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Influence of solar and geomagnetic activity on climate change in Nigeria

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This study investigates the possible effects of solar and geomagnetic activity on climatic parameters in Nigeria. Data of sunspot number and geomagnetic *aa* index from 1950 – 2012 and 1950 – 2010 were used as solar indices respectively. Monthly mean daily rainfall, minimum and maximum temperature data from 1950 – 2012 for 15 stations were used as climatic parameters. Descriptive and bivariate analyses as well as Mann-Kendall trend test were employed in analyzing the data, while power spectral density (PSD) analysis was performed using XLSTAT. The results reveal significant upward trends in the variability of minimum and maximum temperature, whereas no significant trends were observed in the variation trend of rainfall for the period under study. This was ascertained from the Mann-Kendall trend test. The variability in rainfall and temperature could be evidence of climate change. The correlation between solar indices and climatic parameters were statistically insignificant at 0.05 level of significant. Similar periodicities were observed in the spectrum of solar and geomagnetic activity indices, as well as the climatic parameters. There were indications of Schwabe, Hale and Gleissberg cycles on rainfall and temperature spectral. These depict signatures of solar and geomagnetic activities. Hence, we infer that, apart from human activities, solar and geomagnetic activities could play important roles in climate change observed in Nigeria.

Key words: Solar activity, periodicities, climate change, Nigeria.

INTRODUCTION

There is no doubt that the Earth's climate has changed in the past, still changing at present and is expected to change in the near future. Information from historical and geological records has shown that the Earth's climate is constantly changing. The reasons for the observed climate change have been and continue to be subject of intensive scientific research and public debate. This is because climate change affects man, his environment and the ecosystems on which humanity depends for survival.

The Intergovernmental Panel on Climate Change (IPCC, 2013), reported that human activities have been the dominant cause of observed climate change particularly through the emission of greenhouse gases (GHGs). This impact of human activity seems to be severe both continentally and even globally since the

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beginning of the industrial era in the mid-18th century. According to the National Academic of Science and Royal Society (2014), there are well understood physical mechanisms by which changes in the amount of GHGs cause climate change. Extensive works have been carried out on the danger and environmental impact of emitting GHGs into the atmosphere. Awareness has equally been created by different agencies and organization over the years (Aizebeokhai, 2009).

Natural factors such as solar motion, solar activity, geomagnetic activity, volcanic activities, e.t.c. have been linked to the observed climate change. According to Dergachev et al. (2004), influence of solar and geomagnetic activities and the variations of cosmic rays on climate processes are necessary for understanding the causes of climate change. Studies have shown that solar variability has played a crucial role in the past climate changes (Sloan and Wolfendale, 2013). Controversy, however, remains over the levels of solar variability required to generate significant climate change and the mechanisms involved (Laut, 2003). Recent studies have also revealed that past climate changes may have been connected with variations in the Earth's magnetic field elements at various time scales (Dergachev et al., 2012; Kitaba et al., 2013).

Working on the solar influence on global and regional terrestrial climate, Lockwood (2012), noted that solar influence could be stronger at local or regional scale than at global one. Dobrica et al. (2013) made similar observation in their work on the effects of solar variability on the north temperate climate.

Valev (2006) reported that statistically, significant correlations exist between global and hemispheric surface air temperature anomalies and solar and geomagnetic indices. He observed that the correlation between temperature anomalies and geomagnetic indices was about two times higher than the correlation between the temperature anomalies and the solar indices. He attributed his observation to the suggestion that the geomagnetic forcing predominates over the solar activity forcing on the global and hemispheric surface air temperatures.

Working on the possible traces of solar activity effect on the surface air temperature in Turkey, Kilcik et al. (2008), observed that solar activity effect exists on surface air temperature of Turkey. Similarly, El Mallah et al. (2012) concluded that signature of solar activity effect exists on surface air temperature in Egypt.

The results of El-Borie et al. (2012b) show that 40 – 50% of the increase in global solar temperature was due to solar forcing. Also, El-Borie et al. (2012a) revealed that solar variability parameters play an important role in climate change and cannot be excluded from the responsibility of continuous global warming. They therefore concluded that the combine effect of solar-induced changes and increase in the atmospheric greenhouse gases offer the explanation for the observed rise in average global temperature over the recent years.

Using temperature data for six stations in Nigeria, Olusegun et al. (2014), reported that no correlation exists between temperature and solar activity. However, influence of geomagnetic field on temperature was observed in some stations with periodicity of 6-month/cycle and 12-month/cycle.

Some of these studies used global temperature (El-Borie et al., 2011), global and hemispheric temperature (Valev, 2006), temperature of North Temperate Zone (Dobrica et al., 2013), mean monthly temperature (El Mallah et al., 2012), minimum and maximum temperature (Olusegun et al., 2014), while very few used temperature and rainfall as climatic parameters (Dobrica et al., 2009; Rampelotto et al., 2012), which are not even in Africa. In this study, apart from using minimum and maximum temperature, we also used rainfall; since rainfall and temperature are the atmospheric parameters use as climate change indicator. Besides, much works have not been done on the effects of solar and geomagnetic activity on climatic parameters in Nigeria. Hence, this work hopes to investigate the variability of rainfall and temperature in Nigeria and the possible effects of solar and geomagnetic activity on climate change in Nigeria.

DATA SOURCES AND METHODOLOGY

Monthly mean smoothed sunspot numbers, spanning 63 years (1950 – 2012) were obtained from the World Data Center for the sunspot indices, Royal Observatory of Belgium (http://www.sidc.be/sunspot-data). The geomagnetic activity *aa* index from two antipodal observatories in Australia and England were provided by the National Centers for Environmental Information, the data spanned from 1950 – 2010 (61 years). Monthly mean daily rainfall and minimum and maximum temperature data for 15 stations in Nigeria were obtained from Nigeria Meteorological (NIMET) Agency Oshodi, Lagos. The data spanned 63 years (1950 – 2012).

In this study, Nigeria is divided into three regions, namely: northern region (R1), south eastern region (R2) and south western region (R3), while the average of all the regions is denoted as R_{all}. This choice is based on the annual variability of rainfall and temperature in these regions. Meteorological stations and their coordinates in each region are shown in Table 1. Descriptive analysis was employed in analyzing the data.

i) The annual, monthly and daily mean *aa* index were computed from the three-hourly values.
ii) The annual sunspot number, rainfall and temperature were calculated from the monthly mean daily values.
iii) Mann-Kendall trend test was carried out to investigate the variation trends of rainfall and temperature over the period under investigation using MATLAB. Mann-Kendall trend test is one of the statistical tests used for trend analysis of climatic parameters (Amadi et al., 2014).
iv) Bivariate analysis was used to correlate annual mean climatic parameters with solar indices at 0.05 level of significant.
v) Finally, power spectral density (PSD) analysis was performed using Fast Fourier Transform (FFT) method. XLSTAT was employed in this analysis. The spectral obtained were smoothed using Hanning window function. This enables the significant peaks to be clearly defined, while the disturbed features completely disappeared.

Table 1. Meteorological stations and their co-ordinates.

Regions	Station	Latitude (°)	Longitude (°)
	Maiduguri	11.51 N	13.05 E
	Sokoto	12.55 N	5.12 E
Region 1	Bauchi	10.17 N	9.47 E
	Kano	12.03 N	8.32 E
	Kaduna	10.52 N	7.43 E
	Enugu	6.28 N	7.34 E
	Owerri	5.25 N	7.13 E
Region 2	Calabar	4.58 N	8.21 E
	Port-Harcour	5.01 N	6.57 E
	Warri	5.31 N	5.44 E
	Ikeja	6.35 N	3.20 E
	Benin	6.19 N	5.36 E
Region 3	Oshogbo	7.47 N	4.29 E
	Ibadan	7.22 N	3.59 E
	Ilorin	8.26 N	4.30 E

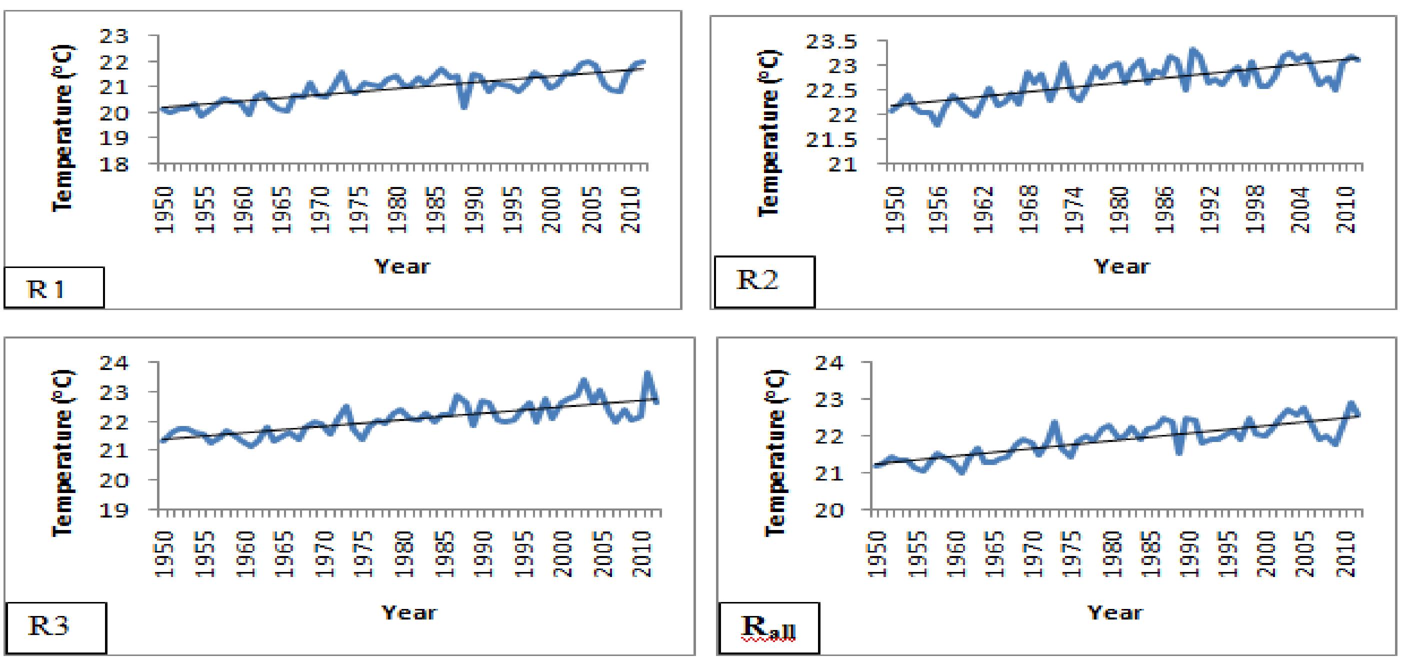

Figure 1. Variation trends of minimum temperature in R1, R2, R3 and R_{all} from 1950-2012.

RESULTS AND DISCUSSION

Increasing trends were observed in the variations of maximum and minimum temperature from 1950 – 2012 (Figures 1 and 2). This was also confirmed from the Mann-Kendall trend test at 0.05 level of significant (Table 2). This depicts increase in temperature, which may be attributed to global warming. The rising trends in temperature especially since the 970s have been observed to be consistent with the global warming patterns (Olusegun et al., 2014; Akinsanola and Ogunjobi, 2014). Similarly, variation trends were also observed in rainfall, but the variability was not as significant as that observed in temperature (Figure 3). This was also

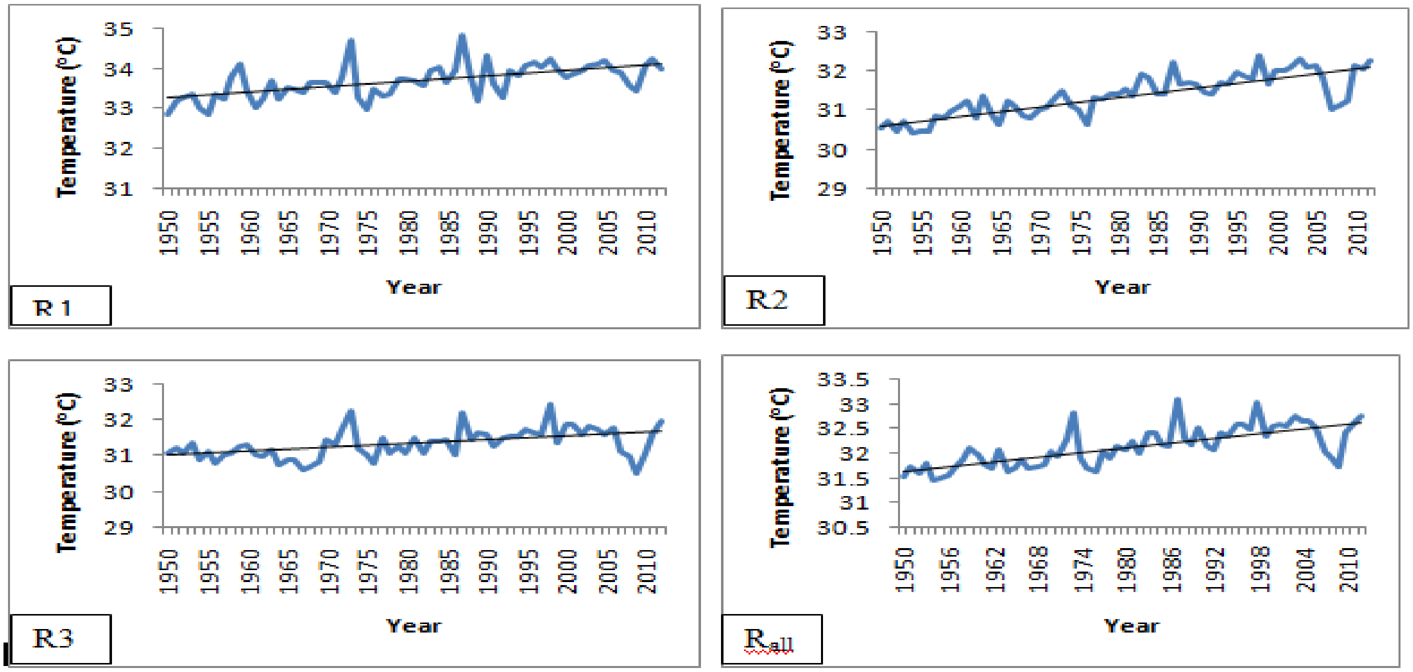

Figure 2. Variation trends of maximum temperature in R1, R2, R3 and R_{all} from 1950-2012.

Table 2. Variation trends of climatic parameters using Mann-Kendall trend test.

Climatic parameters	Region	Kendall tau	Mann Kendall coefficient, S	Z statistic	Trend description (from Z value)	Hypothesis test (h=1: significant, h=0: not significant)	Trend significance
Maximum temperature	R1	0.4675	913	5.4092	Increasing trend	1.0	Significant
	R2	0.6638	1296	7.6809	Increasing trend	1.0	Significant
	R3	0.3823	746	4.4189	Increasing trend	1.0	Significant
	R_{all}	0.5709	1115	6.6072	Increasing trend	1.0	Significant
Minimum temperature	R1	0.5890	1150	6.8149	Increasing trend	1.0	Significant
	R2	0.5177	1011	5.9904	Increasing trend	1.0	Significant
	R3	0.5914	1155	6.8445	Increasing trend	1.0	Significant
	R_{all}	0.6180	1207	7.1529	Increasing trend	1.0	Significant
Rainfall	R1	0.0927	181	1.0676	No trend	0.0	Not significant
	R2	-0.0517	-101	-0.5931	No trend	0.0	Not significant
	R3	0.1152	225	1.3286	No trend	0.0	Not significant
	R_{all}	0.0599	117	0.6880	No trend	0.0	Not significant

observed in the Mann-Kendall trend test (Table 2). These variations of temperature and rainfall could be evidence of climate change, since they are used as climate change indicator.

Both natural and human factors could be responsible for the observed variability in rainfall and temperature. Hence, in this study, we investigate the possible effects of solar and geomagnetic activity due to the fact that solar and geomagnetic activity modulates cosmic rays and cosmic rays in turn affect cloud formation which affects both rainfall and temperature. Bivariate and spectral analyses were used to study the relationship between solar and geomagnetic activity and climatic parameters.

It could be observed that the correlation of climatic parameters with solar indices was statistically insignificant at the 0.05 level of significant; although positive and negative correlations were observed (Table 3). We can

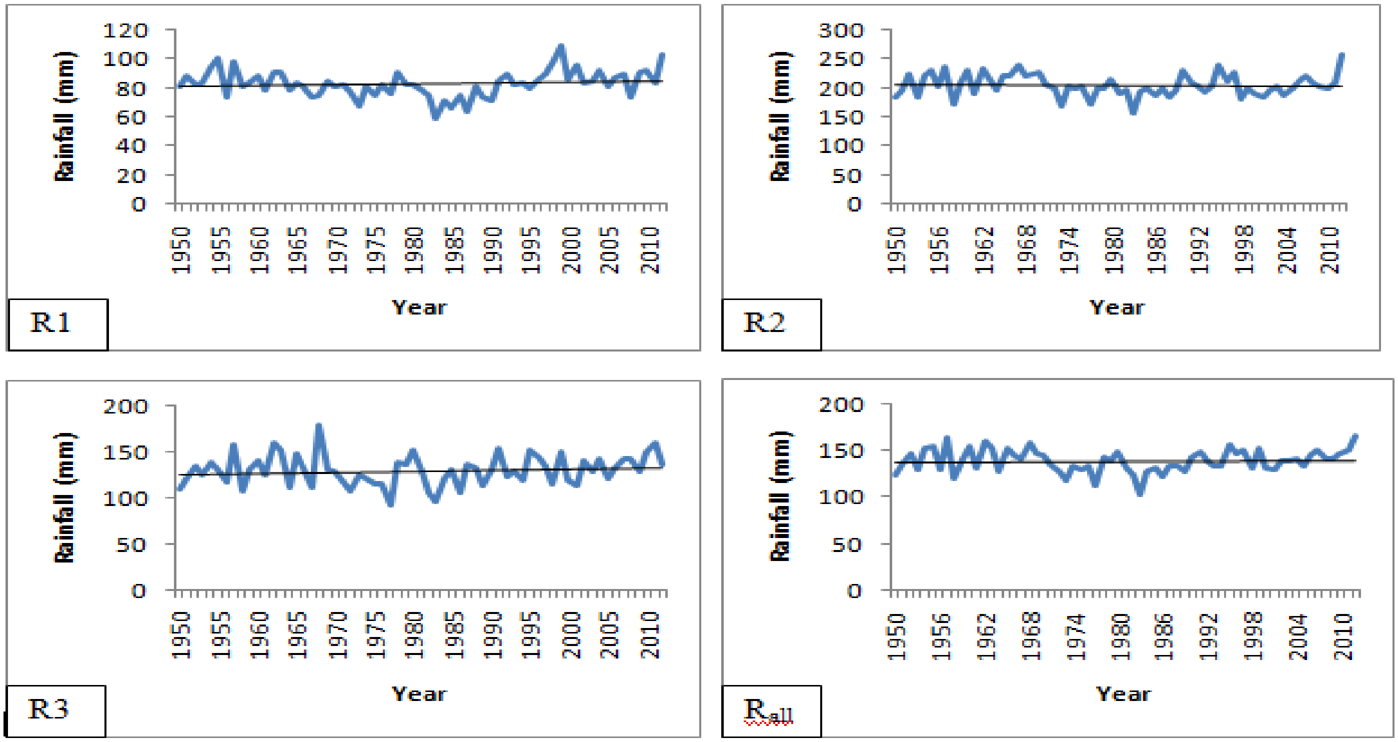

Figure 3. Variation trends of rainfall in R1, R2, R3 and R_{all} from 1950-2012.

Table 3. Correlation coefficient (r) of rainfall and temperature with solar and geomagnetic indices.

Climatic parameters	Region	Sunspot number	aa index
Maximum temperature	R1	-0.041	-0.171
	R2	-0.067	-0.276
	R3	-0.065	-0.231
	R_{all}	-0.062	-0.309
Minimum temperature	R1	-0.035	0.021
	R2	0.049	0.044
	R3	-0.009	-0.001
	R_{all}	0.000	0.024
Rainfall	R1	-0.004	-0.013
	R2	0.030	0.093
	R3	0.105	0.230
	R_{all}	0.063	0.127

infer that solar and geomagnetic activities may have little or no influence on rainfall and temperature. Several researchers have obtained positive, negative and even zero correlations between solar indices and climatic parameters depending on the location (Valev, 2006), but the physical link for these relationships has been the major challenge. Hence, spectral analysis was performed to investigate this association; since the effects of solar and geomagnetic activity on climatic parameters cannot be measure directly.

From Figure 4, a significant peak of 10.5 years was observed in sunspot number. 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

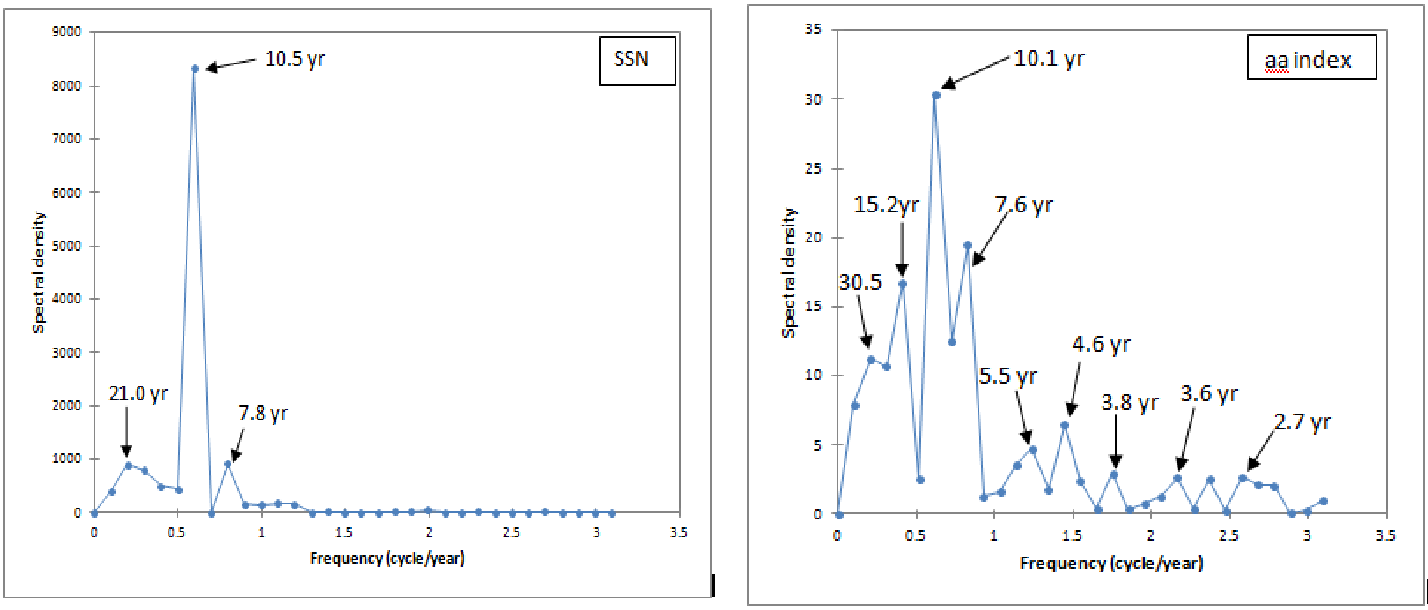

Figure 4. Power spectral density of yearly mean sunspot number and aa index.

of 21.0 years could be referenced to Hale cycle. It could be observed from the spectrum of aa index (Figure 4) that the peaks of 30.5, 15.2, 10.1, 7.6, 5.5, 4.6, 3.8, 3.6 and 2.7 years are identified. The first peaks could be related to Hale cycle, the second and third peaks could be referenced to Schwabe cycle, while the rest of the peaks (short term periodicities) could probably be attributed to solar rotation, evolution of active regions and the outflow of solar wind (Nayar, 2006).

It could be observed from the spectrum of maximum temperature in R1, R2, R3 and R_{all} (Figure 5) that prominent peak of 63.0 as well as peak of 12.6 and short term periods of 7.8, 4.8, 3.5 and 2.8 years were found in R1. Peaks of 63.0, 12.6, and 7.8 years are observed in R2. Peaks of 63.0, 12.6, 7.8, 4.8, 3.5 and 2.7 years are detected in R3 and R_{all}. The significant peak of 63.0 could be related to Gleissberg period. On the other hand, peak of 12.6 and 7.8 years as well as short term periods could be associated to Schwabe cycle and atmospheric phenomena (such as quasi biennial oscillation, QBO) respectively.

From the power spectral of annual minimum temperature in R1, R2, R3 and R_{all} (Figure 6), it could be observed that significant peaks of 63.0 as well as short term peaks of 4.8, 3.9 and 3.0 years were detected in R1. Peaks of 63.0, 4.8, 3.5, and 2.5 are observed in R2. Similarly, peaks of 63.0, 7.8, 4.8, 3.5, and 2.5 are observed in R3 and R_{all}. The prominent peak of 63.0 years and peak of 7.8 could be related to Gleissberg and Schwabe cycles respectively. On the other hand, short term periods could be associated to atmospheric phenomena such as QBO.

From the power spectral of annual mean rainfall in R1, R2, R3 and R_{all} (Figure 7), peaks of short periods of 10.6, 7.0 and 2.6 as well as long term peaks of 21.0 and 63.0 years were observed in R1. Peaks of 63.0, 12.6, 5.2, 2.8, 2.6 and 2.1 years are detected in R2. In R3, peaks of 63.0, 15.7, 10.5, 7.8, 5.7, 3.9, 2.7, 2.6 and 2.1 years are detected. Similarly, peaks of 63.0, 15.7, 10.5, 6.3, 5.2, 3.9, 2.7 and 2.1 are detected in R_{all}. 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 (El-Borie et al., 2012a).

It is interesting to note that similar periodicities were observed in the spectral of solar and geomagnetic activities indices as well as the climatic parameters. The peaks observed in this study were similar to that obtained by other authors such as El-Borie et al. (2011, 2012a, b) and El Mallah et al. (2012), in their works on the effects of solar and geomagnetic activities on temperature. This indicates that solar variability might play an important role in the observed climate change.

Researchers have shown that solar activity alternates between active and quiet phases with an average duration of 11 year (Schwabe cycle), 22 year solar magnetic cycle polarity reversals (Hale cycle) and probably an ~80 year cycle (Gleissberg cycle), with short term periodicities (Nayar, 2006; Kane, 2005; El Mallah and El Sharkawy, 2011; Nagaya et al., 2012; Owen et al., 2015). The Schwabe, Hale and Gleissberg cycles can be stretched/shorten, leading to different harmonized (Miyahara et al., 2009). Also, the presence of short term variations (2 – 7 years) has been associated to atmospheric phenomena such as quasi-biennial oscillation

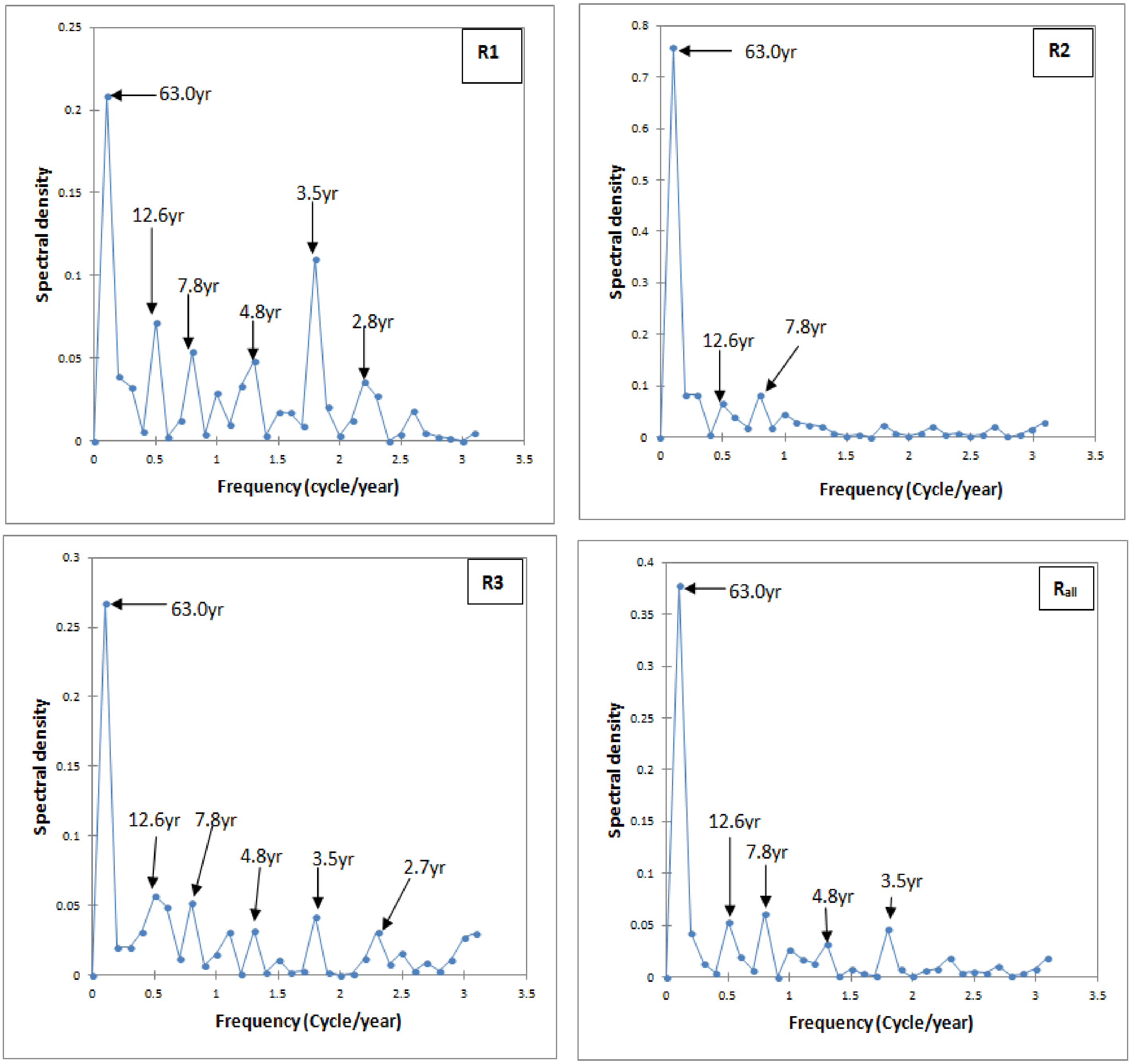

Figure 5. Power spectral density of yearly maximum temperature in R1, R2, R3 and R_{all}.

(El-Borie et al., 2012a; Dobrica et al., 2013).

From these observations, we can infer that the Schwabe, Hale and Gleissberg cycles, as well as atmospheric phenomena were detected in climatic parameters in Nigeria. This indicates that remarkable role of solar and geomagnetic activity indices were obvious on climatic parameters in Nigeria. Therefore, signatures of solar and geomagnetic activity effects exist on rainfall and temperature, which could be linked to the observed climate change in Nigeria. Hence, apart from anthropogenic activities, solar and geomagnetic activities as well as atmospheric phenomena might play important roles in climate change observed in Nigeria. The suggested possible physical link for our findings may be through modulation of cosmic rays by solar and geomagnetic activity. It has been reported that cosmic rays affect cloud formation and cloud in turn influence rainfall and temperature.

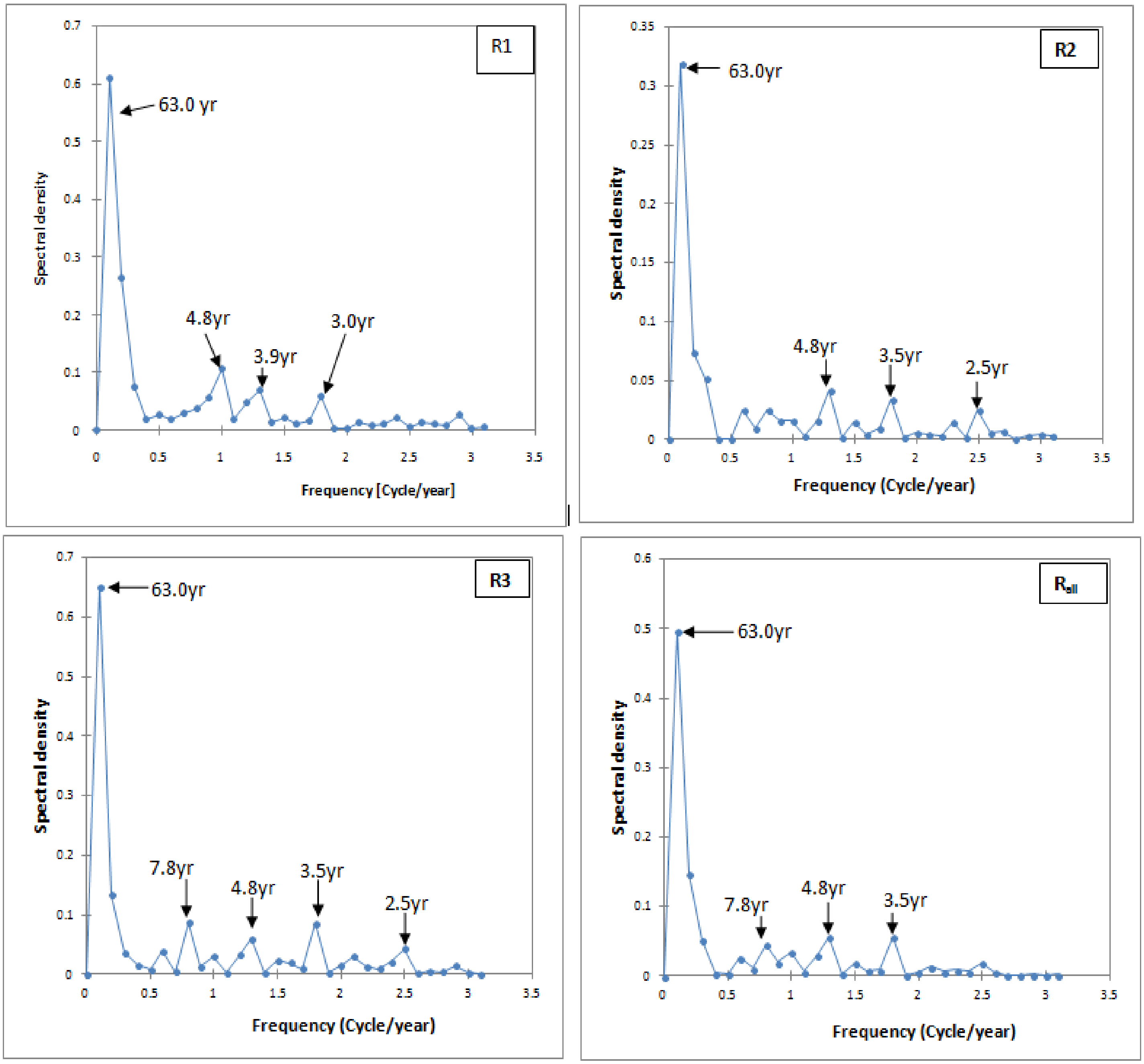

Figure 6. Power spectral density of yearly minimum temperature in R1, R2, R3 and R_{all}.

Conclusion

This study has shown that climate change is obvious in Nigeria based on the variability of rainfall and temperature (observed in this study), which are used as climate change indicators. The correlation between solar indices and climatic parameters were statistically in-significant. However, there were indications of Schwabe, Hale and Gleissberg cycles on the spectrum of rainfall and temperature. This suggests that apart from the effects of greenhouse gases, solar and geomagnetic activity might play an important role in climate change observed in Nigeria. Results from this study have thrown more light on the possible physical link by which solar and geomagnetic activity affect atmospheric parameters.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

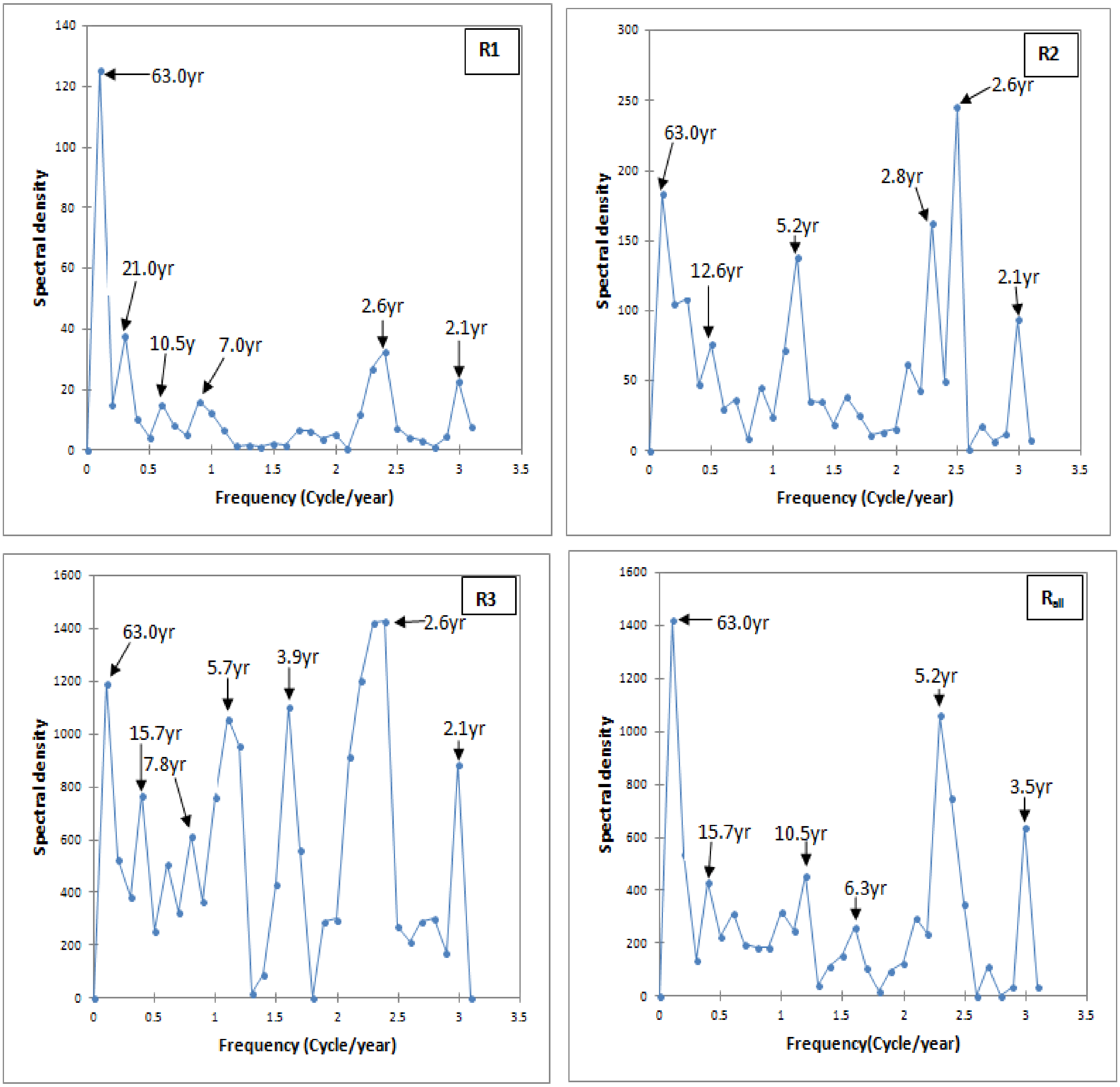

Figure 7. Power spectral density of yearly mean rainfall in R1, R2, R3 and R_{all}.

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