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Geo-Spatial Assessment of Vegetation Response to Drought in North Central Nigeria

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Abstract

The thrust of this paper is to examine the impact of drought risk on vegetation health in North Central Nigeria. The study applied remote sensing, Geographic information system (GIS) and statistical techniques as research methodologies. Monthly rainfall data which span through a period of 56 years (1960-2017) were obtained from Nigeria Meteorological Agency (NIMET) for analysis of variation and drought characterization using SPI. Consequently, drought risk maps were produced for three different periods: 2000-2005, 2005-2010 and 2010-2015. The study made use of the near real time data of Moderate Resolution Imaging Spectroradiometer (MODIS) Terra and Aqua Normalized Difference Vegetation Index (NDVI) of 16 Day L3 Global 250 m resolution from 2000 to 2016 for analysis of vegetation health. The results of the study proved the efficacy of NDVI in highlighting areas that are currently under vegetation stress, reduction and drought. The states with reduced and low vegetation cover corresponded well to those with low rainfall hence, more vulnerable to drought risk. The summary of the NDVI results showed that Niger, plateau and Nasarawa states have low vegetation cover and are more vulnerable to drought risk.

Keywords

Drought, Rainfall, SPI, NDVI, Vegetation Cover, MODIS, Northern Central Nigeria

1. Introduction

Drought has generally been acknowledged as one of the most devastating meteorological disasters mainly due to its slow and accumulating impacts. Most of these impacts cut across hydrological, meteorological, socio-economic and the agricultural sectors (Wilhite et al., 2014). Usually the agricultural sector is the first victim of drought owing to the fact that agricultural drought emanates mainly from deficiency in precipitation which culminates in soil water deficit and differences between actual and potential evapotranspiration (Salerno, 2015). This unpleasant condition often results in water users going through difficulties leading to questions on the likely end of the drought. Therefore, the importance of rainfall as an element of the climate system cannot be over emphasized (Otun, & Adewumi, 2016). However, rainfall in North central Nigeria described as the food basket of the country is highly varied.

In Africa, drought has been a regular event occurring both in high and low rainfall areas. Since the popular devastating Sahelian drought of the 70s, drought occurrence has increased in many parts of Northern Nigeria (Oyebande, 1990). The increase has been attributed to steady decline in annual rainfall in the region since the end of the 60s (Adefolalu, 1986).

The variability of rainfall in terms of duration, amount and intensity over northern part of the country have resulted in dry spells and in amount falling below normal to support crop production and livelihood security. Furthermore, rainfall characteristics examined in Nigeria by (Olaniran, 2002), reveal a progressive early retreat of rainfall especially in Northern Nigeria including the central states. There is empirical scholarly evidence that rainfall trend is declining rapidly in most states in North Central namely Minna, Jos, Lokoja and Ilorin (Atedhor, 2016). The observed decreasing trend couple with delayed onset and early cessation has enormous implication on drought and vegetation cover in the region.

In Nigeria, the standardized precipitation index, remote sensing and GIS have gained tremendous application in recent times in drought trend assessment, generation of drought risk maps for the purpose of classification of drought prone areas into vulnerability and occurrence zones and analysis of vegetation trends.

Similar studies on early detection of drought in East Asia were carried out by (Song, Saito, Kodama, & Sawada, 2004). The result indicated that NDVI from NOAA/AVHRR proved useful as NDVI was applied to detect the intensity and agricultural area affected by drought. The study was successful in detecting and monitoring drought effects on agriculture.

In another Development, (Adegboyega et al., 2016), undertake a recent study of monitoring drought and its effects on vegetation in Sokoto state. They employed SPI, statistical and geo spatial techniques in their assessment. Findings revealed that the SPI values vary significantly from extremely dry condition to wet condition. It was further noted that changes observed from the NDVI and SPI were used to generate drought risk map of the study area. The risk maps indicated that drought trend in Sokoto State was on the increase even though there is remarkable improvement in climatic conditions in recent times.

(Fabeku & Okogbue (2014), in another attempt to unravel the impact of drought on Vegetation, undertook another study on trends in vegetation response to drought in the Sudano-Sahelian parts of Northern Nigeria. Like previous studies, the authors used SPI, GIS remote and remote sensed imageries as part of the assessment and methodologies.

The study outcome indicated the effectiveness of the models in detecting several areas that were under the influence of drought. The Vegetation cover responded well with improvement during the wet years and worsens in the drought years.

Evidence from several research findings reveals that the relationship between NDVI and rainfall is more of spatial variation. Given the sensitivity of NDVI to rainfall variation, it will be safe to argue that vegetation amount and condition are a function of climatic variables such as rainfall.

Most studies on the impact of drought on vegetation are concentrated in the North West and eastern parts of the country with little or no research attention in the central states. North Central Nigeria is a very critical region to the entire country in terms of food productivity and security in Nigeria. Therefore, the occurrence of drought of any intensity can be very disastrous to the economy of the region. This paper is aimed at assessing the occurrence of drought in North Central Nigeria and Vegetation response in the region.

2. Materials and Methods

2.1. The Study Area

The study area is located in northern Nigeria. It lies approximately between 3˚E and 14˚E and latitude 7˚N and 10˚N. The region is made up of six states namely Benue, Kwara, Niger, Plateau, Nassarawa, Kogi and Abuja (the Federal Capital Territory) as shown in Figure 1. The study area is within the Guinea savannah

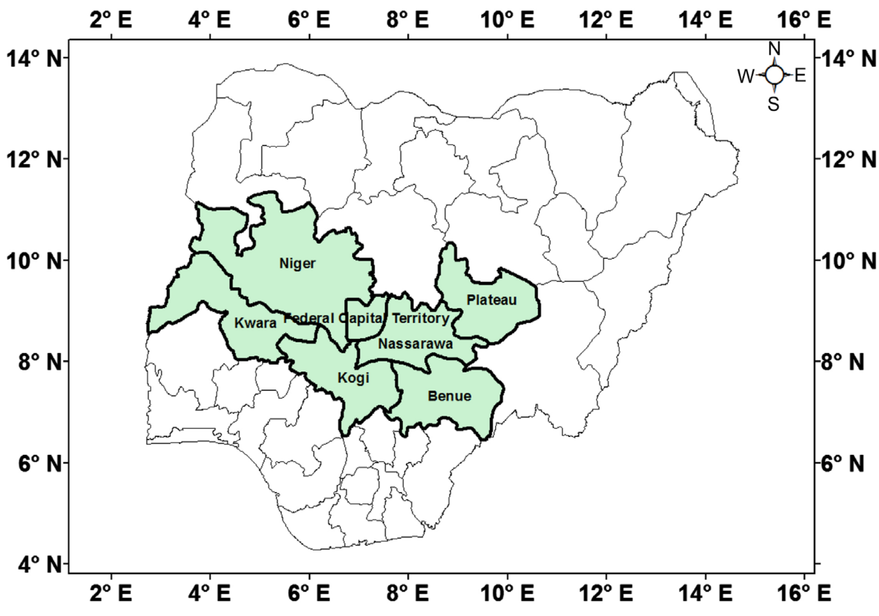

Figure 1. Map of study area. Source: (Ideki, 2019).

vegetation belt. This vegetation belt is mainly of deciduous trees with grasses and shrubs. The natural vegetation pattern has however been altered by widespread human activities. The region constitutes the food basket of Nigeria covering about 730,000 km^2 or about 78% of the total land mass of Nigeria. It is bordered North in the by the republic of Niger in the east, by Republic of Cameroon and in the west by Benin Republic.

The relief of the lower Benue basin which this study falls comprise of two distinctive relief regions. The upper part is located in the northwest axis and is an extension of the steep scarp of the Jos Plateau (Aper, 2006). The lower Benue valley is also divided into two physiographic properties particularly the river and its floodplains, and the adjoining lowland areas which are all susceptible to flooding (Udo, 1970).

The climate of the region is partly influenced by climates in the northern and southern regions of Nigeria. The tropical savannah climate characterized by wet and dry condition affects most parts of north central Nigeria. Rainy seasons decline correspondingly in length as one moves north (Binboll & Edicha, 2016).

Temperature is generally high with values ranging between 27˚C and 30˚C. It can also increase to as high as 38˚C in most parts of the year due to constancy of incoming solar radiation in the region.

2.2. Rainfall Data

56 years monthly rainfall data of each meteorological station in the study area was obtained from the Nigeria Meteorological Agency (NIMET) Abuja for analysis of rainfall variation.

2.3. Remote Sensing and GIS Analysis

2.3.1. Image Geo-Processing for Vegetation Change

The study made use of the near real time data of Moderate Resolution Imaging Spectroradiometer (MODIS)Terra and Aqua Normalized Difference Vegetation Index (NDVI) of 16 Day L3 Global 250 m resolution. NDVI imageries from 2000 to 2016 were considered for this study. One of the most used and implemented indices calculated from multispectral information as normalized ratio between the red and near infrared bands is the NDVI. A direct use of NDVI is to characterize vegetation canopy growth or vigor. NDVI is the most commonly used vegetation index because it has been effective in measuring vegetation vigor, percentage green cover, and biomass. It is a non-linear function that varies between −1 and +1 and is undefined when both P_{red} and P_{nir} are zero, P_{red} and P_{nir} are reflectance in red and near infrared bands of the satellite imageries respectively (Pettorelli et al., 2005).

2.3.2. Inverse Distance Weighted Interpolation

The Inverse Distance Weighted (IDW) technique was used for the generation of drought risk maps for three different periods. This method is based on the assumption that the interpolating surface is easily influenced mostly by near points and less by the more distant points. The algorithm can work even when all points lie in a low-dimensional subspace.

This was achieved by subjecting the analysis to ArcGIS 10.5 environment.

2.4. Statistical Analysis

Analysis of Variance (ANOVA) was employed for test of variation in rainfall in the study area.

Mathematically ANOVA is stated as:

$$F = \frac{MST}{MSE} \quad (1)$$

where

F = Anova Coefficient

MST = Mean of squares due to treatment

MSE = Mean of squares due to error

2.5. Standardized Precipitation Index (SPI)

The standardized Precipitation index (SPI) is a tool widely used in measuring drought intensity. The method was developed by (Mckee et al., 1993), using only observed precipitation as primary variable in its computation.

Mathematically, it is stated as follow:

$$SPI = \frac{X_{ij} - \bar{X}_i}{\sigma_i} \quad (2)$$

where X_{ij} is the rainfall for the ith station and jth observation, $\bar{X}_i$ is the mean rainfall for the ith station and σ_i is the standard deviation for the ith station.

The standardized precipitation index (SPI) drought categorization table shown in Table 1 was used to access possible drought occurrence in each of the stations. SPI values can be positive or negative. All negative SPI values represents drought occurrence, while the positive values shows no drought.

In this study, only the 12 month standardized Precipitation Index (SPI) was applied in each station to determine the risk and vulnerability of drought in the

Table 1. Standardized precipitation index (SPI).

SPI	Drought event
2.0+	Extremely wet
1.5 - 1.99	Very wet
1.0 - 1.49	Moderately wet
−99 - 0.99	Near normal
−0.1 - 1.49	Moderately dry
−1.5 - 1.99	Severely dry
−2 and less	Extremely dry

Source: Mckee, Doesken, & Kleist, 1993.

study area. The 12 month SPI is usually tied to stream-flows and reservoir levels as well as annual drought intensity (WMO, 2012; NIMET, 2011).

3. Results and Discussion

The results of the ANOVA analysis are presented as follows.

The results of the analysis presented in **Table 2** reveal the existence of high temporal variability of rainfall the period of 56 years (1960-2017). There is evidence from the table of statistically significant difference in annual rainfall amount in the study area during the period under investigation since between groups variation is greater than within group variation.

The F calculated value of 5.839 is statistically significant ($P < 0.05$) at 95% confidence level. This implies further that there is significant difference in rainfall regimes in the six states except Abuja the federal capital territory.

To determine were the difference lies, the Duncan statistics is used as shown in **Appendix 1**.

Duncan post hoc test was used to show the level of variation within the stations. The result reveals that Abuja was distinct from the other states in terms of difference in her mean value of 94.8565. This indicates that there is statistical variation in rainfall characteristics in Abuja from the other states in the study area.

3.1. Standardized Precipitation Index and Drought Trend Analysis

For a robust analysis of drought trend, the Standardized Precipitation Index was employed. The results are presented as follow.

The result of the 12 month SPI time scale analysis for the station as shown in **Figure 2** reveal that 1986, 1970, 1974, 1982, 1986, 1994, 2002 and 2008 were dominated by drought.

This implies that Makurdi was affected by drought of different intensities. This is another evidence of decreasing and erratic rainfall, low moisture content, decrease stream flow, reservoir and ground water levels since 12 months SPI represents hydrological and annual drought regimes. This is expected to impact negatively on the rainfall dependent agricultural system and surface water availability (Idoko, 1998; Utser & Aho, 2012).

In Ilorin as reveal in **Figure 3**, the 12 month SPI analysis confirm the following

Table 2. ANOVA results showing temporal variation of rainfall.

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	409,841.699	6	68,306.950	5.839	0.000
Within Groups	5.000E7	4688	11,698.639		
Total	5.041E7	4704			

Df = Degree of Freedom; F = F-calculated value (Used in an *F*-distribution data); It's normally used when comparing statistical means using the least squares model to show variance ratio.

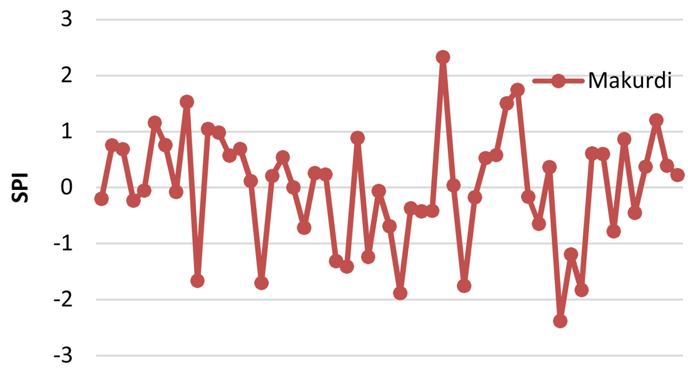

Figure 2. Graph of SPI 12 month time scale for Markurdi.

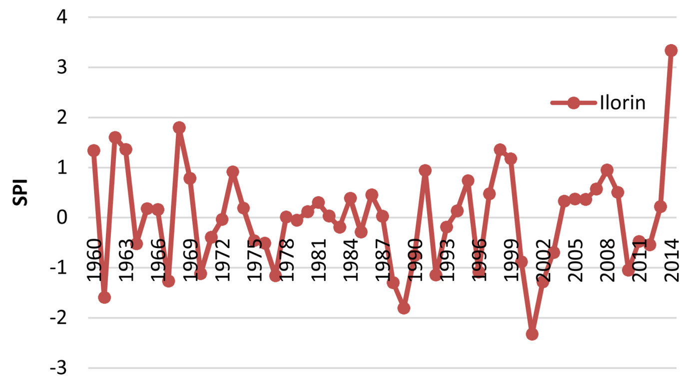

Figure 3. 12 month SPI analysis for Ilorin.

years 1960, 1966, 1970, 1976, 1988, 1992, 1996, 2010 and 2012 as periods of severe drought while year 2000 represents extreme drought considering −2 as the value of the SPI.

The 12 months SPI time series analysis in Lokoja indicate that different intensities of drought have been experienced over the past decades in the station. While 1972 and 1976 has SPI value of 1.0 - 1.49 which is an evidence of moderate drought, severe drought on the other hand was recorded in 1980, 1984 as shown by the negative SPI value of 1.5 as shown in **Figure 4**.

The time series analysis also reveal that the station experience declining rainfall trend between 1972, 1974, 1980, 1984, 1998, and 2004 before it peaking up in 2010.

For the 12 month SPI analysis in Minna as shown in **Figure 5**, moderate drought was reported in 1962, 1970, 1974, 1980, 1982, 1990, 1992 and 2014 while 1974 indicates severe drought dominated 2010 and 1992. Drought of extreme intensity occurred in 1982, 1986 and 1988.

It is evident from the results presented above that Minna is highly vulnerable to drought risk. This vulnerability might be further aggravated by future rainfall declines. Similar research finding affirm that climate change is creating shifts in rainfall pattern (Okeke, 2015).

The 12 months SPI analysis conducted for Jos station is clearly shown in **Figure 6**. The result reveals that extreme drought occurred in 1960, 1996, 1994,

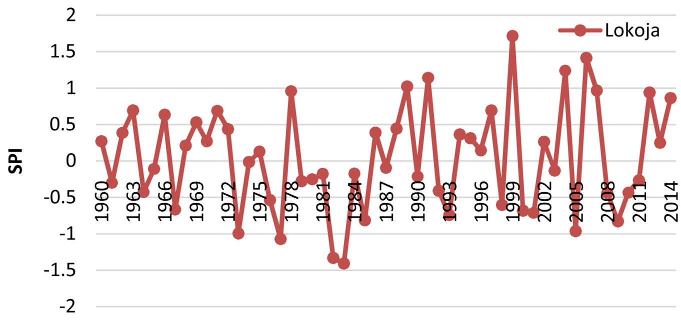

Figure 4. 12 months SPI analysis for Lokoja.

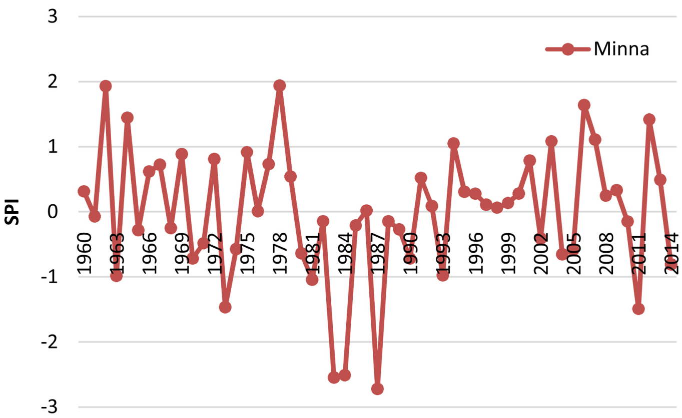

Figure 5. Graph of 12 months SPI analysis for Minna.

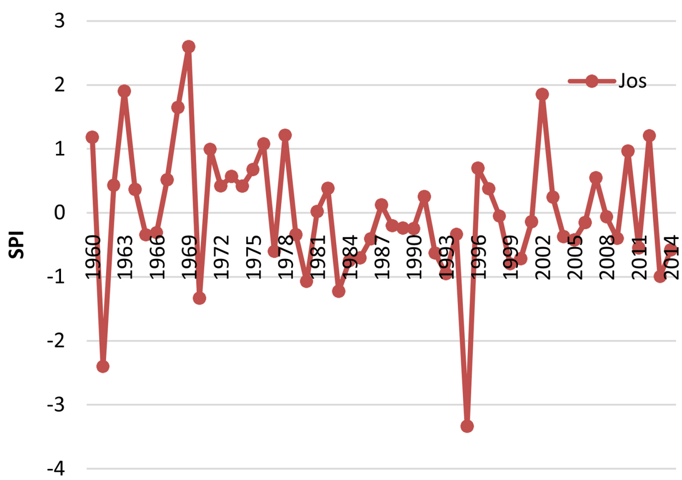

Figure 6. Graph showing 12 months SPI analysis for Jos.

2004 and 2012 as shown with the negative SPI values. On the other hand, severe drought occurred in 1962, 1970, 1980, 1982, 1986, 1988, 1992, 1998 and more recently, 2000 and 2013.

The 1980-1992 decade was generally a period of sustained dryness. The dry spell also extended from 2004 to 2014. The implication of this analysis is that the station experienced decreasing rainfall trend at different times with attendant effect on agriculture, ecosystem and dislocation in socio-economic conditions.

Detail analysis of 12 month SPI time series for the station is shown in **Figure 7**. The result reveals that the station was only affected by drought events of moderate category in 2001, 2004, 2007 and 2010. The implication is that Lafia has low drought risk compared to other stations such as Minna and Jos in the study area.

The analysis of 12 month SPI for Abuja shown in **Figure 8** above, reveal that moderate drought occurred in 1984, 1988, 1990, 1996, 1998 and 2012, while severe dry period was dominant between 2000, 2002 and 2008. The implication of this result is that farmers in the federal capital experienced both poor crop yield and water related problems during the periods of moderate and severe drought.

3.2. SPI Generated Drought Risk Map

This section deals with presentation of SPI generated spatial maps of 3 different intervals. The maps were produced to show the risk level and vulnerability of each station to drought. It further indicates the pattern of drought occurrence in the region using an interval of five years namely 2000-2005, 2005-2010, and 2010-2015.

The drought risk map of the first interval 2000-2005 shown in **Figure 9** reveal that drought risk was low in the study area. This implies that the period was characterized by improved rainfall in all the stations in the study area.

The 2005-2010 spatial map as shown in **Figure 10** was characterized by near normal conditions in the Northern parts of Abuja, plateau and Nasarawa states as indicated by the SPI negative values.

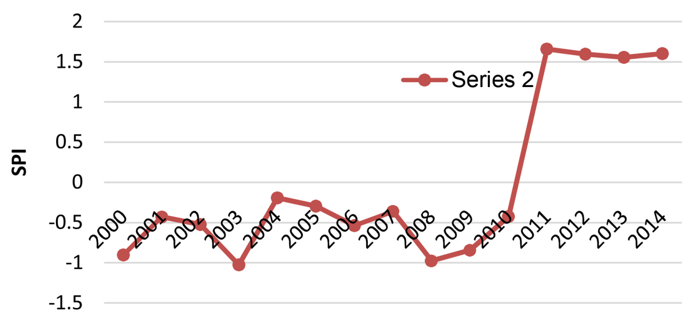

Figure 7. Graph of 12 month SPI analysis for Lafia.

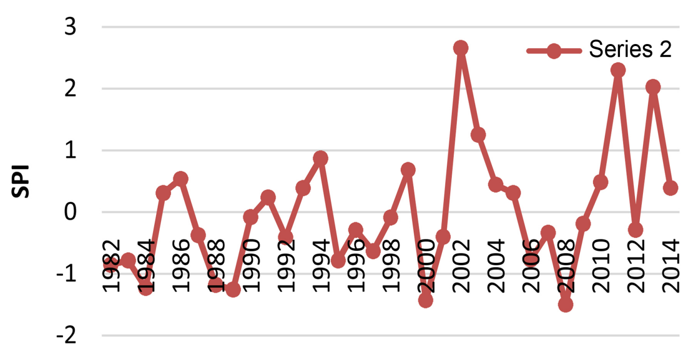

Figure 8. 12 month SPI analysis for Abuja.

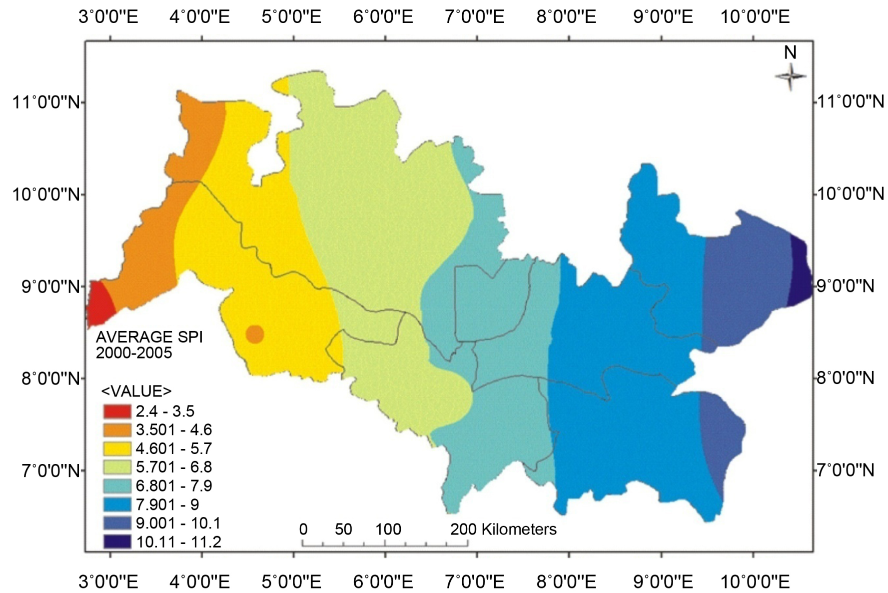

Figure 9. Drought risk map 2000-2005.

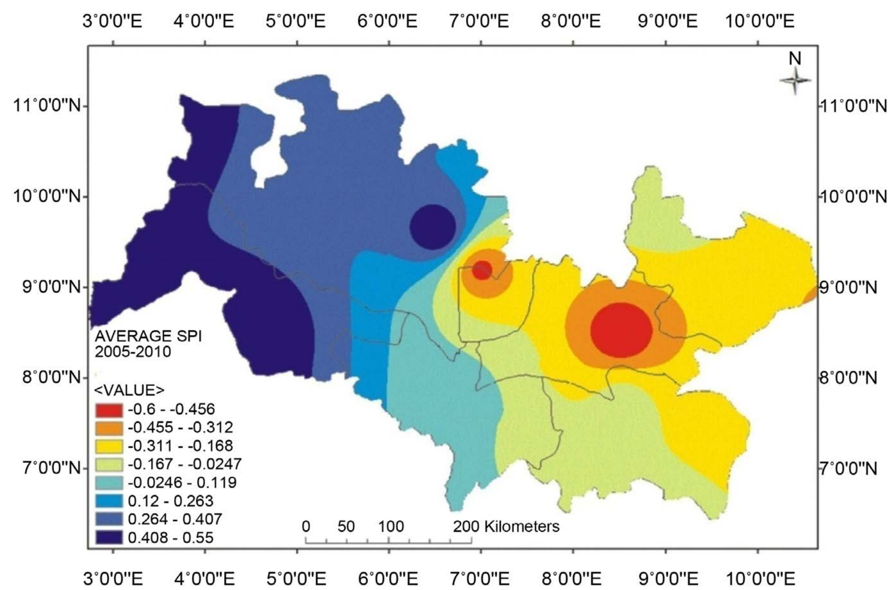

Figure 10. 2005-2010 drought risk map.

The implication is that drought conditions during this period of investigation concentrated in Abuja, Nassarawa, Southern Benue and Plateau States. Another revelation from the spatial map is that decreasing rainfall trend was evident in the aforementioned states.

Thus, Benue, Abuja, Nassarawa and Plateau states were high in the drought vulnerability index. The findings in this study are in agreement with (Abbas, 2005; Oladipo, 1993; Adegboyega et al., 2016).

A close observation of **Figure 11** indicates drought of different intensities in the states considered as most vulnerable. The risk map further reveals that drought advanced in 5 states of the study area except Abuja and Nasarawa

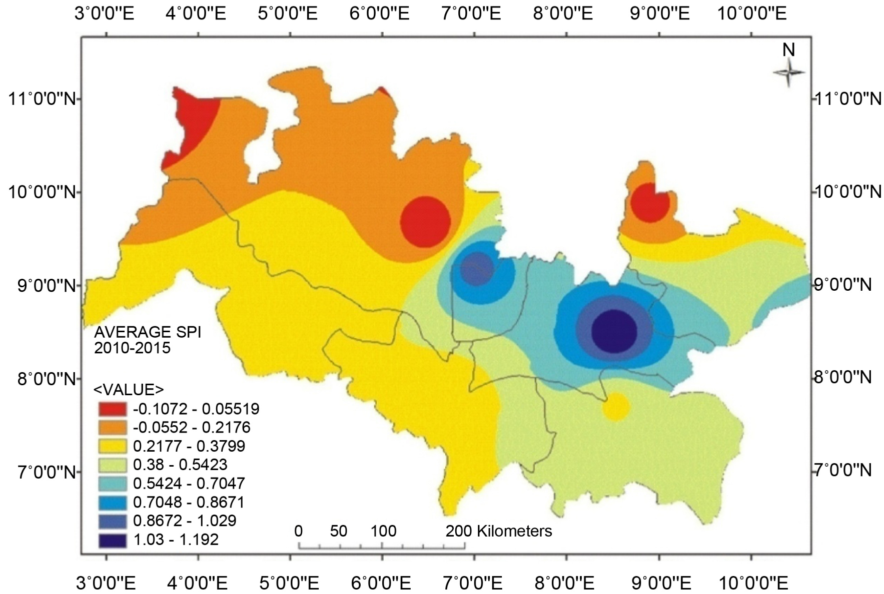

Figure 11. Drought risk 2010-2015.

States.

However, extreme drought was evident in the Northern and Eastern parts of Niger States with the negative SPI values. The Northern part of Plateau State also experience extreme drought conditions. Drought conditions of severe moderate and near normal were also recorded in Kwara, Kogi and Benue States. The reasons adduced for the increasing risk of drought in the aforementioned states are increasing latitude, declining rainfall and climate change among others.

3.3. NDVI and Vegetation Response

For detailed explanation of vegetation response to drought in the study area, NDVI analysis was carried out from 2000-2016. The result of the analysis is presented as follows:

The NDVI map for 2000 presented in Figure 12 reveal that Plateau and Niger States experienced decreasing levels of vegetation index. It is pertinent to emphasized that as rainfall increases, NDVI also increases. This implies that NDVI responds well to rainfall events.

It underscores the role rainfall plays on vegetation health of every location. As shown in the map, NDVI value was low at −0.1999 which reveal a decline in the level of greenness with implication on high drought risk. The state's most affected were Plateau and Niger States. This also shows that Plateau and Niger State are more vulnerable to drought since rainfall is a good index of measure of vegetation cover.

Results of NDVI map for 2003 shown in Figure 13 is not significantly different from that of 2000. Vegetation index values revealed that Plateau state experienced reduced vegetation cover hence decreasing trend in rainfall. It is evident from the results that Plateau, Kwara and Niger states falls in the region with low

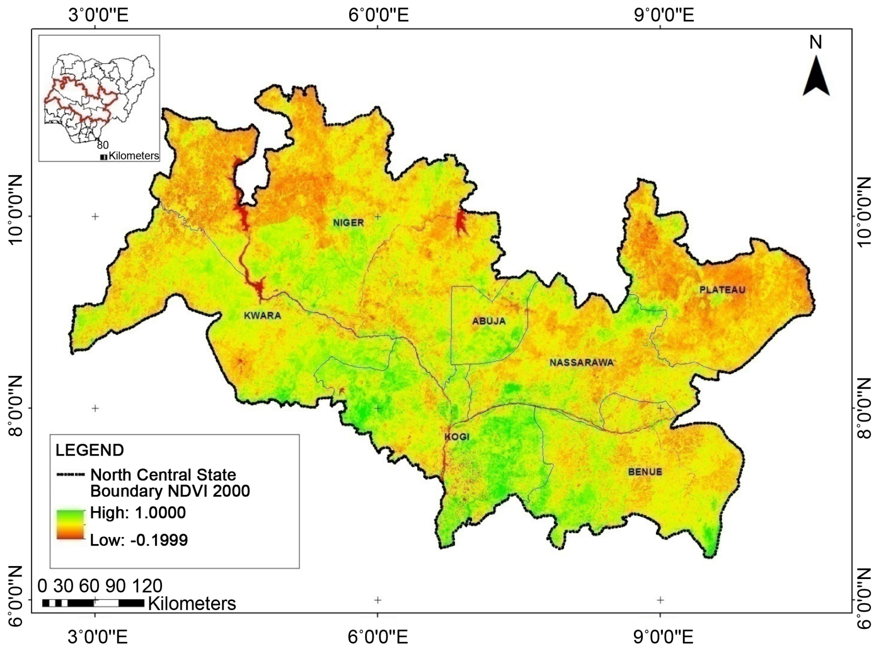

Figure 12. NDVI Map 2000.

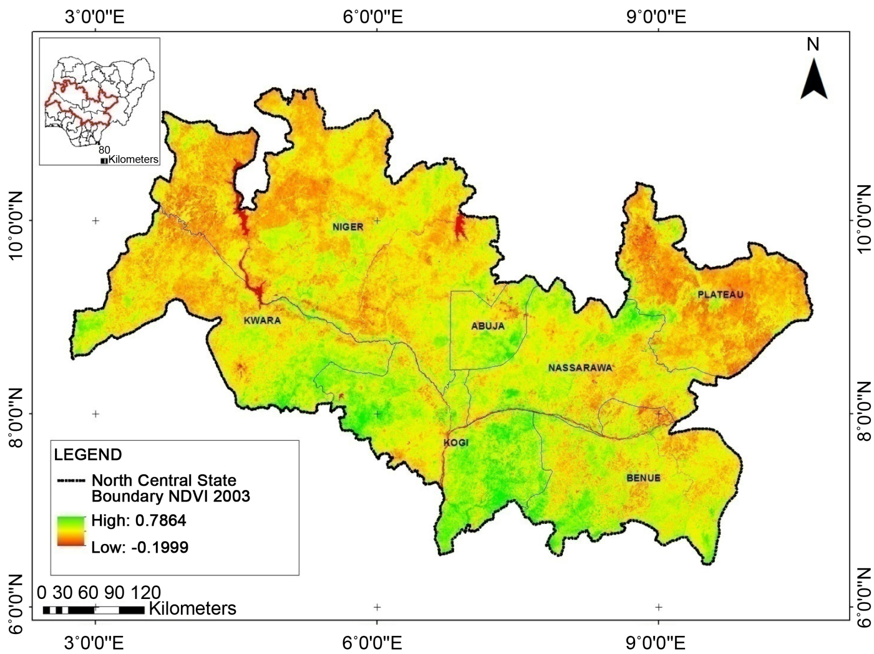

Figure 13. Vegetation health in 2003.

NDVI values. On the other hand, the high NDVI values in Benue, Kogi and Federal Capital Territory Abuja indicate the states experience improved vegetation cover and health as indicated in greenness index.

Since NDVI are good indicators of drought, it implies that Kwara, Niger and Plateau were the most vulnerable to drought risk during the period under review.

The NDVI map generated for the study area in 2006 shown in **Figure 14**

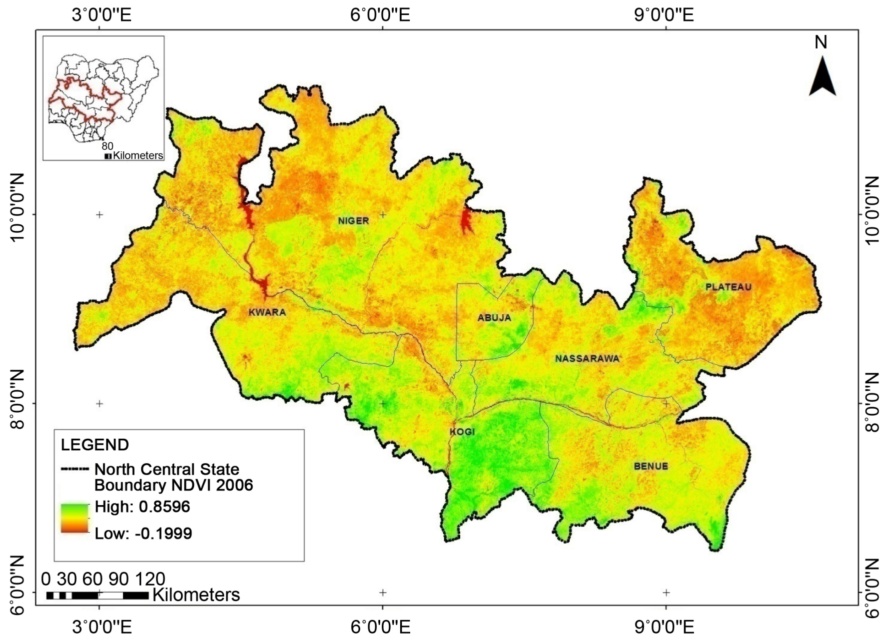

Figure 14. Vegetation health in 2006.

above, indicates that vegetation cover and health experienced continuous decline particularly plateau and Niger states as the lowest NDVI value was put at −0.1999 implying that the aforementioned states were affected by declining rainfall. Furthermore, the 2006 map reveal more greenness in vegetation cover in Kogi and parts of Kwara states as indicated by the high NDVI value of 0.8596. This implies that the quality and density of vegetation cover in Kogi State improved against 2003.

The decline in vegetation cover posted in 2006 follows a linear pattern in which rainfall decline and drought vulnerability increases with distance to the extreme North.

The 2009 NDVI map in **Figure 15** showed a remarkable improvement in vegetation cover in the study area. The North central region has the highest NDVI value of 0.8754 while the lowest was −0.199. The highest NDVI value was clearly observed in Kogi State and South-eastern parts of Kwara State. The least NDVI value was observed in Plateau, Niger and Northern parts of Kwara States. Although the study area experienced increased greenness in States like Benue, Abuja and Nassarawa which indicates healthy and improved vegetation cover. The observation noted above may be attributed to increased rainfall. Given the NDVI result for 2009, it implies that vegetation index performed better for the aforementioned states in 2009 compared to 2006.

From **Figure 16**, the highest limit of the NDVI in the study area was 0.9352 which was higher than 2009. Again the lowest NDVI value of −0.1999 was recorded in Plateau and Niger States. The low NDVI value indicates highly stressed vegetation and declining rainfall. With poor vegetation cover, there will adverse effect on crop yield. Secondly, ecological activities will also be disrupted leading

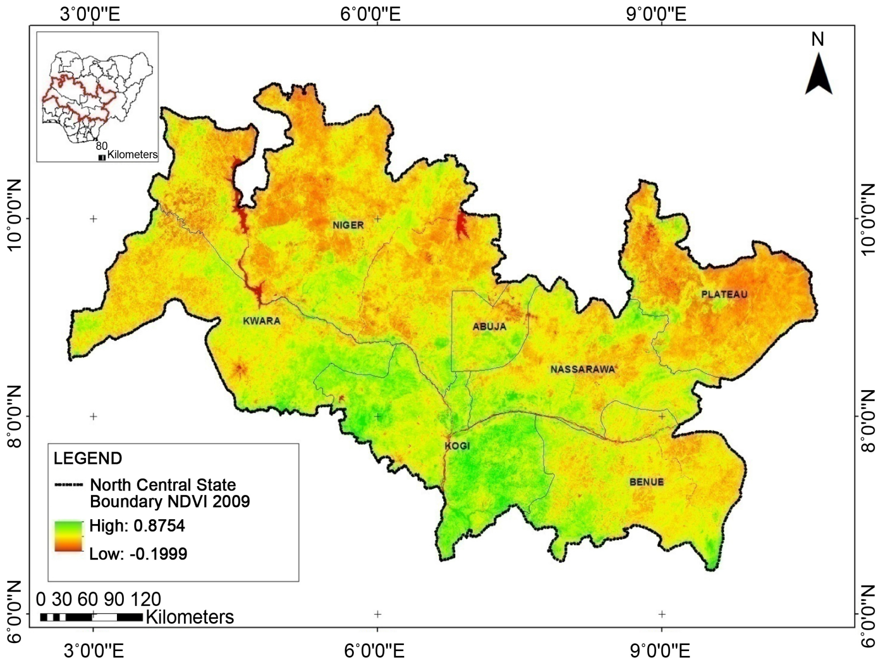

Figure 15. Vegetation health in 2009.

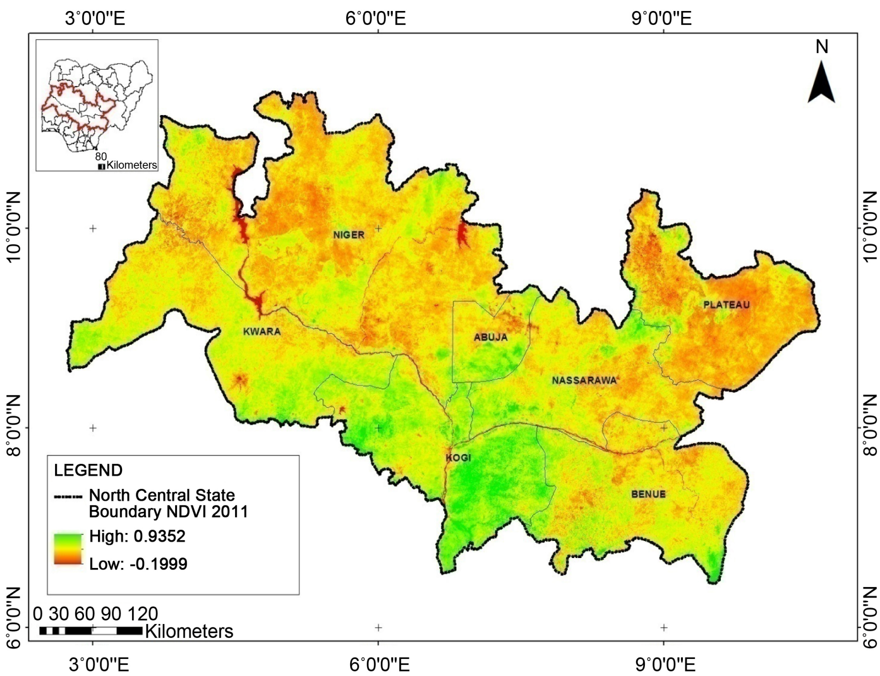

Figure 16. Vegetation health in 2011.

to ecological imbalance.

The main factor that accounts for the poor and stressful vegetation cover in some of the states in the study area are basically proximity to the extreme Northern parts of the country. For instance, Plateau is located close to Kano and other north eastern States, which has been ravaged by drought and low vegetation cover. This same factor is also responsible for the dismal NDVI performance in Niger State. The western and northern parts of Niger also border with Kebbi and Zamfara states which are both characterized by low vegetation cover and recurrent drought.

From Figure 17 shown, the lowest NDVI value was −0.1999 while the highest was 0.9781 respectively. The low NDVI value indicates stressful and poor vegetation response to drought.

With a declining and poor vegetation health, biological processes and activities that depend on healthy vegetation cover will be seriously affected. Since vegetation resources are important component of the physical environment, any alteration in its density, growth and health could result to environmental devastation.

Generally, the northern extremes of the region recorded the lowest NDVI value which corresponds well to declining rainfall and drought (Figure 18). On the other hand, the highest NDVI value of 0.9833 indicates good and healthy vegetation cover in Kogi, Kwara and Abuja the Federal Capital Territory.

The results of the different NDVI maps presented in this study are evidence that vegetation cover is on a steady decline particularly Niger and Plateau states followed by Nassarawa and Kwara states respectively. The NDVI analysis further reveals that both Niger and Plateau states have experienced drought in the past ranging from moderate to severe intensity. Hence, NDVI responded well to drought as indicated in the preceding analysis.

The result of the study further implies that the states with low and stressful vegetation corresponded well with low rainfall while those with high NDVI value suggest high vegetation cover and improve rainfall.

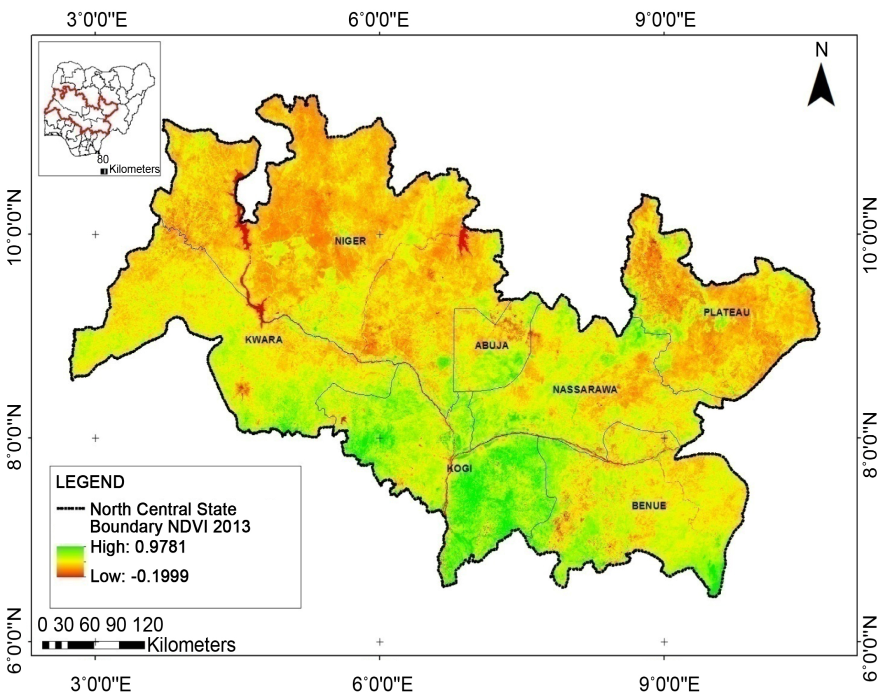

Figure 17. Vegetation health in 2013.

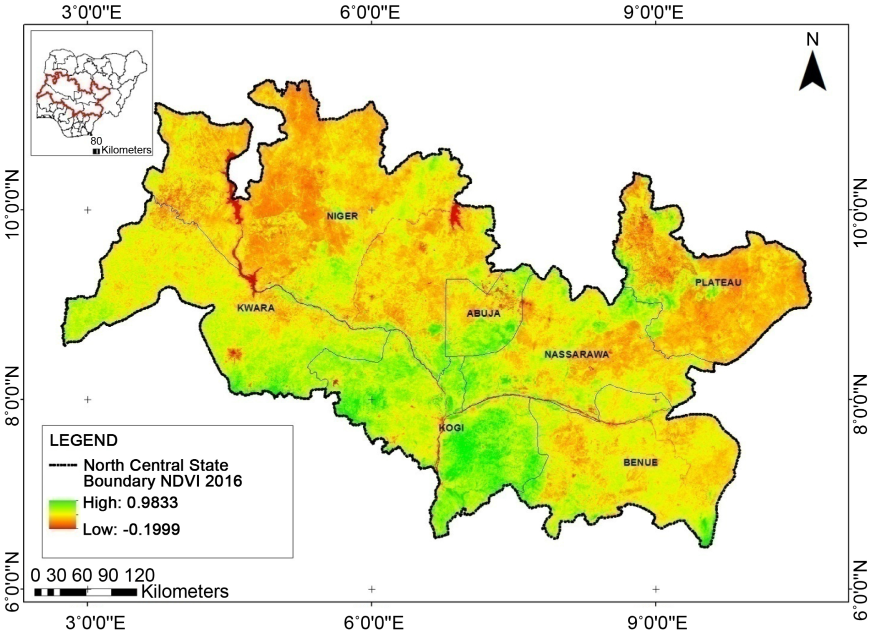

Figure 18. Vegetation health in 2016.

4. Summary and Conclusion

The application of geospatial and statistical assessment of vegetation response to drought in North Central Nigeria has adequately been addressed in this study. The outcome of this research equally revealed that annual and decadal variation in rainfall exists in all the stations that constitute the study area.

The application of the SPI 12-month time scales was effective in detecting the occurrence of drought of different intensities particularly near normal, moderate and severe drought in all the stations considered. The study further indicates that drought trend is on the increase in the study area and likely to intensify in the future. The SPI generated maps also reveal that Minna, Jos and Nassarawa states are the most vulnerable areas to drought high while Benue, Lokoja and F.CT Abuja are low risk areas.

The NDVI result showed marked temporal variation of vegetation in the study area. An existence of a strong relationship between NDVI and rainfall was established in the study. The NDVI was further used to delineate drought risk areas as Niger, Plateau, Ilorin and Nassarawa states responded poorly to drought.

NDVI in this study correlated well with rainfall indicating that areas with low vegetation cover imply declining and erratic rainfall.

The study therefore is a further contribution to knowledge in the area of climate change and drought research particularly the North Central region of Nigeria. With vegetation cover in the extreme northern end already devastated by drought and continuous migration of herdsmen to the central states for pastures, the poor and stressful vegetation cover revealed in the study will intensify the ongoing farmers/herdsmen clashes and worsen the security challenges in the North central region. Changes in rainfall trend need to be carefully studied further. The study also has implication on the agricultural sector, as both the SPI and NDVI results are evidence that crop failures and poor harvest are other social challenges that farmers will have to contend in the region. This will be disastrous for food security in Nigeria as the bulk of food production comes from the North central region.

Finally the study has shed more light on the efficacy of combining SPI, NDVI and other geospatial techniques in the assessment of vegetation health and drought risk in the North Central region of Nigeria by highlighting specific areas that need urgent attention.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Appendix 1. Ducan statistics of spatial variation in rainfall.

Indicators	N	Subset for alpha = 0.05		
		1	2	3
Abuja	684	94.8565		
Lafia	684		100.4253	
Ilorin	684		100.7753	
Lokoja	684		101.0670	
Markurdi	684			101.3387
Minna	684			102.9477
Jos	684			106.7314
Sig.		1.000	0.874	0.890

Means for groups in homogeneous subsets are displayed. a. Uses Harmonic Mean Sample Size = 684.