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Full Length Research Paper

Simulation of precipitation variations in Iran using Kriging interpolation methods

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This study estimated spatial variability of precipitation in the monthly and annual scales in Iran for the period of 1975 to 2014 in 140 stations using kriging interpolation methods. In precipitation variability analysis three procedures were used: Mann-Kendall test, Sen's slope estimator and spatial trend patterns. Results show that there are both increasing and decreasing trends in monthly precipitation in Iran. Based on the magnitude of the significant trend, there are three patterns of the significant trend (average, lower and upper) in the monthly precipitation of Iran that vary from -0.0785 mm/month in October to 0.1536 mm/month in November. As a result, in January, February, March, May, October, and December, the magnitude of negative trends and in April and November the random and positive patterns were estimated in the precipitation in 140 stations, respectively.

Key words: Spatial variations, trend variations, spatial variability, Mann-Kendall, precipitation.

INTRODUCTION

Precipitation is an important element to analyze the environmental process. There are various spatial-temporal methods which were employed for classifying simulations in climatic series. However, the trend pattern and its spatial simulations of precipitation is an important aspect in the analysis of climatic and environmental simulation patterns. Various parametric and non-parametric statistical tests (Sung et al.,2017) have been used in measurement of rainfall trend by many researchers (Javari, 2017b). The Mann-Kendall test, Sen's slope estimator test (Ahmad et al., 2015), and spatial trend analysis tools (ArcGIS$_{10.3}$ tools) were used for trend analysis and forecast, and an upward and a downward trend in the precipitation were found on monthly, seasonal and annual periods (Tabari et al., 2011). The spatial variability and trend pattern of precipitation (Zilli et al., 2017) are important property in the regionalization of climatic condition. The trend patterns and its spatial simulations of precipitation (Guan et al., 2017) was considered by various aspects due to several benefits over spatial methods. Some of these aspects include: (1) does require the spatial variability of precipitation series using geostatistical methods (Cecinati et al., 2017) (Kriging method), (2) compare methods rather than temporal method, and (4) larger control is completed for the precipitation spatial distributions variability (Zeleke and Damtie, 2017). In spite of mentioned aspects, the effectiveness of the spatial variability in the precipitation series (Kutiel and Türkeş, 2017) on the results of trend spatial method has been

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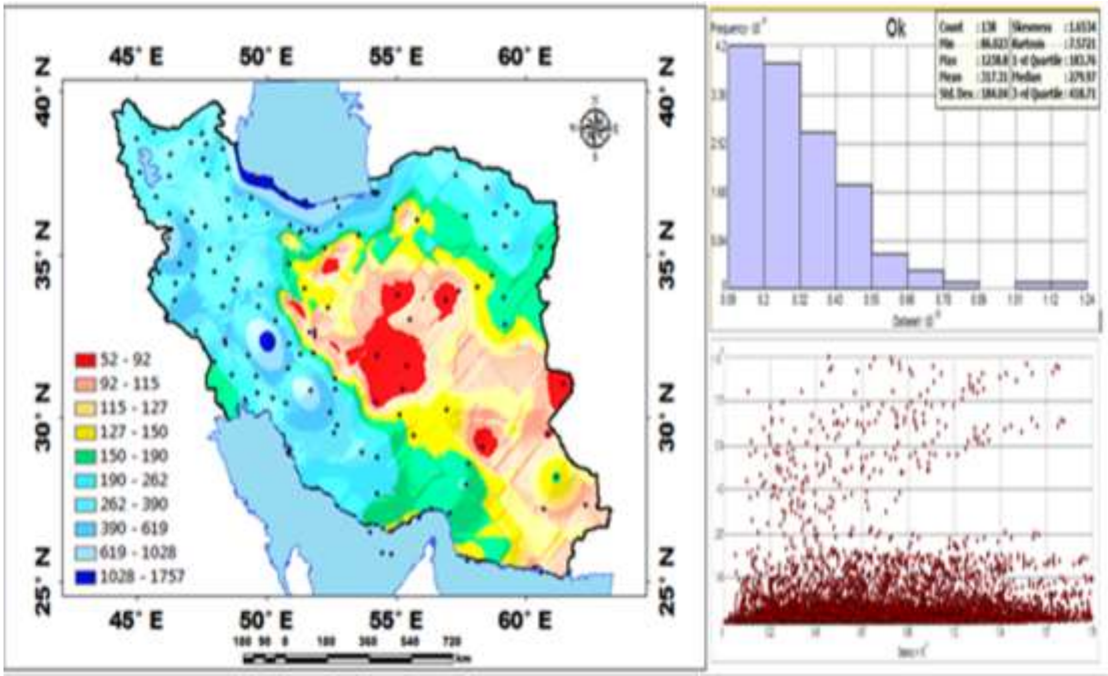


Figure 1. Spatial variability of Annual rainfall using ordinary Kriging.

analyzed using kriging interpolation methods. In addition, considering the Mann–Kendall method as a pattern of the temporal to simulate the precipitation series, Mann–Kendall method (Zarei and Eslamian, 2017) as a factor of the slope variability of precipitation at the significance level (Deng et al., 2017) and as a type of rainfall variability pattern. In the present study, the precipitation series were assessed to detect the data series quality aspects, including: (1) homogeneity over precipitation data (Javari, 2016; Santos and Fragoso, 2013), (2) checking temporally-spatially distribution (Ding, 2017; Javari, 2017b) of precipitation, and (3) long-term reconstruction of the precipitation series based on simulated data by using geostatistical (kriging) methods (Diodato and Ceccarelli, 2005; Ishida and Kavvas, 2017). After detection of data series quality aspects, the precipitation were evaluated for normality of the precipitation series using statistical tests (parametric and non-parametric tests).

To evaluate the homogeneity of the precipitation series (Javari, 2016), the Standard Normal Homogeneity test, Alexanderson’s SNHT test (Alexandersson, 1986) and the Pettitt-Whitney-Mann test (PWM) (Pettitt, 1979) were used at 5% significant level (Javari, 2017a). Finally, for each station series, trend values were analyzed using Mann - Kendall method and to analyze the precipitation spatial variability, geostatistical methods (Kriging method) were used. The major aims of this study are: (1) to analyze precipitation spatial variability across Iran using the statistical tests; (2) to predict the precipitation trend in Iran using the trend tests; (3) to detect and predict the variability patterns of precipitation using Kriging models; and (4) to forecast the spatial variability patterns of precipitation. The findings of this paper could be used, for the management of water resource and environmental planning in Iran. This study provides an extensive review of precipitation spatial variability at the region level and may help climatologists and environmental planners. Thus, the purpose of this study is to predict the spatial variability of precipitation of this region.

METHODOLOGY

Study area and data used

Iran, situated in the southwest of Asia, ranges from 25° 3' to 39° 47' N and from 44° 5' to 63° 18' E. The chosen variables were obtained from meteorological organization and included the monthly, seasonal and annual information of 140 stations in Iran for the period of 1975 to 2014 (Figure 1). The rainfall data used in this study comprise monthly, seasonal and annual series provided by the Iran Meteorological Organization. In addition, all the observed precipitation data were subject to strict quality control obtained from http://www.irimo.ir. Precipitation series quality control is the various tests; however, since tests are parametric and non-parametric tests, they are strong against outliers.

Methods

In this study, three types of patterns, that is, spatial and trend models with downward and upward components as spatial-temporal patterns are estimated. The following steps represent a spatial-trend model which consists of several stages and various parameters of measurement model: RMSE and R^2 control how much validating of measurement model is imposed in each iteration. The spatial-trend model includes the following steps.

Normality measurement methods

In this study, normality was analyzed as temporal-spatial normality. The temporal normality of the precipitation series was tested by using the Kolmogorov-Smirnov and Chi-Squares tests. The spatial normality of the precipitation series was tested by using the exploratory spatial data analysis (ESDA) tools (measures of location, spread and shape) in the ArcGIS. There are two ways to check for normality of residual and is normally carried out through graphical and numerical means. These tests are used to test the normality of the residuals. The detail mathematical basis of these normality test statistics is extensive and is available subsequently.

Application of tests: To study the decision to use spatial-trend models, depending on the nature of precipitation in the stations, two approaches were suggested: first, the parametric tests, use of spatial-trend forecasting. Secondly, non-parametric tests, use of spatial-trend forecasting. In addition, the assessment methods following the order for the analyses; namely, (1) the initial analysis of descriptive statistics of point annual precipitation series was estimated for each station in the period of 1975 to 2014, (2) series are tested for data quality, (3) series are tested by MK test and Sen Slope estimator test are used to detect the direction and magnitude of a trend, (4) root mean square error (RMSE), and geostatistcal tools to predict the spatial variability applied. Kendall's Tau test and runs test were used as non-parametric tests and t test as parametric tests to explore precipitation spatial-trend variations patterns. Model selection criteria were used in this study. Hence, root mean square error (RMSE) and coefficient of determination (R^2) were considered. Hence, the results in R^2 to additive model equal 0.883 and have an acceptable condition and the mentioned constructs of research have a suitable diagnostic validity.

The spatial trend analyzing of monthly rainfall

Spatial trend method is the based linear model and generally used by predicted point layer for the first order data to detect spatial variability of precipitation series. The various geostatistical interpolation types can be obtained from the linear model by applying the generalized least-squares estimation of the expected values. The type of Kriging method depends on the model assumed for the expected values. Kriging methods depend on mathematical and statistical models. The geostatistcal analysis offers several types of Kriging, which are suitable for different types of data and have different underlying assumptions: Ordinary, Simple and Universal. In addition, to investigate the precipitation spatial variability, variogram should be used to predict the spatial characteristics of the precipitation series. The cross-variogram was utilized to identify the spatial relationship of two precipitation series.

RESULTS AND DISCUSSION

The spatial point pattern of the precipitation series is extracted from Kriging models (ordinary, simple and universal). The distribution of point pattern (39042 points) on annual precipitation using OK is presented in Figure 2, which shows a mean of 237.2 mm, with a minimum of 52.06 mm, with a maximum of 1757.8 mm with a standard deviation of 178.09 mm and a variations coefficient of 75.07% in the precipitation using OK across Iran', however, it must be taken into account that the precipitation was not equally concentrated in the latitudes and longitudes. Figure 2 shows result of spatial variability of annual precipitation using the OK methods. The spatial variability of annual rainfall patterns was more irregular with distribution of point patterns by OK. The most possible variability in the annual precipitation was in the Caspian Sea. This was also evident from the distribution of point patterns of 10 regions. Figure 3 demonstrated that no important spatial trend was observed using trend Tools in ArcGIS in annual precipitation data over the entire points series. The most possible distribution of rainfall trend pattern over entire points series was confirmed by monthly precipitation in Iran. The distribution of rainfall point pattern by using SK shows the mean of 257.13 mm, with a minimum of 113.29 mm, with a maximum of 820.38 mm, and with a standard deviation of 117.7 mm and with a variations coefficient of 45.78% in the precipitation using SK across Iran'; however, it must be taken into account that the precipitation was lower ranged in the latitudes and longitudes (Figure 3). Figure 4 shows the spatial trend variability analysis of precipitation series on annual series for entire time period (1975 to 2014) using UK. The universal kriging (UK) changes for the annual precipitation from north and northwestern to central parts and from west to east showing a variability decreasing slope in Iran. The distribution of point pattern (39042 points) on annual precipitation using UK is presented in Figure 4, which shows a mean of 237.23 mm, with a minimum of 52.07 mm, with a maximum of 1757.82 mm, and with a standard deviation of 178.08 mm and with a variations coefficient of 75.07% in the precipitation using UK across Iran'; however, it must be taken into account that the precipitation was similar to OK in the latitudes and longitudes. The rainfall points analysis results showed that the average annual precipitation increased from 35 to 39° N latitude and from 45 to 50° E longitude in the three models. In this study, the temporal trend and trend slope was investigated by using the Mann-Kendall (MK) and Sen.'s slope estimator, respectively. However, the patterns of precipitation series were evaluated through the trend spatial tools (TST) by using the ordinary Kriging. The results of spatial statistical analysis for point series using ordinary Kriging (OK) and point latitude and longitude distribution is as shown in Figure 5. Figure 5 shows the increased variability of the trends in annual over the 35 to 39° N latitude and from 45 to 50 ° E longitude. Figure 5 demonstrates the annual series estimated by the TST method for each station over the time period of 1975-2014. Figure 5 shows a decreasing spatial trend in the annual precipitation with a different trend slope range from north to south and a regular and steady spatial pattern from west to east (52 to 1757 mm) by using the OK in Iran. Furthermore, the results showed

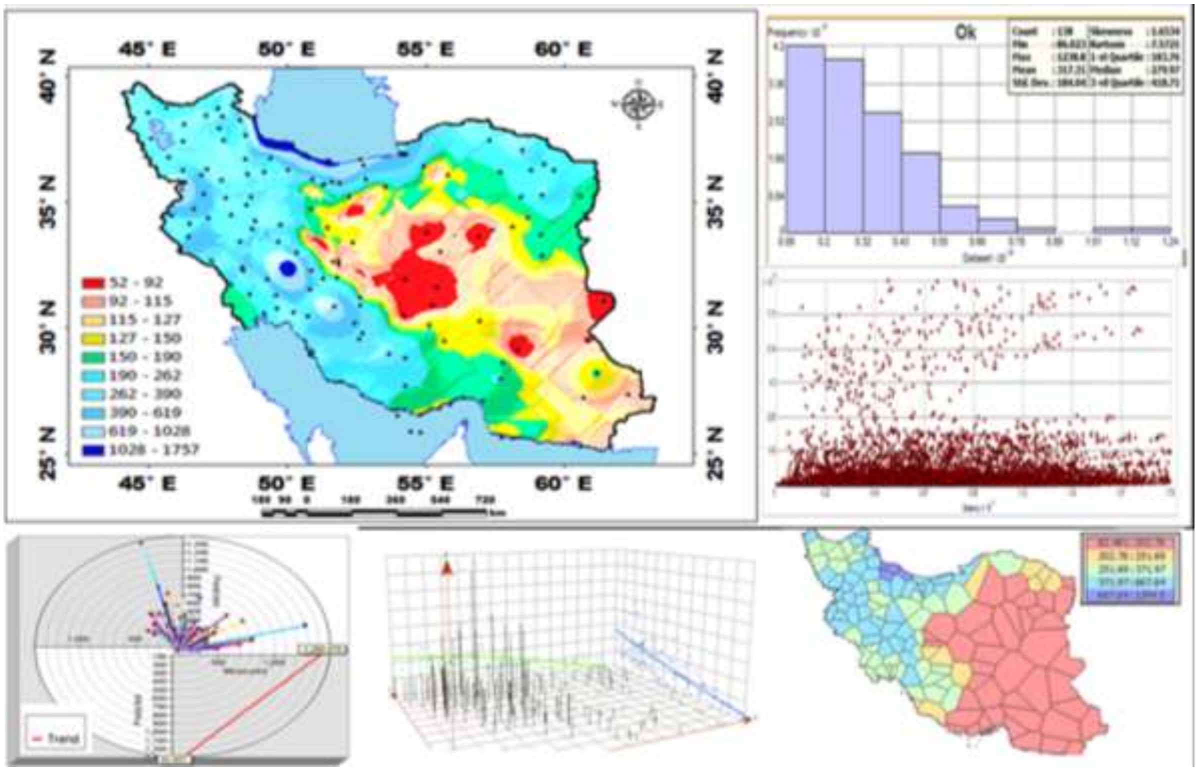


Figure 2. Spatial trend variability of annual rainfall using ordinary Kriging.

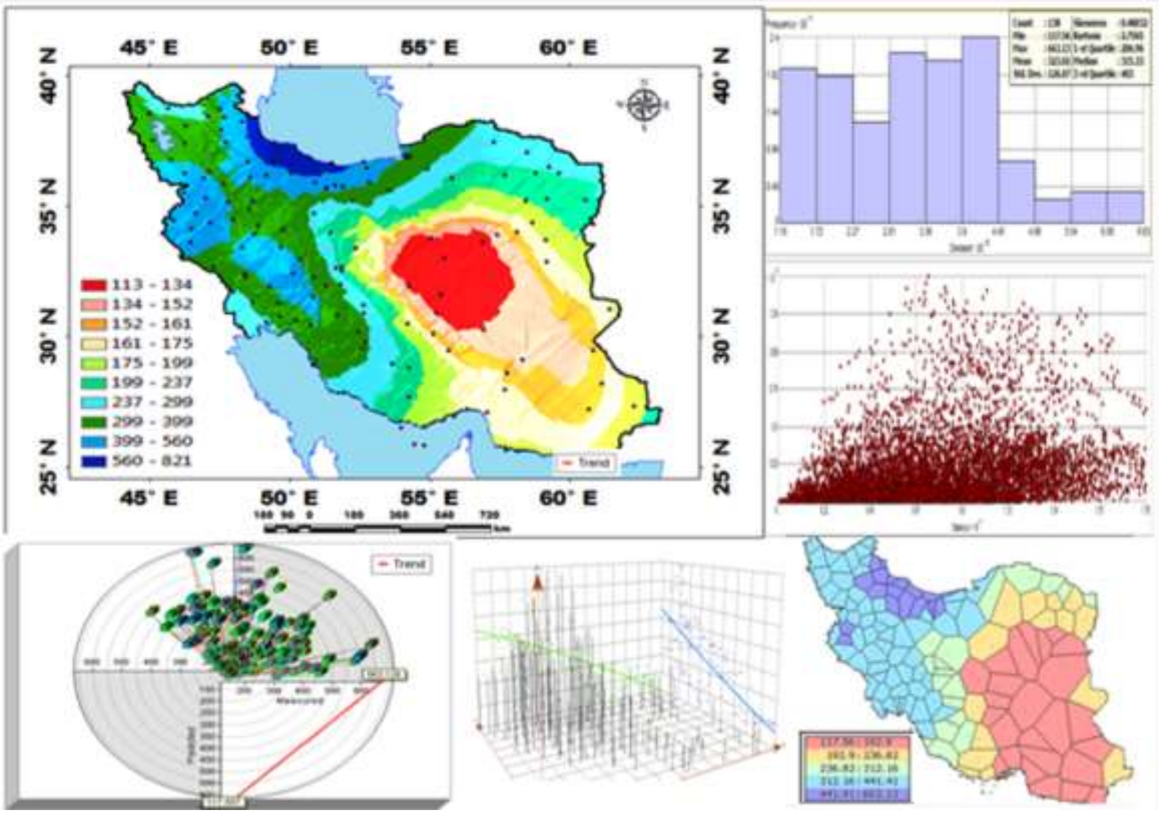


Figure 3. Spatial trend variability of annual rainfall using simple Kriging.

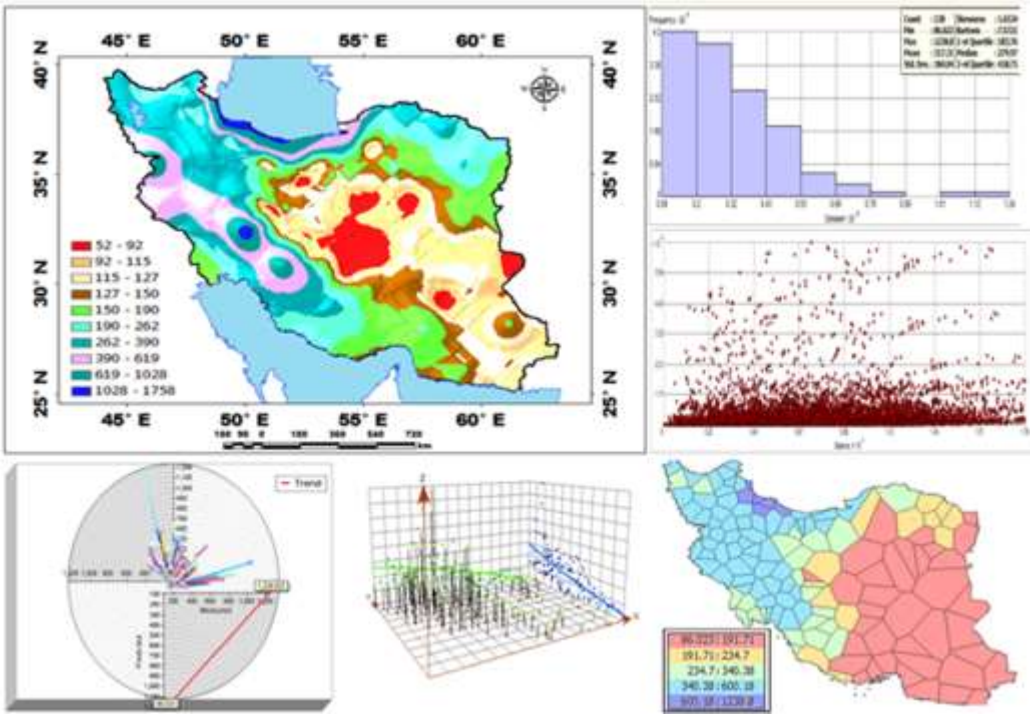
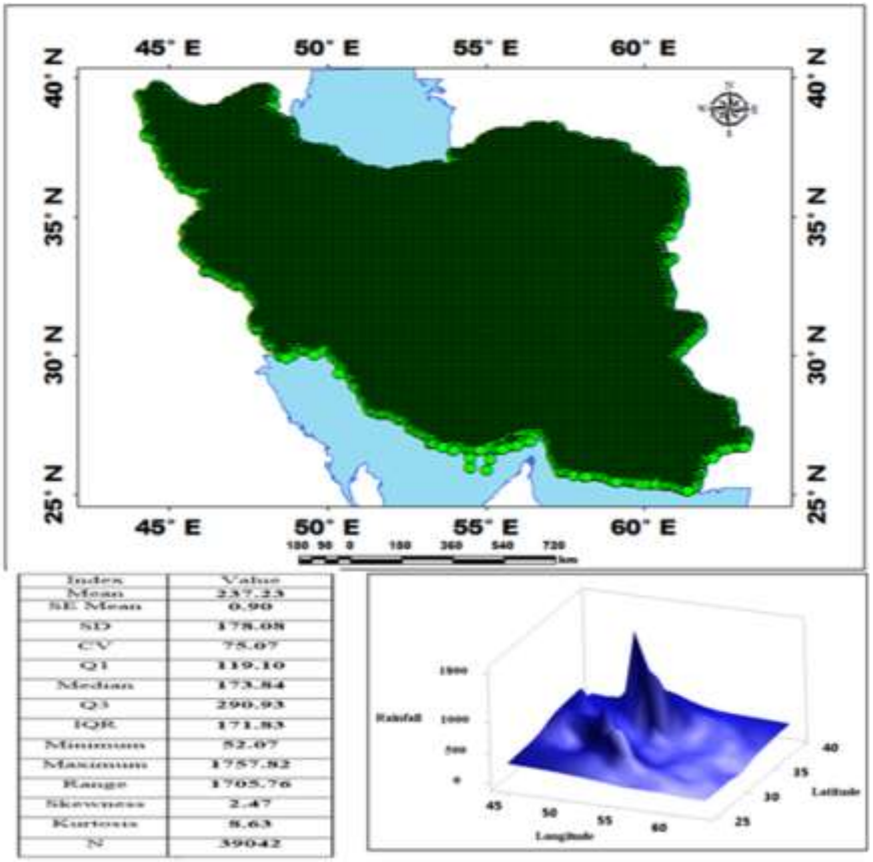
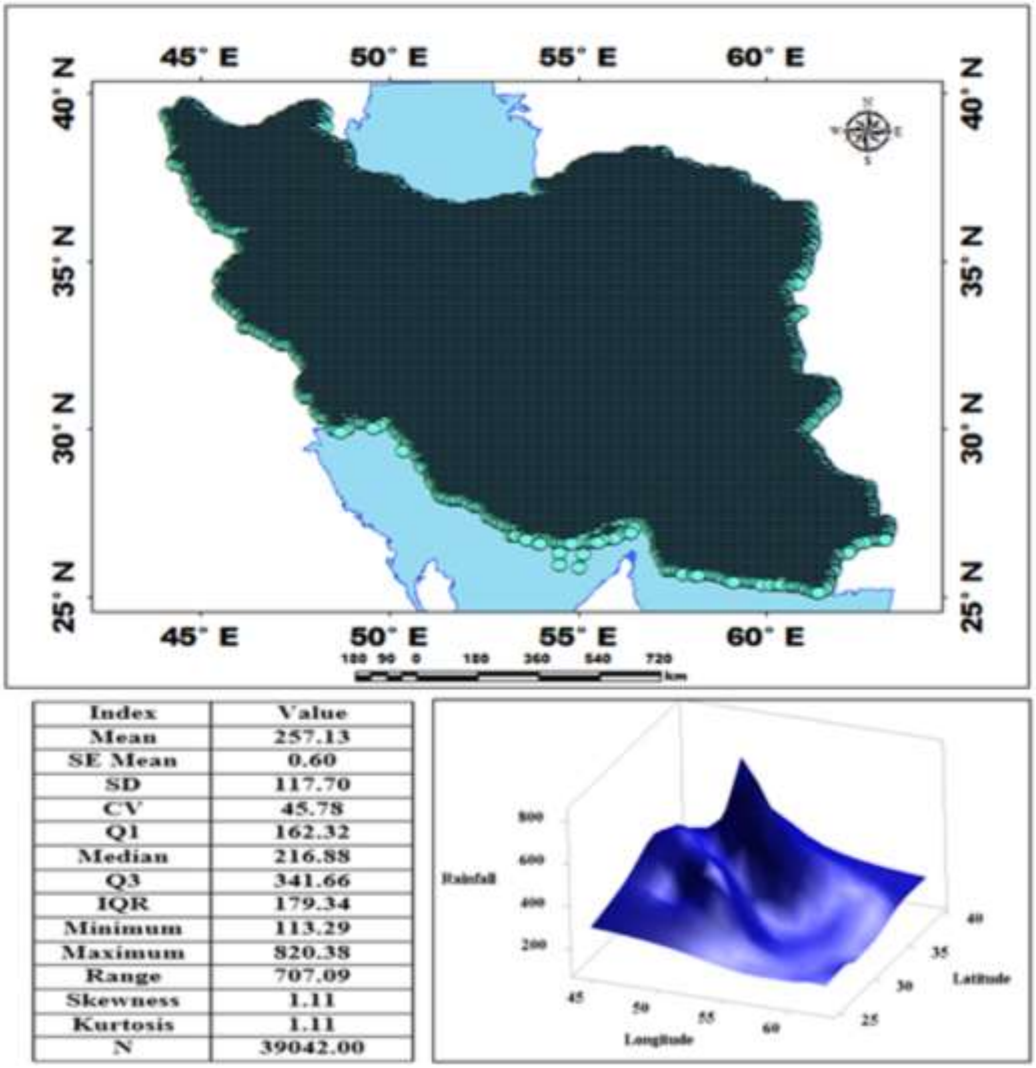


Figure 4. Spatial trend variability of annual rainfall using universal Kriging.



Index	Value
Mean	237.23
SE Mean	0.90
SD	178.08
CV	75.07
Q1	119.10
Median	173.84
Q3	290.93
IQR	171.83
Minimum	52.07
Maximum	1757.82
Range	1705.76
Skewness	2.47
Kurtosis	8.63
N	39042

Figure 5. Spatial trend point analysis of annual rainfall using ordinary Kriging.

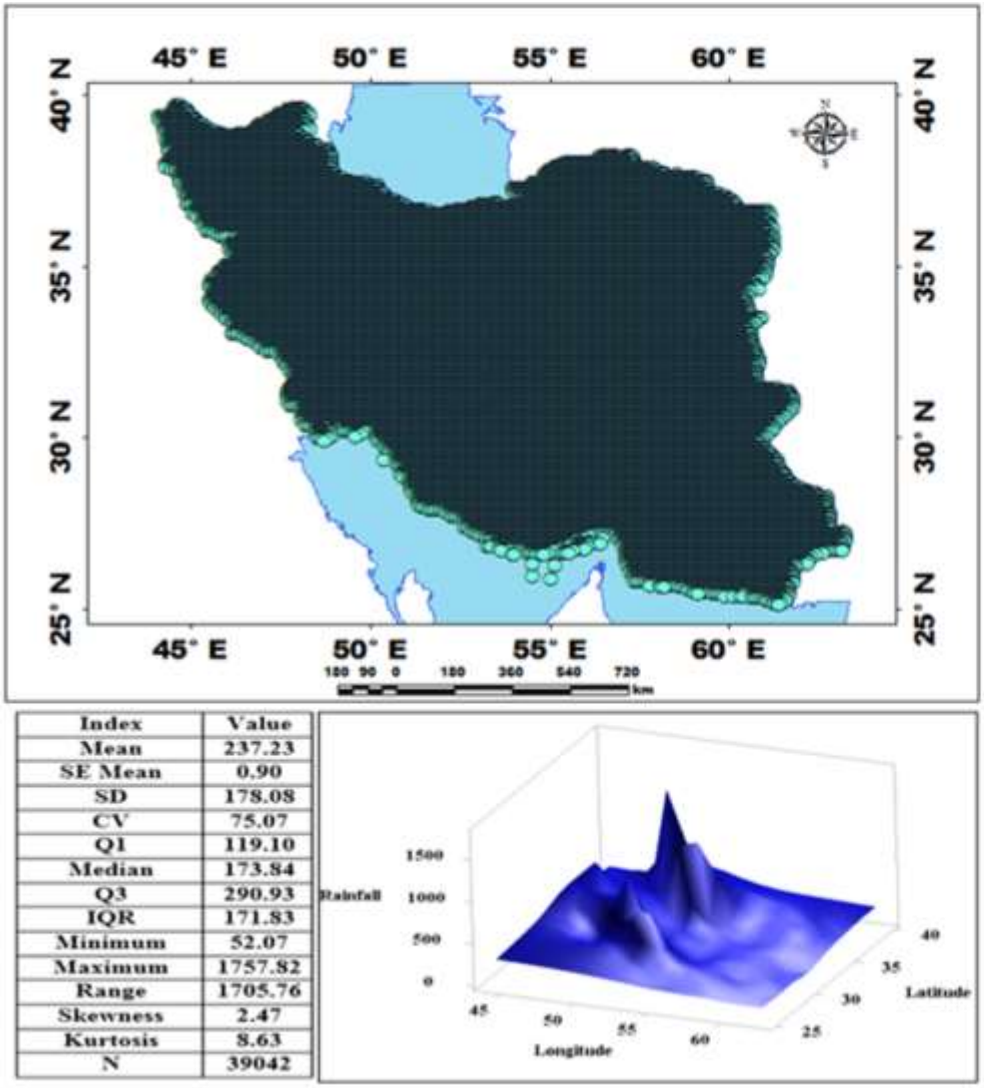


Index	Value
Mean	257.13
SE Mean	0.60
SD	117.70
CV	45.78
Q1	162.32
Median	216.88
Q3	341.66
IQR	179.34
Minimum	113.29
Maximum	820.38
Range	707.09
Skewness	1.11
Kurtosis	1.11
N	39042.00

Figure 6. Spatial trend point analysis of annual rainfall using simple Kriging.

that northwest than central and southeast parts, revealed two spatial variability patterns with a maximum of 202.76 mm (southern parts) in the annual precipitation series with a maximum increase of 1394.5 mm (northern parts); while two regions, presented different spatial variability patterns, with a range of 1312 mm in Iran.

Figure 6 showed a decreasing spatial trend in the annual precipitation with a different trend slope range from northwest to southeast and a regular spatial pattern from west to east (113 to 821 mm) by using the SK in Iran. Furthermore, the results showed that northwest than southeast parts, revealed two spatial variability patterns with a maximum of 192.9 mm (southern parts) in the annual precipitation series with a maximum increase of 663.1 mm (northern parts); while two regions, presented discrete spatial variability patterns, with a range of 708 mm in Iran. The maximum rise in annual precipitation variability was (820.38 mm) monitored by minimum (113.29 mm) precipitation series. The precipitation spatial variability range (707.09 mm) displayed more increase in precipitation than seasonal precipitation (Figure 6) using SK. Figure 7 shows a decreasing spatial trend in the annual precipitation with a different trend slope range from north to south and a regular spatial pattern from west to east (52 to 1758 mm) by using the UK similar to the OK pattern in Iran. The maximum growth in annual precipitation variability was (1757.82 mm) observed by minimum (52.07 mm) precipitation series. The precipitation spatial variability range (1705.76 mm) displayed more spread in precipitation than SK (Figure 7) using UK. Furthermore, the results showed that northwest than central and southeast parts, revealed two spatial variability patterns with a maximum of 191.71 mm (southern parts) in the annual precipitation series with a maximum increase of 1238.8 mm (northern parts); while two regions, presented different spatial variability patterns



Index	Value
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Range	1705.76
Skewness	2.47
Kurtosis	8.63
N	39042

Figure 7. Spatial trend point analysis of annual rainfall using universal Kriging.

and similar to OK pattern, with a range of 1152.8 mm in Iran. However, the spatial variations of the trends in annual rainfall were important using the Kriging and a trend interpolation technique. Kriging and trend technique results showed decreasing trends on an annual scale in most of the west and western north of Iran and no-trend in east and eastern north in Iran. In addition, three orders magnitude of the significant trend (lowest, average and upper) of monthly rainfall varied from -2.176 to 1.4847 mm/month for January. The average slope of trends in rainfall for January showed significant decreasing trends (-0.347) on a monthly scale in most parts of Iran. The spatial variations of the trends on a monthly scale on January rainfall were definite using the Kriging and a trend interpolation technique. Kriging and trend technique results showed decreasing trends on a monthly scale in most of the west and western north of Iran in January and increasing trends in the center parts in Iran and no-trend in east and eastern north in Iran. The magnitude of the significant trend of monthly rainfall varied from -1.43 to 0.77 mm/month for February. The average slope of trends in rainfall for February showed significant decreasing trends (-0.255) on a monthly scale in most parts of Iran. The spatial variations of the trends on a monthly scale on February rainfall were definite using the Kriging and a trend interpolation technique. Kriging and trend technique results showed decreasing trend on a monthly scale in most of the western north of Iran in February and increasing trends in the center parts in Iran and no-trend in eastern south in Iran. The magnitude of the significant trend of monthly rainfall varied from -2.098 to 0.523 mm/month for March. The average slope of trends in rainfall for March showed significant decreasing trends (-0.758) on a monthly scale in most parts of Iran.

The spatial variations of the trends on a monthly scale on March rainfall were definite using the Kriging and a trend interpolation technique. Kriging and trend technique results showed no-trend pattern on a monthly scale in most of the west, Iran in March and increasing trend pattern in the center parts in Iran and decreasing trend pattern in east in Iran. The magnitude of the significant trend of monthly rainfall varied from -0.98 to 1.057 mm/month for April. The average slope of trends in rainfall for April showed significant increasing trends (0.818) on a monthly scale in most parts of Iran. The spatial variations of the trends on a monthly scale in April rainfall were definite using the Kriging and a trend interpolation technique.

Analytical results showed decreasing pattern on a monthly scale in most of the west, Iran in April and increasing trend pattern in the center parts in Iran and no-trend pattern in east in Iran. The magnitude of the significant trend of monthly rainfall varied from -0.633 to 0.471 mm/month for May. The average slope of trends in rainfall for May showed significant decreasing trends (-0.607) on a monthly scale in most parts of Iran. The spatial variations of the trends on a monthly scale on May rainfall were definite using the Kriging and a trend interpolation technique. Kriging and trend technique results showed that decreasing pattern on a monthly scale in most of the west and western north of Iran in May and increasing trend pattern in the center parts in Iran and no-trend pattern in east and eastern north in Iran. The magnitude of the significant trend of monthly rainfall varied from -0.506 to 0.293 mm/month for October. The average slope of trends in rainfall for October showed significant decreasing trends (-0.079) on a monthly scale in most parts of Iran. The spatial variations of the trends on a monthly scale on October rainfall were definite using the Kriging and a trend interpolation technique. Trend analysis results showed no-trend pattern on a monthly scale in most of the west and western north of Iran in October and increasing trend pattern in the center parts in Iran and decreasing trend pattern in east and eastern north in Iran. The magnitude of the significant trend of monthly rainfall varied from -0.757 to 1.064 mm/month for November. The average slope of trends in rainfall for November showed significant increasing trends (0.154) on a monthly scale in most parts of Iran.

The spatial variations of the trends on a monthly scale on November rainfall were definite using the Kriging and a trend interpolation technique. Trend analysis results showed decreasing (downward) pattern on a monthly scale in most of the west and western north of Iran in November and increasing (upward) trend pattern in the center parts in Iran and no-trend pattern in east and eastern north in Iran. The magnitude of the significant trend of monthly rainfall varied from -1.522 to 1.147 mm/month for December. The average slope of trends in rainfall for December showed significant decreasing trends (-0.199) on a monthly scale in most parts of Iran. The spatial variations of the trends on a monthly scale on December rainfall were definite using the Kriging and a trend interpolation technique. Trend analysis results showed no-trend pattern on a monthly scale in most of the west and western south of Iran in December and increasing (upward) trend pattern in the center parts in Iran and decreasing (downward) pattern in east and eastern north in Iran. The magnitude of the significant trend of rainfall varied from -6.059 to 2.474 mm/year for annual rainfall. The average slope of trends in annual rainfall showed significant decreasing trends (-1.526) on a monthly scale in most parts of Iran. The spatial variations of the trends in annual rainfall were definite using the Kriging and a trend interpolation technique. Trend analysis results showed that no-trend pattern on a year scale in most of the west and western north of Iran in annual and increasing (upward) trends, pattern in the center parts in Iran and decreasing (downward) pattern in east and eastern north in Iran.

Conclusions

This study showed a trend analysis and its spatial variability of precipitation series in Iran. This trend analysis and its spatial variability occur at various patterns and levels of intensity. Variogram analysis revealed that precipitation series particularly, spatial patterns are important to predict the spatial variability in Iran. Among the precipitation series' patterns studied, winter and autumn precipitation series showed spatial variability indicating the regularity of factors monitoring the trended precipitation spatial variability. Spatial patterns of precipitation series show an overall decreasing trend from the north and northwest to the south and southeast. The precipitation variability is larger in the various regions; the monthly, seasonal and annual precipitation have different spatial-temporal patterns.

CONFLICT OF INTERESTS

The authors has not declared any conflict of interests.

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

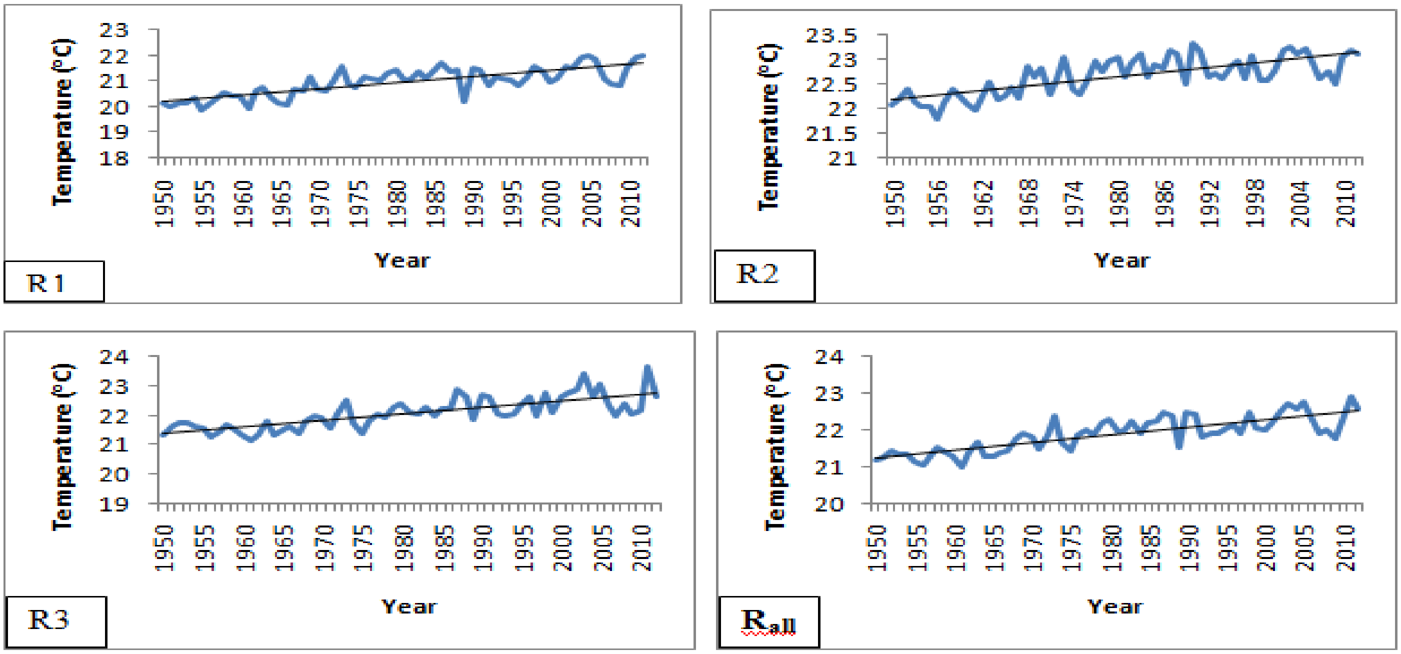

Figure 1. Variation trends of minimum temperature in R1, R2, R3 and R$_{all}$ from 1950-2012.

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

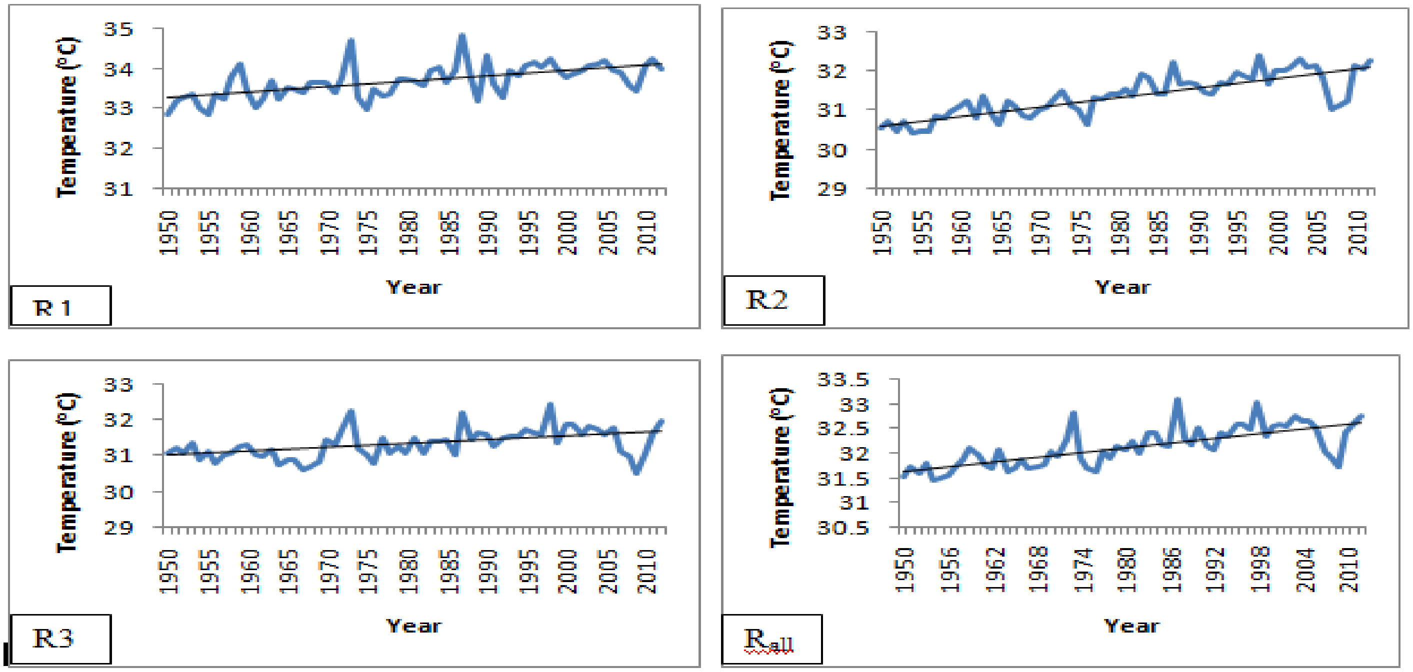

Figure 2. Variation trends of maximum temperature in R1, R2, R3 and R_{all} from 1950-2012.

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

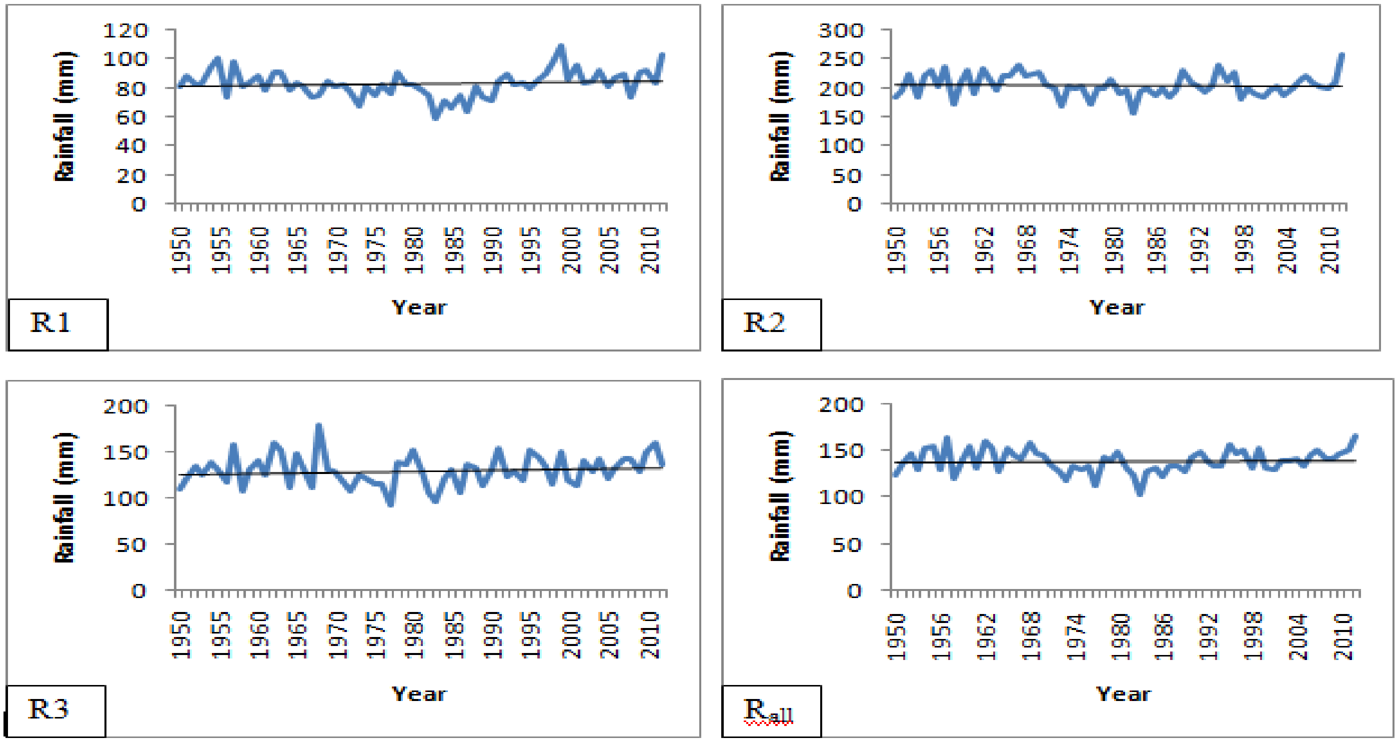

Figure 3. Variation trends of rainfall in R1, R2, R3 and R_{all} from 1950-2012.

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

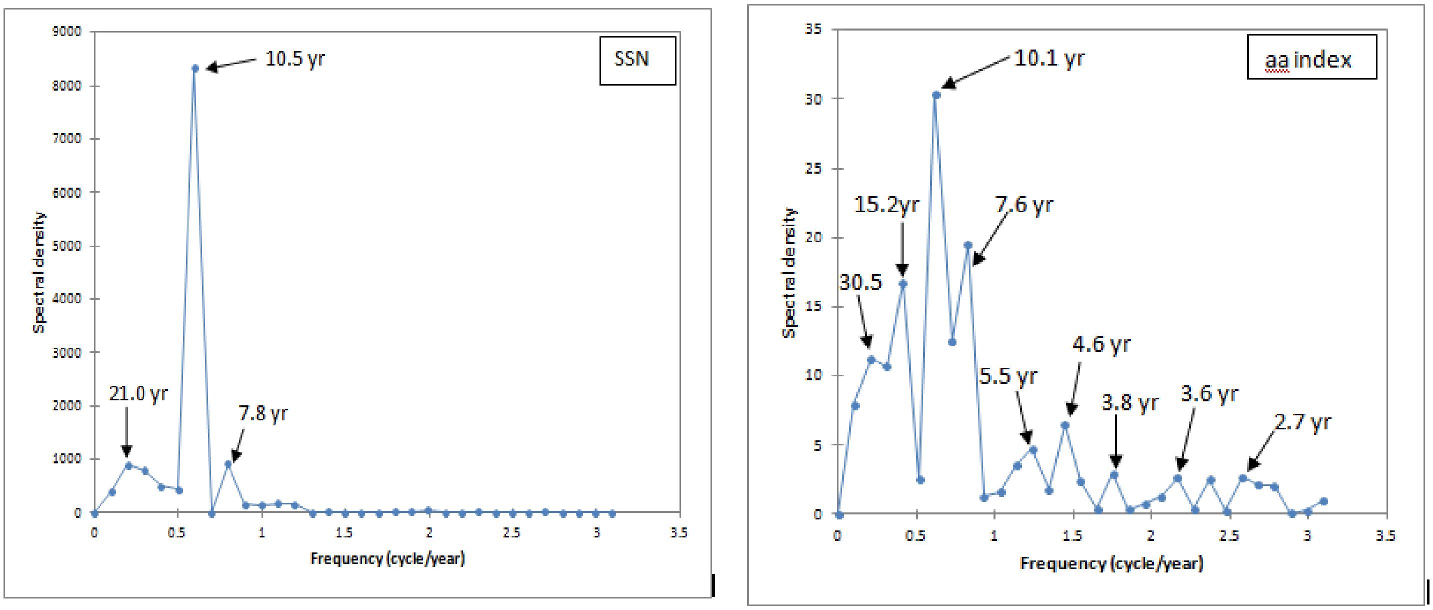

Figure 4. Power spectral density of yearly mean sunspot number and aa index.

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

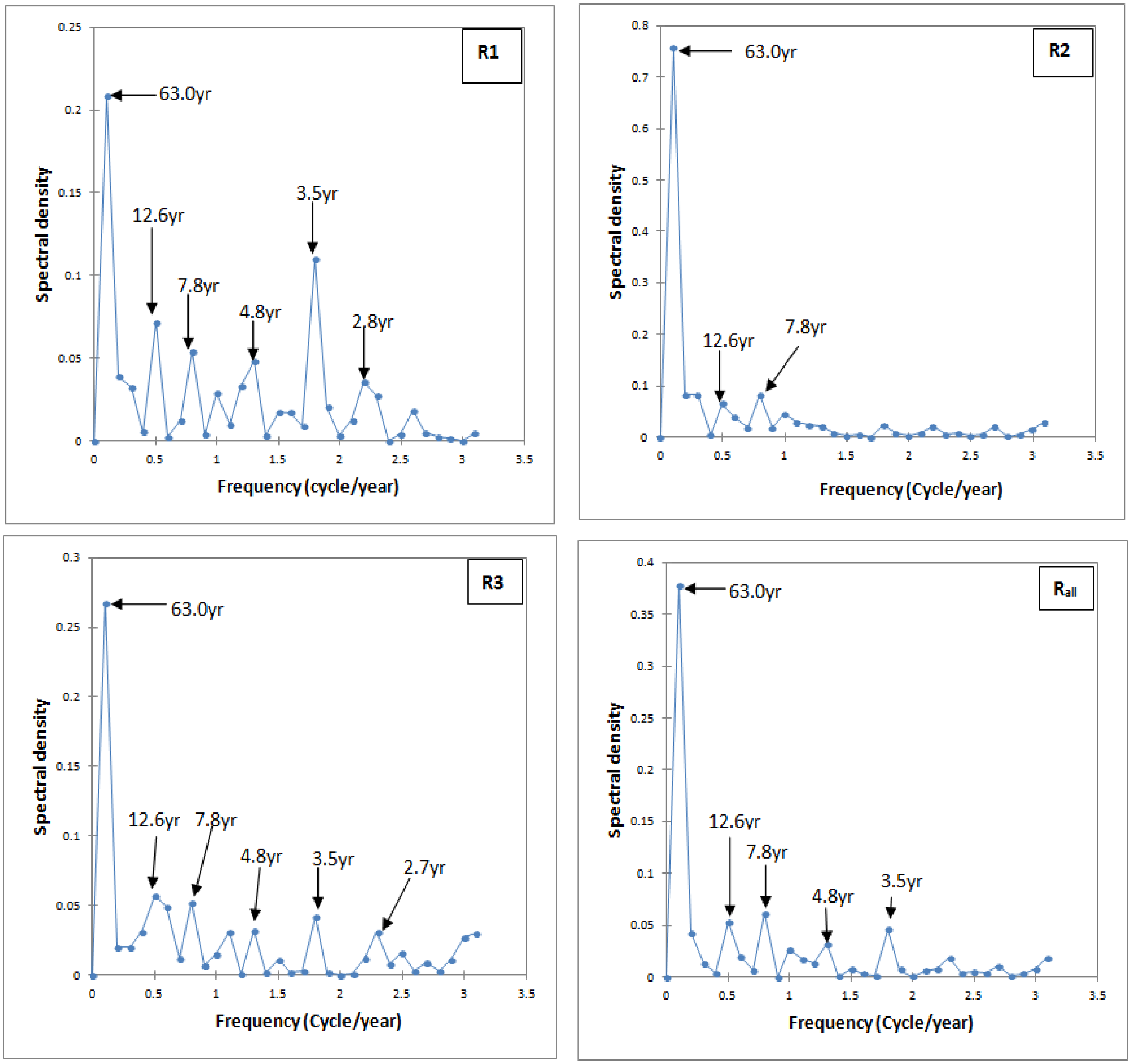

Figure 5. Power spectral density of yearly maximum temperature in R1, R2, R3 and R_{all}.

(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.

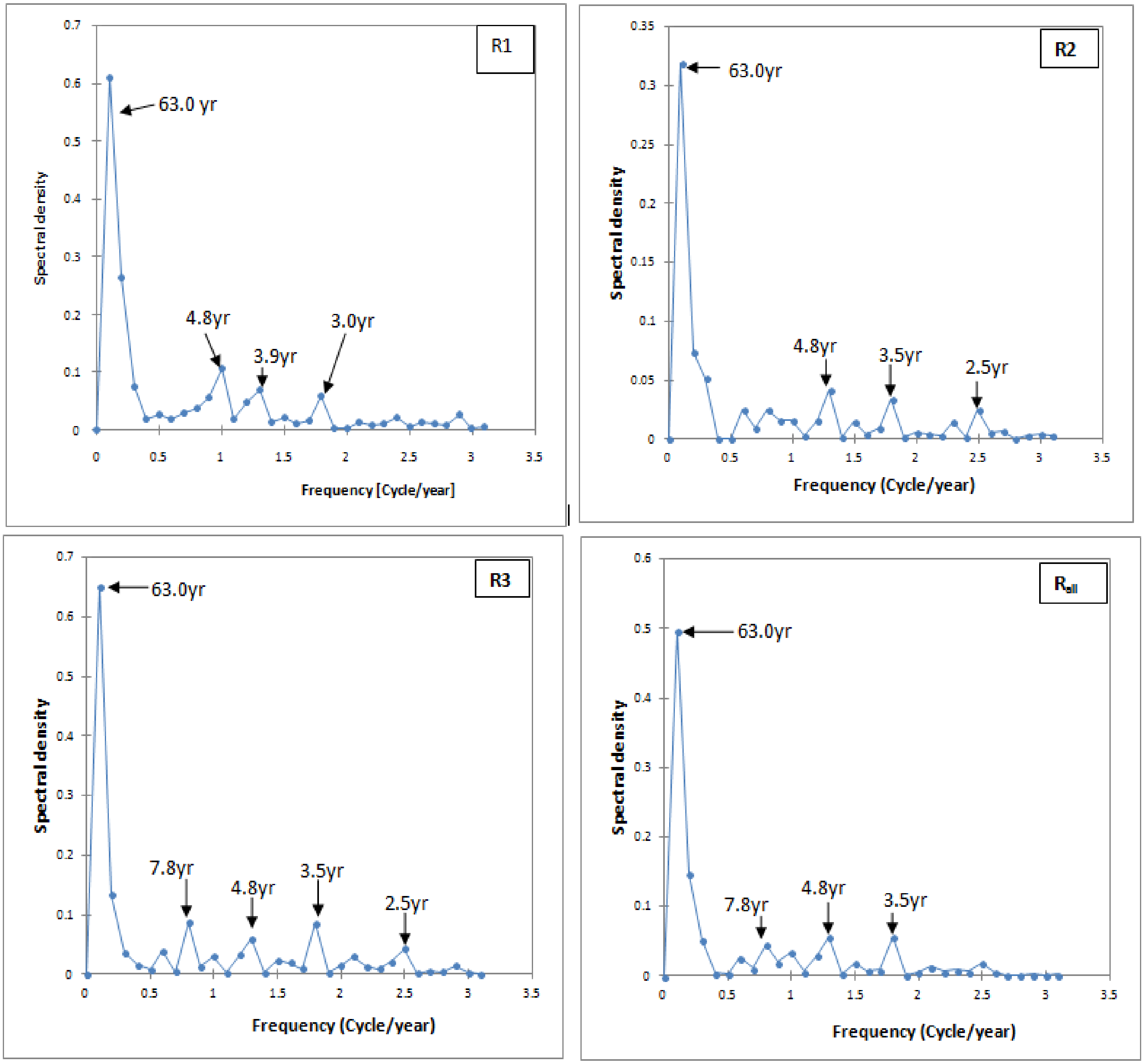

Figure 6. Power spectral density of yearly minimum temperature in R1, R2, R3 and R_{all}.

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.

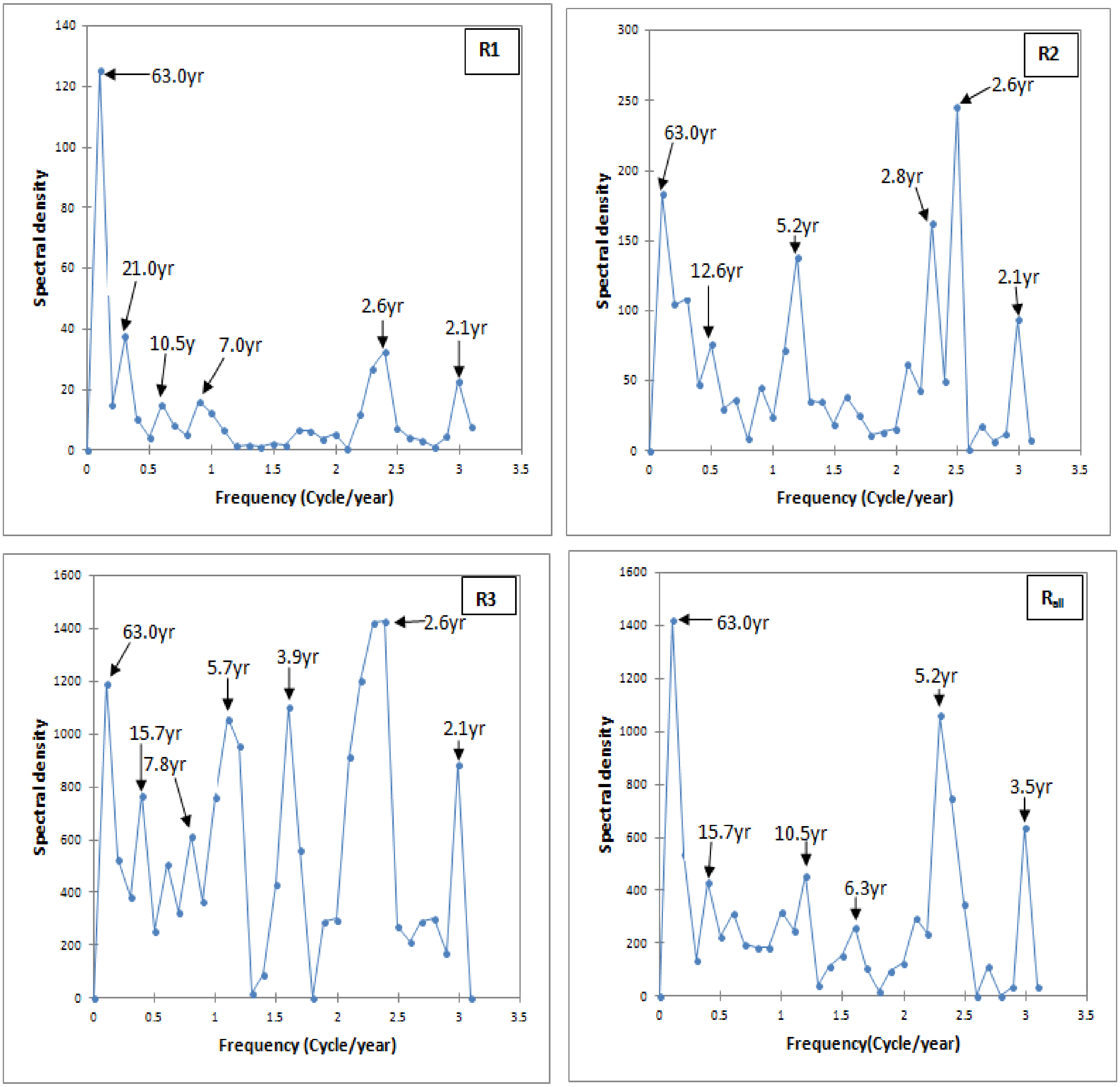

Figure 7. Power spectral density of yearly mean rainfall in R1, R2, R3 and R_{all}.

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