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The Relationships between the Number of Sunspots and Fluctuation in the Trend of Climatic Components in Iran during Recent Decades

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Abstract

The statistical period from 1951 to 2005 was chosen in this research for determining the extent of influence on precipitation and annual temperature from sunspots. This analysis was conducted on 31 synoptic stations in Iran. Initially, the Mann-Kendall test was administered in order to analyze the trend of alterations of these two components over time and the results suggest that 16% of the stations show significant relationship with annual precipitation (positive and negative). More stations showed significant relationships between sunspots and minimum annual temperature (74.19%), maximum annual temperature (48.38%) and mean annual temperature (67.8%). The amounts of the above correlations include all of the significant trends, whether those that show inverse significant trends or those that demonstrate direct significant trends. For further investigating the relationship between variations in the number of sunspots and temperature, 5 temporal ranges were used. This analysis was conducted on raw data (without a moving average) and also on data with a moving average of 5, 8, 11 and 22 years. The general conclusion drawn from different temporal ranges of precipitation data was that a significant amplification for Iran's stations with a frequency coefficient of 25.16% was observed. However, when this relationship is reversed, the frequency the coefficient turned out to be 12.92. Likewise, for different components of temperature, the inverse relationship between the number of sunspots and alterations of temperature possesses a higher frequency position among the stations. This value is 15.46 % for the minimum temperature, 16.12% for the maximum and 12.89% for the annual average temperature.

Keywords: Climate change; Sunspots; Mann-Kendall test; Moving average; Iran.

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1. Introduction

Global climate is constantly changing (Christensen and Sevensmark, 2007). Many hypotheses have been proposed as the main factors responsible for this, some controversial and not universally accepted by the scientific community. Greenhouse gases, aerosol loading and solar factors are among the main causes suggested to explain the changes in observed temperatures in recent decades (Santer *et al.,* 1996). Although most of the Sun-climate mechanisms are not well understood yet, a host of empirical evidence suggests that solar energy changes alter the Earth's climate significantly (Eddy, 1976; Haigh, 1996; Shindell *et al.*, 1999; Marsh and Svensmark, 2003; Lambert et al., 2004; Georgieva *et al.*, 2005; Zanchettin *et al.*, 2008) and that climate sensitivity to solar variations obeys a frequency-dependent transfer function of solar energy, so that the damping effect of the oceanic and atmospheric thermal inertia makes the climate more sensitive to slower solar variations (Wigley, 1988; Foukal *et al.*, 2004; Scafetta and West, 2006; Zanchettin et al.,2008). One of the most strongly advocated theories involves temporal changes in solar activity (Azizi, 2004). Since solar input to the climate system is the main driver of climate, this hypothesis suggests fluctuations in solar income may be influential in causing climate fluctuations (Baldwin and Dunkerton; Landscheidt, 2007).

Solar variability has been suggested as an influential component on climate (Tsiropoula, 2002) and evidence to confirm this on a variety of time scales has been presented (Almeida *et al.*, 2002). In analyzing different climatic parameters, temperature and precipitation, which are usually considered as the representative indicators of climate of a specific zone, are frequently used as important variables in exploring the solar-climate relationship (Tsiropoula, 2003). One of the premises of this research is that since precipitation and temperature are strongly related, small changes in sunspot activity may be amplified in these other parameters. Since 90% of Iran's surface can be described as arid, small fluctuations in temperature and precipitation may be enough to enhance phenomena such as drought, sand storm, etc. and be of critical concern for authorities in the field of macro-planning (Khorshiddoust and Ghavidel, 2004). In this research, not only precipitation but also temperature (minimum, maximum and average) has been taken into consideration. Unfortunately, there are few Iran-based studies in relation to this topic, though solar activity-climate changes causing catastrophes and accidents have been witnessed throughout the world. For example, in a study on Central America, Araya et al (2002), surveyed the probable effects of solar activities on temperature and precipitation and found a significant correlation between the 5, 8 and 11 year phases of sunspots and February temperature and precipitation. Tsiroppoula (2003) achieved important outputs regarding the reaction of different layers of atmosphere such as: stratosphere and troposphere to the solar activities. Another study by Beer and colleagues (2000), showed that sun is the main factor in the climate system and is influential in every major climatic change. Results of the study by Almeida and his colleagues on some regions in Brazil (2004), in the field of analysis of cyclic fluctuations of precipitations regarding 11 and 22 year cycles of sunspots indicated a counter relationship between the sunspots and precipitation. They found that the maximum number of sunspots occur simultaneously with the minimum amounts of precipitation. In another research on Peking, China, results indicated a straight and positive correlation between solar activities and annual precipitation. For the study, Le and colleagues (2003), based their research on continuous wavelet analysis method and took into consideration the 11 year solar cycle. Hiremath (2006) surveyed the effects of solar activities on the trend of seasonal precipitation in India and their cyclic alterations. Using the correlation analysis method for data gathered during 130 years, he revealed a high connection and correlation between seasonal precipitations and solar activities. Among the important points revealed in the course of aforementioned studies and generally in surveying the role of solar activities, is the alteration of effect of solar activities on climatic parameters in different geographical zones. Consequently, the reactions may be positive in some regions, negative and even neutral in others. In a country like Iran with geographical and climatic diversity, different results could be seen.

It goes without saying that identifying the precipitation variations and the conditions of droughts and wet years in Iran regarding solar activities and the trend of these variations will be very useful in providing readiness for adapting to the new environmental and climatic conditions and planning suitable programs ahead involving such sectors as agriculture, agricultural products and nutritional security.

2. Materials and methods

2.1. Climate data and sunspots

Average precipitation data and annual temperature (minimum, maximum and daily) for 31 research stations in Iran were collected, in which the longest periods belonged to the year 1951 to 2005 (Figure 1). It is noteworthy that climate data has been measured since 1951 in Iran. Therefore, there are few stations which have this entire statistical period and others only have a shorter period of data collection (Table 1).

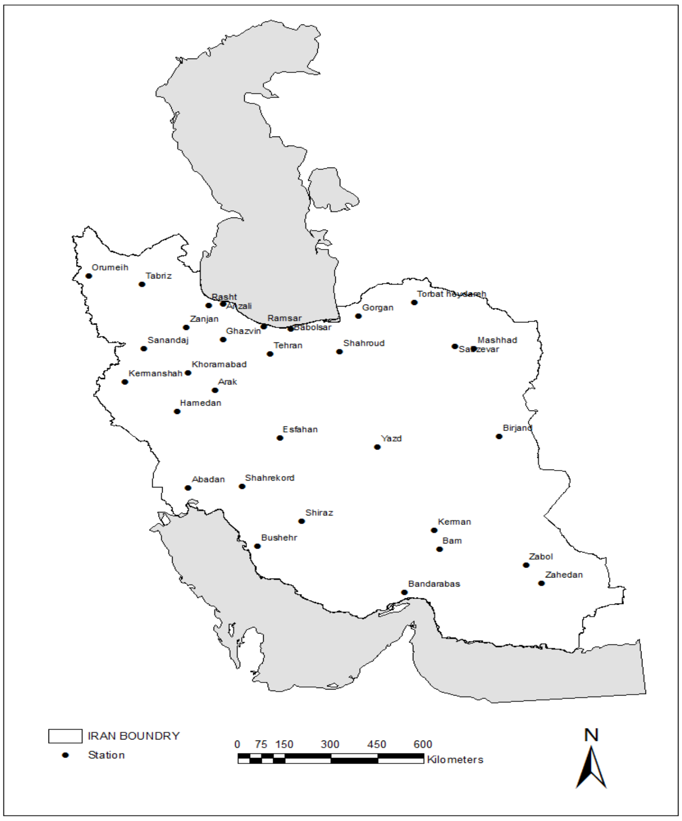

Figure 1. The studied stations according to their distribution in Iran

In the present research, the number of sun spots was used to examine the solar activities. For achieving this goal, data related to the annual average of the number of sun spots for the intended statistical period were collected from National Oceanic and Atmospheric Administration (NOAA) and the National Geophysical Data Center (NGCD) and were used accordingly. These data are demonstrated in Figure 2.

Table 1. Geographical situation and the length of the statistical period of the chosen stations

Station	Latitude	Longitude	Elevation in meter	Time series	Station	Latitude	Longitude	Elevation in meter	Time series
Babolsar	36 43 N	52 39 E	-21.0	1951-2005	Abadan	30 22 N	48 15 E	6.6	1951-2005
Bandarabas	27 13 N	56 22 E	10.0	1957-2003	Anzali	37 28 N	49 28 E	-26.2	1952-2005
Bushehr	28 59 N	50 50 E	19.6	1951-2005	Arak	34 6 N	49 46 E	1708.0	1955-2005
Esfahan	32 37 N	51 40 E	1550.4	1951-2005	Bam	29 6 N	58 21 E	1066.9	1956-2005
Ghazvin	36 15 N	50 3 E	1279.2	1959-2005	Birjand	32 52 N	59 12 E	1491.0	1955-2005
Gorgan	1279.2M	54 16 E	13.3	1952-2005	Hamedan	35 12 N	48 43 E	1679.7	1951-2005
Kerman	30 15 N	56 58 E	1753.8	1951-2005	Khoramabad	33 26 N	48 17 E	1147.8	1951-2005
Kermanshah	34 21 N	47 9 E	1318.6	1951-2003	Orumeih	37 32 N	45 5 E	1315.9	1953-2005
Mashhad	36 16 N	59 38 E	999.2	1951-2005	Ramsar	36 54 N	50 40 E	-20.0	1955-2005
Rasht	37 15 N	49 36 E	-6.9	1956-2005	Sabzevar	36 12 N	57 43 E	977.6	1955-2005
Shahrekord	32 17 N	50 51 E	2048.9	1955-2003	Sanandaj	35 20 N	47 0 E	1373.4	1963-2005
Shiraz	29 32 N	52 36 E	1484.0	1951-2005	Shahroud	36 25 N	54 57 E	1345.3	1951-2005
Tabriz	38 5 N	46 17 E	1361.0	1951-2005	Torbate	35 16 N	59 13 E	1450.8	1959-2005
Tehran	35 41 N	51 19 E	1190.8	1951-2005	Zabol	31 2 N	61 29 E	489.2	1963-2005
Yazd	31 54 N	54 17 E	1237.2	1952-2005	Zanjan	36 41 N	48 29 E	1663.0	1955-2005
Zahedan	29 28 N	60 53 E	1370.0	1951-2005	-	-	-	-	-

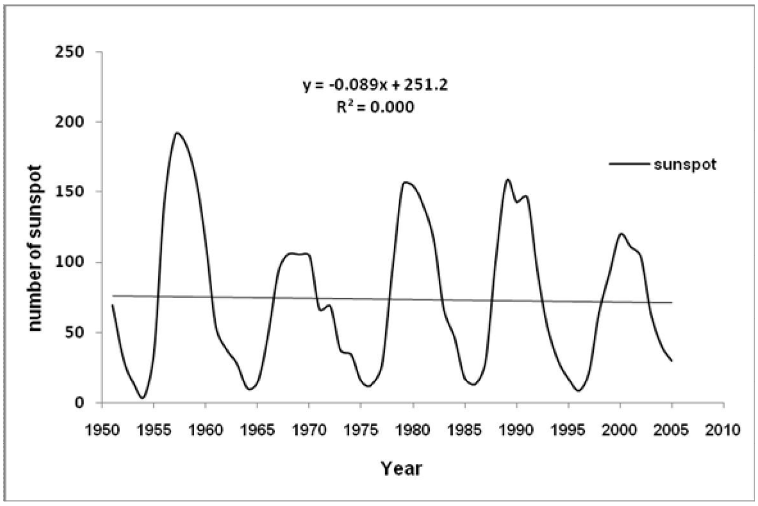

Figure 2. The average number of the sun spots of Wolf or Zurich RZ for the statistical period (Source data: NOAA, 2011).

2.2. Statistical tests for trend analysis

2.2.1. Mann-Kendall test

Initially, for demonstrating the significance of the fluctuations trend of temperature and precipitation in the course of time, the trend test was carried out. In statistical tests, the zero hypothesis trend or H_0 means that the studied series has no trend, whereas H1 indicates that the series have a trend. For surveying and identifying the trend, parametrical and non-parametrical methods are used. However, non-parametrical methods have higher accuracy and are more reliable. Among the non-parametrical methods, the Mann-Kendall test is considered as the best method for identifying steady trends (Rahimzadeh *et al.*, 2009; Tabari and Talaee, 2011).

Therefore, for identifying trends which are steady and have a distinct direction in the temporal series of precipitation and annual temperature (minimum, maximum and daily), the Mann-Kendall test was used. This method is summarized briefly below (Rahimzadeh et al., 2009; Tabari and Talaee, 2011):

The Mann-Kendall test is a non-parametric test and does not need the data to be distributed normally (Tabari and Hosseinzade Talaee 2011). Another benefit of the test is that it has a low sensitivity to sudden breaks because of time series that are non homogeneous. According to the test, the null hypothesis H_0 indicates that the data that has been rejected (x_1, ..., x_n) is an example of n independent variables that have been normally distributed. The alternative hypothesis H_1 of a two-sided test implies that the dispersions of x_k and x_j are not the same for all $k, j \leq n \text{ with } k \neq j$ The test statistic S, which has zero average and a variance that has been calculated using Equation 3, is calculated by Equations 1 and 2 and is asymptotically normal (Tabari and Talaee, 2011):

$$s = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k) \tag{1}$$

$$\text{sgn}(x_j - x_k) = \begin{cases} +1 & if \quad x_j - x_k > 0 \\ 0 & if \quad x_j - x_k = 0 \\ -1 & if \quad x_j - x_k < 0 \end{cases} \tag{2}$$

$$Var(s) = \frac{[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)]}{18} \tag{3}$$

The notation t is the extent of any tie that is given and $\sum_t$ means the sum over all ties. If the size of the sample is n >10, the standard normal variable Z is calculated using Equation 4.

$$\begin{cases} \dfrac{s-1}{\sqrt{\text{var}(s)}} & if \quad s>0 \\ 0 \quad if & s=0 \\ \dfrac{s+1}{\sqrt{\text{var}(s)}} & if \quad s>0 \end{cases} \qquad (4)$$

Positive values of Z show increasing trends whereas negative values of Z demonstrate decreasing trends. When one tests either the increasing or decreasing monotonic trends at the significance level α, the null hypothesis is repudiated for an absolute value of Z that is greater than $Z_{1-\alpha/2}$ obtained from the standard normal cumulative dispersion tables (Partal and Kahya 2006; Modarres and Silva 2007; Tabari and Talaee,2011). In the present research, significance levels of $\alpha = 0.01$ and 0.05 were applied.

2.2.2. Linear regression method

Data from sun spots consisted of two manifest cycles of 11 and 12 years that overtly change with time. Additional to these two manifest cycles, two other small and weak cycles which are 5 and 8 years are identifiable. The 11-year cycle has the maximum fluctuations and is stronger than the 22-year one (Jahanbash and Edalatdoust, 2008).

In this research, the ultimate goal has been to attain further information on the nature of the relationship between precipitation and the annual temperature with the number of sun spots in various periods of the temporal series. For this, no moving average and moving averages of 5, 8, 11, and 22-year periods in Iran have been used in software SPSS, for the coefficient, the correlation coefficient of Pearson and the significance of the variables. In this section, the data related to 0, 5, 8, 11, and 22-year periods have been analyzed. The 0-year period means that the data of precipitation and temperature and the number of sun spots have been used without calculating the moving average. In the same way, the 5, 8, 11, and 22-year periods indicate the moving average of 5, 8, 11, and 22 years from the respective climatic data and the number of sun spots have been included. The moving average is a kind of filter with low frequency that decreases in relation to the amount of the lack of correlation between variables. Linear regression analysis and the Mann–Kendall test are used for identifying and analyzing trends in time series. The slope which is the major statistical parameter taken from the regression analysis shows the average temporal variation of the studied variable. Negative values of the slope demonstrate trends that are increasing, whereas positive values of the slope imply trends that are decreasing. The overall variation during the period under investigation is obtained by multiplying the slope with the number of years (Tabari and Maroofi 2011a; Tabari *et al.*, 20011b).

3. Results

3.1. The trend fluctuations of the annual temperature and precipitation for recent decades

As it can be seen in Figure 5a, generally speaking, the precipitation of most of the observational stations follows an accidental annual trend. However, among the studied stations, there appears two significant and increasing trends; first the station of Babolsar with the Mann-Kendall coefficient by the amount of Man-Kendall Test (MT); 2.505 and the decadal fluctuations of precipitation by the amount of (+32mm/decade), indicates significance in the range of 1 percent and second, the station of Abadan with the Man-Kendall coefficient of (MT=2.011; +7.28mm/decade) indicates the significance of fluctuations of precipitation in the range of 5 percent (Figure 3a,b). Despite this increasing trend for the above stations, the results of Mann-Kendall for the station of Tabriz (MT=-2.621;-11.88mm/decade), the stations of Zahedan (MT= -3.245; -16.71mm/decade), and Orumeih (MT=-2.737; -27.31mm/decade), indicate a decreasing and significant trend of the fluctuations of precipitation in the range of 1 percent (Figure 3c, d, e).

The fluctuations of the average coordinate of the minimum annual temperature for the studied stations demonstrate that about 74.22 percent of the surveyed stations have significant trends (decreasing and increasing). Among these stations 64.52 percent indicate an increasing trend, while approximately 9.7 percent indicate a decreasing trend of temperature (Figure 5b). Therefore, among the studied stations, Hamedan with the Mann-Kendall coefficient of 0.43 (MT=-2.040; -C°/decade), Khoramabad with (MT=-2.669; -0.18C°/decade) and Orumeih with (MT=-2.432; -0.32C°/decade), indicate a decreasing trend in temperature. Apart from the Khoramabad station with its fluctuations significant in the range of 1 percent, in the other two stations the fluctuations of the temperature trend are significant in the range of 5 percent. It is interesting that all three stations are located in the area covering the north-west and west of Iran. As it was stated earlier, most of the studied stations have a positive and increasing trend. The most prominent of these significant trends are (in the order of prominence) the station of Tehran (MT=7.717;0.71C°/decade), Bushehr (MT=7.339; 0.45C°/decade), Bam (MT=6.918; 0.59C°/ decade), Sabzevar (MT=6.570;0.78C°/decade), and Babolsar (MT=6.280; -0.38C°/decade) (Figure 4). The important point here is that this significant increasing trend in temperature is valid for all of these stations in the range of 0.01.

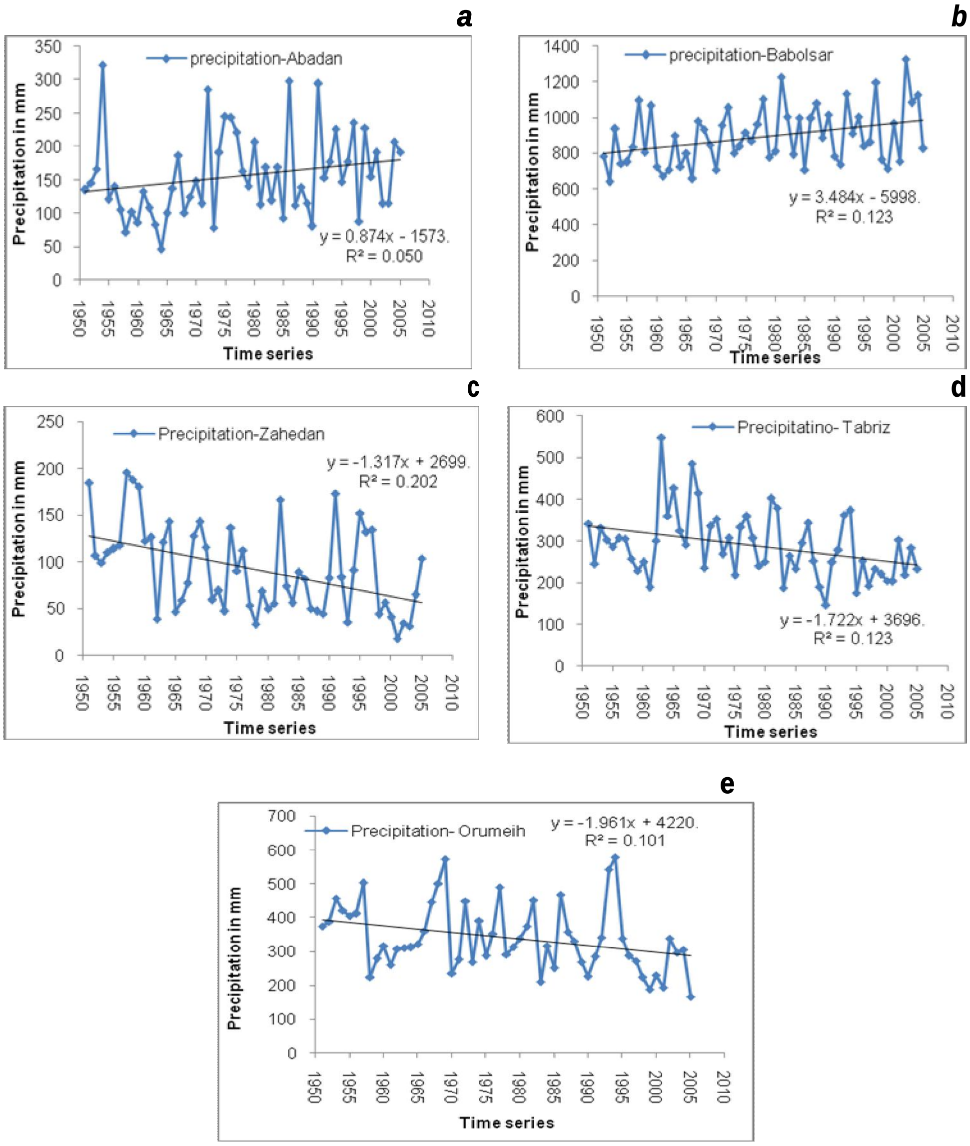

Figure 3. The significant increasing fluctuations of precipitation in the stations of [Babolsar (a) and Abadan (b)] and decreasing annual precipitation in the stations of [Zahedan (c), Tabriz (d) and Orumeih (e)] in the study period 1951-2005

In the case of the maximum annual temperature coordinate, 48.38 percent of the stations have significant temperature fluctuation trends; but 9.67 percent of these stations have significant decreasing trends and 38.70 percent have significant increasing temperature trends. Therefore, the station of Anzali with the decadal decrease of temperature by the amount of -0.11 and the Mann-Kendall significance coefficient with the value of -2.45 and the significant area of 5 percent, the station of Khoramabad with the decadal decrease of temperature by the amount of -0.17 and the significant area of 5 percent, and finally the station of Torbat Heydarie with the decadal decrease of temperature by the amount of -0.17 and the statistical value of the Mann-Kendall coefficient of -2.72, are significant in the range of 1 percent. It is worth noting that apart from the decreasing trend of temperature for the coordinate of minimum temperature in the station of Khoramabad, this decreasing trend of temperature is observed in maximum temperature as well.

The significant trend of the increase in the maximum annual temperature in the order of the magnitude of significance is observed in the stations of Mashhad (Mt=3.85), Yazd (Mt=3.76), Babolsar (Mt=3.58), Bam (Mt=3.56), Sabzevar (Mt=3.40), Sanandaj (Mt=3.27), Shiraz (Mt=3.23), Kermanshah (Mt=3.07), Tabriz (Mt=3), Hamedan (Mt=2.85), Abadan (Mt=2.61), and Tehran (Mt=2.11) (Figure 5c). All in all, the average of the decadal increase in temperature for the stations with a significant trend is 0.31 degrees of centigrade, with fluctuations from its maximum in the station of Bam (0.43 degrees of centigrade) and the minimum decadal increase in temperature in the station of Tehran (0.21 degrees of centigrade).

The fourth aspect is identifying the annual trend of the average temperature for the 31 stations under examination (Figure 5d). Based on these stations, about 67.8 percent, equal to 21 stations have significant trends. Among these stations, only the station of Khoramabad with decreasing and decadal fluctuations by the amount of -0.175 degrees of centigrade and the station of Orumeih with decreasing decadal fluctuation of temperature by the amount of -0.20 degrees centigrade are observed in the range of 1 percent of significance (Figure 4e). However, the sum of the increasing and decadal average of temperature for this coordinate in the 19 stations shows the amount of 0.33 degrees of centigrade. The oscillations of the increase of decadal temperature are as follows: the highest amount belongs to the stations of Bam and Sabzevar with the average of 0.54 degrees centigrade and the lowest amount belongs to the two stations of Zahedan and Anzali with the average decadal increase of 0.15 degrees centigrade.

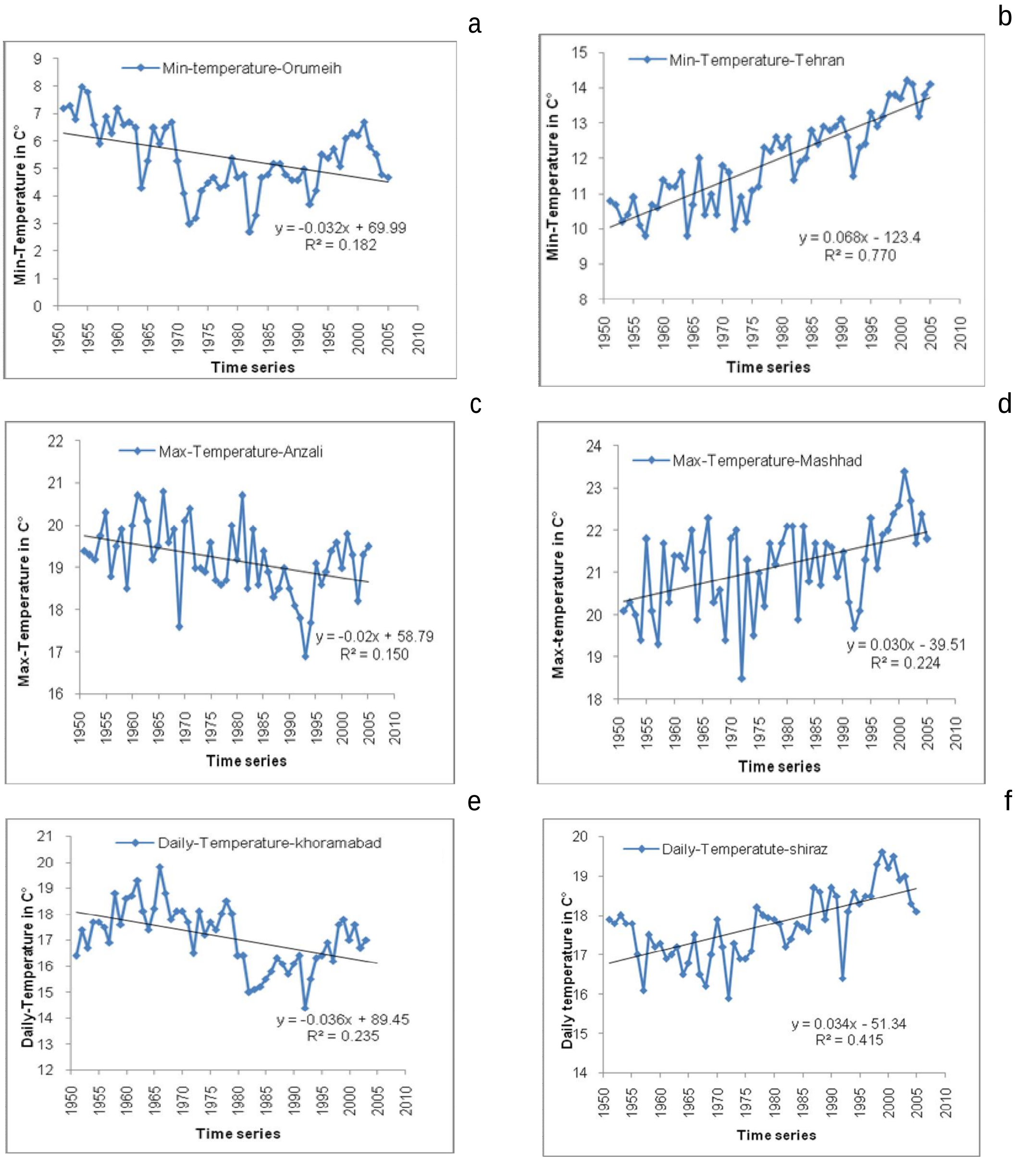

Figure 4. The significant fluctuations of temperature for the coordinates of minimum temperature in the station of Orumeih (a), the maximum temperature in Anzali (c) and the average temperature in the station of Khoramabad (e) and the increasing significant trend of temperature for the coordinates of minimum temperature in the station of Tehran (b), the maximum temperature in Mashhad (d) and the average temperature in the station of Shiraz (f) for the study period 1951-2005.

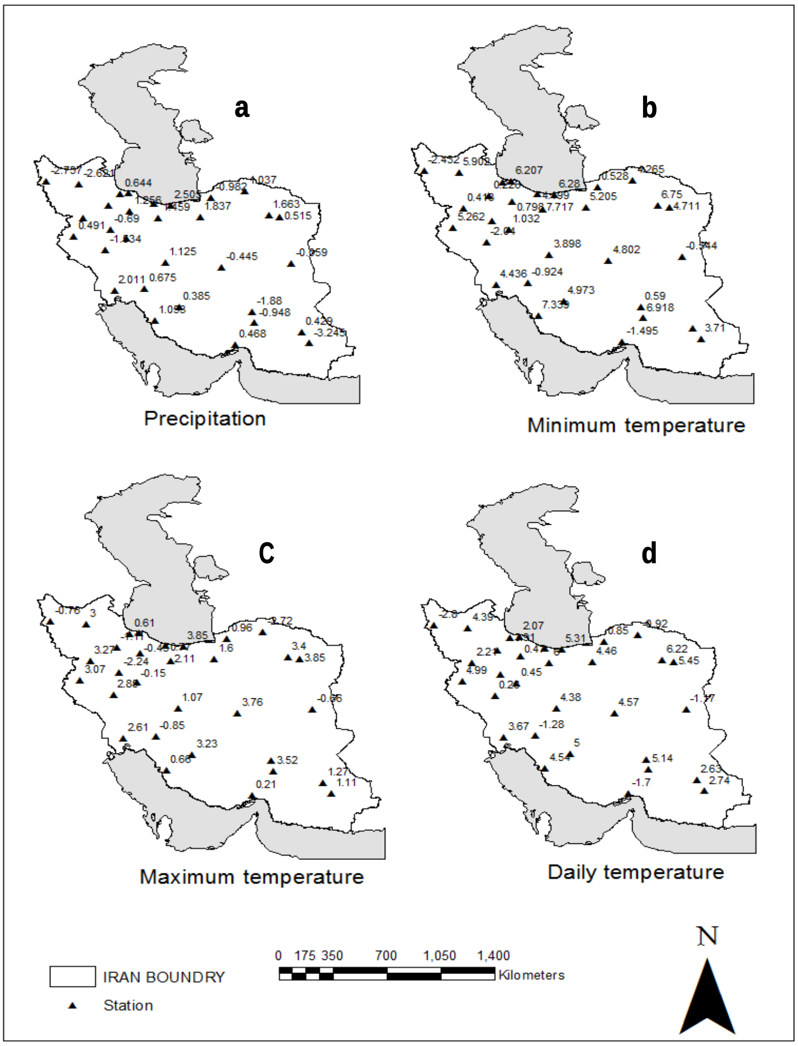

Figure 5. The fluctuations of the annual trend of the coordinates of precipitation (a), minimum temperature (b), maximum temperature(c) and average temperature (d) using the method of Mann-Kendall for the studied stations

3.2. Evaluating the role of sun spots in fluctuations of the coordinates of temperature and precipitation of Iran

Regarding the significance of the matter, in this section we deal with the relationship of the Pearson correlation between the amounts of annual precipitation in Iran and the number of sun spots in 5 normal regions (without the moving average), the moving averages 5, 8, 11, and 22-year periods. The first result is that if we increase the time period of moving averages, the number of significant stations whose precipitation depend on the fluctuations of the number of sun spots, increases as well. This means that the lowest frequency distribution regarding the number of stations with a significant trend belongs to the coordinate of the stations without moving average (12.9%) and the maximum number of stations with a significant trend has occurred for the 22-year moving average (61.3%). However, for the relationship between normal data (without moving average), 13 percent of the stations have a significant trend; 6.5 percent of these have direct relationship between the increase of precipitation and the number of spots and 6.5 percent have inverse relationship between the decrease of precipitation and the increase in the number of spots. For the 5-year moving average, like before, we have an equal proportion between the increasing and decreasing trend and the number of sun spots. Around 12.9 percent indicate direct relationship and an increase in precipitation, whereas 12.9 percent indicate inverse relationship and a decrease in precipitation with the fluctuations of sun spots. On the other hand, from the moving average of 8 to 22 years, the share of direct relationship and an increase (or decrease) in precipitation with the increase (or decrease) in the number of spots is greater than the inverse relationship with precipitation. For the 8-year moving average, this proportion changes from 35.5 percent for the direct trend of precipitation to 6.5 percent for the trend of inverse relationship between the amount of precipitation and the number of sun spots. Moreover, this proportion for the 11-year moving average has fluctuated from 35.5% for direct trend to 19.4 percent for the inverse trend of precipitation and finally, for the 22-year moving average has fluctuated from 38.7 percent for direct trend to 22.6 percent for the inverse trend of the fluctuations of precipitation with the changes of the number of the spots (Table 2). Therefore, we can state that the share of the maximum (minimum) number of sun spots on the increase (decrease) of the amounts of annual precipitation is greater than the decrease (increase) of the number of spots on the increase (decrease) of Iran's annual precipitation. This result for the stations of Bandarabas, Ghazvin, Kerman, Shiraz, Anzali, Birjand, and Hamedan holds in a way that the maximum (minimum) number of spots is simultaneous with the increase (decrease) of the annual precipitation. On the other hand, the increasing (decreasing) effect of the sun spots occurs simultaneously with the decrease (increase) of the annual precipitation for the stations like Kermanshah, Tabriz, Abadan, Arak, Khoramabad, and Zanjan.

Regarding the coordinate of minimum temperature, what is identified at first glance is the increase in the number of stations with the significant trend for the 22-year moving average in proportion to the data of lower moving average. In any case, for normal data (without moving average), the share of stations with a significant trend that the increase (decrease) in their temperature is affected by the increase (decrease) in the number of sun spots, is equal to the stations that the increase (decrease) in their temperature is simultaneous with the maximum (minimum) number of sun spots. This share for each one separately, includes 3.2 percent of the distribution frequency of the studied stations. However, for the 5-year moving average, this amount for the stations whose trend of temperature increase (decrease) is simultaneous with the occurrence of the maximum (minimum) number of spots, includes 9.67 percent of the distribution frequencies. With the increase (decrease) in the number of sun spots, no significant relationship with the decrease (increase) of temperature is observed in any of the stations. But this share for the simultaneity of the occurrence of maximum (minimum) temperature and the appearance of the maximum (minimum) number of sun spots for 8- and 11-year moving averages is 13 and 9.67% of the distribution frequencies respectively. This concordance of the decrease (increase) of temperature and the occurrence of the maximum (minimum) number of spots is 19.3 percent for the 8-year moving average and 25.8 percent for the 11-year moving average. The results for the 22-year moving average indicate that the greatest share of significance of the trend in the fluctuations of the minimum temperature of the stations is the simultaneity of temperature increase and the occurrence of the maximum number of spots with the distribution frequencies of 32.25 percent. On the other hand, those stations which the temperature increase (decrease) is simultaneous with the occurrence of the decrease (increase) in the number of sun spots, demonstrate a share which is approximately 29 percent of the distribution frequencies. For the final conclusion in this section, if the moving average of the distribution frequencies for all the various moving averages is considered sufficient, we conclude that in general when temperature increases (decreases), the minimum (maximum) occurrence of the number of spots achieves a greater share of 15.46 percent of the distribution frequencies. This process is more noticeable in stations like Bandarabas, Ghazvin, Arak, Birjand, and Sanandaj. The share of the stations in which the trend of the increase (decrease) in their minimum temperature is simultaneous with the occurrence of the maximum (decrease) of the number of spots covers 13.5 percent of the distribution frequencies. As an example of this process we may perhaps refer to stations like Torbate Heydarie, Rasht, Hamedan, and Kerman (Table 3).

Table 2. The correlation coefficient between the amounts of annual precipitation and the fluctuations of the number of sun spots with the 5, 8, 11, and 22-year moving averages

Precipitation	Normal series		Moving average 5		Moving average 8		Moving average 11		Moving average 22	
Statical value / Station	R	P	R	P	R	P	R	P	R	P
Babolsar	0.14	0.302	0.26	0.061*	0.08	0.600	-0.08	0.609	0.24	0.171
Bandarabas	0.18	0.235	0.16	0.303	0.27	0.094*	0.48	0.003***	0.87	0.000***
Bushehr	0.16	0.237	0.21	0.142	0.29	0.044**	0.19	0.209	0.34	0.046**
Esfahan	-0.10	0.472	-0.03	0.824	0.14	0.336	-0.07	0.625	0.32	0.066*
Ghazvin	-0.05	0.746	0.22	0.155	0.46	0.003***	0.65	0.000***	0.57	0.002***
Gorgan	0.38	0.005***	0.37	0.008***	0.20	0.178	0.06	0.703	-0.40	0.022**
Kerman	-0.05	0.440	-0.02	0.863	0.39	0.007***	0.63	0.000***	0.44	0.009***
Kermanshah	0.009	0.952	-0.09	0.509	-0.31	0.034**	-0.70	0.000***	-0.57	0.001***
Mashhad	-0.02	0.884	0.07	0.638	0.22	0.134	0.36	0.015**	0.40	0.020**
Rasht	0.004	0.976	-0.008	0.957	0.05	0.748	-0.05	0.776	0.24	0.217
Shahrekord	-0.27	0.069*	-0.39	0.008***	-0.12	0.443	-0.13	0.453	0.17	0.398
Shiraz	-0.04	0.771	0.03	0.810	0.35	0.016**	0.30	0.043**	0.49	0.003***
Tabriz	-0.17	0.216	-0.25	0.073*	-0.21	0.148	-0.25	0.100*	-0.45	0.008***
Tehran	-0.06	0.685	-0.07	0.648	-0.02	0.893	-0.11	0.477	0.22	0.222
Yazd	0.10	0.475	0.26	0.070*	0.29	0.053*	0.24	0.114	0.20	0.270
Zahedan	0.14	0.308	0.18	0.200	0.35	0.016**	0.36	0.014**	-0.02	0.898
Abadan	-0.25	0.068*	-0.30	0.030**	-0.25	0.090*	-0.29	0.057*	0.23	0.196
Anzali	0.23	0.092*	0.33	0.017**	0.52	0.000***	0.62	0.000***	-0.02	0.926
Arak	-0.01	0.950	0.02	0.896	-0.09	0.579	-0.51	0.001***	-0.51	0.005***
Bam	0.015	0.921	-0.22	0.145	-0.11	0.487	-0.06	0.739	0.13	0.494
Birjand	0.07	0.615	0.05	0.719	0.26	0.096*	0.67	0.000***	0.67	0.000***
Hamedan	0.059	0.676	0.22	0.131	0.48	0.001***	0.44	0.003***	0.63	0.000***
Khoramabad	-0.13	0.348	-0.19	0.195	-0.12	0.418	-0.63	0.000***	-0.41	0.019**
Orumeih	-0.09	0.509	-0.11	0.451	0.04	0.774	-0.16	0.299	-0.24	0.173
Ramsar	0.00	0.987	0.12	0.442	0.17	0.279	-0.03	0.846	-0.39	0.035**
Sabzevar	0.05	0.704	0.03	0.838	0.09	0.583	0.17	0.291	0.52	0.003***
Sanandaj	-0.04	0.786	0.04	0.800	0.28	0.082*	0.47	0.004***	-0.05	0.828
Shahrud	0.20	0.137	0.15	0.305	-0.14	0.345	-0.28	0.066*	0.17	0.331
Torbate Heydarie	0.12	0.443	0.19	0.233	0.24	0.155	0.43	0.010***	0.64	0.001***
Zabol	-0.06	0.681	-0.12	0.463	-0.11	0.508	0.09	0.606	0.53	0.012**
Zanjan	-0.04	0.780	-0.26	0.075*	-0.15	0.323	-0.26	0.099*	-0.47	0.011**

R= Pearson correlation; P: Significance value; Trends are significant with *P<0.10; **P<0.05; ***P<0.01

For the trend fluctuations of the maximum coordinate of temperature, evidences do not agree with this. First of all, for temporal series of normal data and the 5-year moving average, only the increase (decrease) in the occurrence of sun spots has a direct and significant relationship with the increase (decrease) of the maximum coordinate of temperature.

Table 3. The correlation coefficient between minimum temperature and the fluctuations of the number of sun spots with the 5, 8, 11, and 22-year moving averages

Min-Temperature	Normal series		Moving average 5		Moving average 8		Moving average 11		Moving average 22	
Statical value / Station	R	P	R	P	R	P	R	P	R	P
Babolsar	0.03	0.853	0.02	0.873	-0.15	0.305	-0.24	0.113	0.19	0.275
Bandarabas	0.18	0.239	0.05	0.741	-0.28	0.076*	-0.49	0.002***	-0.78	0.000***
Bushehr	-0.11	0.429	-0.10	0.495	-0.21	0.144	-0.24	0.113	0.23	0.197
Esfahan	0.12	0.391	0.10	0.487	-0.14	0.360	-0.06	0.705	0.20	0.257
Ghazvin	-0.02	0.871	-0.02	0.899	-0.32	0.045**	-0.73	0.000***	-0.69	0.000***
Gorgan	0.24	0.085*	0.39	0.006***	0.27	0.075*	-0.02	0.559	-0.39	0.027**
Kerman	0.02	0.902	0.18	0.219	0.38	0.007***	0.24	0.112	0.30	0.082
Kermanshah	0.079	0.573	0.10	0.476	-0.02	0.903	0.10	0.513	0.49	0.004***
Mashhad	-0.03	0.854	0.04	0.795	-0.03	0.852	-0.07	0.671	0.28	0.114
Rasht	-0.135	0.350	-0.024	0.875	0.20	0.197	0.47	0.002***	0.46	0.011**
Shahrekord	-0.04	0.783	0.02	0.892	-0.15	0.346	-0.35	0.030**	-0.81	0.000***
Shiraz	-0.05	0.699	0.00	0.999	0.01	0.921	0.03	0.826	0.35	0.041**
Tabriz	-0.03	0.832	-0.03	0.810	-0.20	0.165	-0.24	0.114	0.16	0.365
Tehran	0.02	0.900	0.02	0.888	-0.13	0.396	-0.12	0.450	0.27	0.130
Yazd	0.02	0.908	0.14	0.327	0.04	0.792	-0.11	0.499	0.30	0.092*
Zahedan	0.08	0.539	0.23	0.106	0.21	0.155	0.17	0.264	0.33	0.054**
Abadan	-0.11	0.436	-0.13	0.357	-0.36	0.011**	-0.59	0.000***	-0.05	0.794
Anzali	-0.09	0.516	-0.11	0.424	-0.22	0.128	-0.19	0.210	0.23	0.193
Arak	-0.15	0.356	-0.17	0.265	-0.34	0.027**	-0.62	0.000***	-0.72	0.000***
Bam	-0.075	0.437	0.12	0.447	0.14	0.364	0.11	0.511	0.43	0.022**
Birjand	-0.24	0.085*	-0.24	0.102	-0.41	0.007***	-0.67	0.000***	-0.67	0.000***
Hamedan	-0.007	0.961	0.15	0.318	0.35	0.014**	0.32	0.037**	-0.06	0.732
Khoramabad	-0.13	0.366	-0.14	0.334	-0.21	0.168	-0.39	0.010	-0.62	0.000***
Orumeih	0.04	0.757	0.11	0.431	0.25	0.088*	0.15	0.321	-0.15	0.382
Ramsar	-0.03	0.857	-0.03	0.854	-0.10	0.515	-0.19	0.243	0.08	0.687
Sabzevar	-0.07	0.623	-0.05	0.763	0.02	0.910	0.13	0.412	0.45	0.012**
Sanandaj	0.10	0.518	-0.01	0.935	-0.31	0.057	-0.73	0.000***	-0.51	0.010***
Shahrud	-0.07	0.625	0.02	0.875	0.06	0.673	0.12	0.448	0.34	0.046**
Torbate Heydarie	0.22	0.146	0.38	0.013**	0.40	0.014**	0.68	0.000***	0.79	0.000***
Zabol	0.12	0.447	0.24	0.135	0.08	0.649	-0.02	0.892	0.09	0.686
Zanjan	0.19	0.176	0.27	0.065**	0.22	0.156	0.07	0.661	-0.59	0.001***

R=Pearson correlation; P: Significance value; Trends are significant with *P<0.10; **P<0.05; ***P<0.01

For this purpose, the distribution frequency of the stations with regards to normal data (without moving average), is 3.22 percent and for the 5-year moving average is 6.45 percent. For the 8-year to 22-year moving averages, the results show that the percentage of the distribution frequency of the stations increase with a significant trend and the share of influence of the increase (decrease) in the number of spots upon the decrease (increase) in the maximum temperature is greater. This share indicates the distribution frequency of 6.45 percent for the 8-year moving average, 29 percent for the 11-year moving average, and 45.16% for the 22-year moving average. The correlation coefficients show that there are fewer stations in which the increase (decrease) in the number of sun spots has a direct and significant effect on the increase (decrease) of their temperature. Therefore, these distribution frequencies for the temporal series of data with 8 and 11-year moving averages show 3.22 percent and for the 22-year period show 6.45 percent. However, the sum of the average of distribution frequencies for all the temporal series show that the states in which the increase (decrease) in the number of spots has had a significant effect on the decrease (increase) of the temperature, are about 16.22 percent of the distribution frequency of the stations. This situation is more noticeable in stations like Ghazvin, Bandarabas, Arak, Birjand, Ramsar, and Babol. On the other hand, the sum average of the significance distribution frequency of stations in which the increase (decrease) in the occurrence of spots is accompanied by the increase (decrease) in temperature is just 4.51. The most suitable station that has probably been affected by this process is Bushehr (Table 4).

Finally, we come to the last coordinate which is the average annual temperature. For this coordinate, no significant relationship between normal temporal series and the fluctuations in the number of sun spots is observed. Also, for the 5-year moving average, a significant relationship between the number of spots and the fluctuations of temperature in the stations has low distribution frequency. The significant increase (decrease) of temperature for Isfahan's station only occurs simultaneously with the trend of increase (decrease) in the number of sun spots. By including the 8-, 11-, and 22-year moving averages, it becomes evident that the distribution frequency of stations with a significant trend has increased and this proportion has greater distribution frequency for occurrences in which the increase (decrease) in the number of sun spots is simultaneous with the decrease (increase) of temperature. This distribution frequency for the 8-year moving average is 9.67 percent, for the 11-year is 25.80 and finally for the 22-year average is 29 percent. As was mentioned before, the distribution frequency of the stations in which the increase (decrease) in their temperature is simultaneous with the occurrence of the increase (decrease) in the number of spots is smaller than the former state. As the data indicate, the distribution frequencies for the 8- and 11-year moving average is 6.54 percent for the 22-year moving average is 22.6 percent (Table 5). All in all, the overall average of distribution frequencies between the number of spots and temperature fluctuations, based on all of the temporal series and different moving averages, indicate that the inverse relationship between the occurrence of the number of sun spots and the average annual temperature of Iran has a large share and significance.

Table 4. The correlation coefficient between the amounts of maximum temperature and the fluctuations of the number of sun spots with the 5-, 8-, 11-, and 22-year moving averages

Max-Temperature	Normal series		Moving average 5		Moving average 8		Moving average 11		Moving average 22	
Statical value / Station	R	P	R	P	R	P	R	P	R	P
Babolsar	0.01	0.967	-0.04	0.775	-0.18	0.211	-0.09	0.557	0.18	0.307
Bandarabas	0.19	0.197	0.24	0.114	-0.12	0.478	-0.50	0.002***	-0.67	0.000***
Bushehr	0.14	0.114	0.28	0.045**	0.43	0.002***	0.57	0.000***	0.46	0.006***
Esfahan	0.12	0.389	0.23	0.109	0.22	0.141	0.13	0.413	0.10	0.567
Ghazvin	0.12	0.411	0.01	0.959	-0.31	0.049**	-0.70	0.000***	-0.66	0.000***
Gorgan	-0.03	0.837	-0.05	0.747	0.00	0.979	-0.12	0.155	-0.34	0.060*
Kerman	-0.03	0.804	0.08	0.592	0.05	0.742	-0.08	0.586	0.17	0.351
Kermanshah	-0.010	0.946	0.01	0.942	-0.20	0.188	-0.12	0.438	0.39	0.028**
Mashhad	0.01	0.950	0.03	0.837	-0.14	0.354	-0.15	0.334	0.07	0.683
Rasht	0.086	0.555	0.176	0.246	-0.08	0.628	-0.19	0.243	-0.46	0.012**
Shahrekord	0.06	0.667	0.17	0.269	0.00	0.995	-0.16	0.327	-0.79	0.000***
Shiraz	0.06	0.652	0.08	0.554	-0.17	0.236	-0.30	0.046***	0.15	0.402
Tabriz	0.00	0.999	0.06	0.659	0.00	0.983	-0.06	0.716	0.10	0.566
Tehran	0.04	0.769	0.10	0.496	-0.06	0.689	-0.20	0.180	-0.12	0.507
Yazd	0.16	0.240	0.22	0.128	0.10	0.516	0.04	0.778	0.12	0.501
Zahedan	-0.20	0.136	-0.10	0.473	-0.05	0.740	-0.23	0.133	-0.20	0.251
Abadan	0.00	0.993	0.06	0.689	0.03	0.829	-0.01	0.940	0.13	0.469
Anzali	0.01	0.936	0.03	0.840	0.07	0.639	0.09	0.544	-0.38	0.026
Arak	-0.06	0.773	-0.03	0.821	-0.16	0.296	-0.33	0.035**	-0.64	0.000***
Bam	0.000	1.000	0.33	0.026**	0.20	0.211	-0.37	0.022	-0.07	0.705
Birjand	0.01	0.943	0.07	0.667	-0.18	0.238	-0.47	0.002***	-0.67	0.000***
Hamedan	-0.047	0.736	-0.09	0.540	-0.29	0.048**	-0.31	0.042**	0.13	0.480
Khoramabad	0.14	0.320	0.15	0.301	0.05	0.729	-0.06	0.714	-0.51	0.003***
Orumeih	0.12	0.401	0.20	0.165	0.24	0.106	0.13	0.379	-0.25	0.150
Ramsar	0.13	0.367	0.14	0.359	-0.12	0.457	-0.32	0.045**	-0.57	0.001***
Sabzevar	-0.07	0.628	-0.05	0.715	-0.03	0.846	-0.01	0.927	0.28	0.132
Sanandaj	0.09	0.568	0.17	0.279	0.15	0.356	0.15	0.396	0.32	0.121
Shahrud	0.30	0.028**	0.31	0.024**	0.05	0.734	-0.06	0.679	-0.56	0.001***
Torbate Heydarie	0.08	0.585	0.05	0.744	-0.02	0.917	-0.15	0.394	-0.73	0.000***
Zabol	0.50	0.586	0.17	0.308	-0.06	0.747	-0.46	0.007***	-0.58	0.004***
Zanjan	0.61	0.603	0.11	0.456	0.01	0.951	-0.22	0.166	-0.64	0.000**

R= Pearson correlation; P: Significance value; Trends are significant with *P<0.10; **P<0.05; ***P<0.01

In any case, this distribution frequency on average covers 13 percent of the temperature fluctuations of the stations. Some of the stations which are most affected by this are Bandarabas, Arak, Ghazvin, Birjand, and Khoramabad. However, the average of distribution frequencies for direct and significant relationship between the number of spots and temperature fluctuations is 7.7 percent. This trend has more stability in the stations of Rasht and Hamedan (Table 5).

Table 5. The correlation coefficient between the amounts of daily temperature and the fluctuations of the number of sun spots with the 5-, 8-, 11-, and 22-year moving averages

Daily-Temperature	Normal series		Moving average 5		Moving average 8		Moving average 11		Moving average 22	
Statical value / Station	R	P	R	P	R	P	R	P	R	P
Babolsar	0.01	0.953	-0.01	0.953	-0.18	0.228	-0.19	0.204	0.19	0.275
Bandarabas	0.21	0.361	0.14	0.361	-0.28	0.078*	-0.58	0.000***	-0.82	0.000***
Bushehr	0.03	0.475	0.10	0.475	0.11	0.477	0.15	0.312	0.35	0.043**
Esfahan	0.16	0.082*	0.25	0.082*	0.03	0.838	0.05	0.735	0.25	0.162
Ghazvin	0.05	0.978	0.00	0.978	-0.32	0.045**	-0.72	0.000***	-0.68	0.000***
Gorgan	0.09	0.228	0.18	0.228	0.16	0.290	-0.09	0.157	-0.39	0.027**
Kerman	-0.01	0.299	0.15	0.299	0.27	0.062*	0.11	0.466	0.24	0.166
Kermanshah	0.03	0.700	0.06	0.700	-0.12	0.409	0.00	0.992	0.51	0.003***
Mashhad	-0.01	0.776	0.04	0.776	-0.07	0.657	-0.09	0.539	0.23	0.189
Rasht	-0.10	0.921	-0.015	0.921	0.14	0.377	0.39	0.013	0.39	0.035**
Shahrekord	0.01	0.515	0.10	0.515	-0.07	0.664	-0.25	0.123	-0.80	0.000***
Shiraz	-0.01	0.864	0.02	0.864	-0.04	0.804	-0.04	0.803	0.32	0.066*
Tabriz	-0.01	0.926	0.01	0.926	-0.12	0.427	-0.17	0.268	0.14	0.414
Tehran	0.03	0.724	0.05	0.724	-0.12	0.429	-0.15	0.331	0.22	0.206
Yazd	0.10	0.181	0.19	0.181	0.07	0.660	-0.06	0.692	0.25	0.163
Zahedan	-0.07	0.550	0.09	0.550	0.12	0.416	0.05	0.768	0.23	0.192
Abadan	-0.05	0.754	-0.04	0.754	-0.21	0.153	-0.38	0.009***	0.04	0.832
Anzali	-0.05	0.543	-0.09	0.543	-0.18	0.219	-0.13	0.378	-0.27	0.120
Arak	-0.08	0.530	-0.09	0.530	-0.25	0.113	-0.48	0.002***	-0.68	0.000***
Bam	-0.02	0.198	0.20	0.198	0.16	0.299	-0.03	0.861	0.33	0.091*
Birjand	-0.11	0.554	-0.09	0.554	-0.31	0.042**	-0.62	0.000***	-0.71	0.000***
Hamedan	0.02	0.303	0.15	0.303	0.37	0.010***	0.46	0.002***	0.35	0.050**
Khoramabad	-0.02	0.809	-0.04	0.809	-0.11	0.455	-0.27	0.080*	-0.58	0.000***
Orumeih	0.01	0.716	0.05	0.716	0.14	0.341	0.09	0.574	-0.28	0.113
Ramsar	0.02	0.877	0.02	0.877	-0.12	0.447	-0.25	0.115	-0.11	0.580
Sabzevar	-0.06	0.589	-0.08	0.589	-0.01	0.955	0.12	0.464	0.47	0.008***
Sanandaj	0.11	0.405	0.13	0.405	-0.11	0.493	-0.50	0.002***	-0.24	0.240
Shahrud	0.10	0.283	0.15	0.283	0.08	0.585	0.11	0.475	0.26	0.140
Torbate Heydarie	0.14	0.293	0.17	0.293	0.10	0.569	0.11	0.532	-0.71	0.000***
Zabol	0.12	0.161	0.23	0.161	0.00	0.990	-0.33	0.060*	-0.26	0.247
Zanjan	0.16	0.148	0.22	0.148	0.13	0.412	-0.09	0.576	-0.64	0.000***

R= Pearson correlation; P: Significance value; Trends are significant with *P<0.10; **P<0.05; ***P<0.01

4. Conclusion

The earth's climate constantly changes and numerous theories have been proposed to explain these changes. One of the most reliable theories among these is the dependence of the fluctuations of climate on the changes of the sun. In this research, first Mann-Kendall's method was used for identifying any significant trend in average annual temperature and precipitation data in Iran for 31 synoptic stations. The results indicate that because of the high fluctuation coefficient of precipitation, only 5 stations have significant fluctuations between 1951 and 2005. Among these, two stations, namely Abadan and Babolsar have an increasing trend and three stations, namely Orumeih, Zahedan, and Tabriz, demonstrate a decreasing and significant trend of precipitation. In any case, this significant trend for the coordinates of temperature has had greater distribution frequency in the stations; among the different coordinates of temperature (minimum, maximum and daily temperature), the greatest share of significance by the amount of 74.19 percent of the stations is observed for the minimum coordinate of temperature. It is interesting that among these, 64.52 percent of the stations indicate a significant trend in temperature increase. For identifying the relationship between the fluctuations of precipitation and the temperature of Iran and the occurrence of the number of sun spots, the Pearson's correlation was used for these two coordinates. To do that, we did not consider the temporal series of normal data (without moving average) to be sufficient and the moving averages of 5, 8, 11, and 22-year periods were taken into account. Finally the results for Iran's precipitation show that there is evidence of the concordance of the fluctuations of the number of sun spots and the fluctuations of precipitation, whether direct or inverse. The share that most of the distribution frequencies show is 25.16 percent, which has been calculated from comparing the number of sun spots and the precipitation fluctuations in Iran with the overall average of distribution frequencies. This result has more stability for the stations of Bandarabas, Ghazvin, Kerman, Shiraz, Anzali, Birjand, and Hamedan. The results of the research of Jahanbakhsh and Edalatdoust (2008), like our study, indicates the diverse relationship (direct and inverse relationship) between precipitation fluctuations of Iran's stations and sun spots in different regions. The other similarity is that the precipitation of seashore stations like Anzali, Bandarabas, and Bushehr demonstrate a direct relationship with the increase in the number of sun spots.

The final conclusion for the relationship between the annual average of minimum temperature and the number of spots is that, in general, when the spots increase (decrease), simultaneously the minimum (maximum) occurrence of temperature attains a greater share by the amount of 15.46 percent of the frequency distribution. This process is more noticeable in stations like Bandarabas, Ghazvin, Arak, Birjand, and Sanandaj. On the other hand, the share of the stations that the trend of the increase (decrease) in their annual minimum temperature is

simultaneous with the occurrence of the maximum (decrease) in the number of spots is 13.5 percent of the distribution frequencies. For this process, we may perhaps refer to stations like Torbate Heydarie, Rasht, Hamedan, and Kerman.
The results for the annual average of maximum temperature indicate that the increase (decrease) in the number of spots has had more significant effect on the decrease (increase) of temperature; this share is approximately 16.22 percent of the distribution frequency of the stations. This situation is more noticeable for the stations of Ghazvin, Bandarabas, Arak, Birjand, Ramsar, and Zabol. But on the other hand, the sum average of the significance distribution frequency of stations that the increase (decrease) of the occurrence of spots is simultaneous with the increase (decrease) of temperature is only 4.51 percent. In this situation, the most stable station is Bushehr. Lastly, we may refer to the average annual temperature. This result for the average annual temperature is similar to the other coordinates of temperature; which means that the distribution frequency of the stations that the increase (decrease) in their temperature is simultaneous with the decrease (increase) of the number of spots has the greater share. This amount is approximately 13 percent, but in the case of the direct relationship of the fluctuations of temperature and the number of sun spots, this share is approximately 7.7 percent of the distribution frequencies. To summarize briefly, the increase (decrease) in the number of spots has been simultaneous with the increase (decrease) in the amounts of annual precipitation in Iran and in the case of temperature, the decrease (increase) of the various coordinates of temperature is simultaneous with the increase (decrease) in the number of spots. However, we have to keep in mind that the fluctuations in the trend of the climatic coordinates (temperature and precipitation) are dependent on numerous variables and factors and the fluctuations of the number of sun spots is just one of these factors. As climate change is affected by various human and natural phenomena, it is more advisable to analyze the fluctuations of temperature and precipitation with different components, so that the effect of each factor in the fluctuations may be more clearly evaluated. In any case, by assessing the validity of the results of this research, we can simulate the occurrence of droughts and wet years that are likely to be brought about by the solar activities for future decades and based on that, take necessary steps in risk management in the field of nutritional security and agricultural products.

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