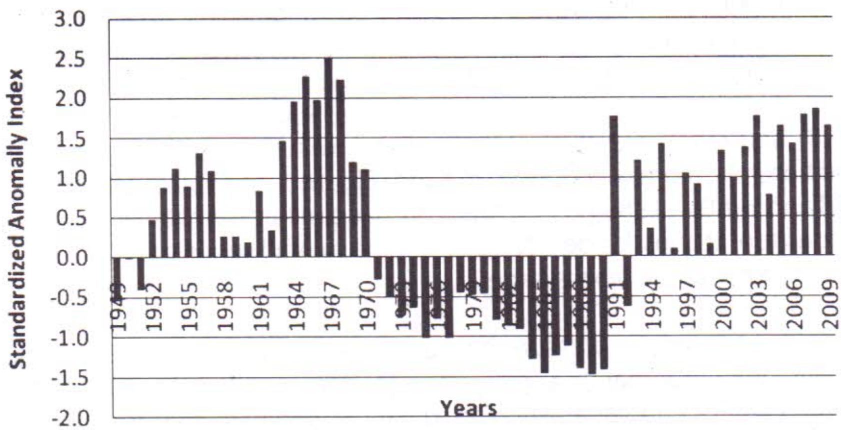

Figure 9 Standardized Anomally Index for Gusau

Figure 9 shows the same pattern in the Standardized Precipitation Index as observed in the earlier figures with more distinct positive and negative values over the entire period under study. Positive SPI were recorded between 1952 and 1969 and 1995 to 2009 which signify wet years while negative SPI was recorded between 1970 and 1990 which signify drought years.

Implications of Drought on Water Resources in the Zone

The study have revealed that due to drought in the zone, the volume of water in the various rivers in the zone has dropped drastically over the last 25 years and consequently reduced the numbers of wet zones. This events was found to be responsible for the reduction of the surface area of River Niger from 37,000 square Kilometers in 1950 to nearly 15,000 square Kilometer in 1990. Similarly, the surface area of Lake Chad was reduced to 7000 square Kilometer during the drought years from its 20,000 square Kilometers during the wet years. Drought has also been found to be responsible for river patterns and low agricultural productions experienced in the zone. Shortage of drinking water that has become a norm in the zone and poor hydro-electric power generation has been attributed to the frequent drought in the zone.

Conclusion

The study reveals that in the 1980s, wet years were rare and drought was the norm for most of the stations studied. In 1983 to 1986, below average rainfall affected the entire study area making the decade a universal drought decade for most of the stations under study.

The most striking temporal characteristics of rainfall variability in the zone is the apparent periods of persistent wet or dry conditions as seen in the rainfall series (Figures 1 to 8). Long and persistent wet and dry conditions of 8 to 10 years are common and this is consistent with the decadal scale rainfall fluctuations reported for the Sahel by Nicholson and Entekhabi (1986), Nicholson (1989), Babatolu, (1988) and Odekunle et al., (2008). Examples of such long term wet and dry conditions are more pronounced in Kano (Figure 1) in 1960 to 1969 (wet), 1970 to 1978 and 1980 to 1989 (dry). This trend was similar to what was obtained at other stations too. It can also be inferred from the rainfall series that rainfall differences from one year to the next is large.

There is an increased pressure on water resources in the zone as a result of the growing water demand, combined with decreased water availability due to climate change and variability. To reduce the negative consequences caused by drought in the zone, the study suggest inter-basin water transfer, rainfall harvesting, planned irrigation practices among other things as a way of reducing the impacts of drought in the zone. The study also identify the need to manage the consequences of drought with less cost by planning in a timely way to reduce environmental degradation and suffering of human as a result of the menace. The planning should include a proper understanding of the drought indices by taking into consideration its timing, magnitude and severity of occurrence at different scales. The formulation of drought policy should be done in such a way that a balance between water demand and supply be made so as to reduce drought hazard intensity and vulnerability.

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