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Variability of maximum temperature and its decadal anomaly over Nigeria: Possible connection with Solar and geomagnetic activity

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This work investigates the variability of maximum temperature and its decadal anomaly in Nigeria and the possible role of Solar and geomagnetic activity. Descriptive, bivariate and spectral analyses, as well as Mann-Kendall trend test, were employed in analyzing the data used in this study. Temperature anomaly was computed using the base period, 1981 – 2010. Results revealed that seasonally, temperature varies across the country from the coastal areas to the northern regions. The highest temperature (38.7 – 40.6°C) was recorded in April (the transition period from dry to rainy seasons), while the lowest temperature (27.5 – 28.5°C) was observed in August (the peak of cloud activity). The results of the decadal temperature anomaly revealed that temperature increases steadily from first decade (1951 – 1960) to sixth decade (2001 – 2010). This was confirmed by the Mann-Kendall trend test. This increasing trend could be understood as a result of global warming. This is an evidence of climate change. The correlations of temperature with solar indices were statistically insignificance. The spectral analysis revealed similar periodicity in the spectral of temperature and solar indices. The significant peaks observed on the spectral of maximum temperature were referenced to Schwabe, Hale and Gleisberg cycles. This suggests that Solar and geomagnetic activity might play a significant role in climate change observed in the country.

Key words: Temperature anomaly, global warming, solar activities, climate change, Nigeria.

INTRODUCTION

It is a clear fact that Nigeria is facing diverse ecological problems which have been linked to the observed climate change. Akinsanola and Ogunjobi (2014) reported that there has been a statisticaally significant increase in precipitation and air temperature in major parts of Nigeria. This is in line with the prediction by Olusina and Odumade (2012). The influence of an increase in temperature has resulted in increased evapotranspiration, drought as well as desertification.

The climate system of Nigeria, located between latitudes 4° and 14°N and longitudes 2° and 15°E is largely controlled by two dominants air masses. The dry,

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dusty, tropical-continental air mass originating from the Sahara region and the warm, tropical-maritime air mass, originate from the Atlantic Ocean. The influence of both air masses is determined by the movement of the inter-tropical discontinuity (ITD); a demarcation between the two air masses. The interplay of these two air masses greatly influence the atmospheric conditions in Nigeria from being cloudy, heavily laden with harmattan dust, cloudless to dustless. Hence, the two distinct seasons (wet and dry seasons) are experienced in Nigeria (Audu et al., 2014; Audu and Isikwue, 2015). Nigeria's climate varies attitudinally becoming progressively drier and hotter as one travels from the coast to the northern regions. Nigeria has a unique warm tropical climate system with relatively high temperatures all year round due to its location in the equatorial region.

Increase in the concentration of greenhouse gases especially since the industrial revolution, due to human activities have been linked to the observed climate change. This is because they affect the absorption, scattering, and emission of radiation within the atmosphere and at the Earth's surface (IPCC, 2007). In line with that, many of the climate scientists are of the view that climate change over the past century is very likely due to human activities. The IPCC (2013) reported that human impact has been the dominant cause of observed climate change.

On the other hand, several researchers have reported that solar variability is one of the potential agents of climate change (Gray et al., 2010; Lockwood, 2012; Sloan and Wolfendale, 2013), while many others argued about such claim (Laut, 2003). Similar debate on the impact of the geomagnetic activity on climate change is also ongoing (Bochnicek et al., 2001; Gray et al., 2010; El-Borie et al., 2012b; Olusegun et al., 2014). Okeke (2015) observed that the coupling of Earth's magnetic field with the sun's magnetic field determined how solar activity could affect the Earth's atmosphere. Since climate change is a major problem to man and his environment, there is a need for more research works in this area, especially now that the impact of climate change seems to be more severe.

Studies have shown that the average surface air temperature has increased, especially since the industrial revolution. Working on air temperature variability and trends over Greece from 1951 – 2000, Philandras et al. (2006) noted that a cooling trend was observed since the early 1960's until the middle of the decade of 1970 when the trend reverses to heating until nowadays. Similarly, Olusegun et al. (2014) revealed that a slight decrease in temperature was observed in the temperature pattern in Nigeria before the 1970s while almost all the warming was observed after 1970s. According to the IPCC, the warmest years of global surface temperature since 1850 were observed in the period, 1995 – 2006 (IPCC, 2014).

It has been reported that annual or seasonal averages of temperature and precipitation are the most important atmospheric parameters used as climate change indicator (Rampelotto et al., 2012). Hence, this study investigates the variability of maximum temperature and its decadal anomaly over Nigeria and the possible link to Solar and geomagnetic activity. This research is very significant as it hopes to proffer solution to the controversy about the possible role of Solar and geomagnetic activity on climate change.

MATERIALS AND METHODS

Sources of data

Monthly mean daily rainfall data for 20 stations, spanning 63 years (1950 – 2012) were obtained from Nigeria Meteorological (NIMET) Agency Oshodi, Lagos (Figure 1). Sunspot numbers and geomagnetic activity *aa* index data were obtained from the World Data Center and National Centers for Environmental Information. The data spanned from 1950 –2012 and 1950 – 2010, respectively.

Method of data analysis

Descriptive analysis was employed in analyzing the temperature, sunspot and aa index data.

1. The monthly and annual mean sunspot number were calculated from the daily values, while the daily, monthly and annual mean aa index were computed from the three-hourly values.
2. The annual maximum temperature for each station was computed from the monthly values.
3. Decadal temperature anomaly for each station was calculated using the mean of the base period (1981 - 2010) in line with the recommendation of the World Meteorological Organization (WMO) Policy.
4. The results of the monthly and decadal temperature anomaly were presented using ArcGIS.
5. A Mann-Kendall trend test was carried out to investigate the variation trends of maximum temperature in each station from 1950 – 2012.
6. Subsequently, bivariate analysis was employed to investigate the relationship between temperature and solar indices at 95% significance level.
7. Finally, power spectral density analysis was employed using Fast Fourier Transform (FFT), to investigate the periodicity of temperature, sunspot number and aa index at 95% significant level using XLSTAT. The spectral obtained were smoothed using Hanning Windom.

RESULTS AND DISCUSSION

Figures 2 to 4 show monthly variations of maximum temperature over Nigeria from 1950 – 2012. Stations such as Kano recorded low temperature in January, while the high temperature was observed in regions such as Minna, Makurdi and Yola (Figure 2). Similar variations were also observed in February. This may be attributed to the influence of harmattan dust which reflects most of the solar radiation, hence the low temperature observed during this period. Generally, high temperature was

Figure 1. Map of Nigeria showing the meteorological station.

observed across the country in the month of March and April, while temperature increases from the coastal areas to the northern regions from May to August (Figure 3). From September to November (Figure 4), the temperature was not only increasing from the coastal area to the hinterland but there was a general increase in temperature across the country. On the other hand, there was a gradual decrease in temperature in December, most likely due to the influence of harmattan dust (Figure 4).

The lowest temperature (27.5 - 28.5°C) was observed in August. This could be due to the rain bearing clouds during the rainy season which may obscure incoming solar radiation and hence temperature. The highest temperature was recorded in April (38.7 to 40.6, Figure 4), probably because it is the transition period from dry to

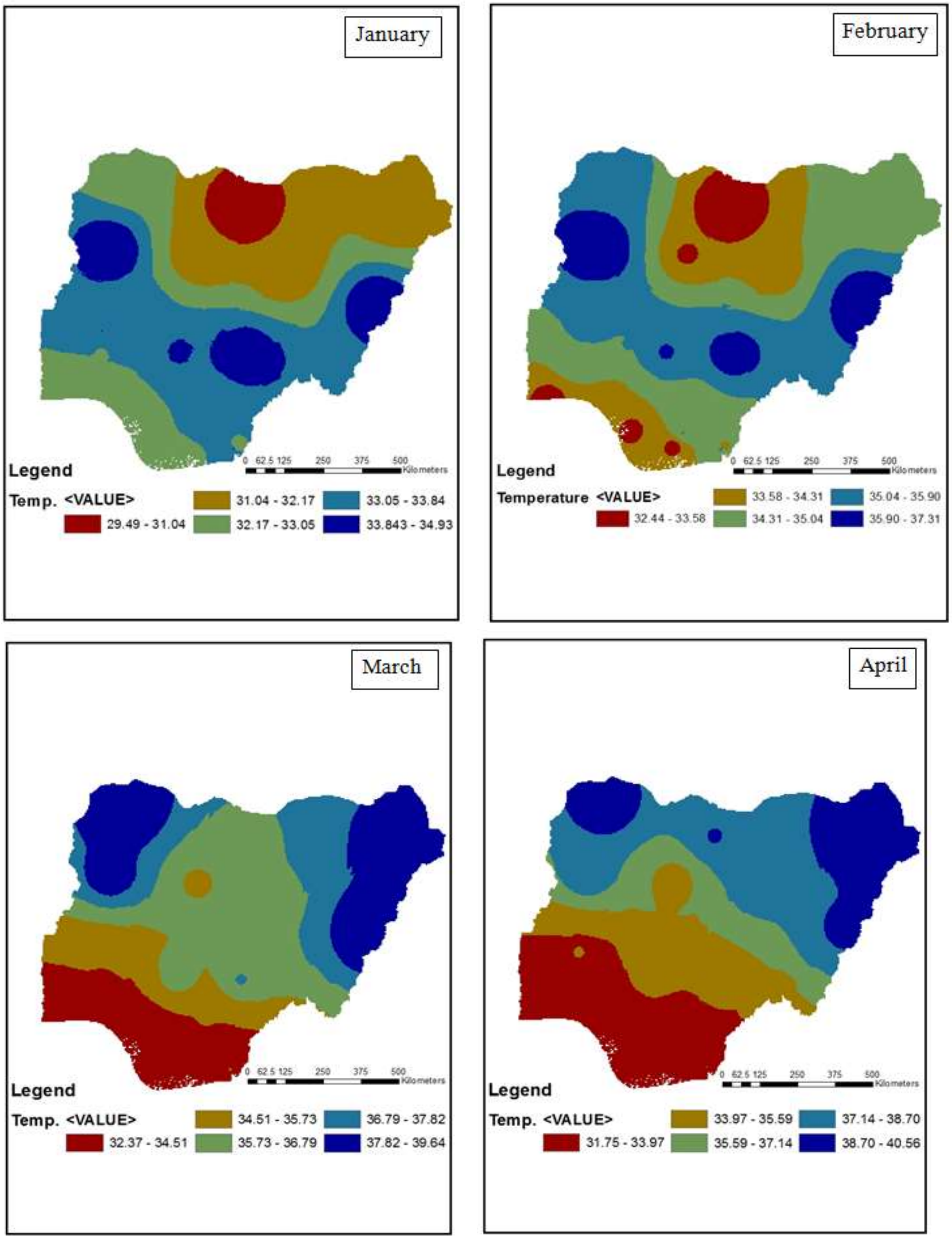

Figure 2. Variability of maximum temperature in Nigeria from 1950 – 2012 (January – April).

rainy seasons when the sky is relatively free from Harmattan dust and cloud cover. The seasonal variability of maximum temperature could be attributed to the interplay of the two air masses which control the climatic condition over Nigeria.

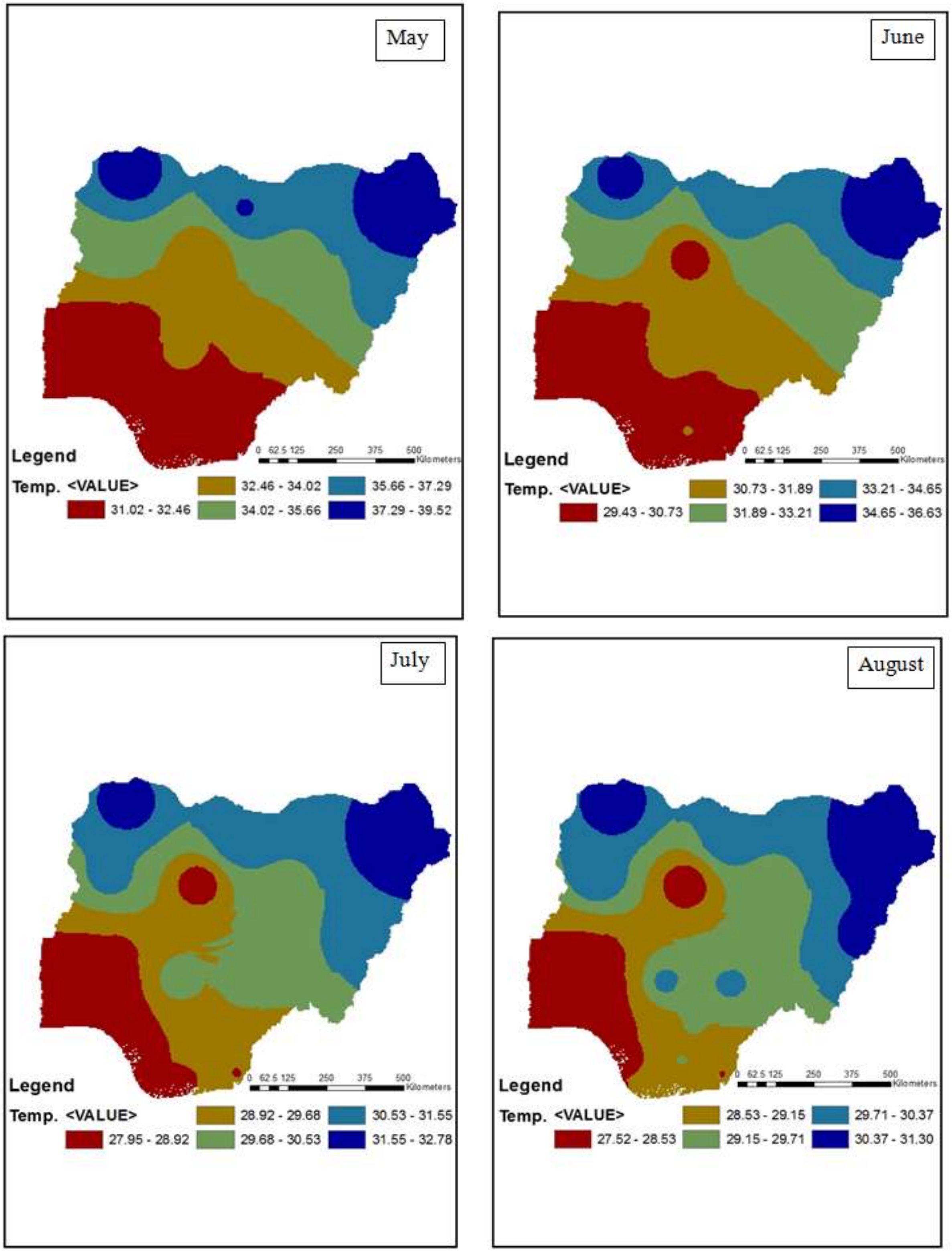

Figure 3. Variability of maximum temperature in Nigeria from 1950 – 2012 (May – August).

From the standardized decadal anomalies of maximum temperature over Nigeria (Figures 5 and 6), it could be observed that in the first decade (1951 – 1960), the normal temperature was observed in most part of the

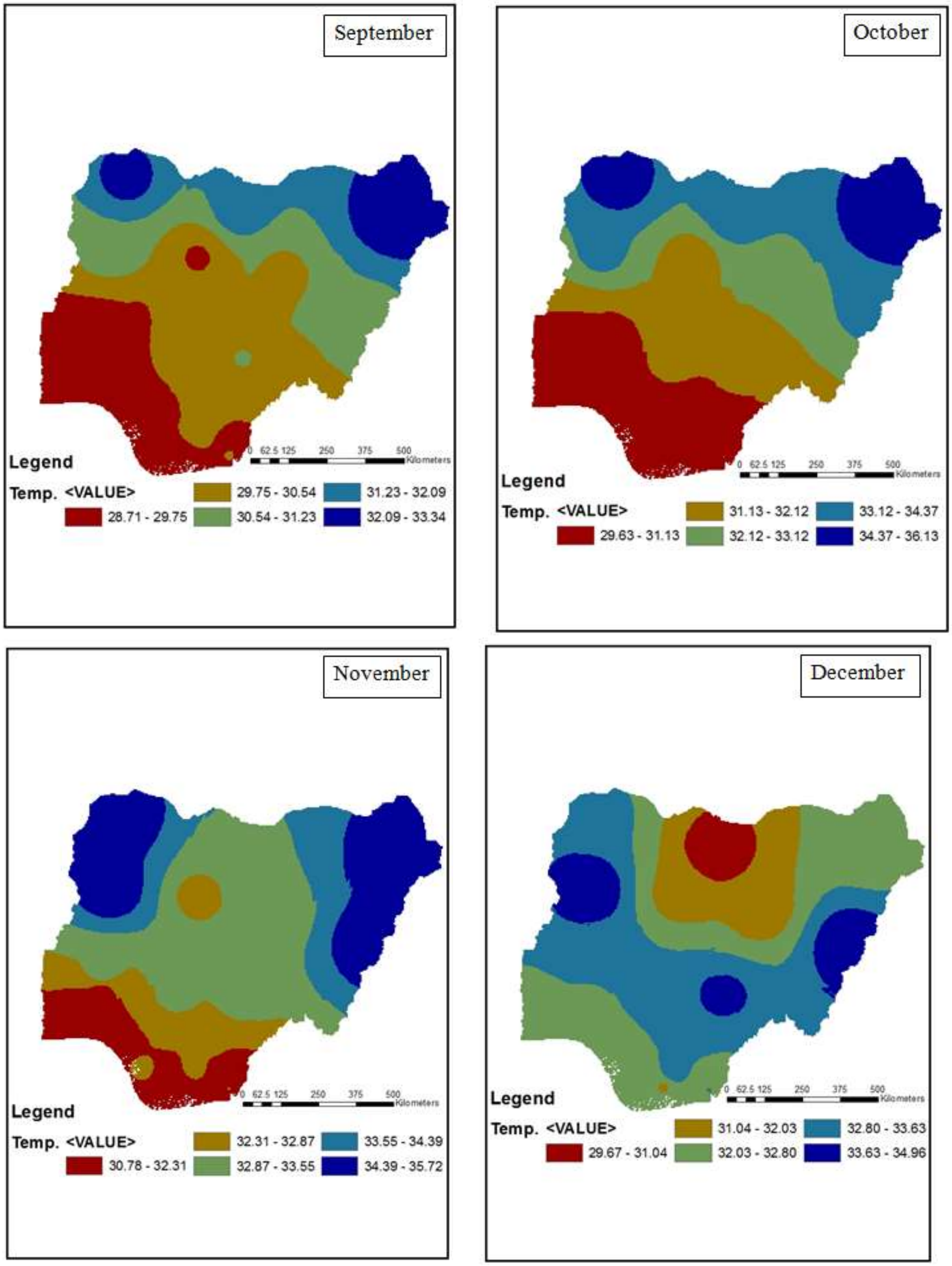

Figure 4. Variability of maximum temperature in Nigeria from 1950 – 2012 (September – December).

country. Places in the extreme northwestern region (e.g Sokoto) and northeastern region (e.g. Maiduguri) were warmer than normal with corresponding positive anomalies. On the other hand, places in the southeastern

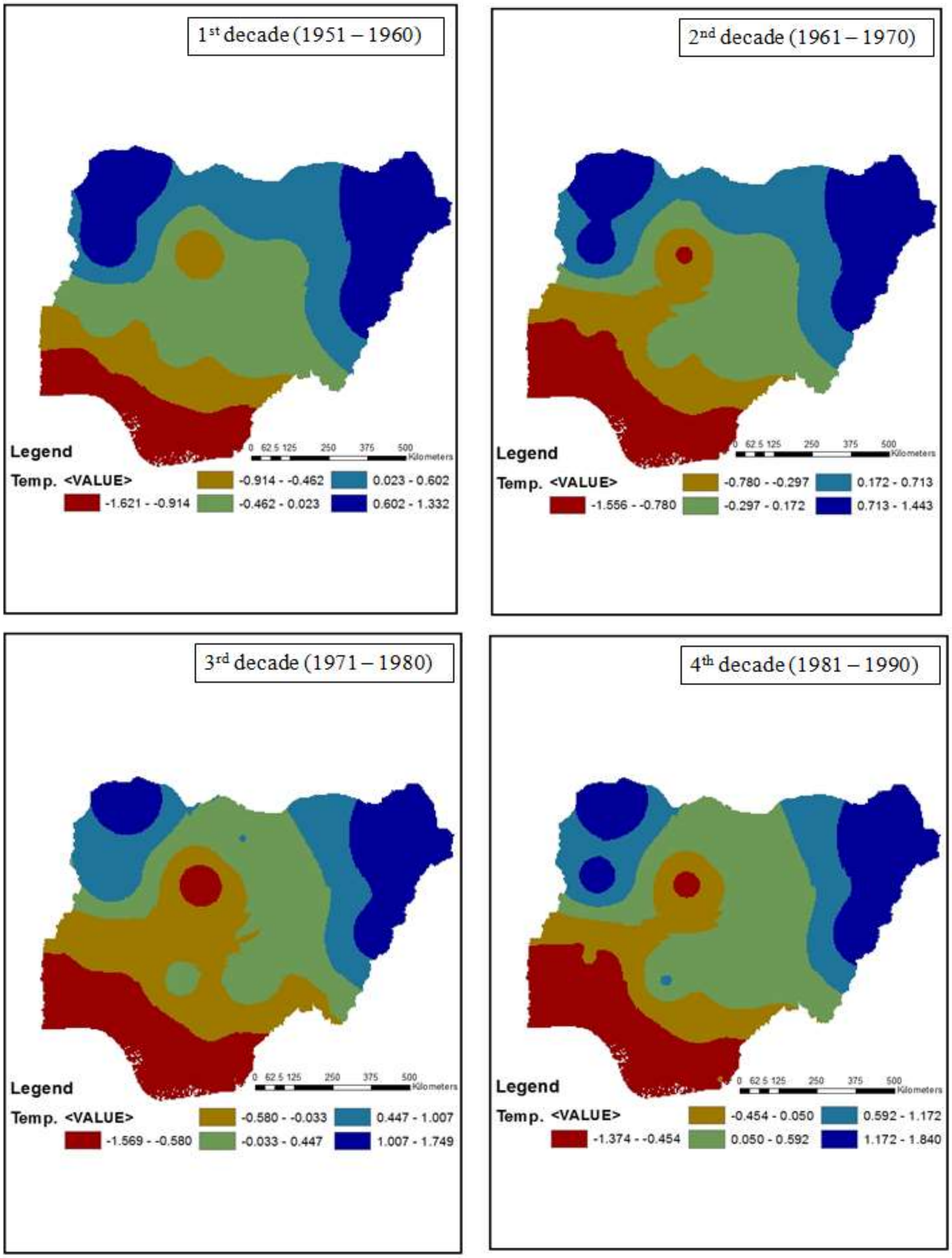

Figure 5. Decadal variability of maximum temperature anomalies in Nigeria.

regions and southwestern regions were cooler than normal with corresponding negative anomalies. This observation of normal temperature in most parts of the country, positive anomalies in the extreme northeast and

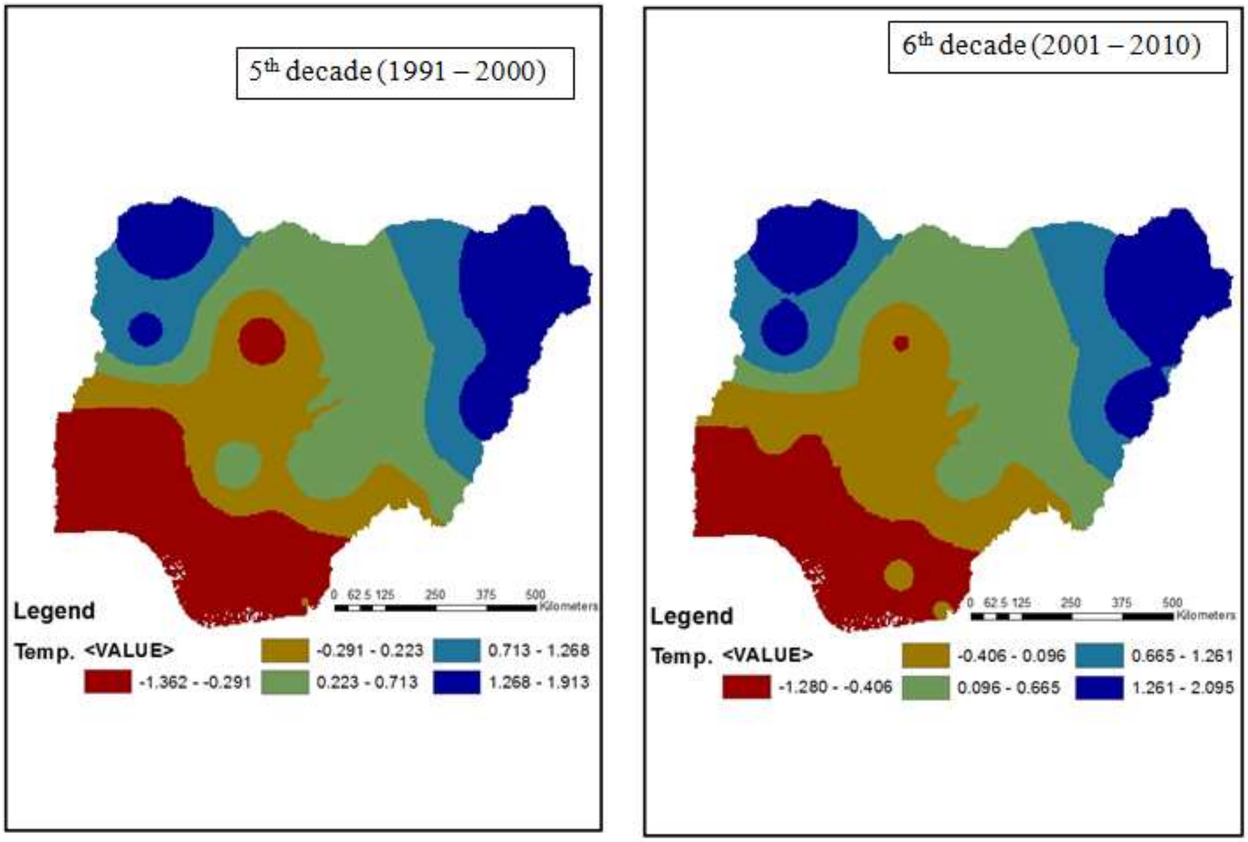

Figure 6. Decadal variability of maximum temperature anomalies in Nigeria.

northwest and negative anomalies in the southeast and southwest regions were also observed in the second decade (1961 – 1970) to the sixth decade (2001 – 2010), respectively.

This implies that there was an increase in temperature over the years in the northern region making the environment to be warmer than normal (positive anomalies). Similarly, places in the southern region tend to observe normal temperature over the years rather than being cooler than normal; that is, a decrease in negative anomalies. It is interesting to note that positive anomalies increase steadily from the first decade to sixth decades, whereas there was a decrease in negative anomalies. This depicts an increase in temperature. This was further confirmed by the Mann-Kendall trend test. Rising trend was observed in the variation trend of maximum temperature from 1950 – 2012 in all the stations except in Ilorin and Oshogbo (Table 1). This rising trend which was statistically significant depicts an increase in temperature.

These findings have shown that temperature over Nigeria has increased significantly, due to global warming and this has resulted in climate change. This is in agreement with Philandras et al. (2006), Akinsanola and Ogunjobi, (2014) and Olusegun et al. (2014), who reported separately that, the cooling trend was observed since the early 1960's until 1970 when the trend reverses to heating until nowadays.

The rising trend in the variability of maximum temperature could be as a result of the combine effects of human and natural activities (e.g. solar and geomagnetic forcing). In this study, the possible connection between Solar and geomagnetic activity with temperature variations was investigated using bivariate and spectral analyses.

Results of the correlation test revealed that both negative and positive correlations were observed between maximum temperature, sunspot number and aa index (Table 2). However, the correlations were statistically insignificant. Many authors have reported positive, negative or even zero correlation between solar indices and climatic parameters depending on the geographical location (Valev, 2006; Rampelotto et al., 2012).

From Figure 7, peaks of 21.0, 10.5 and 7.8 years were observed in the spectrum of sunspot number. These peaks could be referenced to Schwabe cycle (10.5 and 7.8 years) and Hale cycle (21.0 years). The spectrum of aa index shows significant peaks of 30.5, 15.2, 10.1, 7.6, 5.5, 4.6, 3.8, 3.6 and 2.7 years (Figure 8). The significant periods of 30.5, 15.2-10.1 and 7.6-2.7 could be related to

Table 1. Variation trends of maximum temperature using Mann-Kendall trend test.

Stations	Kendall tau	Mann-Kendall coefficient, S	Z statistic	Trend description (from Z value)	Hypothesis test (h=1: significant, h=0: not significant)	Trend significance
Yelwe	0.3651	713	4.2234	Increasing trend	1	Significant
Sokoto	0.4869	951	5.6349	Increasing trend	1	Significant
Kaduna	0.4711	920	5.4510	Increasing trend	1	Significant
Kano	0.2130	416	2.4615	Increasing trend	1	Significant
Bauchi	0.2929	572	3.3870	Increasing trend	1	Significant
Maiduguri	0.3953	772	4.5739	Increasing trend	1	Significant
Ilorin	-0.0102	-20	-0.1127	Decreasing trend	0	Not significant
Yola	0.2380	465	2.7523	Increasing trend	1	Significant
Ikeja	0.4542	887	5.2555	Increasing trend	1	Significant
Ibadan	0.5100	996	5.9017	Increasing trend	1	Significant
Oshogbo	0.1475	288	1.7024	Decreasing trend	0	Not significant
Benin	0.3994	780	4.6209	Increasing trend	1	Significant
Warri	0.3477	679	4.0218	Increasing trend	1	Significant
Lokoja	0.2862	559	3.3099	Increasing trend	1	Significant
Port Harcourt	0.5202	1016	6.0208	Increasing trend	1	Significant
Owerri	0.4414	294	3.8334	Increasing trend	1	Significant
Enugu	0.3728	728	4.3128	Increasing trend	1	Significant
Calabar	0.4593	897	5.3148	Increasing trend	1	Significant
Makurdi	0.4378	855	5.0661	Increasing trend	1	Significant
Ogoja	0.4700	313	4.0824	Increasing trend	1	Significant

Table 2. Correlation coefficient (r) of annual maximum temperature with sunspot number, and aa index.

Stations	Sunspot number	aa index
Yelwe	-0.1754	-0.0405
Sokoto	-0.1882	-0.234
Kaduna	-0.0215	-0.0368
Kano	-0.0927	-0.1846
Bauchi	-0.1595	-0.0679
Maiduguri	-0.0922	-0.1025
Ilorin	-0.0387	0.1152
Yola	0.1395	0.1395
Ikeja	0.0229	0.1771
Ibadan	0.0655	0.0997
Oshogbo	0.052	0.0556
Benin	0.1429	0.2109
Warri	0.2369	0.1863
Lokoja	0.3365	0.2307
Port Harcourt	0.0101	0.0386
Owerri	-0.1696	-0.2032
Enugu	0.0552	0.1503
Calabar	0.0853	0.1626
Makurdi	0.138	0.15
Ogoja	0.0982	0.0692

Hale cycle, Schwabe cycle and solar variability respectively (El-Borie et al., 2012a; Nayar, 2006).

Significant periods of 63.0, as well as the peak of 12.6 years and short term periods of 7.8, 6.3, 4.8, 3.5 and 2.7

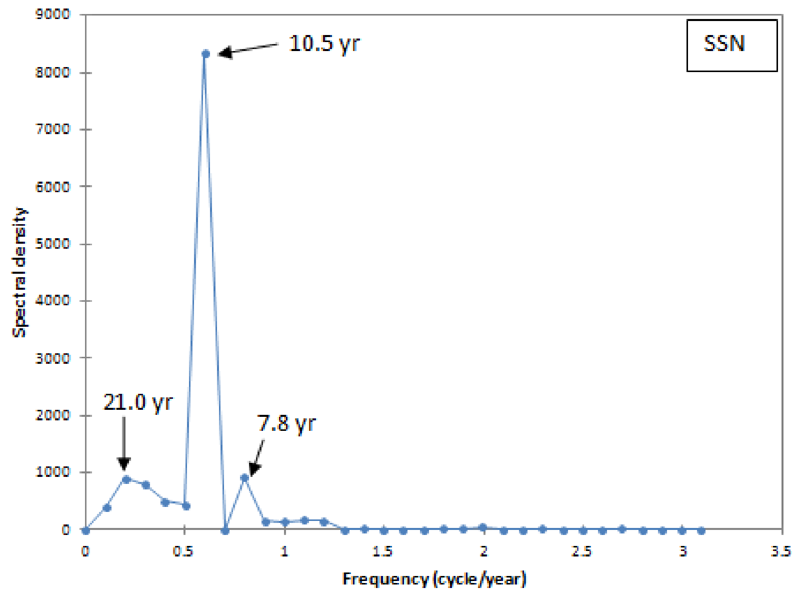

Figure 7. Power spectral density of yearly mean sunspot number.

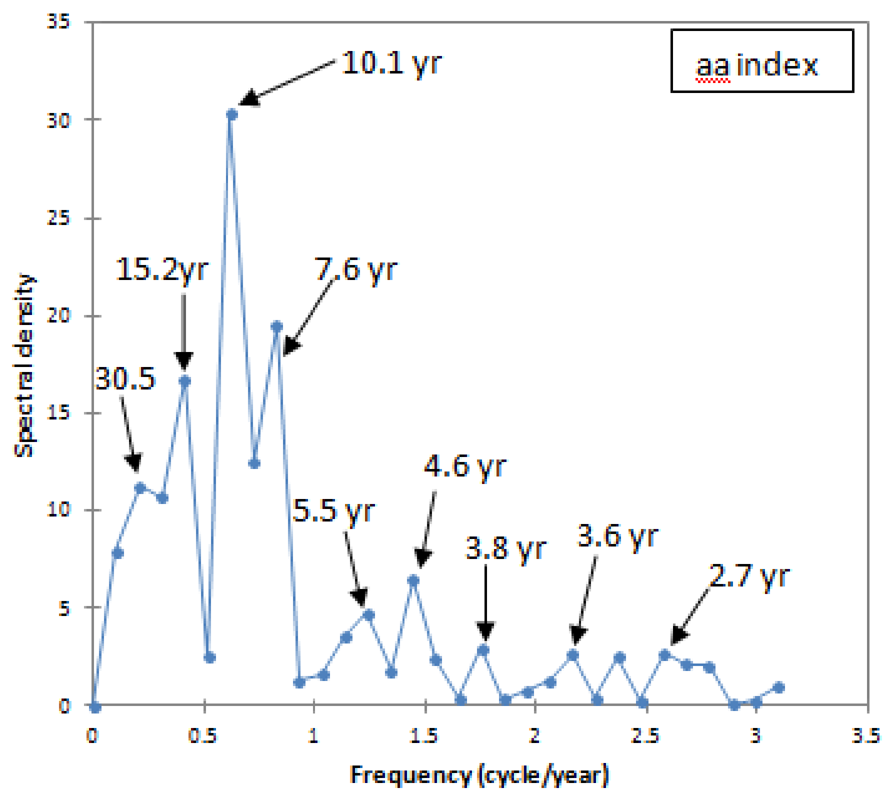

Figure 8. Power spectral density of yearly mean geomagnetic activity aa index.

years, were observed from the spectrum of maximum temperature (Figure 9). Peaks of 63.0, 12.6 and 7.8-2.7 years could be related to Gleissberg cycle, Schwabe cycle and atmospheric phenomena (such as quasi-biennial oscillation), respectively (El-Borie et al., 2012a).

The results of this study are in line with the findings of

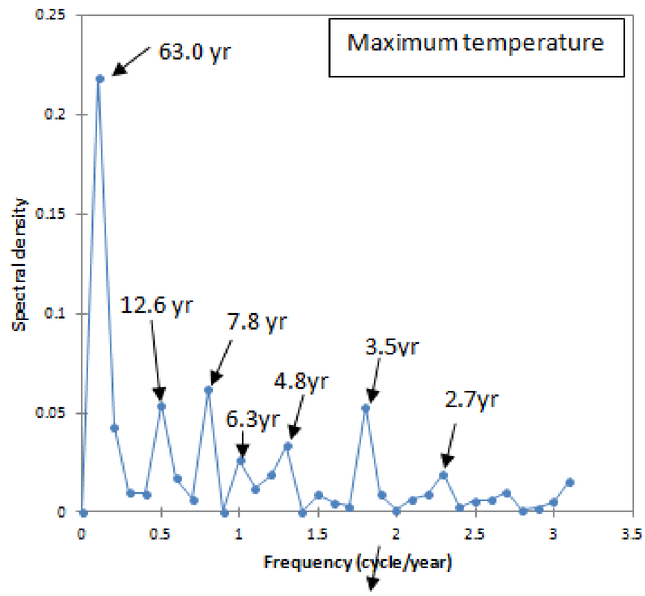

Figure 9. Power spectral density of yearly maximum temperature.

Rampelotto et al. (2012), El-Borie et al. (2012a, b) and El Mallah et al. (2012), in their works on the relationship between Solar and geomagnetic activity and climatic parameters. The periodicity observed in this work may be attributed to Solar and geomagnetic activity. Over the years, it has been reported that Solar and geomagnetic activity exhibits this periodicity (Rampelotto et al., 2012). Hence, Schwabe, Hale and Gleissberg cycles, as well as atmospheric phenomena were detected on the spectrum of maximum temperature. This suggests that Solar and geomagnetic activity might play a significant role in climate change observed in the country.

It has been reported that geomagnetic activity indices reflect variations in the solar wind plasma and solar activity parameters. Therefore, geomagnetic activity seems to be the possible link through which solar activity controls the earth's climate (El-Borie et al., 2012a). Variations in this parameters modulate cosmic rays intensity observed on the earth, which in turn affect global electric circuit and cloud nucleation, and subsequently, meteorological parameters. Hence, this could be attributed to the physical mechanism for the relationship between solar indices and temperature observed in this study.

Conclusion

Most of the results are in line with well-known variation trends of temperature in Nigeria. However, the findings have also shown that for the period under investigation, there was an increase in temperature across the country. A Mann-Kendall trend test was used to ascertain this variation trends. The variability could be due to global warming which has resulted in climate change. The possible role of Solar and geomagnetic activity in temperature variability was investigated. The correlation analysis revealed that maximum temperature was weakly and negatively correlated with sunspot number and aa index. From the spectral analysis, the periodicities observed in this study have long been recognized to be exhibited by Solar and geomagnetic activity. This depicts that signature of Solar and geomagnetic activity effects exist in the variability of temperature. This suggests that Solar and geomagnetic activity might play a significant role in climate change observed in the country.

CONFLICT OF INTERESTS

The authors declared no conflict of interests.

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