Ethiopian Journal of Environmental Studies & Management 9 (1): 56 – 69, 2016.
ISSN:1998-0507 doi: http://dx.doi.org/10.4314/ejesm.v9i1.6
Submitted: August 19, 2015 Accepted: January 11, 2016

MONITORING DROUGHT AND EFFECTS ON VEGETATION IN SOKOTO STATE, NIGERIA USING STATISTICAL AND GEOSPATIAL TECHNIQUES

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Abstract

This paper aimed at assessing drought occurrences and its effects on vegetation cover in Sokoto State, Nigeria using geospatial and statistical techniques. Monthly precipitation data which span through a period of 40 years (1980-2010) and 30 years (1982-2011) respectively were used for generating Standardized Precipitation Index (SPI) graphs and maps. LandSat imageries of bands 3 and 4 acquired by Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) Sensor were used for generating Normalized Difference Vegetation Index (NDVI). SPI and NDVI were generated for the study area based on inter-annual and decadal timescale. Findings showed that SPI values varied from extremely dry condition to extreme wet condition although near normal condition ranked highest while extremely wet condition ranked least. It also revealed that most of the Local Government Areas experienced near normal conditions but Isa, Sabon Birni and little part of the boundary between Goronyo and Wurno experienced moderately wet conditions between 1982 and 1991. It was further observed that the whole region was dominated with near normal condition except Sabon Birni and Isa LGAs that experienced extremely, severely and moderately wet condition between 1992 and 2001. In contrast, the SPI values for over 90% of the state between 2002 and 2011 fall within the severely dry conditions. Findings further showed that change scenarios observed from the derived NDVI and SPI maps indicated that the climatic variability currently being experienced is likely to increase and intensify in future. It is obvious that urgent attention on drought management over this region is needed.

Key Words: *Drought, SPI, NDVI, Vegetation Cover, Landsat Imageries, Northern Nigeria*

Introduction

Generally climate change and global warming has significant impact on society and environment (IPCC, 2007a). The consequences are believed to have started manifesting in the higher frequency of extreme of unusual weather pattern which are characterized by increase in temperature and decline rainfall responsible for dry and harsh ecosystem including drought.

Drought is a major natural occurrence that plays significant role in the existence and survival of living and non-living things as a whole. It is a natural disaster which occurs as a result of climatic change variable factors such as precipitation deficiency, high temperature, high wind,

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low relative humidity, greater sunshine, less cloud cover, increase evaporation and transpiration, reduced infiltration, run off, deep percolation and ground water recharge. It is a deficiency in precipitation over an extended period usually a season or more resulting in a water shortage causing adverse impact on vegetation, animal and people (Lambo, 1980)

Drought is one of such harsh weather occurrences rampant in some parts of Africa. Since the popular devastating Sahelian drought of the 70s, drought has been noticed to occur in many parts of Africa (Oguntoyinbo and Richard, 1977; Lamb, 1980). There has been a consistent decline in annual rainfall in West Africa since the end of the 1960s (Dai *et al.*, (2004); Adefolalu, 1986).

The northern Nigeria have witnessed four severe droughts between the last five decades (1960 and 2010) causing widespread dislocation to social and economic activities with substantial modification of ecosystem and general discomfort to the populace (Van Apeldon, 1981). Accordingly, water resources within these regions have been negatively impacted by recurrent droughts. The problem of water shortage in this region of northern Nigeria will also possibly continue since global climate change will adversely affect water resources and general water availability, especially in semi-arid regions (IPCC, 2007b). Therefore, recurrent droughts in the northern Nigeria, together with rising temperatures and declining rainfall do not portend any good for water availability in the region (Ekpo and Ekpenyong, 2011). Studies have indicated that the quantity and quality of water in some parts of the northern Nigeria have been seriously affected by increased evaporation from rising temperatures and sedimentation of surface stream by mobile sand dunes leading to a drop in the water table around the Fadama areas. The Munwadata Lake in Sokoto has dried up creating serious hydrological changes in the region (Odjugo, 2010).

Drought has become a common phenomenon in sub - Africa in which the North western region of Nigeria is not exclusive. Rainfall measurement in Nigeria dated back to 80 years and some period within the last century are widely reported to have experienced low rainfall and drought conditions (Adefolalu, 1986). The Sahelian drought of the late 60's that lingered on till 1985/1987 affected Northern Nigeria with tremendous socio-economic impact on the areas where pressure on available resources are on increase in the face of a fluctuating rainfall regime, impoverishing the farmers and responsible for social backwardness and poor qualities of life (Ati *et al.*, 2007; Alatise and Ikumawoyi, 2007). Sokoto is a major area where drought has climatically affected agricultural productivity with respect to vegetation. Tackling the issue of drought in Sokoto State or Northern Nigeria at large requires in-depth studies and scientific approaches that can foster formulation of policies to reduce its effect.

This paper is aimed at assessing the occurrence of drought and its effects on vegetation cover in Sokoto State, using geospatial techniques with a view to investigating the spatio-temporal variations of dry and wet spells in Sahelian region, particularly Sokoto State for effective drought monitoring and management.

Materials and Methods

Study Area

Sokoto is located on latitude 13˚04'N and longitude 5˚14'E is the most northern region of Nigeria bordering the Sahara desert (Figure 1). This Sahelian state which is surrounded by sandy savannah and isolated hills have over 3.2 million populations (Alatise and Ikumawoyi, 2007). It records annual rainfall between 300mm-800mm and mean temperature of 34.5˚ C. The dry season temperatures do exceed 45^{o} C during the day time which is the highest recorded in Nigeria. It is dominated by the North-East Trade wind (Harmattan) blowing Sahara dust over the land when dusts hang in the air. Northern Nigeria receives the least amount of rainfall in Nigeria because of its hinterland location and being the transition zone between humid tropical Africa and arid Sahara. The Sahel is particularly sensitive to changes in the African monsoon, which are modulated by changes in solar radiation and Sea-surface temperatures in the southern Pacific called El Nino. The Sahel has experienced numerous dry episodes in the past.

Database Description

This work is predicated on the use of meteorological data, satellite data and geographical information of the study area. Rainfall data of the main meteorological station in Sokoto (1980 - 2010) were obtained from the Nigerian Meteorological Agency and supplemented with satellite rainfall data extracted from the Climate Research Unit (CRU) datasets (1982 - 2011). Satellite data used are Landsat Thematic Mapper imageries for year 1986, and Enhanced Thematic Mapper for 2000, and 2005 obtained from the Global Land Cover Facility (GLCF) website.

Statistical and geospatial techniques were adopted for this study. The major statistical analyses used are Mean, standard deviation, and Standardized precipitation index (SPI) or anomaly. The Standardized Precipitation Index is a probability index that was developed to give a better representation of abnormal wetness and dryness. SPI method has been acknowledged and recommended by the World Meteorological Organization (WMO) for all national meteorological and hydrological services for monitoring of dry spells. The algorithm for computation of SPI is written mathematically below.

$$SPI = \frac{C_R - A_R}{\sigma} = \frac{Departure}{\sigma} \quad \text{................. (1)}$$

C_R= Climatological mean, A_R= Annual mean of each year

$C_R - A_R$ the departure of annual rainfall from Climatological mean, σ =Standard deviation of the departure

The geospatial techniques require various processes which are explained below:

Inverse Distance Weighted Interpolation

This is a commonly used technique for interpolation of scatter points which is based on the assumption that the interpolating surface should be influenced most by the near points and less by the more distant points. The function is readily available in ArcGIS 9.3 software.

Image Pre –Processing

Data Processing and Geo-referencing

The area of interest in the Landsat imagery was extracted using ILWIS 3.3. The imagery was zoomed to a satisfactory resolution and joined through a process known as Mosaicing. Georeferencing of the satellite image was required so as to bring them to the same ground coordinates. Georeferencing of the satellite image was later carried out. The projection of the datasets was projected to WGS 1984, Universal Transverse Mercator, Datum 100 Minna –Nigeria, Zone 32^{0}N.

Database

After Georeferencing, a geodatabase was created in ArcCatalog. This was followed by creation of feature dataset and feature classes namely; Local Government Area (LGA) base map, Sokoto State base map, Major Rivers.

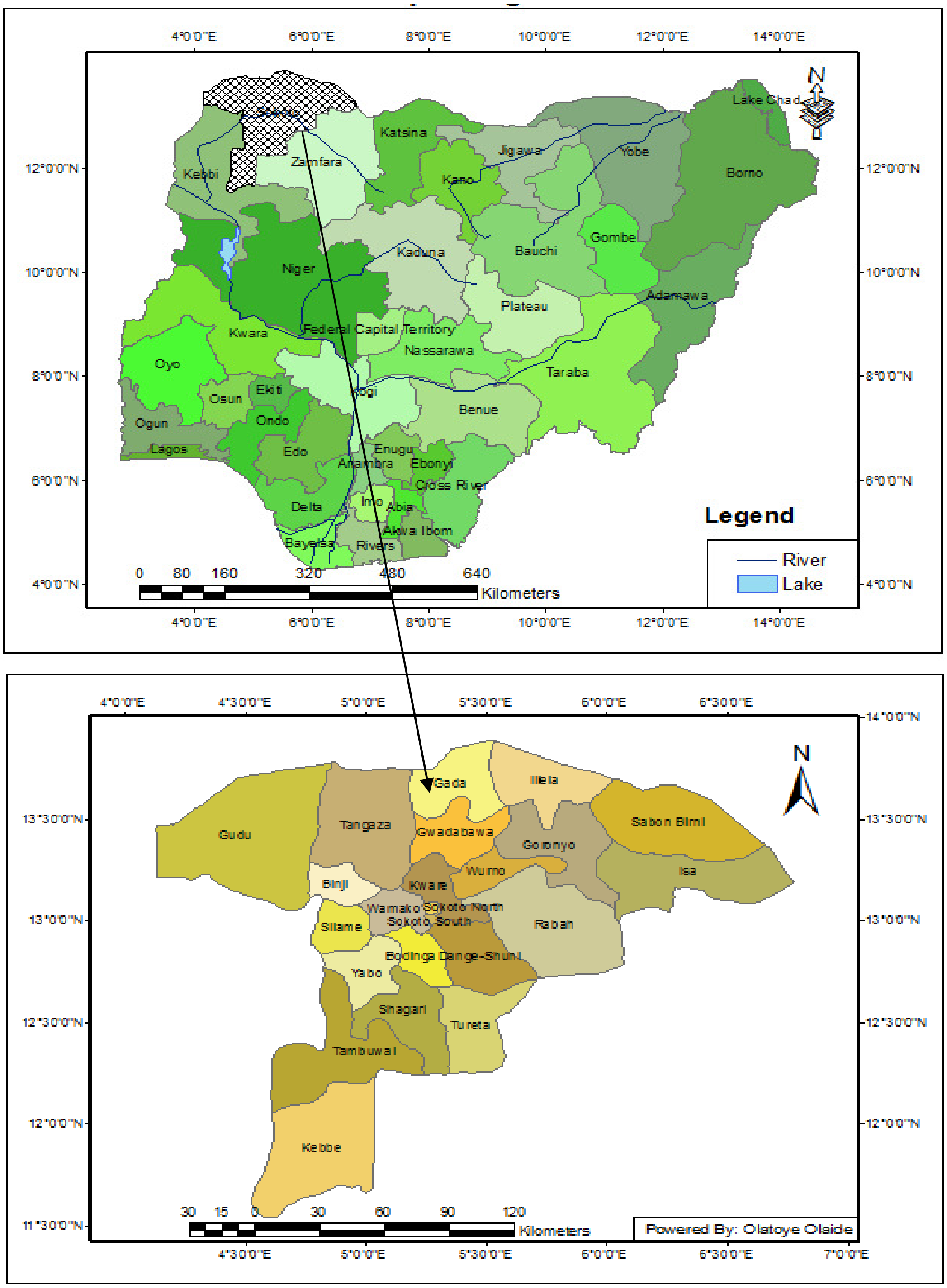

Figure 1: Map of the study Area (Sokoto) indicating and Local Government Areas

On-Screen Digitizing

The digitizing process converts the geographical features from an analogue or raster map into vector format. Layers digitized for the purpose of this work includes, the local Government Area (LGA) and Sokoto state map as base map and polygon feature; while the rivers were digitized as line features.

Generation of Normalized Difference Vegetation Index (NDVI) Map

The NDVI was calculated using the following formula (Rouse et al. 1974):

$$NDVI = \frac{IR-R}{IR+R} \quad \text{......................} (2)$$

This algorithm subtracts the red reflectance (R) values from the near-infrared (IR) and divides it by the sum of near-infrared (IR) and red bands (R).

Result and Discussion

Mean Monthly Rainfall Pattern over Sokoto State

Figures 2, 3 and 4 present the mean monthly rainfall distribution for Sokoto within the period 1982 to 2011 using Selected Climate Research Unit Observation stations and Nigeria Meteorological Agency Station for different locations.

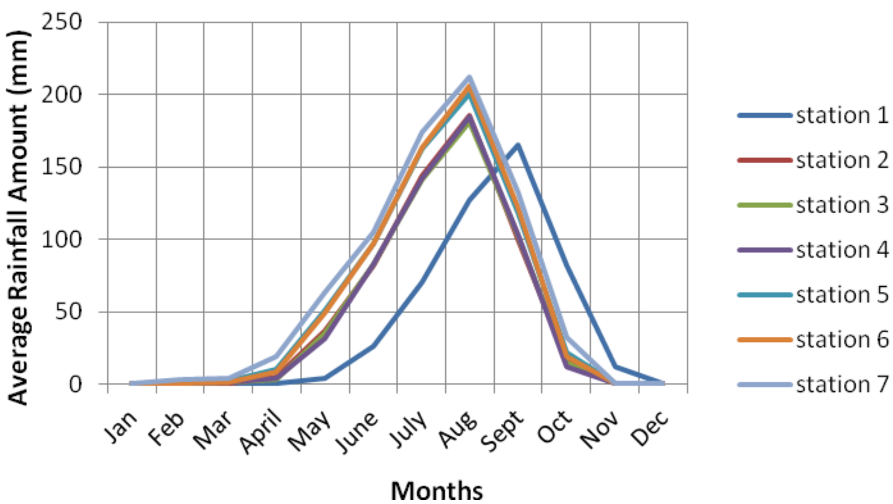

Figure 2: Mean Monthly Rainfall over Sokoto State within 1982 – 2011 using Climate Research Unit Observing Station

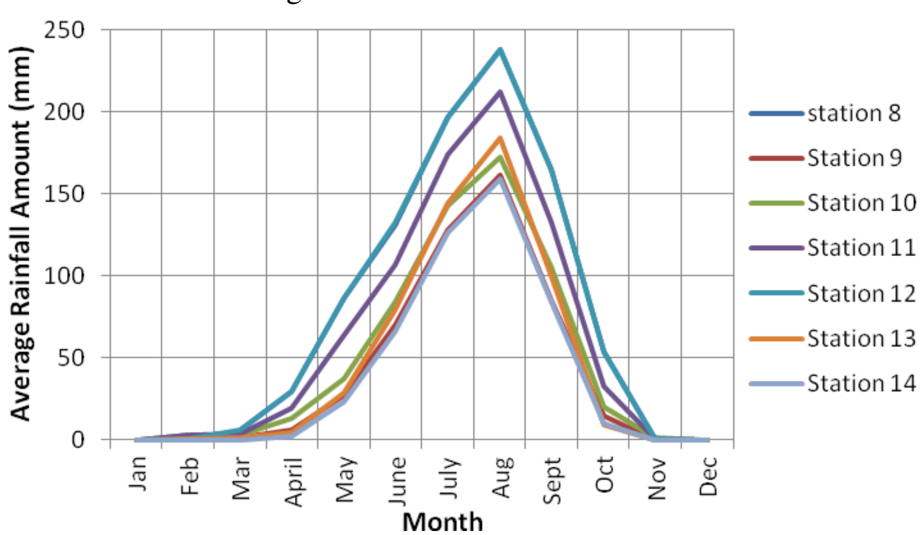

Figure 3: Monthly Mean Rainfall over Sokoto State within 1982 – 2011 using Climate Research Unit Observing Station

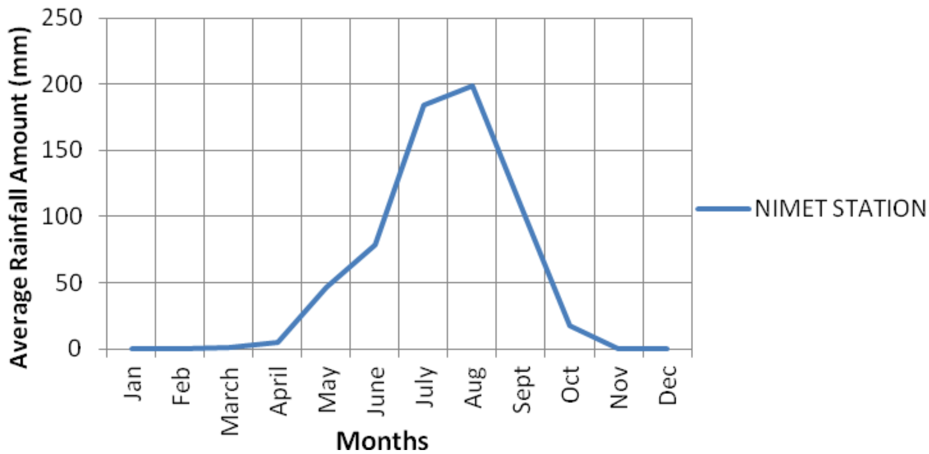

Figure 4: Monthly Mean Rainfall over Sokoto State within 1980 – 2010 using NIMET Observing Station

The result shows that Sokoto falls within the unimodal rainfall pattern region of Nigeria which has its agriculturally meaningful rainfall between June and September. On the average, August has maximum rainfall record for the period under review.

Derived Standardized Precipitation Index (SPI) for Sokoto State

The SPI for all the stations revealed a composite nature in which some dry years were mixed with wet years and this occurred throughout in all the stations. Analysis indicates the existence of much negative anomalies in all the datasets for the station except for few stations (units 4, 5 and 12) that have more years of positive anomalies than the negatives. The annual SPI values obtained from the Meteorological Observing Station datasets from 1981-2011 is presented in Figure 5.

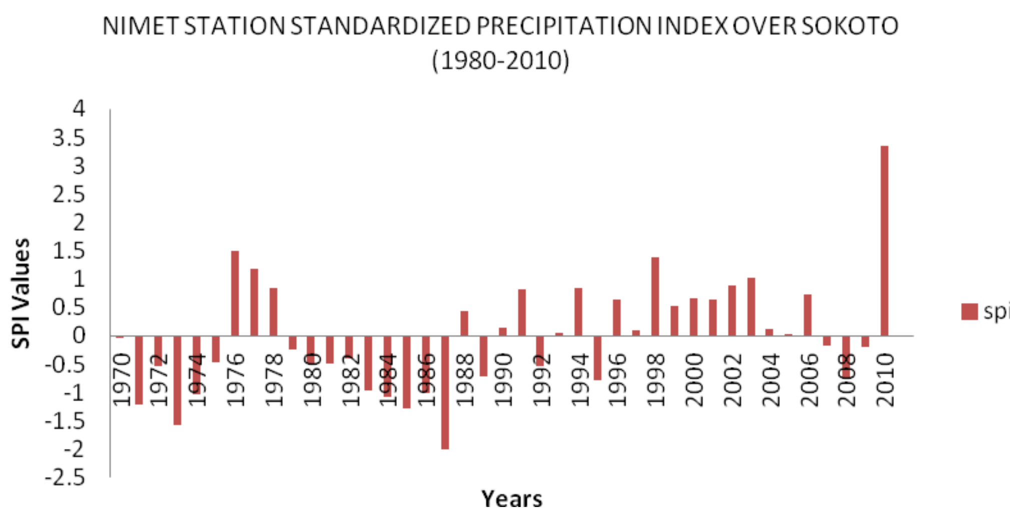

Figure 5: SPI graphical representation of Meteorological observing Station

Results from the dataset of the Meteorological Station illustrate that SPI values varies from extremely dry condition to extreme wet condition in the station. The Sahelian droughts of the early 70s and majority of the 80s are clearly revealed in this figure with 1987 being the year of worst drought hit. A considerable improvement in the Sokoto rainfall is noticeable in the last decade. Researchers have been signifying improvements in the Sahelian rainfall since the early 2000s. The most noticeable of the wet years occurred in 2010. The year was extremely wet and associated with some flooding events in the region. Comparing the NIMET and CRU observing station, it was evident that both observing stations indicated dry and wet occurrences but with varying intensities. In most of the cases, the intensity of CRU stations is always higher than that of Meteorological station in Sokoto State. Result of the number of different ranges of occurrence and their frequencies are obtained from the Standardized Precipitation Index (SPI) and presented in Table 1. It was obvious that the percentage average of drought occurence intensity in the period showed Near Normal condition as the highest and Extremely Wet condition as the least.

Table 1: Table showing the percentage average of drought occurrence intensity range of 16 CRU observing Stations (1982 – 2011) and NIMET station (1980 – 2010)

Range	NN	MD	MW	SW	SD	ED	EW
%Average (CRU)	72.18%	8.67%	7.05%	2.22%	4.60%	3.84%	1.62%
% Average (NIMET)	74.19%	12.90%	6.45%	__	__	3.23%	3.23%

NN-Near Normal Condition, MW- Moderately Wet Condition , MD- Moderately Dry Condition, SW- Severely Wet Condition, SD-Severely Dry Condition, EW-Extremely Wet Condition and ED-Extremely Dry Condition

Decadal Distribution of Standardized Precipitation Index (SPI)

Standardized Precipitation Index is spatially invariant (Guttman, 1998; Heim, 2002) therefore the values of the SPI can readily be compared across time and space. Although the SPI can be calculated in all climatic regions at different time steps, this section investigates drought occurrence on decadal scale within the period of thirty years. SPI Maps of three different decades (1982 – 1991; 1992 – 2001 and 2002 - 2011) were produced for Sokoto State (Figures 6, 7 and 8).

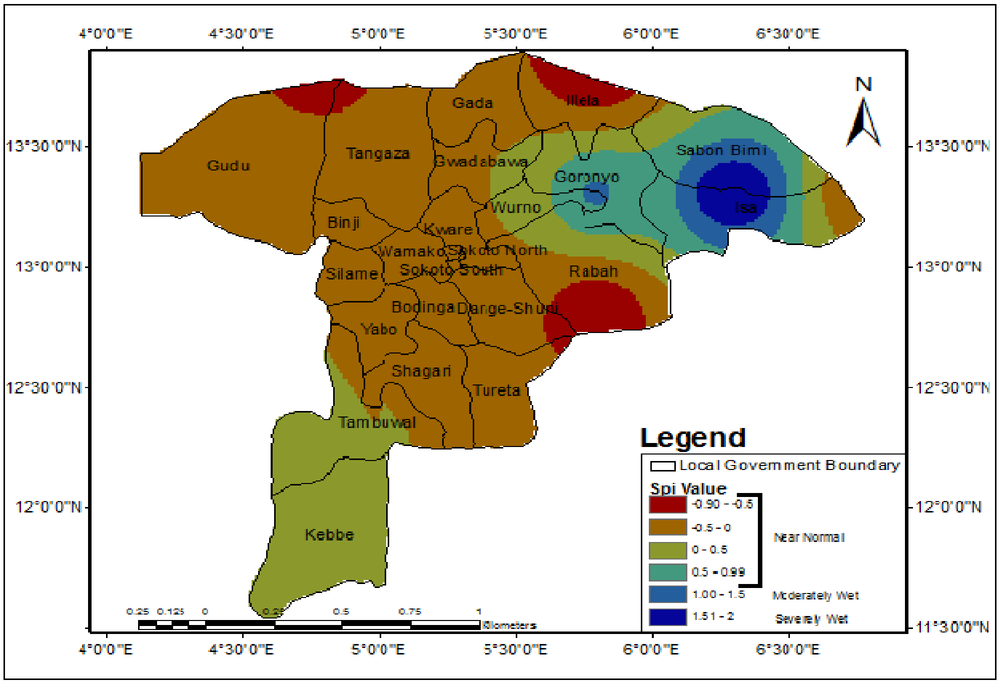

Figure 6: Standardized Precipitation Index (SPI) Map of Sokoto State (1982 – 1991)

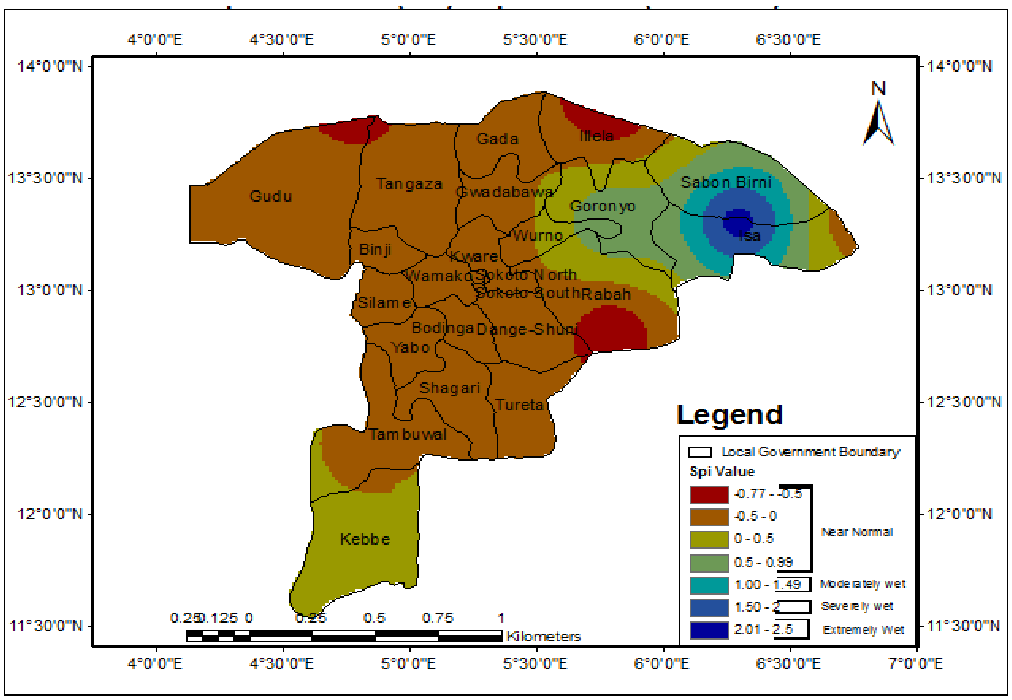

Figure 7: Standardized Precipitation Index (SPI) Map of Sokoto State (1992 - 2001)

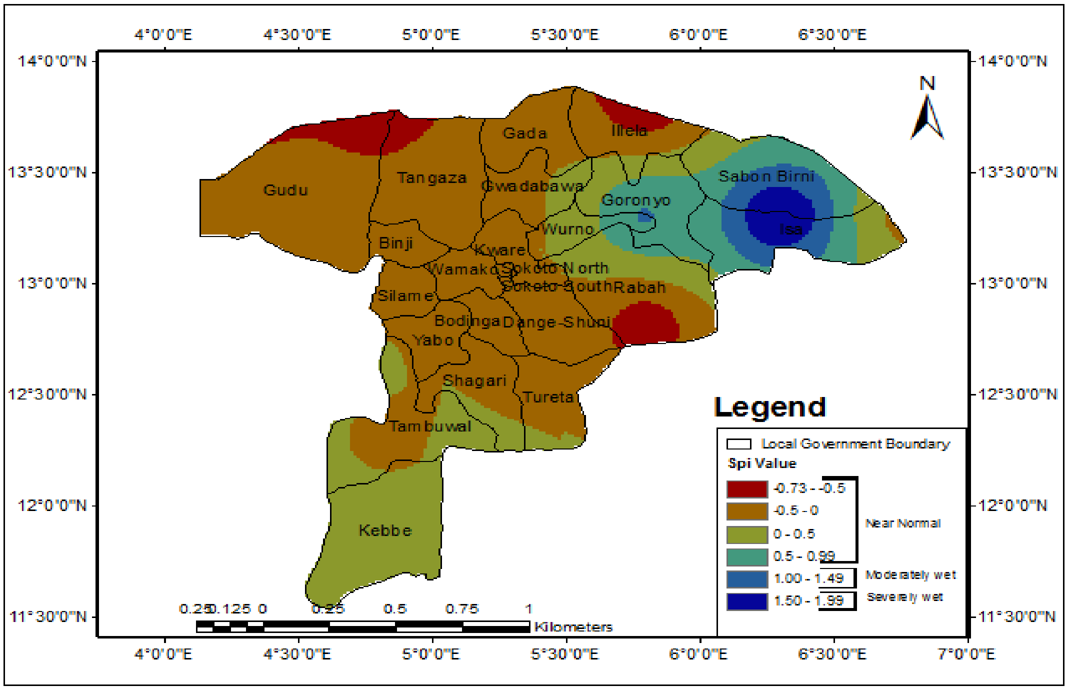

Figure 8: Standardized Precipitation Index (SPI) Map of Sokoto State (2002 – 2011)

Results from earlier section have actually shown that Sokoto had experienced various conditions of extreme wet and dry conditions during the period under investigation. However, maps of the spatio- temporal variation of drought conditions over Sokoto within the last three decades (1982-1991, 1992-2001, and 2002-2011) are presented in Figures 6, 7 and 8 for apparent monitoring of drought occurrences during the period. This was produced using the Inverse Distance Weighted (IDW) over the different Climate Research Stations.

During the first decade (1982-1991), the state experienced Severely Wet, Moderately Wet and Near Normal conditions. Most of the Local Government Areas (LGAs) experienced Near Normal conditions except Isa, Sabon Birni and little part of the boundary between Goronyo and Wurno that experienced Moderately Wet conditions. Situations during the second decade (1992-2001) were also similar to that of the first decade.

The whole region was dominated with Near Normal condition except Sabon Birni and Isa LGAs that experienced Extremely, Severely and Moderately wet condition. But in the last decade (2002-2011), the SPI ranges from a Moderately Wet condition to Near Normal condition. All the LGAs experienced Near Normal condition with the exception of Sabon Birni and Isa LGA that experienced a Moderate and Severe Wet condition that are not significant in terms of spatial extent compare to that of first decade.

It is obvious that urgent attention on drought management over this region is needed, because it is apparent that only a little section within the eastern flank of the state experienced wet conditions within the decades of assessment. This shows that Sokoto State is prone to frequent drought conditions.

Standardized Precipitation Index (SPI) and Normalized Differences Vegetation Index (NDVI) Conformation

The common method of monitoring surface vegetation is through the Normalized Difference Vegetation Index. NDVI for vegetation generally range 0.3-0.8, with the larger values representing "greener" surfaces. Bare soils range from about 0.2- 0.3, negative values indicate lakes, rivers and ocean. The Normalized Difference Vegetation Index (NDVI) is produced for October, 1986, January 2000 and October, 2005. Figures 9, 11 and 10, 12 clearly show the variation of surface vegetation over Sokoto state alongside the SPI map respectively for 1986 and 2005 only. The SPI map could not be produced for the year 2000 because January in the region is usually extremely dry but the NDVI map is presented in figure 13.

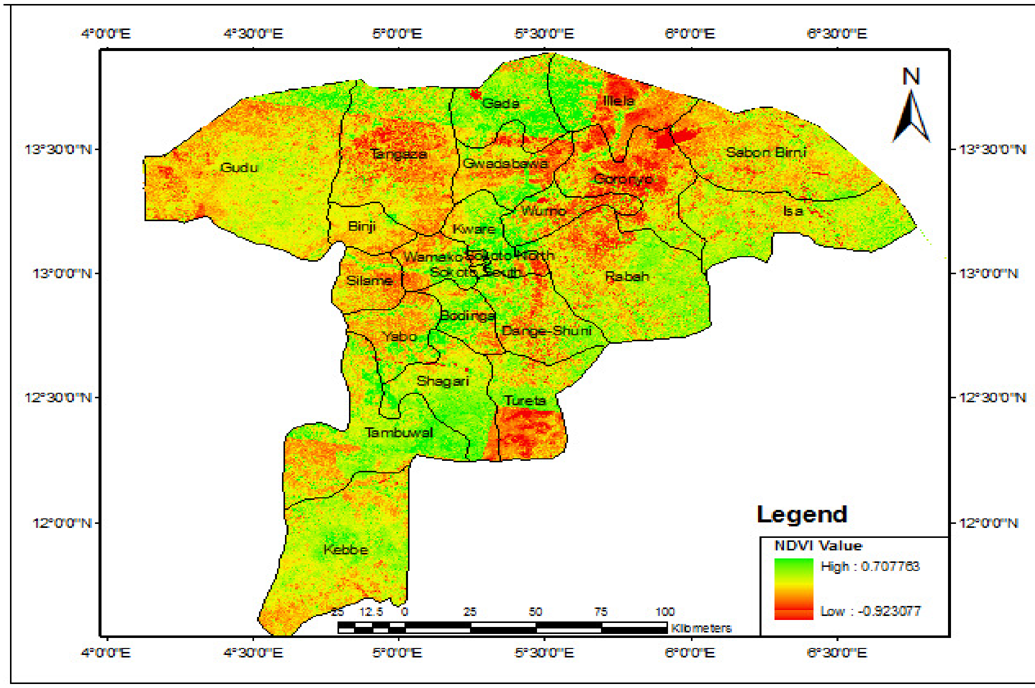

Figure 9: Normalized Difference Vegetation Index (NDVI) of Sokoto State, Nigeria in October, 1986

Figure 9 shows the NDVI map for October, 1986 over the study area. The obtained NDVI values ranges from -0.92 to 0.71. October is considered for the generation of the map because it marks the onset of the long dry season in the state. The green part of the NDVI map indicates the densely vegetated area; there is still much greenness in vegetation cover during this period. The SPI map presented in figure 10 indicates that during this period of the year, the SPI value ranges from severely dry condition (-1.61) to Moderately Wet condition (1.03). Though this period marks the onset of the prolong dry season in the Sahelian region, some local government areas still experienced moderately wet years, severely dry condition and near normal conditions.

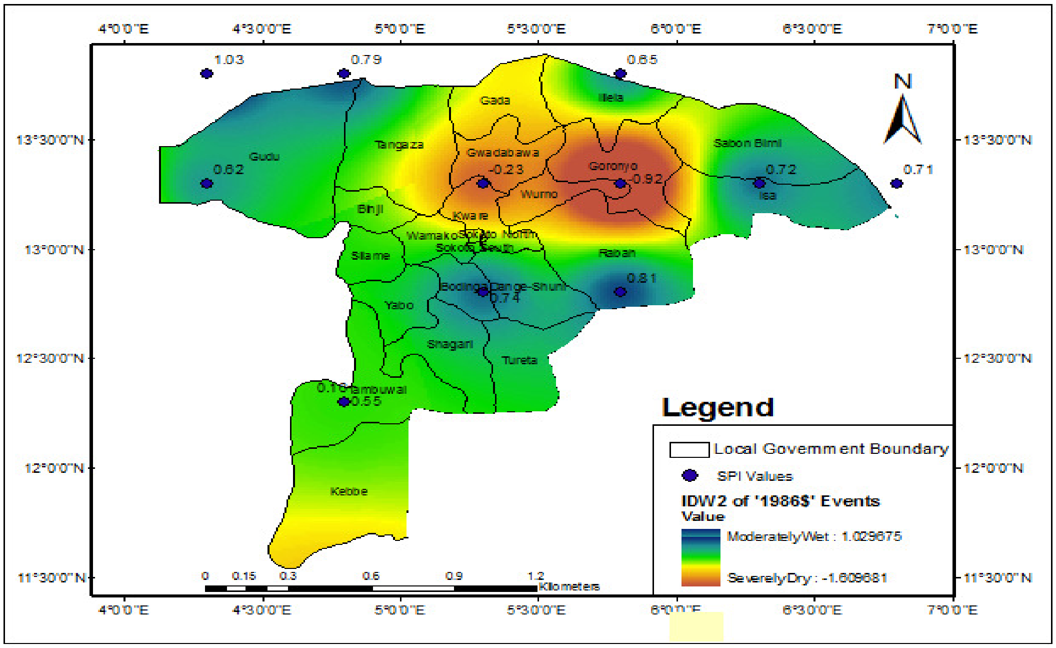

Figure 10: Standardized Precipitation Index (SPI) of Sokoto, Northern Nigeria in October, 1986

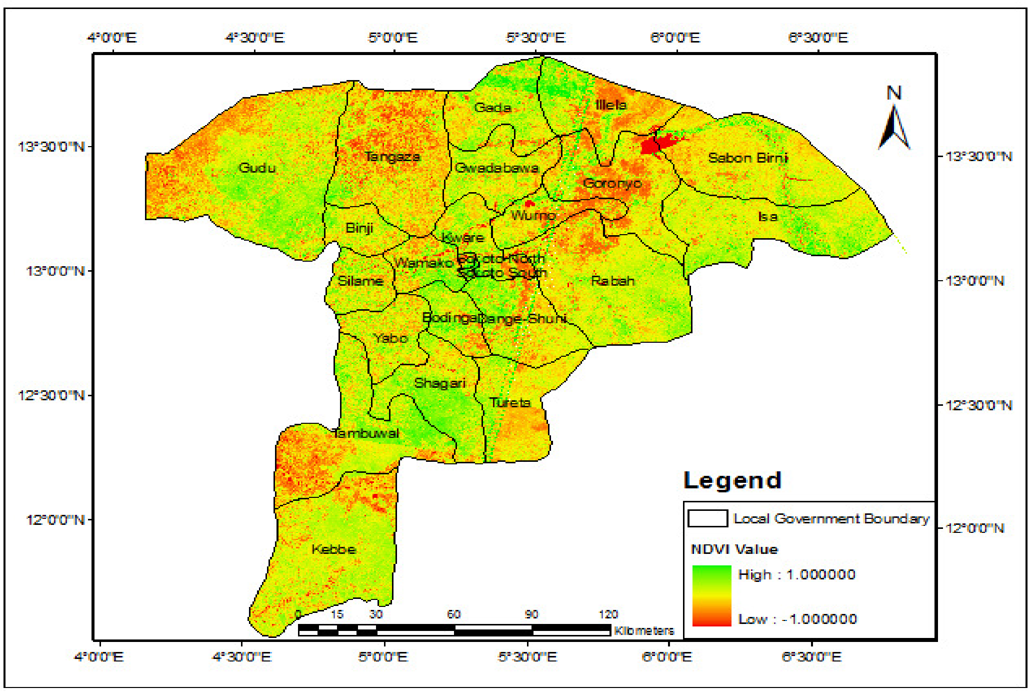

Figure 11: Normalized Difference Vegetation Index (NDVI) of Sokoto, Northern Nigeria in October, 2005

Figure 11 shows the NDVI map of Sokoto for October 2005, it is indicated in the map that the NDVI values range from -1 to +1. The green part of the map indicates the densely vegetated areas. The SPI Map presented in figure 8b ranges from Severely Dry Condition (-1.83) to Near Normal Condition (0.54). However, the SPI values for almost 90% of the state falls within the severely dry condition. The near normal condition (0.54) is recorded only in Goronyo axis of the state. The local government areas experienced a Near Normal, Moderately, and severely dry condition.

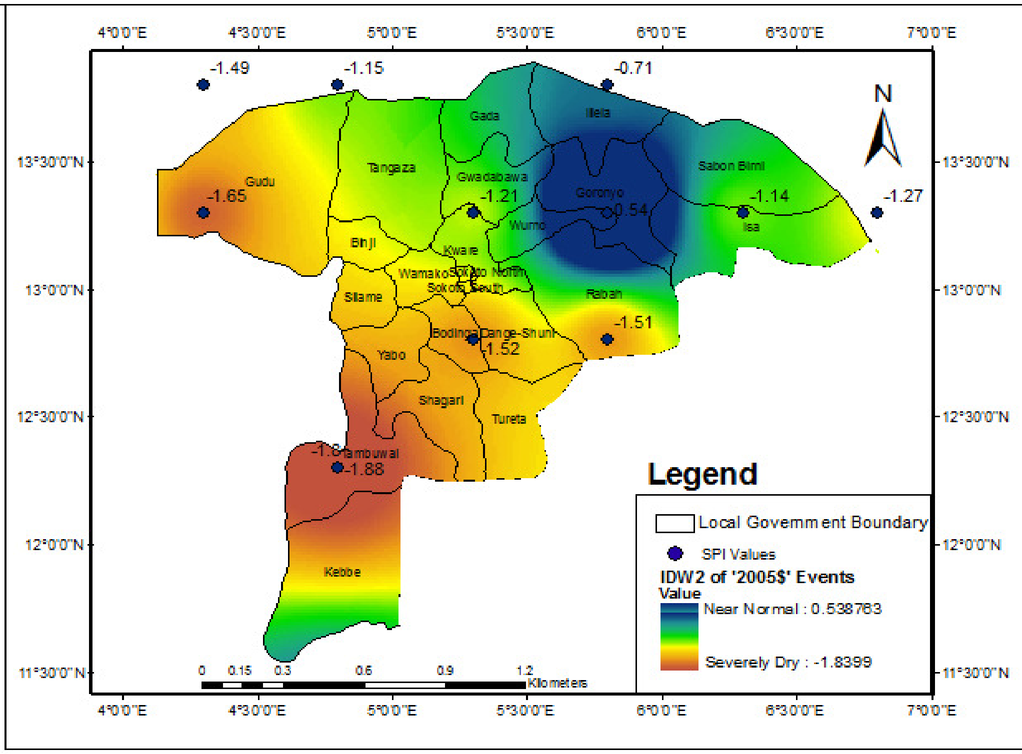

Figure 12: Standardized Precipitation Index (SPI) of Sokoto State, Nigeria in October, 2005

Assessing the Normalized Difference Vegetation Index (NDVI) and Standardized Precipitation Index (SPI) produced for October 1986, October 2005 which mark the period of onset of prolong dry season in Sokoto and January 2000 which usually marks the period of intense dry condition. It was observed that that the greenness in vegetation cover obtained from NDVI of October 1986 and 2005 is high compared to that of January 2000 which marks the period of prolonged dry season. The reduction in vegetation cover in January is due to usual lack of precipitation. Comparing the SPI and NDVI map of October 2005 and 1986, it is evident that the intensity of dry condition in 2005 is higher than that of 1986 which is attributed to reduction in precipitation amount and its effect on the greenness of vegetation cover. A distinct relationship between the SPI and NDVI is observed in this study. However, both are good indices for assessment of drought occurrence.

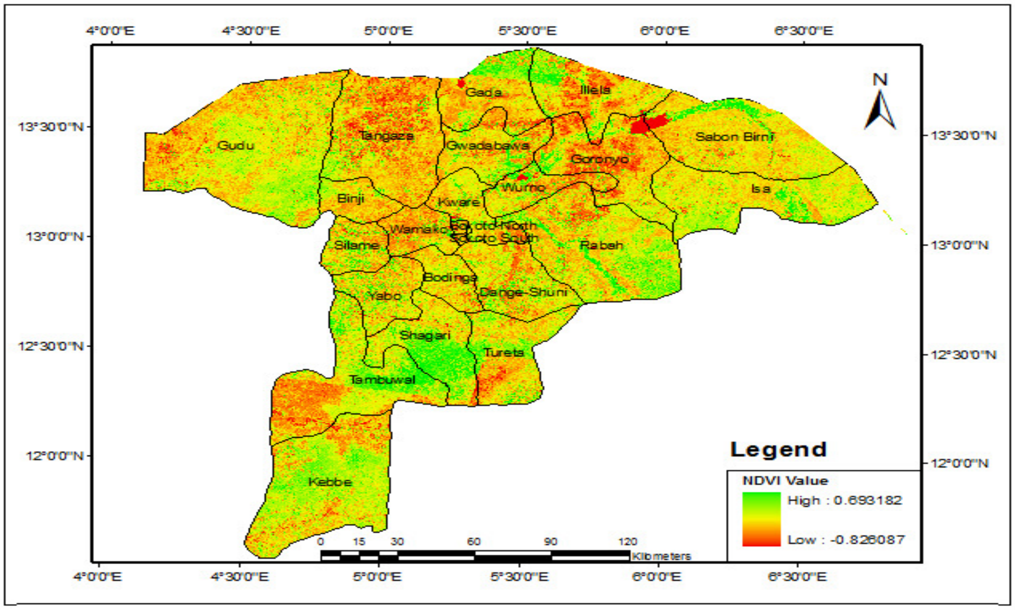

Figure 13: Normalized Difference Vegetation Index (NDVI) of Sokoto, Northern Nigeria in January, 2000

Conclusion

This study has utilised geospatial and statistical techniques to assessing drought occurrences and its effect on vegetation cover in Sokoto state. The effects of drought occurrences and its effect on vegetation cover in the state have also been established. This research has indicated the seasonal and inter-annual variation to the decadal timescale of spatial variation of dry and wet spells in Sokoto state. Change scenarios observed from the derived NDVI and SPI maps indicated that the climatic variability currently being experienced is likely to increase and intensify in future. Results from the geospatial analysis have suggested the likelihood of increase in both frequency and intensity of droughts in the region. Location around longitude 4^0E to 6.8^0E and latitude 13^0N to 14^0N (Gada, Illela, Sabon Binin, Tangaza, Gudu, Binji, Kware, Gwadawa, Goronyo and Isa) receive the least amount of rainfall while Kebbe and Tambuwal on lower latitude in Sokoto receive the highest amount of mean rainfall. At the later part of the rainy season, regions up-north around longitude 4.5°E- 5.2°E and latitude 13.5°N - 14°N (part of Tangaza and Gudu), Tambuwal and Kebbe recorded the highest mean rainfall amount in the state.

The Standardized Precipitation Index over all the station also indicated that there was a composite nature in which some of dry years were mixed with wet years and vice-versa this occurred throughout in all the stations but it was observed that there were more dry years than wet years in Sokoto. During the onset of the prolonged dry season (October) in the sahelian region, the SPI value ranges from severely dry condition to Moderately Wet condition. However in the recent years, the SPI values for over 90% of the state falls within the severely dry conditions with scanty near normal condition in Goronyo axis of the state.

The Sahelian droughts of the early 70s and majority of the 80s are clearly revealed in this study. Area affected by droughts may increase, considering the climate change and its associated global warming that are expected to cause characteristic fluctuations of climate patterns in different climatic regions with negative impact on the ecosystem. Therefore, changes in climate factors such as rainfall should not be taken for granted. Though a distinct relationship between the SPI and NDVI was reported in this study, both have been demonstrated as good indices for assessment of drought occurrence over the study area.

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