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ORIGINAL PAPER

Investigating the trend of average changes of annual temperatures in Iran

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Abstract

Temperature is one of the key elements of climate formation and its changes can alter the climate structure of each region. To study the trend of temperature changes in Iran, the data from the three variables of average minimum temperature, average maximum temperature and average annual temperature of 43 synoptic stations were obtained from the Iranian Meteorological Organization for a 48-year statistical period (1966–2016). Moreover, in order to detect the trend of average changes of minimum, maximum and annual temperatures, fuzzy possibilistic regression and classical linear regression models were used. The comparison of the results of the slope of the change trend obtained from the two models clearly showed that, in most cases, the fuzzy possibilistic regression shows the slope of the change trend more than the classical linear regression. The statistics of root-mean-square error also showed that the function of classical linear regression was much better than fuzzy possibilistic regression. Therefore, based on the results of classical linear regression, the maximum amount of the average change trend of maximum annual temperatures of Iran is first observed in the west and northwest, and then in the northeastern of Iran. However, the average trend of minimum annual temperatures in Iran has shown more different spatial configurations than the average of maximum annual temperatures in Iran, with the highest rates of change in the east half, especially in the northeast. Finally, based on the classical linear regression model, it was observed that in the whole study period, 1.40 °C has been added to the average of maximum annual temperatures and 1.68 °C to the average of minimum annual temperatures in Iran.

Keywords Climate change · Classical linear regression · Fuzzy possibilistic regression · Trend

Introduction

Since temperature is one of the key elements of climate formation and its changes can alter the climate structure of each region, the study of temperature trend at temporal and spatial scales has devoted a large part of the climatological research; from the point of view of spatial scale, they can be categorized into three categories of regional (Brazdil et al. 1995; Jiang and You 1996), hemispheric (Jones and Moberg 2003; Stern and Kaufmann 2000) and planetary (Nicolas et al. 1996; Rahmstorf and Ganopolski 1999) studies, as well as from the point of view of temporal scale to monthly (Zhang et al. 2009; Gemmer et al. 2004), seasonal (Kadioglu et al. 2001; Tonkaz et al. 2007) and annual (Türkes et al. 2007; Nasri and Modarres 2008) scales.

Research has suggested that since the beginning of the twentieth century, we have witnessed an increase of about 0.6 °C in the average of the earth's temperature (Easterling et al. 1997) and this increase was due to an increase in the minimum temperatures, which is almost twice the increase in maximum temperatures (Walter et al. 2002). In addition, the decrease in daily temperature changes in recent decades has led to a decrease in the frequency of minimum temperature occurrence, especially in winter (Scheifinger et al. 2003). Moreover, between 1950 and 1993, the

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minimum night temperature has increased by about 0.2 °C on average in every decade, which is approximately twice the increase in the daily maximum temperature of 0.1 °C in the same statistical period for every decade (IPCC 2001). Despite the fact that a sharp increase in global scale has been demonstrated at minimum temperatures, significant variations in local and regional scales are also noticeable. For example, Kumar et al. (2005) in Firenze, Italy, Tayanç et al. (2009) in Turkey, Domonkos and Tar (2003) in Hungary, Lettenmaier et al. (1994) in the USA and Domroes and El-Tantawi (2005) in Egypt have confirmed trends in time series at minimum and maximum temperatures.

In Iran, changes have been reported in the average minimum and maximum annual temperatures; but these changes in the average minimum temperatures have been almost twice the changes in the average maximum temperatures (Alijani et al. 2012). There was also a displacement in the spatial cores of cold index waves in the west and northwest of Iran, insofar as the displacement has been from geographic latitudes around 35° to geographic latitudes higher than 36° (Alijani et al. 2011). The trend of substituting semi-arid climate for semi-humid arid and semi-humid climate in the west and northwest of Iran and the replacement of the hyper-arid climate instead of the arid climate in southeastern Iran has also been reported by Tavosi et al. (2010). Moreover, Shirgholami and Ghahraman (2005) investigated the long-term trend of the average annual temperature of 34 synoptic stations across the country. The results of their study showed that in 59% of the stations, temperature changes had a positive trend and in 41% of the stations had a negative trend. In addition, the average annual increase in the minimum temperature up to 0.68 °C in Tehran for a decade (Bidokhti and Ranjbar 2003), the confirmation of an increase of 2 °C in Iran over a 100 years (Masoudian 2004), and the prediction of an increase of 2.75 °C in the northeast of Iran (Alizadeh and Kamali 2002) are examples of the results of regional-scale studies in Iran.

The results of the above-mentioned studies conducted in Iran and the world have been based on the use of parametric and nonparametric methods. However, in natural systems such as the earth's atmosphere, we encounter obscure relationships between the variables. In such a situation, we have to use models that are able to provide more suitable patterns, so that these models can adapt to the real world and its inner changes. The Fuzzy Set Theory, first established by Zadeh in 1965, is a method that can be used in many climatological studies, especially the fuzzy regression that can be used in the field of trend studies. Therefore, this study aims to explore the trend of time series of Iran's temperatures using two methods of fuzzy regression and classical regression. Then, the results of these two models will be compared in a comparative study and their ability in this area of climatological studies will be measured.

This research was conducted in 2016 at the department of physical geography, faculty of geography and environmental planning, University of Sistan and Baluchestan, Zahedan, Iran.

Materials and methods

In order to study the trend of annual temperature changes in Iran, the data from the three variables including average minimum temperature, average maximum temperature and average annual temperature of 43 synoptic meteorological stations were obtained from the Iran Meteorological Organization for a 48-year statistical period (1966–2016). These stations have the complete statistical period among all the stations in Iran, and it has been attempted to use stations with 5% or fewer statistical flaws during the statistical period. Data reconstitution was performed using correlation and the regression model, and homogeneity of data was also done by using a run-test and the homogeneity of the data was ensured during the statistical period. Distribution and dispersion of the stations studied in the country are presented in Fig. 1.

In order to evaluate the trend of annual temperatures in Iran, two models of fuzzy possibilistic regression and classical linear regression were used. But before introducing the mathematical structure of these two models, it is necessary to point out that the normality assumption of the time series is one of the essential conditions for the use of these two models in trend studies. Thus, in this study, Kolmogorov–Smirnov test (K–S) was used to test the normality of the time series. For the significance of the trends, the F test of the analysis of variance (ANOVA) table was used for both models.

Classical linear regression

The general form of the classical linear regression equation is the relation (1) in which y is the output variable, $x_1, x_2, \ldots, x_n$ are the input variables, and $a_0, a_1, \ldots, a_n$ are the coefficients of the equation.

$$y = a_0 + a_1 x_1 + \cdots + a_n x_n \quad (1)$$

Relationship (2) is a univariate mode of classical linear regression that is used in this study.

$$y = a_0 + a_1 x \quad (2)$$

Suppose a set of pairs of observational variables is available in the form of $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$. Generally, by minimizing the sum of squares errors between observational and computational data which relation is in the form

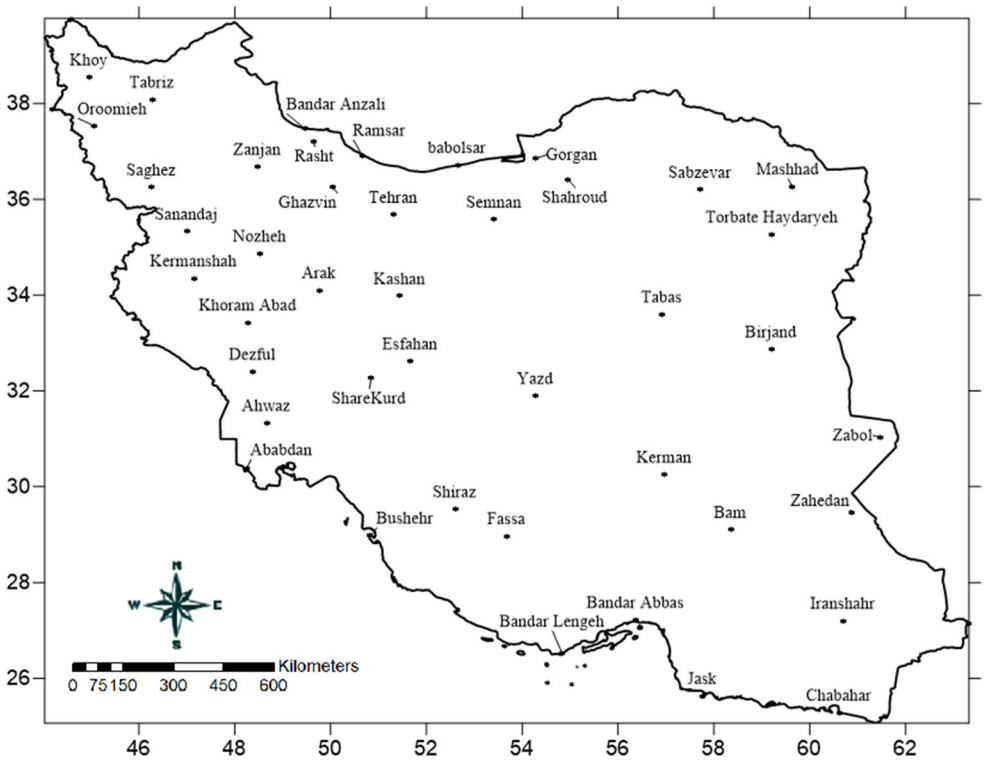


Fig. 1 Location and distribution map of the studied stations

of $\sum_{i=1}^{n}\left[y_i-\left(a_0+a_1x_1\right)\right]$, the equation coefficients (i.e., a_0 and a_1) are calculated as follows.

$$a_1=\frac{m\sum_{i=1}^{m}x_iy_i-\sum_{i=1}^{m}x_i\sum_{i=1}^{m}y_i}{m\sum_{i=1}^{m}x_i^2-\left(\sum_{i=1}^{m}x_i\right)^2} \tag{3}$$

$$a_0=\frac{\sum_{i=1}^{m}y_i-a_1\sum_{i=1}^{m}x_i}{m} \tag{4}$$

Fuzzy possibilistic regression

The fuzzy linear regression estimates an interval of possible values for the output variable, but, for each series of input variables, the classical linear regression calculates only a specific value for the output variable. In this research, fuzzy possibilistic regression models were used. Fuzzy possibilistic regression models were first introduced by Tanaka et al. (1982). This model gains the best regression equation by minimizing the amount of fuzziness, and this is accomplished by minimizing the sum of the total width of the membership functions of fuzzy coefficients. One of the possible models for fuzzy possibilistic regression is a model in which the coefficients, fuzzy and observational inputs and outputs are non-fuzzy. In general terms, this model is expressed by Eq. (5).

$$\tilde{Y}=\tilde{A}_0+\tilde{A}_1x_1+\tilde{A}_2x_2+\cdots+\tilde{A}_nx_n \tag{5}$$

The coefficients of the above equation, namely $\tilde{A}_0$, $\tilde{A}_1$, $\tilde{A}_2$, … and $\tilde{A}_n$ are fuzzy numbers, and the input variables namely x_1, x_2, …, and x_2 are ordinary numbers. Given the Eq. (5), for each input variable (here is an input), a fuzzy number like $\tilde{Y}$ is obtained as an output. Therefore, based on a set of observational data, the purpose of this model is to obtain the coefficients of Eq. (5) in such a way that the equation has the best fit on the data. For more information on the structure of fuzzy regression models, one can refer to the source of Tanaka et al. (1982).

Finally, for estimating and verifying the accuracy of the results of the two models, the statistics of root-mean-square error (RMSE) has been used. This statistic is calculated as follows:

$$\mathrm{RMSE}=\sqrt{\sum_{i=1}^{N}\left(X_i-Y_i\right)^2/N} \tag{6}$$

In which N is the number of datasets, X is the calculated output value and Y is the measured output value.

Results and discussion

The minimum temperature is the result of the balance of emitted radiation and the maximum temperature is the result of the balance of incoming radiation. On the other

hand, greenhouse gases such as water vapor and carbon dioxide are effective factors on the balance of the emission of radiation, while the incoming radiation depends on the radiant properties of the atmosphere, including the transparency of the atmosphere. Therefore, the minimum temperature and maximum temperature are affected by different factors, and the behavior of their trend may vary with each other. Researchers' reports also show that generally the trend of minimum and maximum temperature is different, and, in most cases, the increase rate of the minimum temperature has been greater than the increase rate of the maximum temperature (IPCC 2001; Walter et al. 2002; Alijani et al. 2012). Therefore, in order to reveal the trend of average changes of minimum temperatures, the average of maximum and annual temperatures of Iran was implemented for each of the 43 stations being studied by the fuzzy possibilistic regression and classical linear regression models and the results were presented separately for each station and finally were compared with each other.

Since one of the main assumptions of the use of regression models is the normalization of time series, the normalization of all time series was tested at first using the Kolmogorov–Smirnov test. The results of this test showed that all the studied time series follow the normal distribution.

Annual maximum temperature

The spatial distribution map of the average maximum annual temperature of Iran, shown in Fig. 2, shows that the spatial arrangement of this variable in Iran is a function of latitude and is the result of the gradual reduction of the solar radiation angle. Although in the northern part of Iran, this order is partially collapsed by the Zagros and Alborz heights, its overall arrangement is still on a regional scale. Therefore, considering this type of spatial arrangement, the highest average maximum annual temperatures of Iran are observed in the southern coastal strip (Iranshahr, 34.3 °C) and the lowest in the west and northwest (Oroomieh, 17.6 °C).

The results of the trend of changes slope in the average maximum annual temperatures of the stations, obtained from the two classical linear regression and fuzzy possibilistic regression models, are presented in two separate maps (Fig. 3a, b). In these two maps, we see almost identical spatial patterns for the trends obtained for changes in the maximum annual temperatures in Iran so that the maximum amount of the changes trend of average maximum annual temperatures of Iran is first observed in the west and northwest and then in a limited part of northeast of Iran. The lowest amount of change trend in average maximum annual temperature has been related to the southeast of Iran. Although there are other sparse spots in the north and west of Iran, the trend of their changes has been very small and even negative. It should be noted

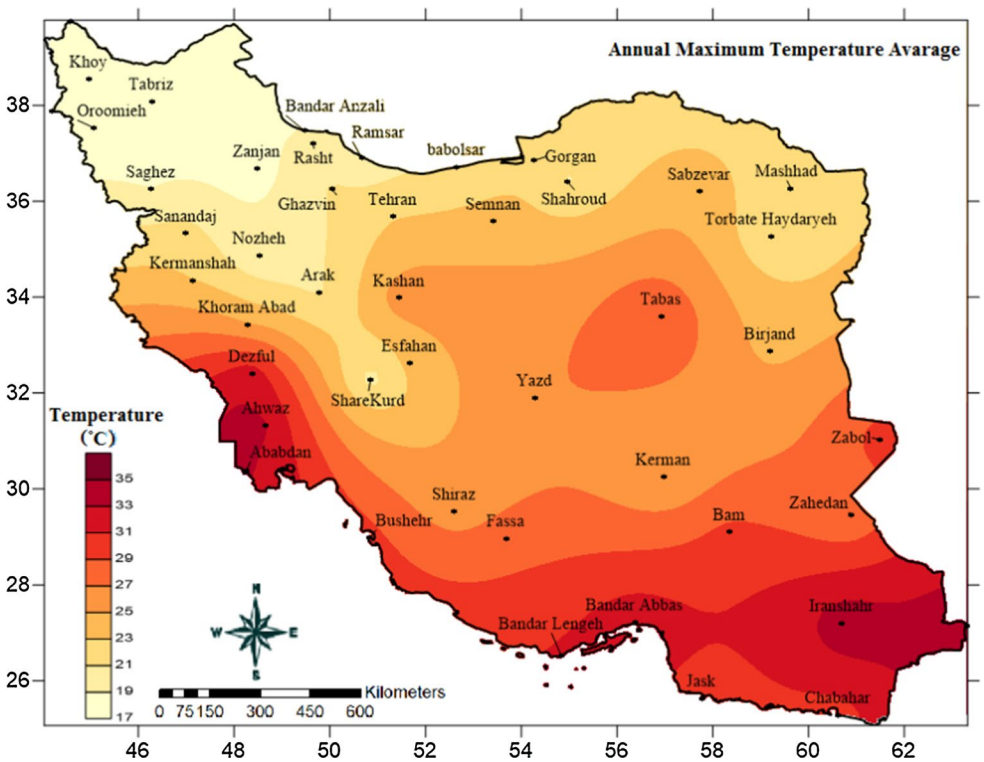


Fig. 2 Spatial distribution map of the average maximum annual temperature of Iran (1966–2016)

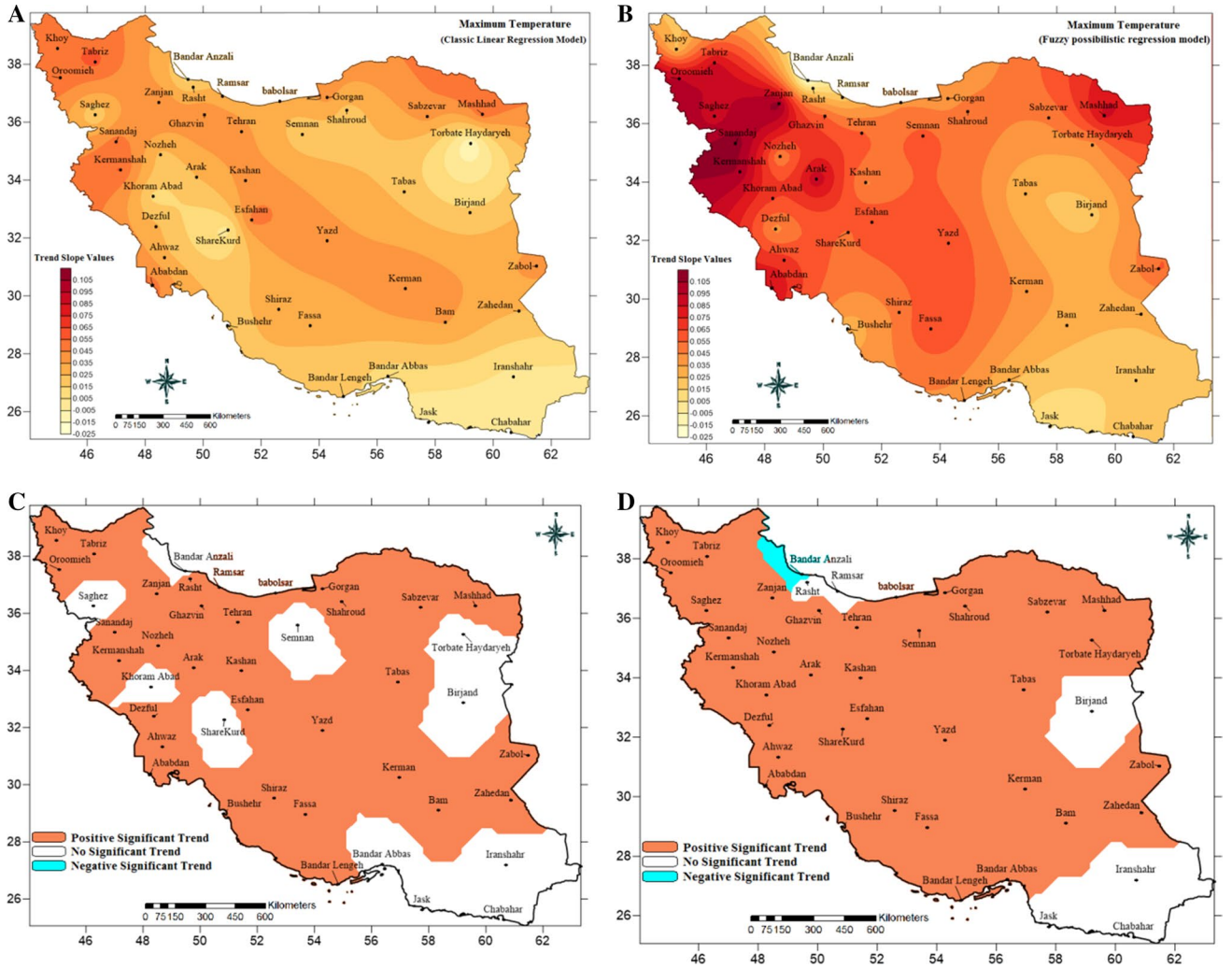


Fig. 3 The trend maps of the average maximum annual temperatures of Iran and their significance at the level of $\alpha = 0.05$: **a** the trend map based on the classical linear regression model, **b** the trend map based on the fuzzy possibilistic regression model, **c** the significant map of trends at the level of $\alpha = 0.05$ for classical linear regression and **d** the significant map of the trends at the $\alpha = 0.05$ level for fuzzy possibilistic regression

that most of the trends obtained from these two models have had an incremental trend for the average maximum annual temperatures of Iran, except for the three stations of Torbate Haydaryeh, Jask and Chabahar for the classical linear regression model and Bandar Anzali station for the fuzzy possibilistic regression model. But all the trends obtained from these two models have not been statistically significant. So that at the significance level of $\alpha = 0.05$ for the classical linear regression model of 11 stations (Bandar Anzali, Bandar Abbas, Chabahar, Nozheh, Iranshahr, Khoram Abad, Saghez, Torbate Haydaryeh, Semnan, Birjand and Shahre Kurd) (Fig. 3c) and for the fuzzy possibilistic regression model of 6 stations (Chabahar, Iranshahr, Jask, Ramsar, Rasht and Birjand) (Fig. 3d) among 43 stations, the trend has not been significant and the rest of the stations have had a meaningful trend. In the map 3b and d, stations with significant or no significant trend at the level of $\alpha = 0.05$, respectively, for two models of classical linear regression and fuzzy possibilistic regression are well separated and have been specified as three stations with significant upward trend (bright brown color), stations with a significant downward trend (bright blue color) and, finally, stations with no significant trend (white color). Therefore, according to these maps, it can be concluded that there is no significant change in average maximum annual temperatures of the southeast of Iran that has a warm and dry climate. The reason for this lack of change can be related to the moderating effects of the high humidity of the atmosphere on coastal stations such as Jask and Chabahar, lower altitudes, as well as being at lower geographic latitudes compared to mountainous and highlands of the west and northwest of Iran. But for

other stations where their trends have not been meaningful and have been identified dispersedly and irregularly on the meaningful map of Iran's trends, one cannot search for a regional reason and other local causes such as urban development, population growth, topographic type, user change and should be further sought. In any case, the increase in average maximum annual temperatures in Iran will certainly have significant effects on the severity, duration and frequency of Iran's warm and cold waves in the two warm and cold seasons. In addition, it increases the moisture content of the atmosphere, thereby increasing evaporation and transpiration from the surface of the earth, which, in the latter case, can have various water stresses for the plants.

But the point that is more significant when comparing the trend maps for these two models is the difference in the amount of changes trend made by the two models. The fuzzy possibilistic regression model in 33 stations out of the 43 stations shows the slope of changes trend of the maximum annual temperature much more than the classical linear regression model, and only in 10 stations, this situation is reversed. In addition, with the exception of the four stations of Bandar Anzali, Chabahar, Jask and Torbate Haydaryeh which differ in the direction of their changes trend, the rest of the trends derived from these two models have had the same direction and they all have had an increasing trend.

By calculating the arithmetic mean of the slope of trends for each of the 43 series of average maximum annual temperatures of the stations, it was found that for the fuzzy possibilistic regression, this mean was 0.05 and for classical linear regression, it was equal to 0.03 °C for each year. The results of classical linear regression show an increase of 1.4 °C, and the results of fuzzy possibilistic regression show an increase of 2.4 °C in the mean of maximum annual temperatures during the statistical period for Iran; that is, during the 48 years, based on the classical linear regression model, 1.4 °C, and based on the fuzzy possibilistic regression model, 2.4 °C, the mean of maximum annual temperatures of Iran has been increased.

Minimum annual temperature

In analyzing the arrangement of spatial patterns, the average minimum annual temperatures of Iran (1966–2016) are plotted on the graphic map of Fig. 4 that the highest average minimum annual temperature in Iran is observed across the southern latitudes of Iran, especially on the low southeast coast of Iran (Jask, 23.9 °C). However, by moving from the southern latitudes to the northern latitudes and especially the mountainous areas of the west and northwest of Iran, the average annual temperatures of Iran are severely reduced, so that at the Nozheh station, this mean is 2.5 °C.

The results of the values of the trend slope of the changes made by the implementation of the two classical linear regression and fuzzy possibilistic regression models on the average minimum annual temperatures of 43 stations

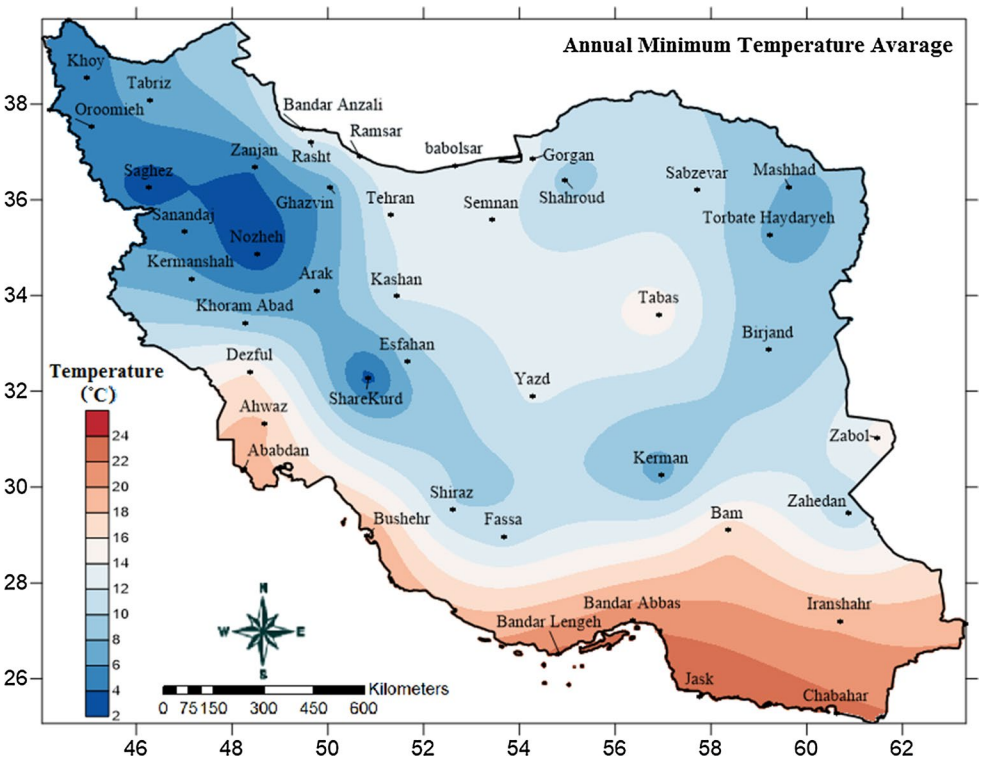


Fig. 4 The spatial distribution map of the average minimum annual temperature of Iran (1966–2016)

are presented in Fig. 5 in the form of two maps A and B. By comparing these two maps, it can be easily found that the spatial arrangement of the changes trend in these two models has been close to each other in the Iranian context, given the differences that they have with each other. Based on these two maps, it can be seen that the maximum amount of changes trend of this variable has been focused on the average maximum annual temperatures in the eastern part of Iran. Based on the results of the classical linear regression model, the highest amount of incremental trend in the average minimum annual temperature of Iran is related to two stations of Tabas (0.111 °C) and Mashhad (0.105 °C), respectively, and based on the results of the fuzzy possibilistic regression model, to two stations of Bam (0.121 °C) and Mashhad (0.111 °C). In addition, the results of the classical linear regression model only for six stations of Shahre Kurd, Isfahan, Fassa, Khoram Abad, Gorgan and Saghez (Fig. 5a) and the fuzzy possibilistic regression model only for four stations of Isfahan, Shahre Kurd, Gorgan and Birjand (Fig. 5b) showed a decreasing trend in Iran's average minimum annual temperatures. According to these results, it can be concluded that nearly 86% of the stations using classical linear regression and about 90% of stations using fuzzy possibilistic regression have an incremental trend at average minimum annual temperatures.

But, as it is evident, the statistical significance of these trends should be considered. Therefore, all the trends, obtained by these two models for all the 43 stations, have not been significant at the probability level of $\alpha = 0.05$. According to the results of the classical linear regression model, from 43 stations, the trend of only seven stations of Arak, Gorgan, Khoram Abad, Saghez, Birjand, Kashan

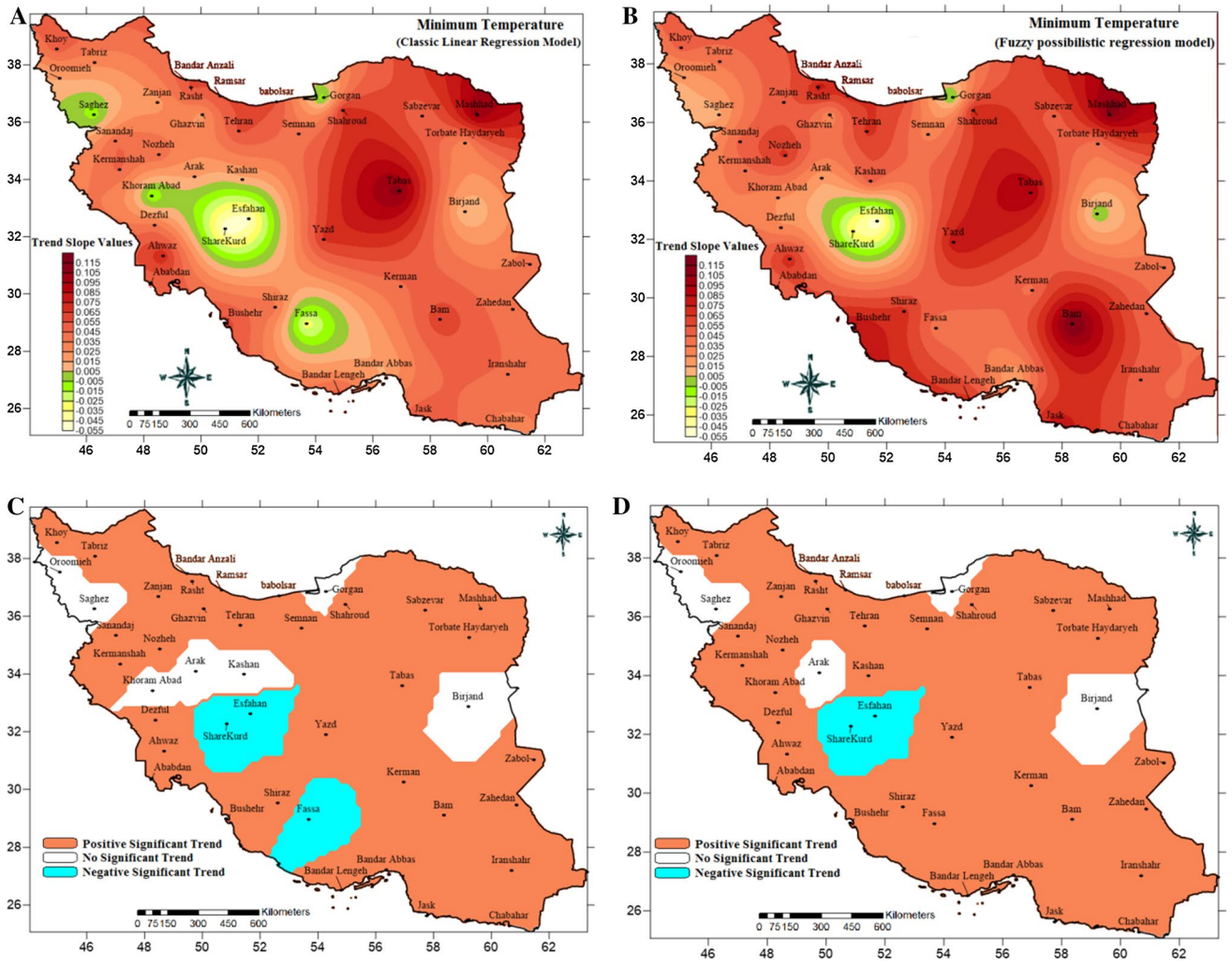


Fig. 5 The trend maps of the average minimum annual temperatures of Iran and their significance at the level of $\alpha = 0.05$: **a** the trend map based on the classical linear regression model, **b** the trend map based on the fuzzy possibilistic regression model, **c** the significant map of trends at the level of $\alpha = 0.05$ for classical linear regression and **d** the significant map of the trends at the $\alpha = 0.05$ level for fuzzy possibilistic regression

and Oroomieh has not been significant (Fig. 5c), while for fuzzy possibilistic regression, this number is limited to five stations of Arak, Gorgan, Saghez, Birjand and Oroomieh (Fig. 5d). However, stations with decreasing trend and statistically significant level ($\alpha = 0.05$) were used for classical linear regression of Isfahan, Shahre Kurd and Fassa stations, and for fuzzy possibilistic regression, only two stations of Shahre Kurd and Isfahan were used. This increase in average minimum annual temperatures will cause a shift in the occurrence of the first and last frost in the fall and spring in Iran, which will result in an increase in the growth period in Iran.

But the important point, mentioned in the section on the analysis of average maximum annual temperature of Iran, is that, in many cases, the fuzzy possibilistic regression shows the value of the trend slope more than the classical linear regression, so that in the analysis of the values of the trend slope of the average minimum annual temperatures in Iran, we again see this difference. In 30 stations, the values of the trend slope estimated by the fuzzy possibilistic regression were greater than the classical linear regression.

The arithmetic mean of the trend slope of the 43-time series related to the average minimum annual temperatures of the stations was calculated. The results of this averaging showed that for the fuzzy possibilistic regression, the average of changes slope was 0.046 °C and for classical linear regression, it was 0.034 °C per year for the whole of Iran. In other words, during the statistical period, based on the classical linear regression, 1.68 and based on the fuzzy possibilistic regression, 2.24 °C were added to the average minimum annual temperature of Iran.

Average annual temperatures of Iran

The spatial arrangement of the average annual temperatures in Iran is not very different from the spatial arrangement of the two other variables, namely the average of the maximum and minimum annual temperatures. The lowest average annual temperatures in Iran correspond well to the mountainous areas of the west and northwest [(Nozheh (11.1), Saghez (11.2), Oroomieh (11.2), Zanjan (11.3) and Shahre Kurd (11.6)), and most of it corresponds to the southeast of Iran (Jask (27), Iranshahr (27), Bandar Abbas (26.9), Bandar Lengeh (26.9) and Chabahar (26.4)] (Fig. 6).

The results of the implementation of the two classical linear regression and fuzzy possibilistic regression models on 43-time series of average annual temperatures in Iran show that with the exception of Shahre Kurd station, which the classical linear regression model shows its negative trend, the rest of the stations have an incremental trend. The arrangement of the spatial pattern of changes trend in the average annual temperature of Iran is approximately similar to the spatial pattern of changes trend of the average maximum temperatures of Iran. The highest changes trend in the average annual temperatures of Iran was first observed in the northeast and then in the west and northwest of Iran, but

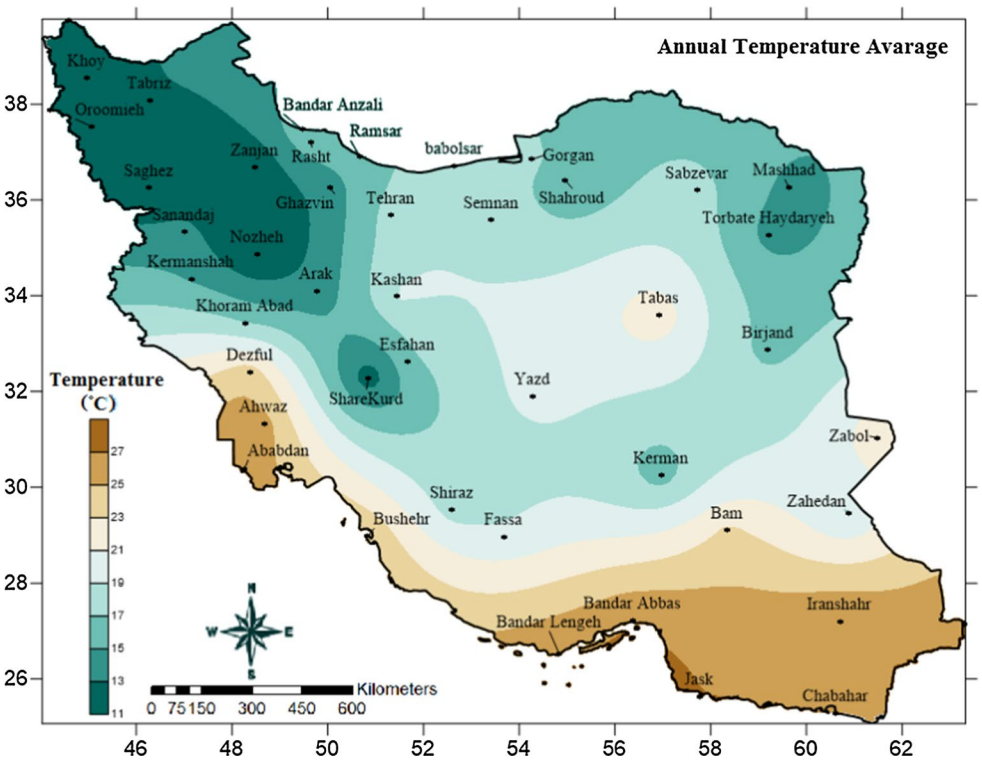


Fig. 6 The spatial distribution map of the average minimum annual temperature of Iran (1966–2016)

the smallest amount of changes trend in the average annual temperatures in Iran does not follow a specific regional order. However, if we specifically want to mention several areas, we can point to the southeast, east, and western part of the center of Iran, where the trend of changes in their average temperatures has been very small. Among the 43 stations, the classical linear regression for Mashhad station (0.777 °C) and fuzzy possibilistic regression for Zanjan station (0.11 °C) have shown the highest value of trend slope. But in terms of the significance of these trends, it should be noted that all the obtained trends for average annual temperatures in Iran are not significant at $\alpha = 0.05$. The results of classical linear regression show that from the 43-time series of average annual temperatures, the trend of 10 of them, which were related to the stations of Arak, Bandar Abbas, Chabahar, Fassa, Gorgan, Khoram Abad, Saghez, Torbate Haydaryeh, Isfahan and Kashan, was not significant (Fig. 7c). However, the number of time series that the fuzzy possibilistic regression identified their trend as non-significance was 5-time series belonging to the stations of Bandar Anzali, Chabahar, Gorgan, Birjand and Shahre Kurd (Fig. 7d). In the case of the significance of the trend of the time series of the average annual temperatures in Iran, the point that should be considered is that in most cases, when the trend of one or both of the time series of average maximum or minimum temperatures is not significant, it affects the trend of time series of average annual temperatures and made them significant at the probability level of $\alpha = 0.05$. But it should be noted that this rule cannot be generalized for all the series of the study.

The arithmetic mean of the slope of changes trend of average annual temperatures was calculated for 43 stations.

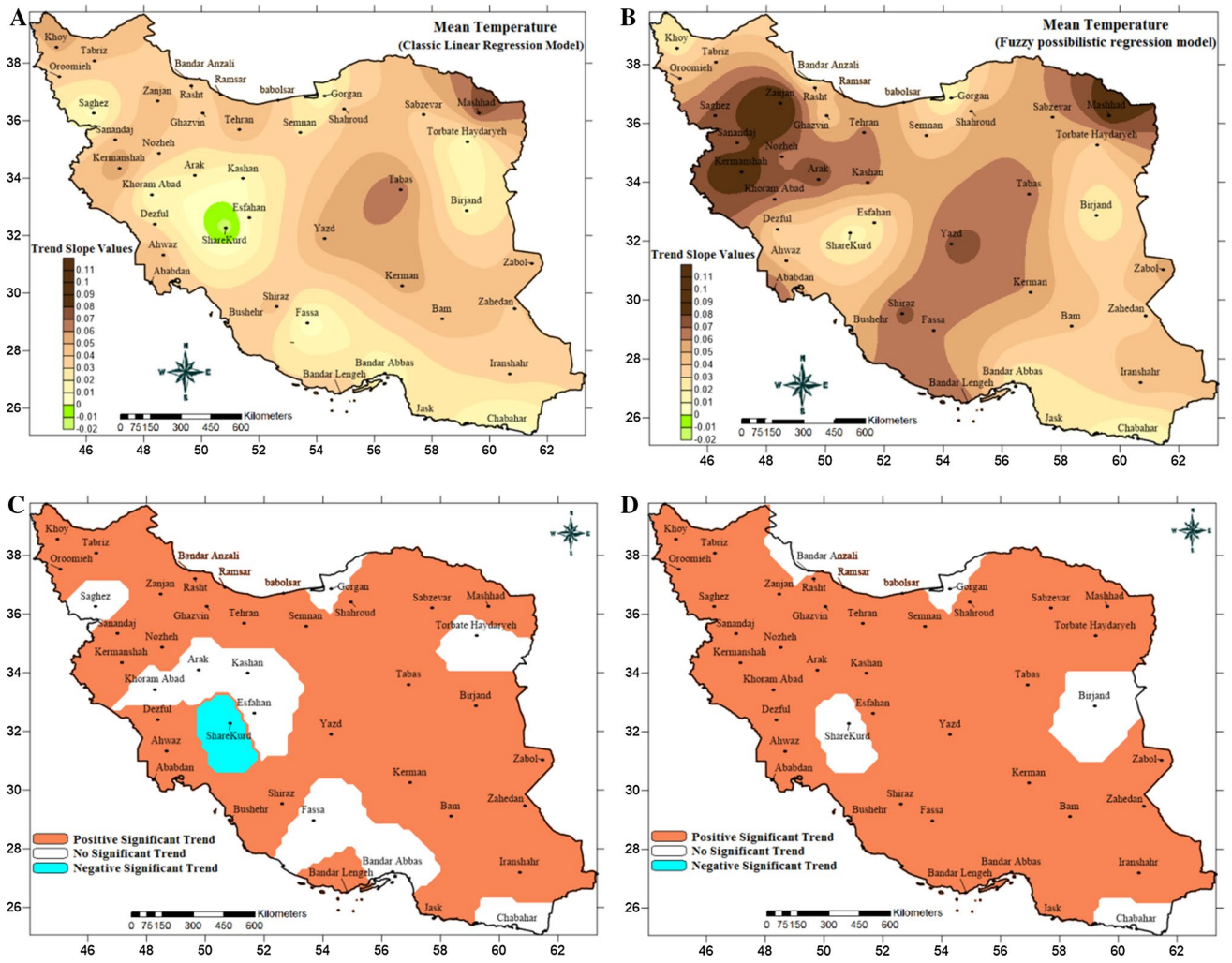


Fig. 7 The trend maps of the average annual temperatures of Iran and their significance at the level of $\alpha = 0.05$: **a** the trend map based on the classical linear regression model, **b** the trend map based on the fuzzy possibilistic regression model, **c** the significant map of trends at the level of $\alpha = 0.05$ for classical linear regression and **d** the significant map of the trends at the $\alpha = 0.05$ level for fuzzy possibilistic regression

The results of the classical linear regression model show the trend of changes slope of 0.033 °C for the whole of Iran; that is, during the study, 1.42 °C was added to the average annual temperature in Iran. However, the fuzzy possibilistic regression estimates this value at 0.050 °C for the whole of Iran per year, indicating an increase of 2.15 °C throughout the study period.

Evaluating classical linear regression and fuzzy possibilistic regression models

In order to evaluate the performance of two classical linear regression and fuzzy possibilistic regression models in studying the trend of long-term changes in Iran's average annual temperatures, the root-mean-square error (RMSE) was used. The results of this criterion for both models are fully presented for all stations under study in Table 1. Based on this table, it can be seen that the RMSE evaluation criterion for the three variables has always been lower for the classical linear regression model compared to the fuzzy possibilistic regression model. In other words, the results of this criterion indicate that the function of classical linear regression was better than the fuzzy possibilistic regression in studying the trend of long-term changes in the temperatures of Iran.

One of the important reasons for this difference between the two models is the difference in the estimation of the constant coefficients of these two models. In the classical linear regression model, the constant coefficients of the model are estimated in a way that the sum of squares of errors is minimized, whereas in the fuzzy possibilistic regression model, constant coefficients are determined in such a way that the difference between the estimated and observable values does not exceed a specified value. In other words, the fuzzy possibilistic regression models determine fuzzy coefficients in such a way that the fuzzy output width is minimized for the entire data set. Therefore, in the time series having high-dispersion data or, in other words, outliers, the fuzzy possibilistic regression model has a greater error than the classical linear regression in estimating the slope of the trend of changes. Therefore, considering this issue and studying the values of the time series of the intended stations, it was observed that most of the time series of the average annual temperatures of the stations under study are highly dispersed due to their inherent nature; this has caused fuzzy possibilistic regression show a greater error in estimating the slope of changes, even in some stations, it has shown a trend opposite to the classical linear regression trend. In Fig. 8, two examples of time series, when the scattering of data in them is high and low, are given. In Fig. 8a, which refers to the average minimum annual temperatures of the Ahwaz station, we clearly see the correlation between the two classical linear regression and fuzzy possibilistic regression models. This adaptation is the result of the lack of outliers as well as the low dispersion of data from each other over time. But in the second sample, which relates to the average minimum annual temperatures of the Bam station, the difference in the estimation of the slope of the changes by these two models can be easily seen. The reason for this difference is the existence of outliers as well as the high dispersion of data from each other over time. It should be noted that in the charts of Fig. 8, four lines of the trend can be seen that the two red lines represent the lower limit and above the output width of the fuzzy possibilistic regression model, and the black line represents the average output width of this model, which has been analyzed in this study. The blue line is also related to the classical linear regression.

Conclusion

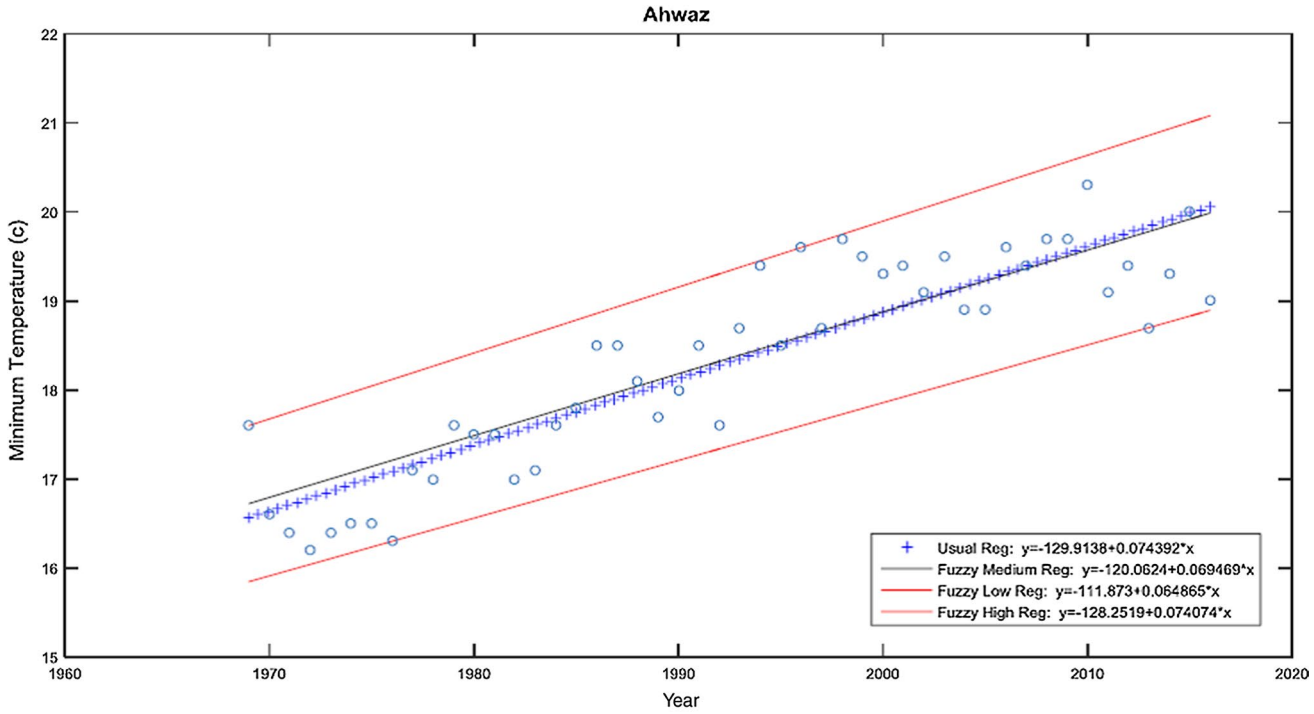
The existence of high mountains and topographic diversity has caused the spatial distribution of temperature in Iran not to follow a regular pattern. However, according to the spatial distribution maps of temperature in Iran, temperature rises from north to south and from west to east. The reason for this feature is the presence of heights in the north and west and the gradual reduction of the sun's angle to the northern latitudes. This variation in the spatial distribution of temperatures has caused the temperature changes in Iran to be particularly complex.

The highest amount of changes trend in average maximum annual temperature of Iran, which was actually an incremental trend, was first observed in the west and northwest, and then in a limited part of northeastern Iran. The southeast of Iran has been one of the areas that have seen the slightest changes in the trend of this variable. However, there are also limited stations that show a downward trend in average maximum annual temperatures. But the trend of average minimum annual temperatures in Iran has shown more different spatial arrangement than the average maximum annual temperatures of Iran, so that the highest changes trend has been observed in the eastern half, especially in the northeast. But regarding the average annual temperatures in Iran, it should be noted that the spatial arrangement of its changes trend follows the spatial arrangement of changes trend of maximum temperatures in Iran. In other words, the largest changes trend, which is actually an incremental trend, is first observed in the west and northwest, and then in northeastern Iran. The southeast of Iran was also one of the areas with no significant trend in average annual temperatures. Various reasons can be presented for the incremental trend of average maximum, minimum and average annual temperatures in the west, northwest and northeast of Iran over the course of these 48 years. The most important of these factors can be the change in land use, physical development of cities, population increase, the occurrence of successive droughts,

Table 1 The results of RMSE for the three variables of maximum, average and minimum annual temperatures of the intended stations in Iran

Station	Minimum		Average		Maximum	
	Classic	Fuzzy	Classic	Fuzzy	Classic	Fuzzy
Ababdan	0.540	0.547	0.561	0.682	0.689	0.907
Ahwaz	0.525	0.531	0.678	0.705	0.665	1.011
Arak	0.949	1.166	1.005	1.365	1.108	1.587
Babolsar	0.408	0.436	0.497	0.514	0.637	0.676
Bam	2.430	3.782	0.622	0.632	0.770	0.783
Bandar Anzali	0.504	0.516	0.564	0.610	0.764	0.971
Bandar Abbas	0.534	0.540	0.540	0.567	0.651	0.739
Bandar Lengeh	0.412	0.499	0.449	0.634	0.563	0.674
Chabahar	0.768	1.065	0.561	0.569	1.088	1.256
Dezful	0.799	0.816	0.515	0.551	0.604	0.628
Fassa	0.958	1.425	0.819	1.257	0.814	1.076
Ghazvin	0.799	0.802	0.862	0.866	0.972	0.988
Gorgan	0.726	0.733	0.648	0.648	0.720	0.727
Nozheh	0.832	1.043	0.754	0.919	0.888	0.941
Iranshahr	0.484	0.486	0.588	0.613	0.755	0.789
Jask	0.637	0.954	0.331	0.341	0.672	0.732
Kerman	0.593	0.594	0.578	0.586	0.697	0.712
Kermanshah	0.594	0.599	0.566	0.834	0.841	1.155
Khoram Abad	1.128	1.308	0.644	1.336	0.807	1.234
Ramsar	0.465	0.560	0.514	0.575	0.644	0.693
Rasht	0.901	1.072	0.621	0.643	0.661	0.734
Sabzevar	0.914	1.021	0.746	0.815	0.769	0.800
Saghez	1.187	1.236	1.074	1.584	1.075	1.582
Sanandaj	0.947	0.971	0.779	0.925	0.849	1.380
Semnan	0.654	0.667	0.626	0.667	0.948	1.132
Shahroud	0.676	0.684	0.658	0.733	0.804	1.038
Shiraz	0.948	1.032	0.577	0.791	0.710	0.798
Tabas	0.780	0.832	0.640	0.719	0.733	0.735
Torbate Haydaryeh	0.528	0.555	0.739	0.920	1.073	1.440
Yazd	0.510	0.606	0.567	0.667	0.702	0.790
Zabol	0.507	0.510	0.701	0.708	0.994	1.023
Zahedan	0.630	0.650	0.593	0.622	0.712	0.716
Zanjan	0.891	1.011	1.012	1.379	1.027	1.463
Esfahan	1.090	1.103	0.643	0.687	0.722	0.764
Birjand	0.745	0.772	0.736	0.740	0.854	0.859
Bushehr	0.482	0.618	0.455	0.482	0.662	0.666
Kashan	0.765	1.039	0.829	1.197	2.489	2.554
Khoy	0.829	0.844	0.948	1.039	1.015	1.099
Mashhad	0.778	0.813	0.679	0.734	0.869	1.011
Oroomieh	0.832	0.833	0.799	0.815	0.912	1.098
Shahre Kurd	0.832	0.874	0.784	0.929	0.991	1.285
Tabriz	0.748	0.758	0.758	0.770	0.811	0.912
Tehran	0.681	0.720	0.633	0.700	0.726	0.793

and, as a result, the decrease of soil moisture in these parts of Iran. In addition, along with these factors, which many of them are caused by human being, global warming has also been a major contributor to these changes. This trend of changes will logically increase the country's climatic abnormalities. An example of these abnormalities can be seen in increasing the intensity, duration and frequency of thermal waves, reducing the number of frosty days and, consequently, increasing the length of the growth period. It can also be expected that the climatic classes of Iran will



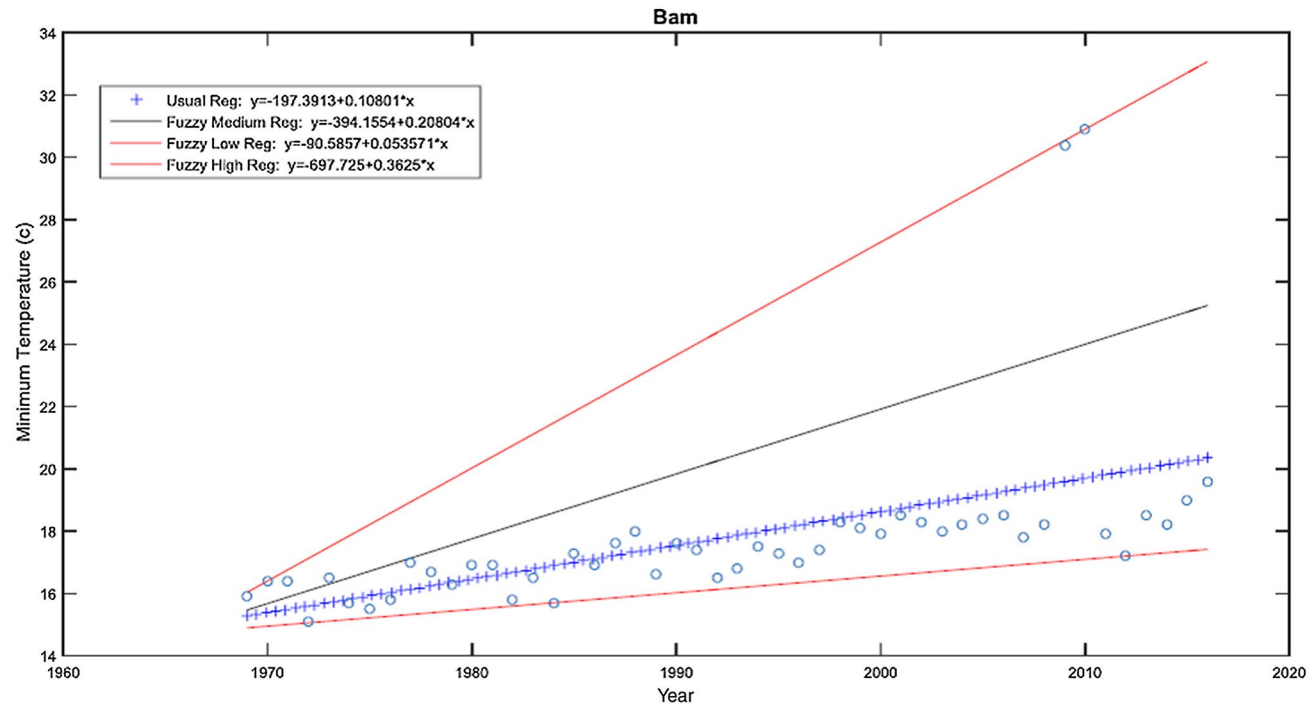


Fig. 8 Two examples of charts of estimating changes slope of the average minimum annual temperature of two stations in Ahwaz (high) and Bam station (low). The two red lines represent the lower limit and above the output width of the fuzzy possibilistic regression model, and the black line represents the average output width of this model. The blue line is also related to the changes slope of the classical linear regression

undergo changes that certainly require more studies and research in Iran.

The comparison of the results of the slope of changes trend obtained from the two classical linear regression and fuzzy possibilistic regression models clearly shows that in most cases, the fuzzy possibilistic regression shows the slope of the change trend more than the classical linear regression. This difference in estimating the values of the trends slope by these two models is due to the difference in estimating the constant coefficients of these models. The root-mean-square error (RMSE) criterion, used to evaluate the performance of these two models in estimating the values of changes slope, shows that the classical linear regression performed much better than fuzzy possibilistic regression.

Therefore, based on the classical linear regression model, which showed better performance than the fuzzy possibilistic regression, it was observed that in the whole study period, 1.40 °C was added to the average maximum annual temperatures and 1.68 °C to the average minimum annual temperatures, and 1.42 °C to the average annual temperatures in Iran. Thus, the amount of increase in average minimum annual temperature was more than the average maximum annual temperatures, which was consistent with the results of the research of Walter et al. (2002), the Intergovernmental Panel on Climate Change (IPCC) (2001), Alizadeh and Kamali (2002) and Masoudian (2004).

But with all these details, the researchers of this study believe that the fuzzy regression models have the ability to involve uncertainties in estimating the slope of change. In a comparative study, different types of fuzzy regression models can be investigated with other methods of estimating the trend of changes slope such as parametric methods (linear regression) and nonparametric (Mann–Kendall and slope estimator).

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References

Alijani B, Mahmoudi P, Panahi A (2011) Investigation of displacement of minimum temperatures temporal and spatial cores in west and northern west of Iran. Geogr Environ Plan J 41:53–68 **(In Persian)**

Alijani B, Mahmoudi P, Salighe M, Rigi Chahi A (2012) Study of annual maximum and minimum temperature changes in Iran. Geogr Res 26:101–122 **(In Persian)**

Alizadeh A, Kamali G (2002) Effect of climate change of agricultural water use in Mashhad valley. Geogr Res 2–3:189–201 **(In Persian)**

Bidokhti AA, Ranjbar AA (2003) Study of climatic effect of heat island for Tehran. In: Third regional and first national conference on climate change, 21–23 October, Isfahan, Iran (**In Persian**)

Brazdil R, Budikova M, Fasko P, Laplin M (1995) Fluctuation of maximum and minimum air temperatures in the Czech and the Slovak Republics. Atmos Res 37:53–65

Domonkos P, Tar K (2003) Long-term changes in observed temperature and precipitation series 1901–1998 from Hungary and their relations to larger scale changes. Theor Appl Climatol 75:131–147

Domroes M, El-Tantawi A (2005) Recent temporal and spatial temperature changes in Egypt. Int J Climatol 25:51–63

Easterling DR, Horton B, Jones PD, Peterson TC, Karl TR, Parker DE, Saliger MJ, Razuvayev V, Plummer N, Jamason P, Folland CK (1997) Maximum and minimum temperature trends for the globe. Science 277:364–366

Freiwan M, Kadioğlu M (2008) Climate variability in Jordan. Int J Climatol 28:69–89

Gemmer M, Becker S, Jiang T (2004) Observed monthly precipitation trends in China 1951-2002. Theor Appl Climatol 77:39–45

IPCC (2001) In climatic change 2001: the scientific basis. University Press, Cambridge

Jiang JM, You XT (1996) Where and when did an abrupt climatic change occur in China during the last 43 years? Theor Appl Climatol 55:33–39

Jones PD, Moberg A (2003) Hemispheric and large-scale surface air temperature variations: an extensive revision and an update to 2001. J Clim 16:206–223

Kadioğlu M, Şen Z, Gültekin L (2001) Variation and trends in Turkish seasonal heating and cooling degree-days. Clim Change 49:209–223

Kumar PV, Bindi M, Crisci A, Maracchi G (2005) Detection of variations in air temperature at different time scales the period 1889–1998 at Firenze, Italy. Clim Change 72:123–150

Lettenmaier DP, Wood EF, Wallis JR (1994) Hydro-climatological trends in the continental United States, 1948–1988. J Clim 7:586–607

Masoudian SA (2004) Temperature trends in Iran the last half century. Geogr Dev 2:89–106 **(In Persian)**

Nasri M, Modarres R (2008) Dry spell trend analysis of Isfahan Province, Iran. Int J Climatol 29:1430–1438

Nicolas N, Gruza G, Jouzel J, Carl T, Ogallo L, Parker D (1996) Observed climate variability and change. In: Houghton J, Meira Filho L (eds) IPCC 1995. The Second IPCC scientific assessment of climate change. Cambridge University Press, Cambridge

Rahmstorf S, Ganopolski A (1999) Long-term global warming scenarios computed with an efficient model. Clim Change 43:353–367

Scheifinger H, Menzel A, Koch E, Peter C (2003) Trends of spring time frost events and phonological dates in central Europe. Theor Appl Climatol 74:41–51

Shirgholami H, Ghahraman B (2005) Study of time trend changes in annual mean temperature of Iran. JWSS-Isfahan Univ Technol 9:9–24 **(In Persian)**

Stern DI, Kaufmann RK (2000) Detecting a global warming signal in hemispheric series: a structural time series analysis. Clim Change 47:411–438

Tanaka H, Uejima S, Asai K (1982) linear regression analysis with fuzzy model. IEEE Trans Syst Man Cybern 12:903–907

Tavosi T, Mahmoudi P, Moghadam FS (2010) Comparison of spatial spreading of arid and semi-arid climates in Iran during 1976–2005. Iran J Range Desert Res 17:94–105 **(In Persian)**

Tayanç M, Im U, Doğruel M, Karaca M (2009) Climate change in Turkey for the last half century. Clim Change 94:483–502

Todisco F, Vergni L (2008) Climatic change in central Italy and their potential effects on corn water consumption. Agric For Meteorl 148:205–209

Tonkaz T, Çetin M, Tülücü K (2007) The impact of water resources development projects on water vapor pressure trends in a semi-arid region, Turkey. Clim Change 82:195–209

Türkes M, Sümer UM, Kiliç G (2007) Variations and trends in annual mean air temperature in Turkey with respect to climatic variability. Int J Climatol 15:557–569

Walter GR, Post E, Convey P, Menzel A, Parmesean C, Beebee TJ, Formentin JM, Hoegh-Guldberg O, Bairlein F (2002) Ecological responses to recent climate change. Nature 416:389–395

Zadeh LA (1965) Fuzzy sets. Inf Comput 8:338–353

Zhang Q, Xu CY, Zhang Z (2009) Observed changes of drought/wetness episodes in the Pearl River basin, China, using the standardized precipitation index and aridity index. Theor Appl Climatol 98:89–99