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# Seasonal Variability of Rainfall and its Decadal Anomaly over Nigeria: Possible Role of Solar and Geomagnetic Activities

Audu, Moses Owoicho[1] and Okeke, Francisca Nneka[2]

[1] Department of Physics, Federal University of Agriculture Makurdi, Nigeria.
[2] Department of Physics and Astronomy, University of Nigeria, Nsukka Nigeria.
Corresponding author: audumoses53@yahoo.com
Postal Address: Physics Department, Federal University of Agriculture, P.M.B. 2372, Makurdi Benue State Nigeria
Phone Number: +234 7035829620

***Abstract***— *This study investigates seasonal variations of rainfall and its decadal anomaly over Nigeria and the possible role of solar and geomagnetic activities. Sunspot number and geomagnetic aa index were used as solar indices. Monthly mean rainfall data from Nigeria Meteorological Agency was used in this study. Bivariate and power spectral density analyses were employed in analyzing the data. Rainfall anomaly was calculated using the mean of the base period, 1981 – 2010. Seasonally, rainfall varies from the coastal areas to the hinterland from January to December during rainy and dry seasons. On the decadal rainfall anomaly, positive anomalies increases steadily towards the coastal regions; indicating an increase in rainfall characteristic, whereas negative anomalies increases towards the northern regions; depicting decrease in rainfall characteristic. This was confirmed from the Mann-Kendall trend test. These variations are evidence of climate change. Correlation analysis revealed that the correlation of rainfall with sunspot and aa index were statistically insignificant. The spectral analysis revealed signatures of solar and geomagnetic activities on the rainfall spectrum. We therefore infer that, in addition to anthropogenic activities, solar and geomagnetic activities might play important role in the observed climate change in Nigeria; since rainfall is used as climate change indicator.*

***Keywords— Climate change, climate change indicator, rainfall variability, solar and geomagnetic activities, Nigeria.***

## I. INTRODUCTION

It is a clear fact that the Earth's climate has changed in the past, still changing at present and is expected to change in the future. These changes are observed in the day-to-day weather [1]. According to [2], the observed climate change is based on evidence from different sources. The evidence of climate change is observed globally.

[3] reported that the evidence of climate change correspond to the patterns scientists expected to see due to rising levels of carbon dioxide and other human-induced changes. Climate change has catastrophic effects on man and its environment. The impacts of climate change have been observed both locally and globally.

The climate of any location can easily be understood in terms of annual or seasonal variations of temperature and precipitation, since they are used as climate change indicator [4], [5]. Hence, this work hopes to investigate the seasonal variability of rainfall and its decadal anomaly over Nigeria from 1950 – 2012 and the possible role of solar and geomagnetic activities on climate change in Nigeria.

Nigeria, located in West Africa lies between latitudes 4° and 14° N and longitudes 2° and 15° E of the equator. The climate of Nigeria is majorly controlled by the dry, dusty, tropical-continental air mass, and the warm, tropical-maritime air mass. The influence of both air masses is determined by the movement of the Inter-Tropical Convergence Zone (ITCZ), a zone demarcating the two air masses. The interplay of the two air masses gives rise to the rainfall characteristics and the two distinct seasons in Nigeria; the rainy and dry seasons [6], [7].

Research works on rainfall variability and flood frequency in Nigeria have been carried out by [8], as well as studies on rainfall variability and drought by [9]. Effects of El Nino and La Nina and the impact of Atlantic sea surface temperature on precipitation in Nigeria have also been studied [10].

[6] reported that rainfall in northern Nigeria from 1953 – 2002 has generally increased in the last decade. They concluded that increased in annual rainfall may lead to

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improvement of water supply in some areas, while flooding, dam collapse due to excessive rainfall could lead to damage of life and properties in some other areas.

On the contrary, [11] found out from his research that the annual rainfall in Nigeria over both time and space has declined. He noted that the greatest change occurred in the onset of the rainy season which has resulted in a reduction of the growing season by nearly one month thereby increasing the risk of early planting. He concluded that there were fewer wet days and higher rainfall intensities in most part of the country thereby causing erosion. [12] reported that the mean annual rainfall in Nigeria diminished from the coast to the inland.

[5] observed that there has been statistically significant increase in precipitation and air temperature in the vast majority of the country. They also noted that the analyses of long-time trends and decadal trends in the time series further suggested a sequence of alternately decreasing and increasing trends in mean annual precipitation and air temperature in Nigeria during the studied period.

[13] predicted from the results of their work on future climatic prediction, 2000 – 2050, that the northern region will experience more decrease in rainfall even during wet season resulting in desertification, while the southern region will experience a reverse situation. They also predicted that the climatic variability currently experienced is likely to increase and intensify in future; drought, floods, and storms are likely to increase in both frequency and intensity.

Among the several researches on rainfall variability in Nigeria, most of them were based on records of the late 1980s, 1990s and early 2000s. This study is an attempt to give more information about the variations of rainfall from the 1950s to 2012. It will also investigate the link between solar and geomagnetic activities with variability of rainfall in Nigeria.

## II. SOURCES OF DATA

Monthly mean smoothed sunspot numbers, spanning for 63 years (1950 – 2012) were obtained from the World Data Center (http://www.sidc.be/sunspot-data), while geomagnetic activity *aa* index covering a period of 61 years (1950 – 2010) was obtained from the National Oceanic and Aeronautic Agency. Monthly mean daily rainfall data for 20 stations in Nigeria were obtained from Nigeria Meteorological (NIMET) Agency Oshodi, Lagos. The data spanned for 63 years (1950 – 2012). Map of Nigeria showing the meteorological stations is shown in Figure 1.

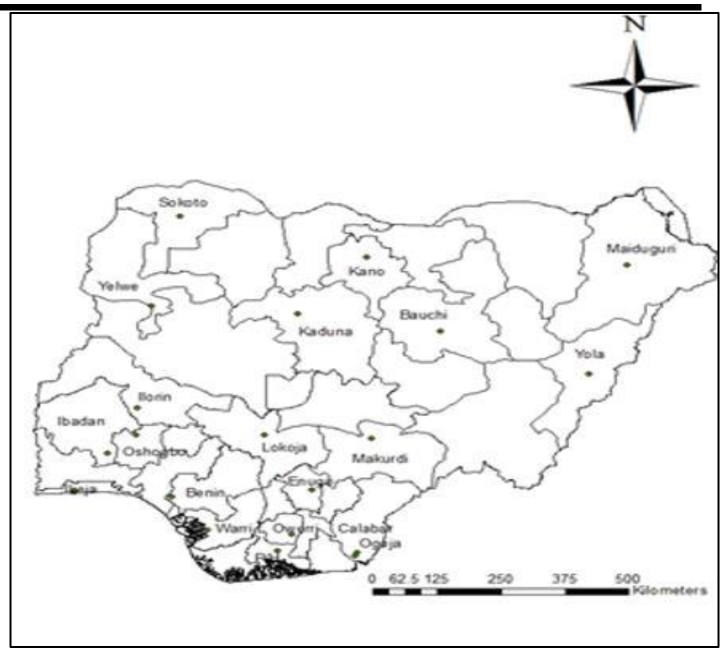


*Fig.1: Map of Nigeria showing the meteorological station*

## III. METHODS OF DATA ANALYSIS

Descriptive analysis was employed in analysing the rainfall, sunspot number and aa index

i. The daily, monthly and annual mean geomagnetic *aa* index were calculated from the three-hourly values, while the annual mean sunspot number was calculated from the monthly mean daily values.
ii. The monthly and annual mean rainfall for each station was calculated from the daily values.
iii. The mean of the base period (1981 - 2010) was used to compute the decadal rainfall anomaly for each station, in line with the recommendation of the World Meteorological Organization (WMO) Policy.
iv. The results of the monthly variations and the decadal rainfall anomaly were presented using ArcGIS software.
v. Bivariate analysis was employed to correlate annual mean rainfall with sunspot and aa index at 0.05 level of significant.
vi. Mann-Kendall trend test was used to investigate the variation trends of annual rainfall from 1950 - 2012. Mann-Kendall trend test is one of the statistical tests used for trend analysis of time series data [14].
vii. Finally, power spectral density (PSD) analysis was performed using Fast Fourier Transform (FFT) to investigate the periodicities of annual sunspot number, aa index and rainfall (i.e. over all the stations) using XLSTAT. The spectrum of each parameter obtained was smoothed using Hanning window function.

## IV. RESULTS AND DISCUSSION

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It could be observed from the monthly mean rainfall variability over Nigeria from 1950 – 2012 (Figures 2 - 4), that rainfall across the country was very low from January to March with little or no rainfall in the northern region. It increases from April (the transition period from dry to rainy seasons) steadily until July and then decreases again in August. It thereafter increases again in September in major parts of the country except in the northern region and finally decreases steadily from October (the onset of dry season in major part of the country) to December.

Generally, rainfall was very high across the country in the month of July. July is recognized as the peak of rainy season in the northern region. On the other hand, July and September are the double peaks of rainfall observed in the southwest and south eastern regions of the country, while August is the period when there is reduction in the amount of rainfall popularly called August break. This result is in line with [5], who reported that rainfall pattern below latitude $10^{o}$ N is bimodal having a primary peak in June-July and secondary peak in September with little dry season in August as a result of absence of the easterly jet.

Observation of rainfall from January to December as shown in Figures 2 - 4, depicts that rainfall decreases from the coastal areas to the hinterland during both rainy and dry seasons. Similarly, increasing and decreasing trends were also observed in variation trends of annual rainfall using Mann-Kendall trend test from 1950 – 2012 (Table 1). This could be due to the influence of the two air masses from Sahara region and Atlantic Ocean [12]. According to [10], the movement of the Inter-Tropical Convergence Zone (ITCZ) across the country control the variations of rainfall in Nigeria.

Figures 5 - 6 present the decadal patterns of rainfall anomalies over Nigeria from 1951 – 2010. It could be observed in the first decade (1951 – 1960), that most parts of the country experienced normal rainfall (i.e. SPI ranging from -0.99 – 0.99). However, regions such as Calabar and Warri that were exception were extremely wet with SPI ranging from 1.399 – 2.213. It is obvious that major part of the north was moderately dry (Table 2).

In the second decade (1961 – 1970), major parts of the country experienced normal rainfall, except some stations in the northern and coastal areas. It is interesting to note that most places in the northern region were not only moderately dry, but there was a decrease in the number of stations as compared to the first decade. On the other hand, more stations in the coastal area were very wet as compared to the first decade (Table 2).

Similarly, this observation of normal rainfall patterns in major parts of the country, decrease in stations experiencing moderate dryness in the northern region and increase in places that were very wet in the coastal area were also observed from third decade (1971 – 1980) to sixth decade (2001 – 2010) respectively (Figures 5 – 6). Generally, it is interesting to note that stations experiencing moderate dryness decreases towards the extreme northeast and north western regions as observed from first to sixth decades. This implies that even though the northern region experiences dryness, there is reduction in the number of places that experience this effect. The reverse is the case in the coastal areas as there was an increase in the number of stations having positive trends. This demonstrates that the regions were very wet as a result of increase in rainfall. This may result in the increase in flood and erosion in the coastal areas.

According to [4], rainfall is one of the climatic parameters used as climate change indicator. Based on the variability of rainfall observed in this study, it has clearly shown that climate change is obvious in Nigeria. The causes of this observed climate change may be due to natural or man-made activities. Natural factors such as solar motion, solar activity, geomagnetic activity, volcanic activity, e.t.c. have been linked to climate change. Hence, we investigate the effects of solar and geomagnetic activities on climate change in Nigeria using correlation and spectral analyses.

From Table 3, both positive and negative correlations were observed in the correlation of rainfall with sunspot number and aa index. However, the correlations were not significant at 0.05 significant levels. We can infer that solar and geomagnetic activities may have little or no influence on rainfall. Many authors have observed positive, negative and even zero correlation between solar indices and climatic parameters (e.g. [4]), but the physical mechanism for this relationship has been the major challenge. Hence, spectral analysis was further used to investigate the relationship between rainfall and solar indices (sunspot number and aa index); since the impact of solar and geomagnetic activities on climatic parameters cannot be directly measured.

From the spectral analysis, significant peak of 10.5 years was observed in sunspot number (Figure 7a). Other peaks observed include 21.0 and 7.8 years. The peaks of 10.5 and 7.8 years could be related to Schwabe cycle, while the peak of 21.0 years could be referenced to Hale cycle. It could be observed from the spectrum of aa index (Figure 7b) that the peaks of 30.5, 15.2, 10.1, 7.6, 5.5, 4.6, 3.8, 3.6 and 2.7 years were found. These peaks could be referenced to Hale cycle and Schwabe cycle, while the short term periodicities may be due to the evolution of active regions of the Sun [15].

From the spectrum of rainfall (Figure 8), peaks of 63.0, 15.7, 10.5, 6.3, 5.2, 3.9, 2.7 and 2.1 years were detected. The significant peak of 63.0 years could be related to Gleissberg cycle. The peaks of 15.7 and 10.5 years could be referenced to Schwabe cycle, while the short term periods could be related to atmospheric phenomena such as quasi-biennial oscillation [16]. Similar periodicities were observed in the spectral of solar indices and rainfall. Other authors such as [16], [17], [18] have obtained similar periodicities between solar indices and climatic parameters.

It has been reported that solar activity varies between active and quiet phases with 11 year solar cycle known as Schwabe cycle, 22 year polarity reversals called Hale cycle and 80 year cycle known as Gleissberg cycle [19], [20]. The Schwabe, Hale, and Gleissberg cycles can be stretched or shortened, leading to different harmonics [21].

From these observations, we can infer that Schwabe, Hale and Gleissberg cycles, as well as atmospheric phenomena, were detected in the spectral of rainfall. This suggests that signature of solar and geomagnetic activities exist on rainfall in Nigeria, which could be linked to the observed climate change in Nigeria.

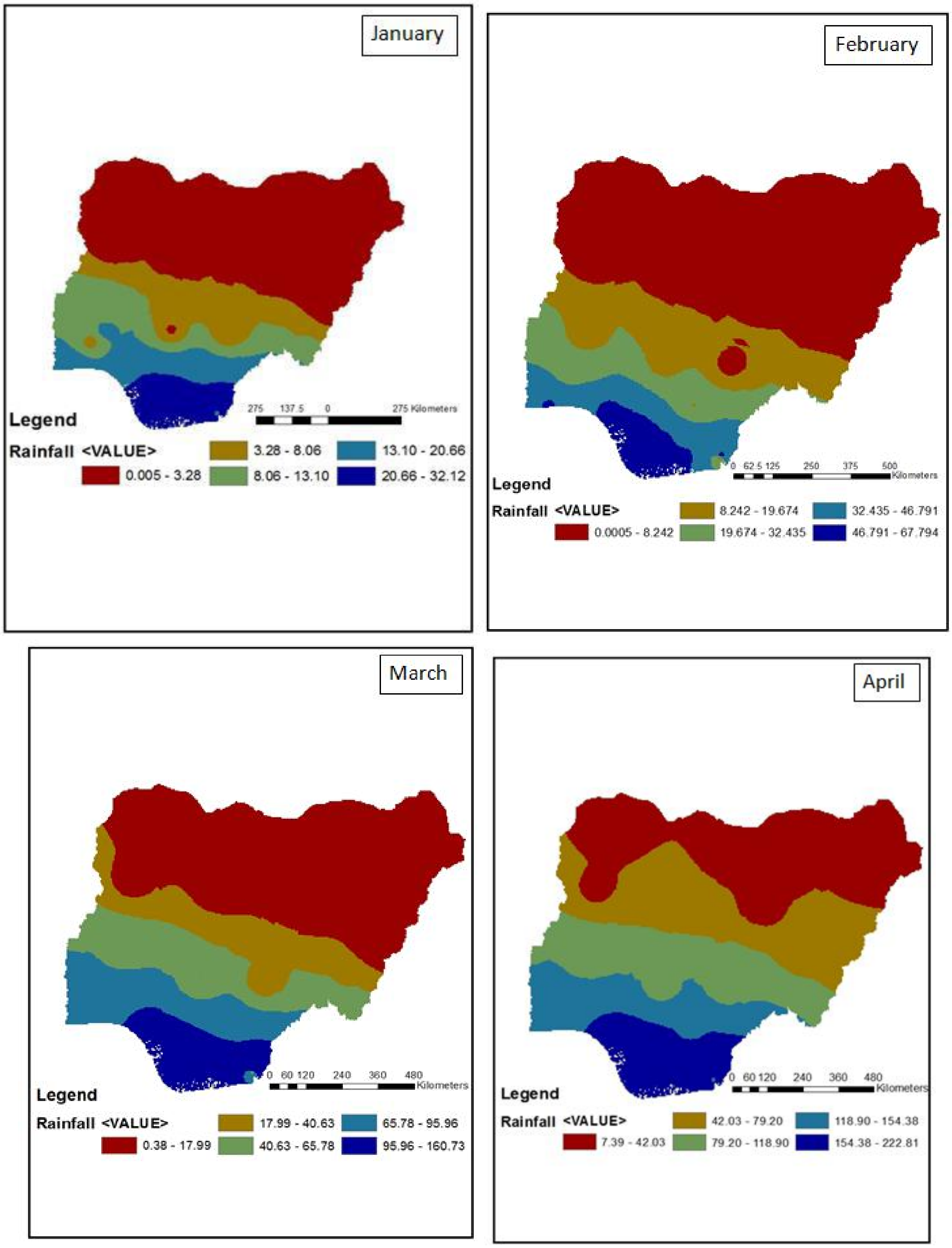


*Fig.2: Monthly mean rainfall variability over Nigeria (1950 – 2012)*

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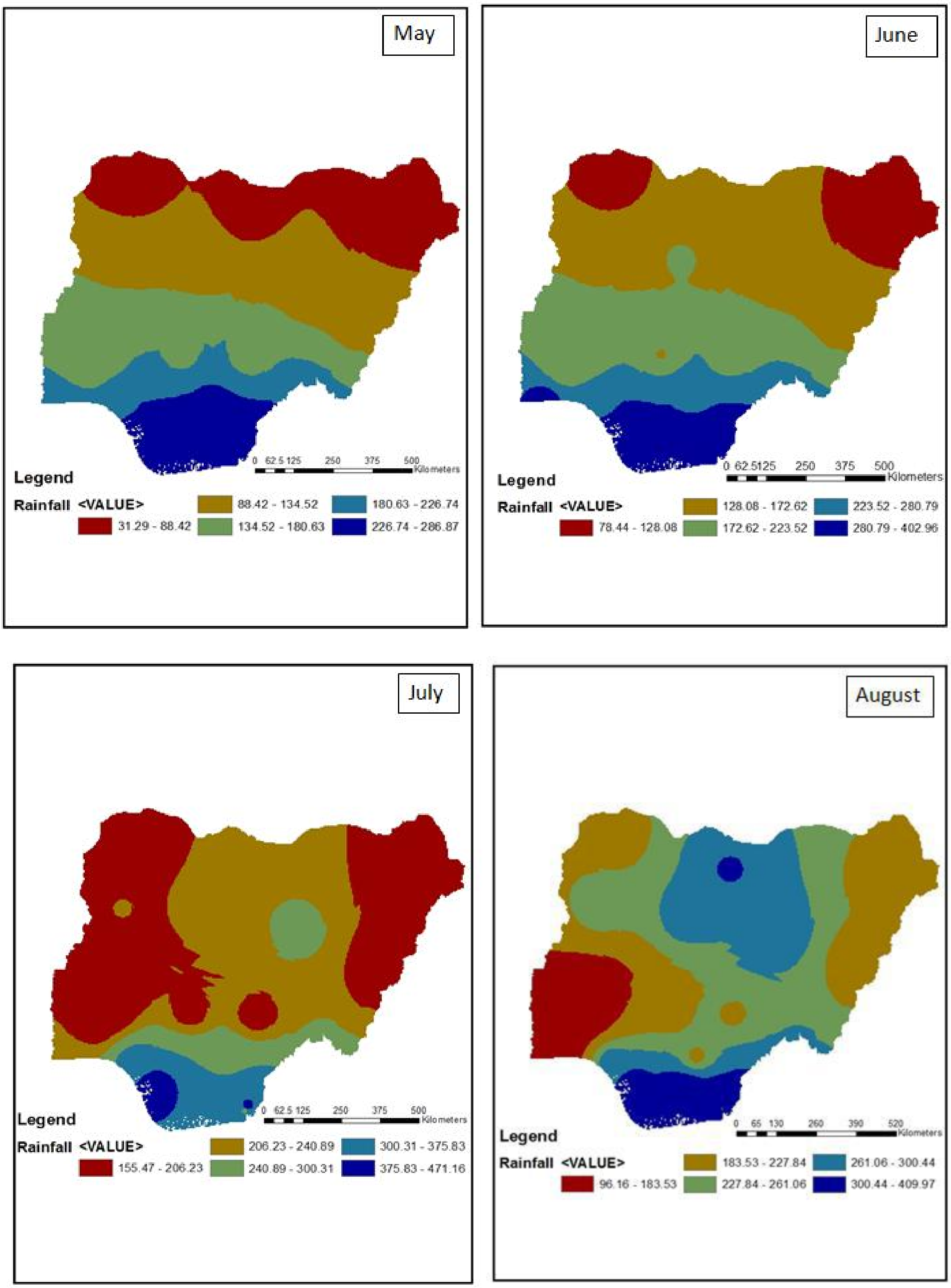


*Fig.3: Monthly mean rainfall variability over Nigeria (1950 – 2012)*

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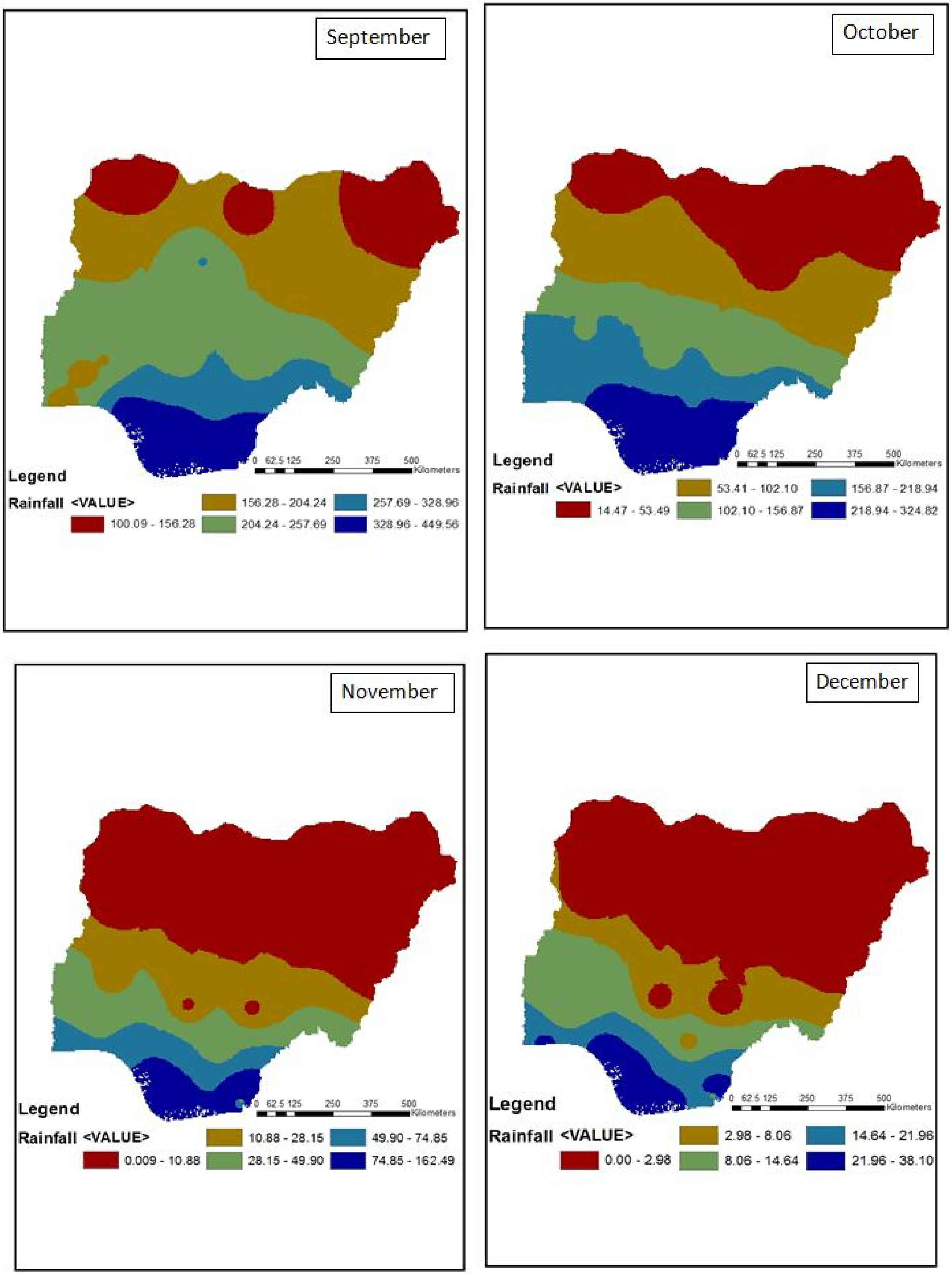


*Fig.4: Monthly mean rainfall variability over Nigeria (1950 – 2012)*

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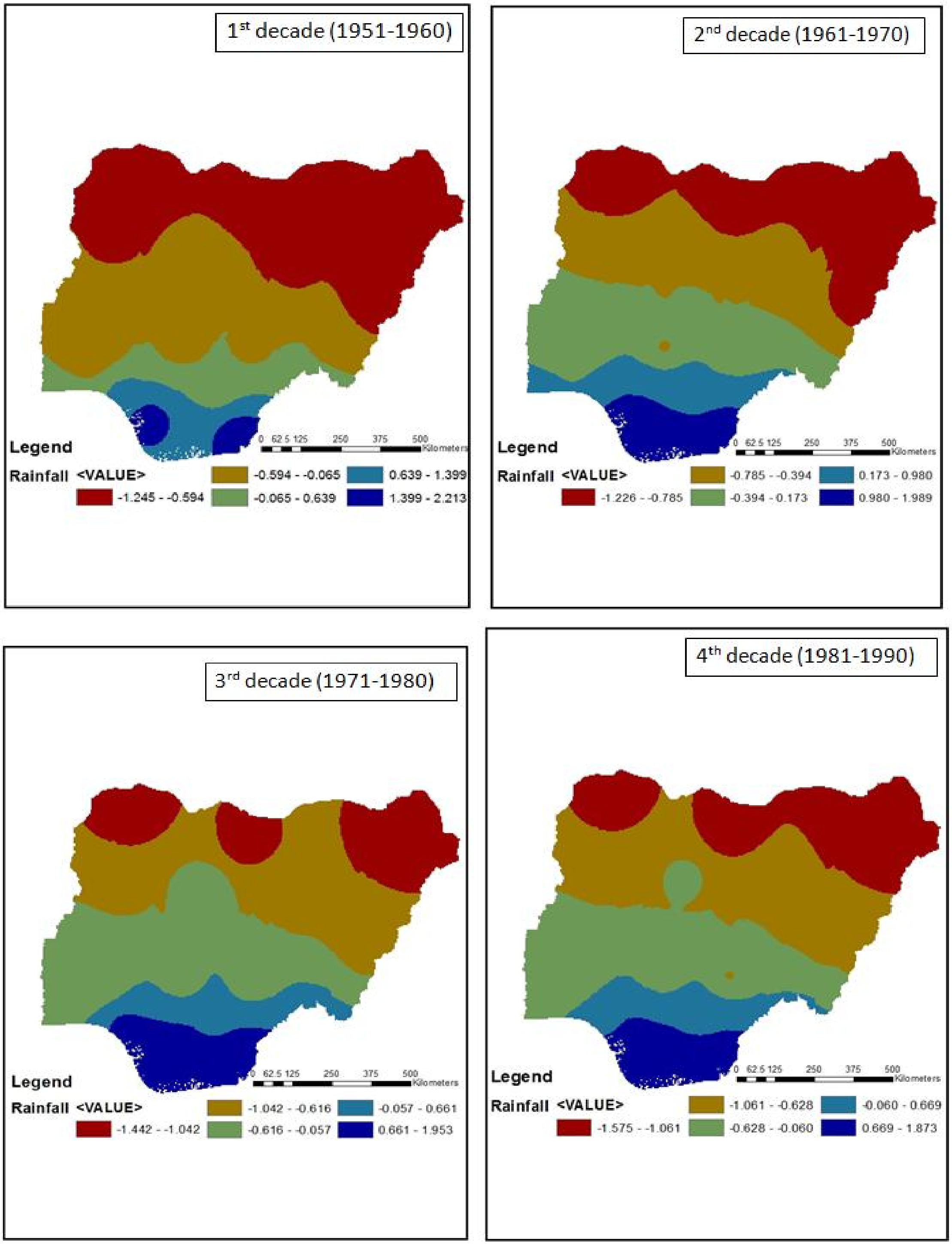


*Fig.5: Decadal rainfall anomalies over Nigeria (1st – 4th decades)*

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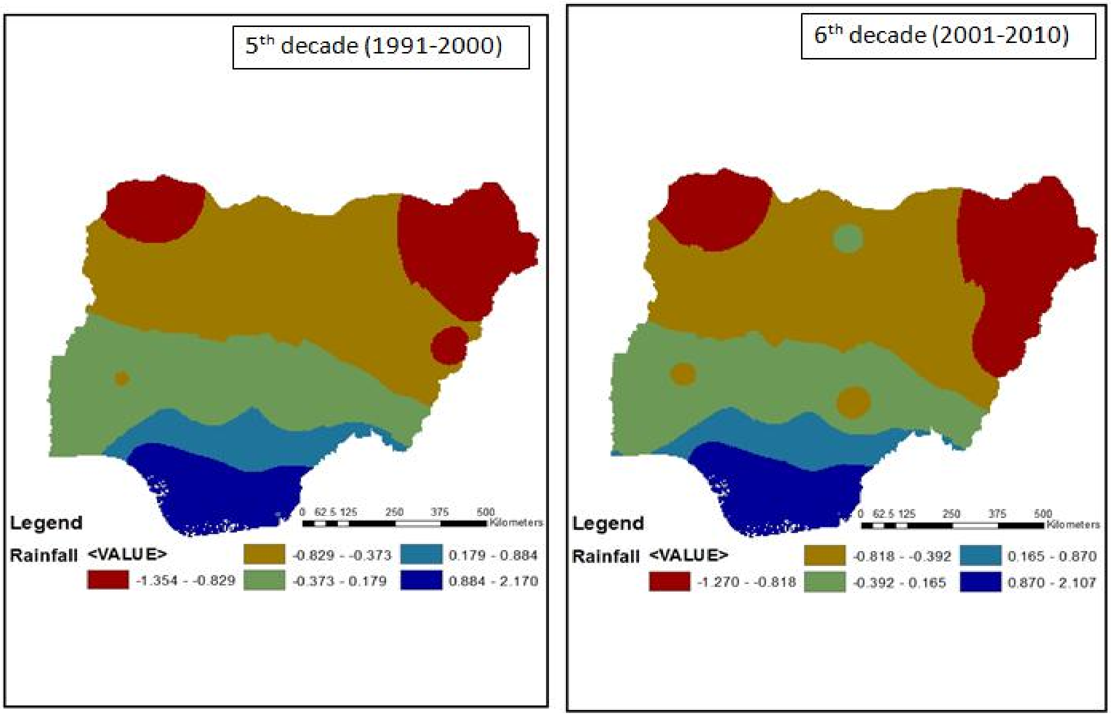


*Fig.6: Decadal rainfall anomalies over Nigeria (5th and 6th decades)*

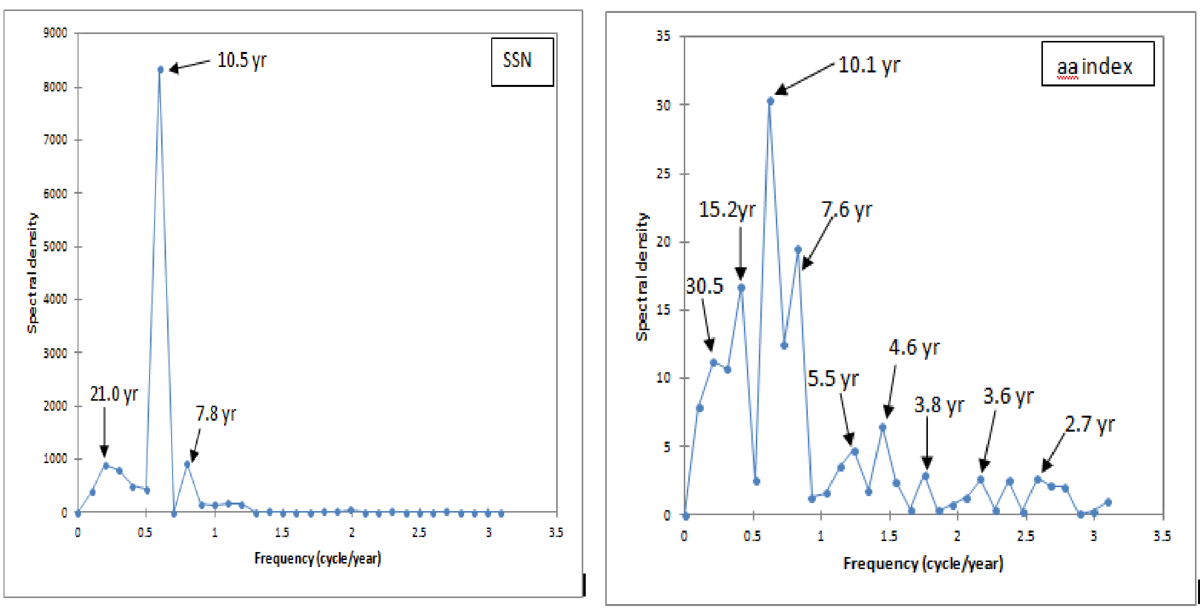


*Fig.7: Power spectral density of yearly mean (a) sunspot number and (b) aa index*

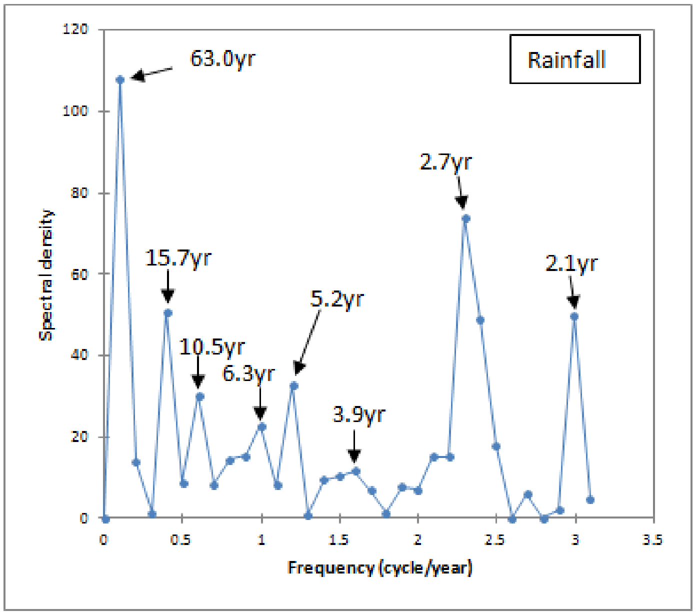


*Fig.8: Power spectral density of yearly mean rainfall*

*Table.1: Variation trends of annual rainfall using Mann-Kendall trend test (1950 -2012)*

| Stations | Kendall tau | Mann-Kendall coefficient, S | Z statistic | Trend description (from Z values) | Hypothesis test (h=1: significant, h=0: not significant) | Trend significance |
|---|---|---|---|---|---|---|
| Yelwe | -0.0077 | -15 | -0.0830 | Decreasing trend | 0 | Not significant |
| Sokoto | -0.0722 | -141 | -0.8304 | Decreasing trend | 0 | Not significant |
| Kaduna | -0.1695 | -331 | -1.9573 | Decreasing trend | 0 | Not significant |
| Kano | 0.2535 | 495 | 2.9300 | Increasing trend | 1 | Significant |
| Bauchi | 0.0476 | 93 | 0.5459 | Increasing trend | 0 | Not significant |
| Maiduguri | -0.0763 | -341 | -2.0166 | Decreasing trend | 0 | Not significant |
| Ilorin | -0.1746 | -341 | -2.0166 | Decreasing trend | 1 | Significant |
| Yola | -0.0497 | -97 | -0.5694 | Decreasing trend | 0 | Not significant |
| Ikeja | -0.0067 | -13 | -0.0712 | Decreasing trend | 0 | Not significant |
| Ibadan | 0.1639 | 320 | 1.8921 | Increasing trend | 0 | Not significant |
| Oshogbo | 0.1121 | 219 | 1.2930 | Increasing trend | 0 | Not significant |
| Benin | 0.2033 | 397 | 2.3487 | Increasing trend | 1 | Significant |
| Warri | -0.0148 | -29 | -0.1661 | Decreasing trend | 0 | Not significant |
| Lokoja | 0.1347 | 263 | 1.5539 | Increasing trend | 0 | Not significant |
| Port Harcourt | -0.0712 | -139 | -0.8185 | Decreasing trend | 0 | Not significant |
| Enugu | 0.1869 | 365 | 2.1589 | Increasing trend | 1 | Significant |
| Calabar | 0.0271 | 53 | 0.3084 | Increasing trend | 0 | Not significant |
| Makurdi | -0.1367 | -267 | -1.5777 | Decreasing trend | 0 | Not significant |

*Table.2: Standardized precipitation index [22]*

| RANGE | MEANING |
|---|---|
| 2.0 + | Extremely wet |
| 1.5 to 1.99 | Very wet |
| 1.0 to 1.49 | Moderately wet |

| | |
|---|---|
| -0.99 to 0.99 | Near normal |
| -1.0 to -1.49 | Moderately dry |
| -1.5 to -1.99 | Severely dry |
| -2 and less | Extremely dry |

*Table.3: Correlation coefficient (r) of rainfall with sunspot number and aa index*

| Stations | sunspot number | aa index |
|---|---|---|
| Yelwe | 0.0134 | 0.0665 |
| Sokoto | 0.0150 | 0.0496 |
| Kaduna | 0.1450 | 0.1224 |
| Kano | -0.0607 | -0.2347 |
| Bauchi | 0.0184 | -0.1007 |
| Maiduguri | -0.0038 | -0.1279 |
| Ilorin | -0.1440 | -0.0267 |
| Yola | 0.0919 | 0.0799 |
| Ikeja | -0.0115 | -0.2069 |
| Ibadan | -0.0655 | -0.2053 |
| Oshogbo | 0.0614 | 0.0206 |
| Benin | -0.0565 | -0.2271 |
| Warri | -0.0507 | 0.0432 |
| Lokoja | -0.1271 | -0.2893 |
| Port Harcourt | -0.0700 | -0.2315 |
| Owerri | 0.1617 | 0.0567 |
| Enugu | -0.1327 | -0.2665 |
| Calabar | 0.0718 | -0.2537 |
| Makurdi | -0.0167 | -0.2509 |
| Ogoja | -0.1415 | -0.1910 |

## V. CONCLUSION

Most of our findings are in agreement with well-known climatic pattern in different parts of Nigeria, little or no rain during the dry season (November to March) and heavy rain between March and October with a break in August. Furthermore, we found that positive anomalies were not only dominant in the coastal regions, but were also on the increase for the six decades under investigation. This established the fact that there was an increase in rainfall characteristic in the coastal area, hence, the increase in flood and erosion in the coastal region. On the other hand, negative anomalies were dominant in the northern region, showing that rainfall decreases towards the extreme northeast and north western regions, resulting in drought and desertification. These variations of rainfall are evidence of climate change. The correlation analysis revealed that the correlation of rainfall with sunspot number and aa index were statistically insignificant. The results of the spectral analysis have shown that signatures of solar and geomagnetic activities might exist on rainfall in Nigeria. This suggests that solar and geomagnetic activities could be linked to the observed climate change in Nigeria.

## ACKNOWLEDGEMENTS

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