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Analysis of Rainfall Variability Using Remote Sensing and GIS in North Central Nigeria

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Abstract

The importance of rainfall variability in successfully understanding the dynamics of climate change in any region cannot be overemphasized. This study examines rainfall variability in the North Central region including the Federal Capital Territory Abuja using remote sensing and geographic information system (GIS) application. The study employed satellite data basically from near real time data of Moderate Resolution Imaging Spectroradiometer (MODIS). Thereafter, the point data of rainfall was clipped to the shape file of Nigeria Boundary and interpolation using Inverse Distance Weight (IDW) was done to generate rainfall spatial maps from 2000-2017. The result reveal high temporal variation in rainfall particularly Niger, Plateau, Benue and Nassarawa states. The study therefore recommends close monitoring of periodic pattern of rainfall characteristics in the region by the Nigerian meteorological agency and to encourage farmers into drought tolerant and irrigation farming.

Keywords

Rainfall, Variability, Climate Change, Remote Sensing, GIS North Central Nigeria

1. Introduction

There is increasing evidence that climate change is exacerbating rainfall variability and the frequency of extreme events such as drought, floods, and hurricanes [1]. Rainfall is one meteorological parameter that affects virtually all human activities [2]. For instance, the amount of rainfall received in an area is an important determining factor in estimating or quantifying the amount of water available to meet various demands, such as agricultural, industrial, domestic water supply and power generation [3].

According to [4], the availability or non-availability of rainfall is normally employed to determine the level of wetness or dryness during the growing season which makes rainfall the single most important element of the climate system affecting the agricultural and water resource management of any region. However, in recent time, the occurrence of dry spell in Northern Nigeria has increased public concern that the north central region might be undergoing climatic shift towards aridity. This is against the backdrop that declining rainfall has adverse impact on water resources, agricultural output and economic performance of a given region [5].

Arising from above, it is pertinent to emphasize that studies of rainfall variability are crucial in mitigating the consequences of extreme climate hazards such as droughts and floods [1]. This is premised on the fact that the amount of water available in the soil which crops utilize is dependent on important rainfall characteristics such as onset, length and cessation which influence the success/failure of the cropping season [6]. It then follows, that a clear understanding of rainfall variability as an element of the climate system is vital in developing and improving adaptation strategies of a drought vulnerable region like North central Nigeria whose sources of livelihood is rainfall dependent [7]. Given the current precarious situation in Northern Nigeria where rainfall is highly unpredictable, the importance of analysis of rainfall variation in drought characterization cannot be over emphasized [8] [9].

In other to fully harness and optimize the vast agricultural potentials and productivity in the North central region, studies of rainfall variation at local and regional level provide the antidote in combating the adverse effects of droughts and crop failure in the study area [10]. In the light of this revelation, the knowledge of analysis of trend, effect and spatiotemporal variation of rainfall from geospatial perspective is very apt in formulating adaptation and mitigation strategies to the risk of drought in North central Nigeria and this is where this paper derives its relevance.

Furthermore, the relevance of this research is also predicated on the fact that previous studies on rainfall variability in Northern Nigeria such as [11] [12] [13] and [14] relied mainly on statistical analysis of rainfall variation in their assessment of rainfall trend and drought. The use of geospatial techniques like remote sensing and GIS to establish spatio temporal variation in rainfall in the study area reveal the efficacy of applying modern climatological techniques in highlighting specific areas in North Central region that are confronted with declining rainfall and how the onslaught of drought can be mitigated in a changing climate. The authors affirm that the geospatial techniques employed were effective in revealing seasonal and annual variation in rainfall and this variability account for the vulnerability of the North Central region to drought and this is the gap which this study seeks to fill in the literature. The observed variability is expected to intensify in the future given the current climate change projection in Africa.

2. Study Area

North central Nigeria lies approximately between 3˚ and 14˚E and latitude 7˚ 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** [15].

It 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 in the North by the republic of Niger in the east, by republic of Cameroon and in the west by Benin republic. The total population of north central Nigeria is over 20 million [16]. The relief of the north central region is dissected by hills, undulating plains and lowlands. Its valley and troughs which extend inland for 30 kilometers is made up of flood plains lying generally below 250 meters. In terms of drainage, north central Nigeria has an excellent network of drainage network. This extensive drainage forms tributaries that flow from the Benue River and River Niger.

The climate of the region is partly influenced by climates in the northern and southern region 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 move northward. Temperature is generally high in the region. This is mainly due to the fact that the region lies within the tropics where the apparent movement of the sun is limited. In terms of relative humidity, there is also a mark variation in the study area with relative humidity ranging from 60% - 80% [17]. The major vegetation of the North central region of Nigeria is basically the Guinea Savannah Zone which occupies same 90% of the land mass. This vegetation belt is mainly of deciduous trees with grasses and shrubs [18]. The soils of the region are generally characterized by a sandy surface horizon overlying a weakly structured clay accumulation.

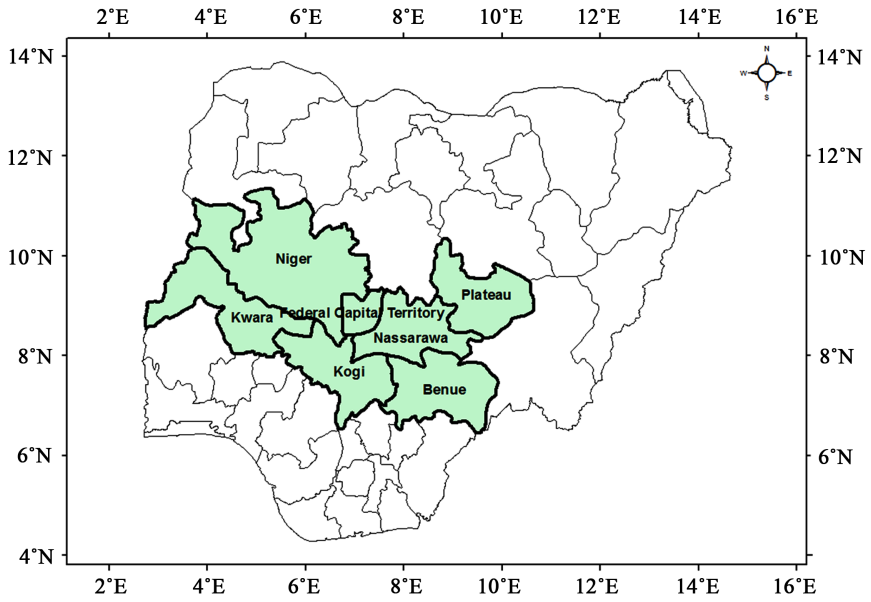

Figure 1. Map of study area. Source: (Authors field work, 2019).

In terms of geology, the region is characterized by deep Sedimentation which commenced with the marine Neo-comain—Albia Asu River group. The Asu River Group sediments in the region comprises predominately of shale's with localized sandstones, silts stones and limestone as well as extrusive and intrusive material of the Abakaliki formation in the Abakaliki area and the Mfamosing limestone in the Calabar frank [19].

3. Materials and Method

To examine the variability of rainfall using geospatial techniques, The point grid pattern of meteorological data was obtained for total precipitation from 2000 to 2017 from https://gisclimatechange.ucar.edu/gis-data. The point data of each of rainfall were clipped to the shape file of Nigeria Boundary and thereafter interpolation using Inverse Distance Weight (IDW) was done to generate values of climate data for the unsampled places. IDW assumes that each measured point has a local influence that diminishes with distance. The shape file of the study area (North Central States) was further used to delineate the raster format of each of the climate data. Zonal statistics were used to extract the mean values of total precipitation after which spatial maps were generated on three year interval 2000-2003, 2003-2006, 2006-2009, 2009-2011, 2011-2013, 2013-2016 and 2017.

4. Results and Discussion

The result of the analysis is presented below:

The geo spatial analysis of rainfall for all the stations in the study area for year 2000 is presented in **Figure 2**. The low rainfall value of 925.159 mm represents areas experiencing declining rainfall trend. In the analysis under review, these low rainfall areas are Plateau, Benue, Nassarawa, northern part of Niger state and the federal capital territory Abuja.

Similarly, the high rainfall value of 1616.36 mm is used to describe areas with sufficient rainfall amount. Again, these areas are Kogi, Ilorin and southern Niger states.

The down ward rainfall trend in plateau, Nasarawa and Benue and Niger states may be disastrous for the water resources and agricultural sectors and another indicator of drought risk assessment.

In 2003, annual rainfall performance for the rainfall abundant areas was 1552.39 mm while low rainfall areas recorded only 868 mm annual in the same year as shown in **Figure 3**. Like the preceding year, the states affected by low rainfall amount are Plateau, Benue, Nassarawa and parts of northern Nigerstates. This implies that there was early retreat, late onset and reduced duration of the raining season.

The result further reveals high variation in rainfall between the rainfall abundant areas and the regions with continuous decline in rainfall which signpost increase risk of drought especially the low rainfall areas.

The result of the analysis for 2006 as presented in **Figure 4** indicates remarkable improvement particularly in the low rainfall areas. Annual rainfall amount of

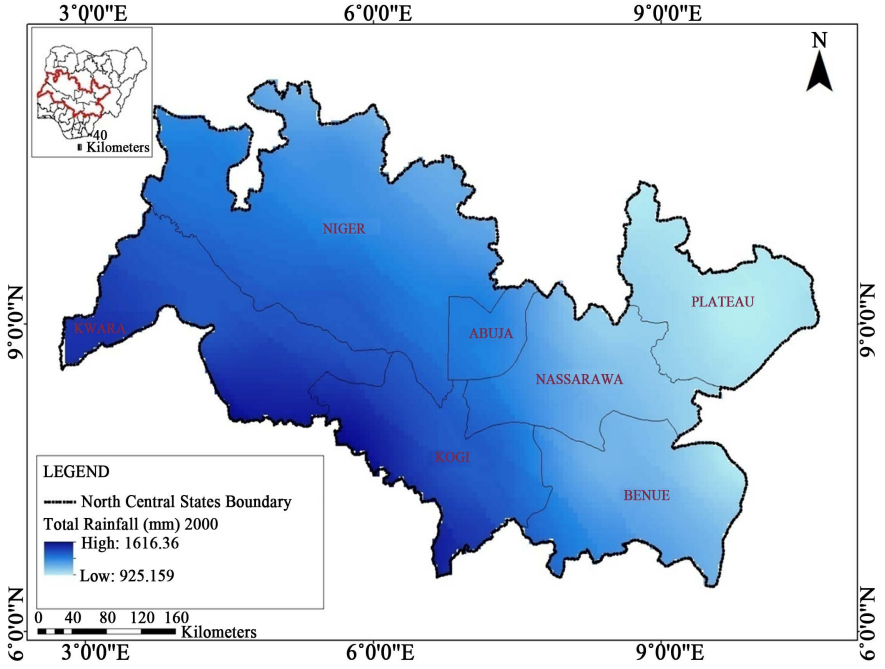

Figure 2. Rainfall variation in 2000.

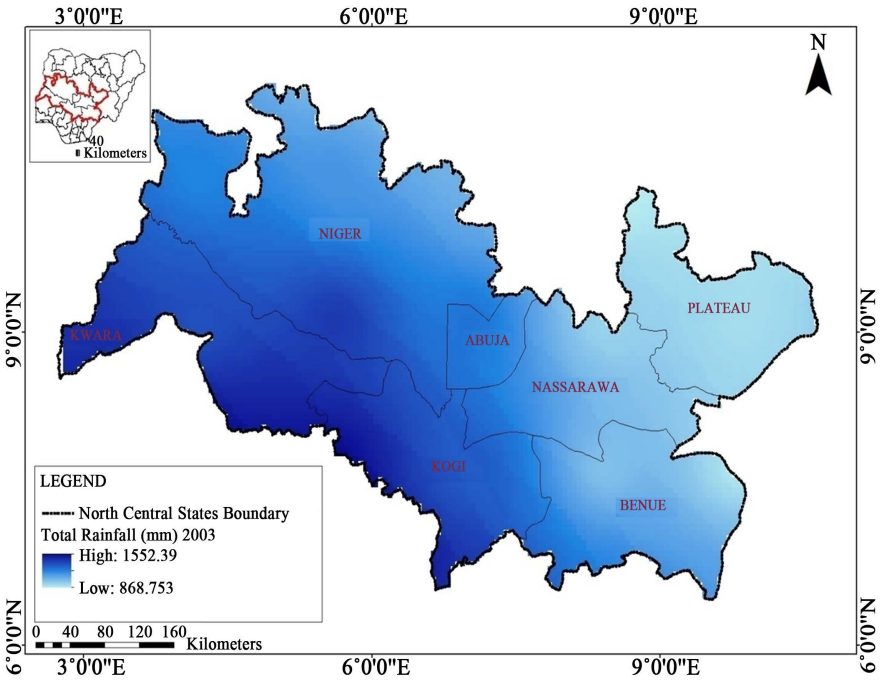

Figure 3. Rainfall variation in 2003.

1605.82 mm was recorded for the high rainfall areas while an improved rainfall value of 907.136 mm for Plateau, Benue, and Nassarawa states. The result lends credence to previous studies by [20] that rainfall is generally retreating in parts of the North Central Region of Nigeria. Early cessation, late onset of rainfall of and shortened rain days are evidence of drought vulnerability.

As in the previous year, Benue, Plateau, Nassarawa and Abuja represents low

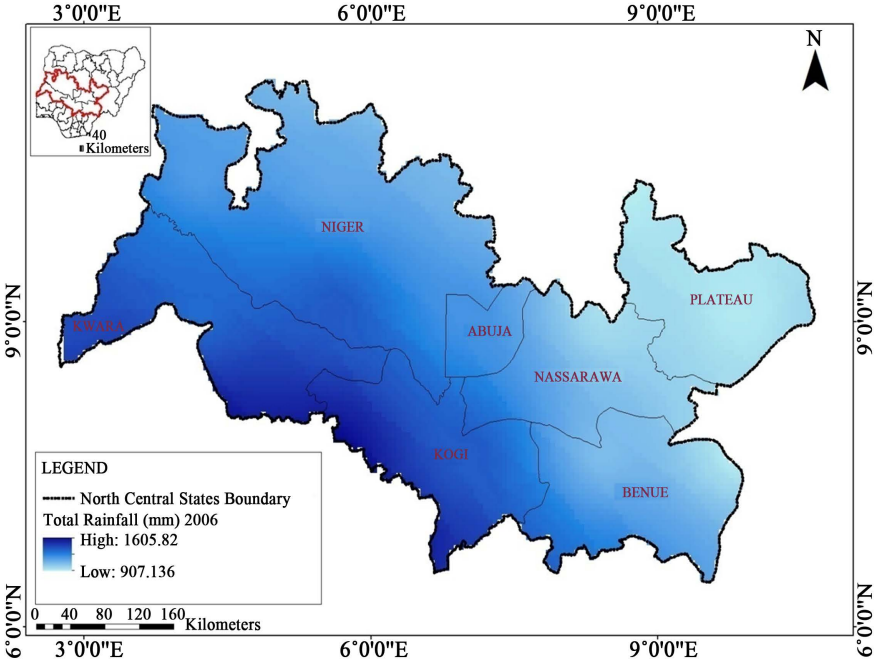

Figure 4. Rainfall variation in 2006.

rainfall areas as the annual amount of rainfall received increased slightly from 907 mm in 2003 to 927.277 mm as shown in Figure 5. In the same vein, rainfall appreciated from 1605.82 mm in 2006 to 1624.13 mm in 2009 in the high rainfall areas.

The improved rainfall amount in 2009 implies sufficient soil moisture condition, improved water supply, vegetal cover and high agricultural productivity in the region. As its expected farmers, took advantage of the improve rainfall condition and started the farming season much earlier recorded mark variation in rainfall with annual range of 0 - 994.58 mm. While the normal and increased rainfall signifies wet years and likelihood of flood occurrence, the low rainfall values and indicates dry spells and greater risk of drought.

The result of the geospatial analysis in 2011 as shown in Figure 6 reveals a downward trend in rainfall in Plateau, Benue, Nassarawa and Abuja. The lowest rainfall for the aforementioned states is 852.357 mm compared to 907927.277 mm obtained in 2011 while 1513.71 mm of rainfall was recorded for the high rainfall areas. Of dry spells occasioned by fluctuating and declining rainfall continued to hold sway in major parts of the North Central States as shown in Figure 6.

The variation in annual rainfall recorded in 2011 summarily indicates that rainfall is on a steady decline in most of the states in the North Central.

This result lends credence to previous studies by [20] that rainfall is generally retreating in many parts of the North Central Region of Nigeria. Early cessation, late onset of rainfall of and shortened rain days are evidence of drought vulnerability.

As shown in Figure 7, annual rainfall in the high rainfall areas increased to 1563.41 mm in 2013 while those in low rainfall areas also recorded significant

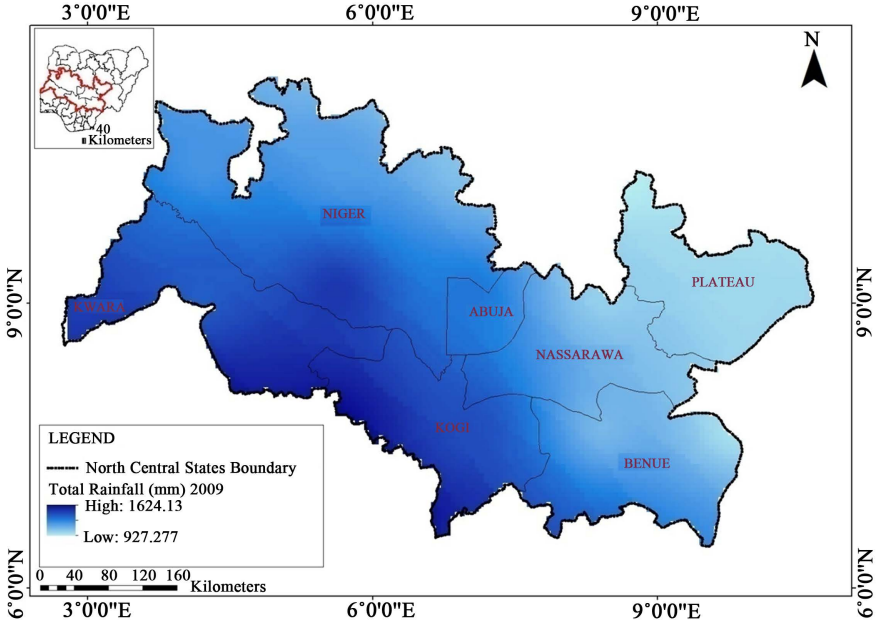

Figure 5. Rainfall variation in 2009.

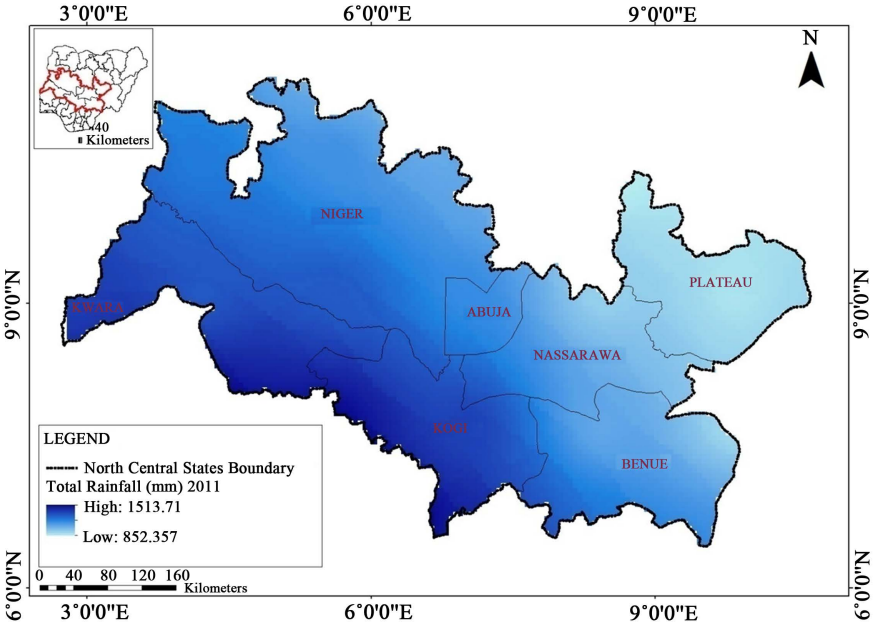

Figure 6. Rainfall variation in 2011.

increase in rainfall intensity as the value rose from 852.357 mm in 2011 to 857.377 mm in the current year.

The implication of this result is that 2013 recorded prolong rainfall and flood especially in the high rainfall areas while the rainfall deficient areas continue to grapple with the menace of drought.

There is high variability of rainfall in all the states that constitute the North Central region as revealed in Figure 8. Downward rainfall trend was observed in Plateau, Benue Nassarawa and Abuja, the FCT.

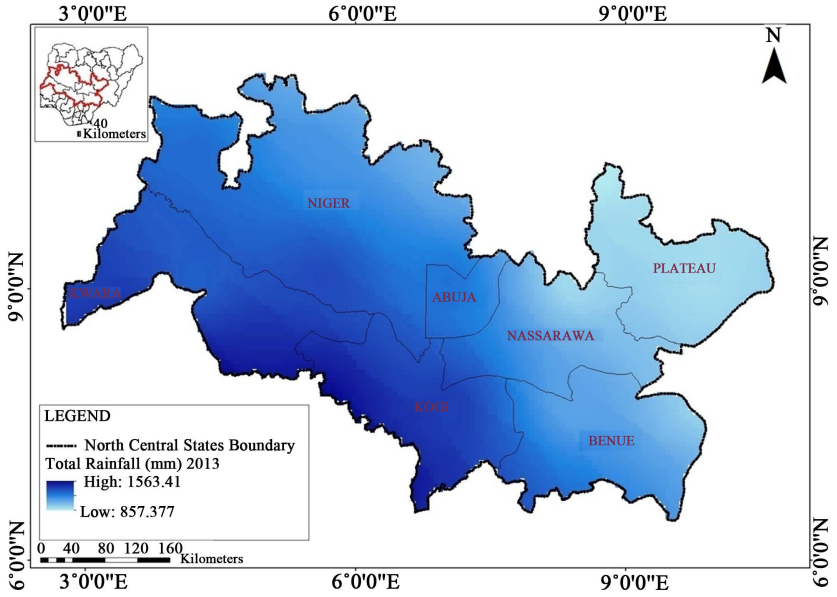

Figure 7. Rainfall variation in 2013.

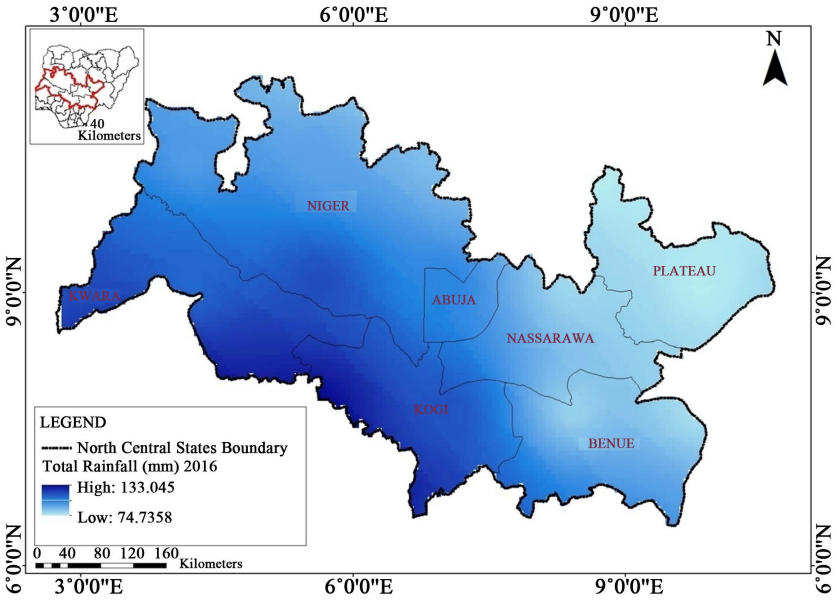

Figure 8. Rainfall variation in 2016.

The reduced rainfall value of 74.7358 mm of rainfall is an indication of prolong dry spell with attendant impact on crops and surface water availability. While people in the low rainfall areas are confronted with water scarcity, disruptions in the growing season and drought, the rainfall abundant areas experienced increased rainfall intensity with 133.045 mm as the maximum amount of rainfall. This is expected to bolster food productivity and reduced water shortages.

The reasons adduced for the variability in rainfall mirrors the climatic conditions obtained in the Northern part of Nigeria and secondly the movement of the North easterly trade wind that prevails in the Northern region.

The result of the geospatial analysis as shown in **Figure 9** reveals that 2017

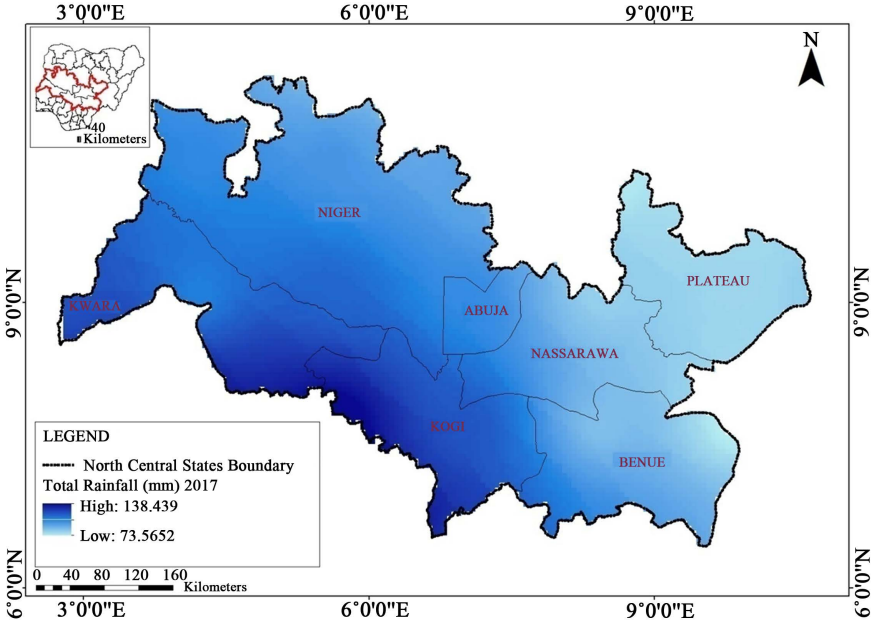

Figure 9. Rainfall variation in 2017.

recorded the lowest rainfall value of 74.5652 mm particularly in the low rainfall areas. The result implies that the risk of drought was high in 2017 compared to previous years. On the other hand, rainfall was at its peak in the high rainfall areas with a value of 138.439 mm indicating an upward rainfall trend.

An assessment of the geo spatial analysis on rainfall trend presented in this study are in agreement with previous research findings by [21], on trend analysis of drought in the guinea and Sudan savannah regions. Also, attempts have been made in the past to investigate the influence of rainfall variability in Northern Nigeria [11] [12] [13] [14] [18] [22] [23] [24], and none used remote sensing and GIS to show how rainfall variability contributes to the vulnerability of the region to drought.

Assessment of the analysis reveals that while the North central region receives 2541.519mm of rainfall in 2000, only 212.0042 mm rainfall was recorded in 2017 in the region. Similarly, average annual rainfall variation during the period under investigation (2000-2017) remains 896.1 mm. This indicates that the trend of rainfall within the 17 years study period is on a downward trend and a negative change.

5. Conclusions

The use of remote sensing and geographic information system (GIS) to analyze rainfall variability has been address in this study. The study further affirms that there is substantial evidence of rainfall variability in the study area within the period of investigation. The results of the analysis presented in this study affirm that rainfall is on a downward trend in Plateau, Nassarawa and Benue States which is considered most vulnerable to incidence of drought. The high variability in rainfall observed in the north central region is another confirmation of shift

in the climatic condition of the region which points to the stack reality of climate change.

The study is therefore a further contribution to knowledge on the efficacy of using geospatial techniques in studies of rainfall variability in Nigeria.

6. Recommendation

The following are some of the recommendations of the study:

- More meteorological stations should be established in the region in other to closely monitor the changing pattern and trend of rainfall fluctuation.
- There is need to embark on robust education and enlightenment programs so as to increase the awareness of the populace on the effect of declining rainfall trend on the agricultural and water resources sectors of the region.
- Farmers should be encouraged to focus on irrigation and drought tolerant crops while government continues to scale up support to the agricultural sector.

Conflicts of Interest

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

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