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ORIGINAL PAPER

Recent trends of mean maximum and minimum air temperatures in the western half of Iran

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Abstract In this study, the trends of the annual, seasonal and monthly maximum (T_{max}) and minimum (T_{min}) air temperatures time series were investigated for 20 stations in the western half of Iran during 1966–2005. Three statistical tests including Mann–Kendall, Sen's slope estimator and linear regression were used for the analysis. The annual T_{max} and T_{min} series showed a positive trend in 85% of the stations and a negative trend in 15% of the stations in the study region. The highest increase of T_{max} and T_{min} values were obtained over Kermanshah and Ahwaz at the rates of (+)0.597°C/decade and (+)0.911°C/decade, respectively. On the seasonal scale, the strongest increasing trends were identified in T_{max} and T_{min} data in summer. The highest numbers of stations with positive significant trends occurred in the monthly T_{max} and T_{min} series in August. In contrast, the lowest numbers of stations with significant positive trends were observed between November and March. Overall, the results showed similar increasing trends for the study variables, although T_{min} generally increased at a higher rate than T_{max} in the study period.

1 Introduction

Atmospheric carbon dioxide levels have recorded continual increases since 1950s, a phenomenon that may significantly alter global and local climate characteristics such as temperature and precipitation (Yu et al. 2002). Analysis of air temperature data at global scales with respect to climate change indicates a 0.4–0.8°C rise since 1860. Warming since the mid-1970s has been particularly rapid with all eight of the warmest years on record occurring since 1983 (Feidas et al. 2004). It is noted that the temperature increase is not globally uniform. Regional variations can be much larger and considerable spatial and temporal variations may exist between climatically different regions (Yue and Hashino 2003).

The effects of climatic change and variability have been investigated by many researchers throughout the world. The results of these studies have clearly shown that there is climate variability as a result of human interference on the ecosystems. Yue and Hashino (2003) found increasing trends in annual, seasonal and monthly mean temperature in Japan during 1900–1996. Most of the trends were statistically significant and the increases were largest in winter and spring. Domonkos and Tar (2003) studied long-term changes in observed temperature and precipitation series by the Student's *t* test for the linear trends and the Mann–Kendall test in Hungary during 1901–1998. Their results indicated that the increase of mean temperature during the twentieth century was not significant while annual precipitation substantially decreased.

Turkes and Sumer (2004) studied the spatial and temporal patterns of trends in maximum and minimum temperatures and diurnal temperature range in Turkey for the period 1929–1999. Maximum temperature has shown weak warming and cooling in comparison with significant warming of minimum temperature in many regions of the country and in most seasons. Gadgil and Dhorde (2005) investigated temporal variation in temperature over Pune city, India, during the period 1901–2000. Their analysis revealed significant decrease in mean annual and mean maximum temperature.

Su et al. (2006) analyzed observed extreme temperature and precipitation trends over Yangtze from 1960 to 2002

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on the basis of the daily data from 108 meteorological stations. Their results showed that annual and seasonal mean maximum and minimum temperatures trend was characterized by a positive trend and that the strongest trend was found in the winter mean minimum temperature in the Yangtze. In addition, trend test revealed a significant trend in summer rainfall and statistically significant change was observed in heavy rain intensity. Ghahraman (2006) evaluated the long-term trend of mean annual temperature at 34 synoptic stations in Iran with a minimum record of 30 years by the Student's *t* test. He concluded that there was a positive trend in 50% of the stations, while 41% of the stations had a negative trend. In addition, the behavior of trend direction was different for different climates and no specific pattern was found. Smadi (2006) examined changes in minimum and maximum air temperatures variations in Jordan during the twentieth century. The results showed a significant warming trend after the years 1957 and 1967 for minimum and maximum air temperatures, respectively.

del Rio et al. (2007) detected the monthly, seasonal and annual trends of mean maximum and minimum temperatures over a region in the northwest of Spain for the period 1961–1997. They found quite similar pattern for mean maximum and minimum temperatures at monthly and annual time-scales. However, maximum temperature increased at a higher rate than minimum temperature in this period. Zhang et al. (2008) analyzed the spatial and temporal patterns of temperature extremes using the Mann–Kendall test and the linear regression method. Their analysis indicated that seasonal minimum temperature was in stronger increasing trend than seasonal maximum temperature. In comparison with the changes of the maximum temperature, more stations displayed significantly increasing trends of minimum temperature in frequency and intensity. Soltani and Soltani (2008) evaluated trends in air temperature and precipitation time series using the linear regression at Bojnord, Mashhad and Birjand stations in the northeast of Iran. They found a significant positive trend in minimum air temperature at Bojnord and Mashhad stations and a significant negative trend at Birjand station. In addition, the study showed significant positive and negative trends in maximum air temperature at Mashhad and Birjand stations, respectively. There was no considerable trend in monthly and annual precipitation. Tabari et al. (2011) studied temporal trends in climatic variables in the western half of Iran. They indicated an increasing trend in reference evapotranspiration and mean air temperature, and a decreasing trend in diurnal temperature range. In addition, both positive and negative trends were found in relative humidity and wind speed.

The western half of Iran (27°16′–39°47′N and 44°2′–54°8′E) with an area of 456,553 km^2 is bordered on the north by Armenia, Azerbaijan and the Caspian Sea, on the west by Iraq, on the northwest by Turkey and on the south by the Persian Gulf. The region is mostly mountainous and has only two expanses of lowlands: the Khuzestan plain in the south and the Caspian Sea coastal plain in the north. In addition, the region consists of rugged, mountainous rims surrounding high interior basins. The main mountain chain of Iran, the Zagros Mountains, is located in the region and stretch in northwest–southeast direction.

The northern part of the region is rich in biodiversity with 8,000 plant species representative of many different life forms (Herb, Grass, Shrub and tree) due to humid temperate climate and suitable soil. In contrast, the lowest plant diversity is in the southern part, which is a flat area with sub-equatorial climate. The western part is affected by Mediterranean and Black sea moisture which brings snow in the winter. The dominant species are low growing plant species with forbs, grass, shrub and tree life forms (Heshmati 2007).

There have been few international published works on temperature changes over the past century in the Middle East. Therefore, this study was carried out for analysis of the monthly, seasonal and annual trends in mean maximum and minimum air temperatures using the Mann–Kendall test, the Sen's slope estimator and the linear regression in the western half of Iran from 1966 to 2005.

2 Materials and methods

2.1 Data

Reliable data and adequate record length are the prerequisite to climate research and increase validity of the results. Therefore, a set of monthly mean maximum air temperature (T_{max}) and mean minimum air temperature (T_{min}) series from 20 meteorological stations in the western half of Iran for the period 1966–2005 has been used (IRIMO 2007). This period is the maximum common time period of T_{max} and T_{min} data recorded at all the 20 stations. The information about the stations is presented in Table 1 and the geographical location of the stations is shown in Fig. 1.

Several strategies have been described in the literature, which have been developed to detect non-homogeneities in the data series (Peterson et al. 1998). In this study, both the double-mass curve analysis (Kohler 1949) and the correlation analysis were used to the T_{max} and T_{min} time series of each station. Double-mass curve analysis tests the consistency of observations by comparing the accumulated values of the observations, such as air temperature, over time with the corresponding accumulated values over time for a nearby representative station (Linsley et al. 1982).

Table 1 Geographic characteristics of the stations used in the study

Station	Longitude (E)	Latitude (N)	Elevation (m a.s.l.)
1. Abadan	52°40′	31°11′	2,030
2. Ahwaz	48°40′	31°20′	23
3. Arak	49°46′	34°06′	1,708
4. Babolsar	52°39′	36°43′	−21
5. Bushehr	50°50′	28°59′	20
6. Dezful	48°23′	32°24′	143
7. Ghazvin	50°03′	36°15′	1,279
8. Hamedan	48°43′	35°12′	1,680
9. Kermanshah	47°09′	34°21′	1,319
10. Khorram-Abad	48°17′	33°26′	1,148
11. Khoy	44°58′	38°33′	1,103
12. Oroomieh	45°05′	37°32′	1,316
13. Ramsar	50°40′	36°54′	−20
14. Rasht	49°36′	37°15′	−7
15. Saghez	46°16′	36°15′	1,523
16. Sanandaj	47°00′	35°20′	1,373
17. Shahrekord	50°51′	32°17′	2,049
18. Tabriz	46°17′	38°05′	1,361
19. Tehran	51°19′	35°41′	1,191
20. Zanjan	48°29′	36°41′	1,663

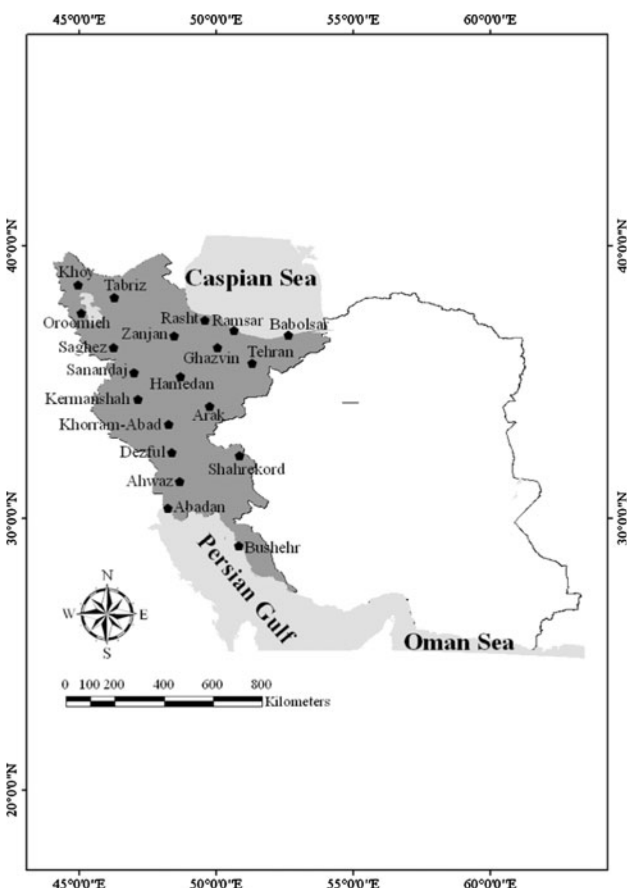


Fig. 1 Spatial distribution of the stations in the western half of Iran

The results of the correlation analysis and the double-mass curve analysis were checked in order to contrast both series and to use them alternatively when a segment of anyone of the series was missing. The first method showed considerable close correlations with average correlation coefficients of 0.94 and 0.95 for the $T_{\max}$ and $T_{\min}$ time series, respectively. The second method indicated average correlation coefficients of 0.98 and 0.99 for the $T_{\max}$ and $T_{\min}$ time series, respectively. Results of the double-mass curves of all stations are almost a straight line, and no obvious breakpoints are detected in the time series.

2.2 Statistical tests for trend analysis

2.2.1 Mann–Kendall test

The Mann–Kendall test is a non-parametric test, which does not require the data to be distributed normally (Tabari and Hosseinzadeh Talaee 2011). The second advantage of the test is its low sensitivity to abrupt breaks due to inhomogeneous time series (Jaagus 2006). According to this test, the null hypothesis H_0 states that the deseasonalized data $(x_1, \ldots, x_n)$ is a sample of n independent and identically distributed random variables. The alternative hypothesis H_1 of a two-sided test is that the distributions of x_k and x_j are not identical for all $k, j \le n$ with $k \ne j$. The test statistic S, which has mean zero and a variance computed by Eq. 3, is calculated using Eqs. 1 and 2, and is asymptotically normal:

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

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

$$\operatorname{Var}(S) = \frac{\left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)\right]}{18}. \tag{3}$$

The notation t is the extent of any given tie and $\sum_t$ denotes the summation over all ties. In cases where the sample size $n > 10$, the standard normal variable Z is computed using Eq. 4.

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{if} \quad S > 0 \\ 0 & \text{if} \quad S = 0\,. \\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{if} \quad S < 0 \end{cases} \tag{4}$$

Positive values of Z indicate increasing trends while negative Z show decreasing trends. When testing either increasing or decreasing monotonic trends at the α significance level, the null hypothesis was rejected for an absolute value of Z greater than $Z_{1-\alpha/2}$, obtained from the standard normal cumulative distribution tables (Partal and

Kahya 2006; Modarres and Silva 2007). In this research, significance levels of $\alpha = 0.01$ and 0.05 were applied.

2.2.2 *Sen's slope estimator*

If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated using a simple non-parametric procedure developed by Sen (1968). The slope estimates of N pairs of data are first computed by

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{for } i = 1, \ldots, N, \tag{5}$$

where x_j and x_k are data values at times j and $k (j > k)$, respectively. The median of these N values of Q_i is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by

$$Q_{\text{med}} = Q_{[(N+1)/2]}. \tag{6}$$

If N is even, then Sen's estimator is computed by

$$Q_{med} = \frac{1}{2}\left(Q_{[N/2]} + Q_{[(N+2)/2]}\right) \tag{7}$$

Finally, Q_{med} is tested with a two-sided test at the $100(1-\alpha)\%$ confidence interval and the true slope may be obtained with the non-parametric test (Partal and Kahya 2006).

In this work, the confidence interval was computed at two different confidence levels ($\alpha = 0.01$ and $\alpha = 0.05$) as follows:

$$C_\alpha = Z_{1-\alpha/2}\sqrt{\text{Var}(S)}, \tag{8}$$

where Var(S) has been defined in Eq. 3, and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution.

Then, $M_1 = (N - C_\alpha)/2$ and $M_2 = (N + C_\alpha)/2$ are computed. The lower and upper limits of the confidence interval, $Q_{\min}$ and $Q_{\max}$, are the M_1th largest and the $(M_1 + 1)$th largest of the N ordered slope estimates Q_i. If M_1 is not a whole number the lower limit is interpolated. Correspondingly, if M_2 is not a whole number the upper limit is interpolated (Salmi et al. 2002).

2.2.3 *Linear regression method*

Linear regression analysis, as well as the Mann–Kendall test and the Sen's slope estimator, is applied for detecting and analyzing trends in time series. The main statistical parameter drawn from the regression analysis, the slope, indicates the mean temporal change of the studied variable. Positive values of the slope show increasing trends, while negative values of the slope indicate decreasing trends. The total change during the period under observation is obtained with multiplying the slope with the number of years (Tabari and Marofi 2011; Tabari et al. 2010).

3 Results and discussions

The Mann–Kendall test, the Sen's slope estimator and the linear regression were applied to detect the annual, seasonal and monthly trends in the $T_{\max}$ and $T_{\min}$ series. The similarity is very large between the results from the three statistical methods. The results of the Mann–Kendall test on the annual $T_{\max}$ and $T_{\min}$ series are shown in Fig. 2. The methods detected increasing trends in annual $T_{\max}$ and $T_{\min}$ at all the stations except to Khorram-Abad, Saghez, Shahrekord and Arak stations. The increasing $T_{\max}$ and $T_{\min}$ trends were significant at the 95 and 99% confidence levels by the statistical tests at eight and ten stations, respectively. The negative $T_{\min}$ trends were significant at

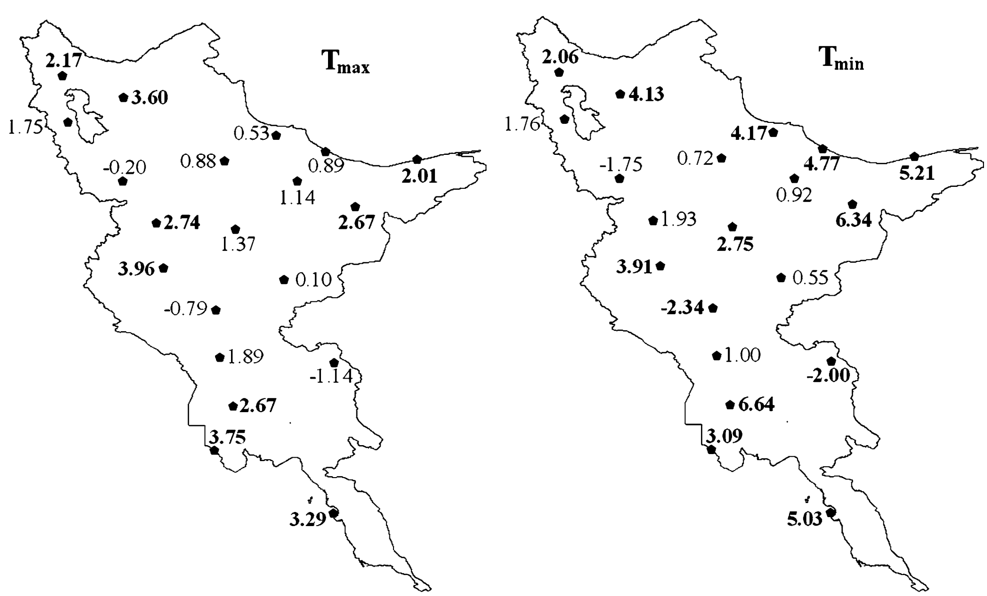


Fig. 2 Values of the statistics Z of the Mann–Kendall test for the annual means of $T_{\max}$ and $T_{\min}$ during 1966–2005 (*bold values* indicate significant trends)

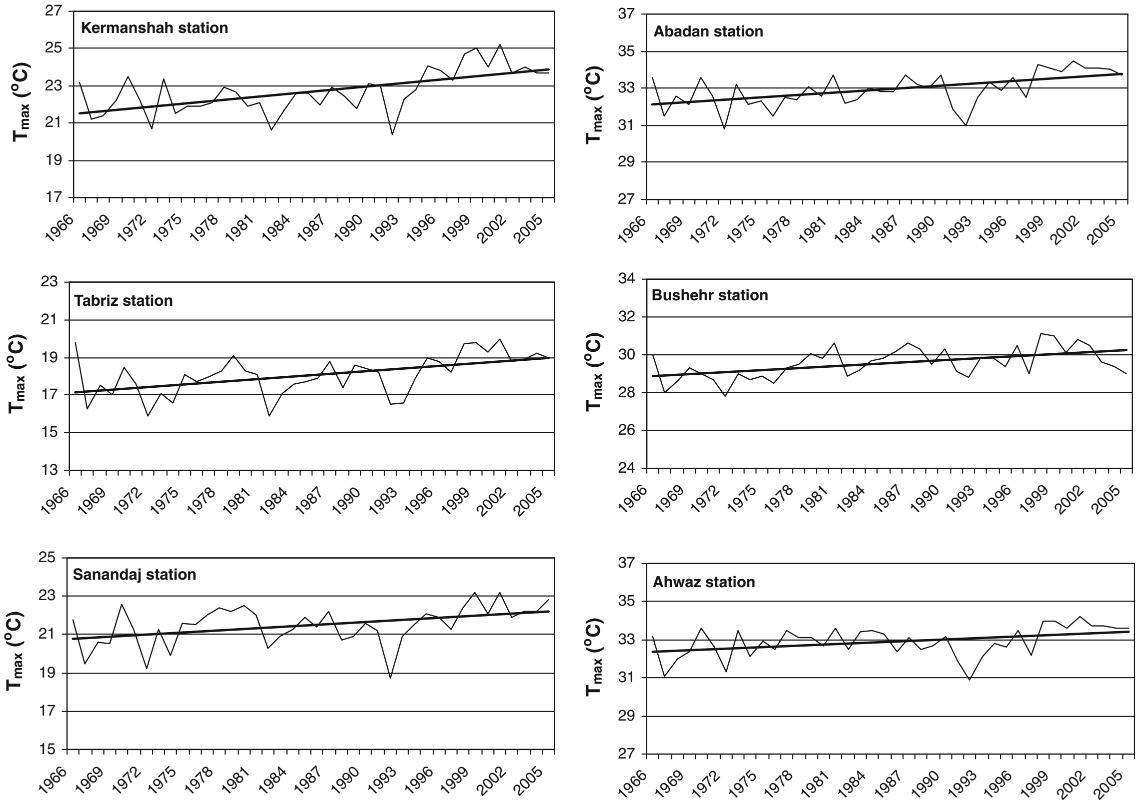


Fig. 3 Time series and linear trends of T_{max} at the stations with the most significant trends

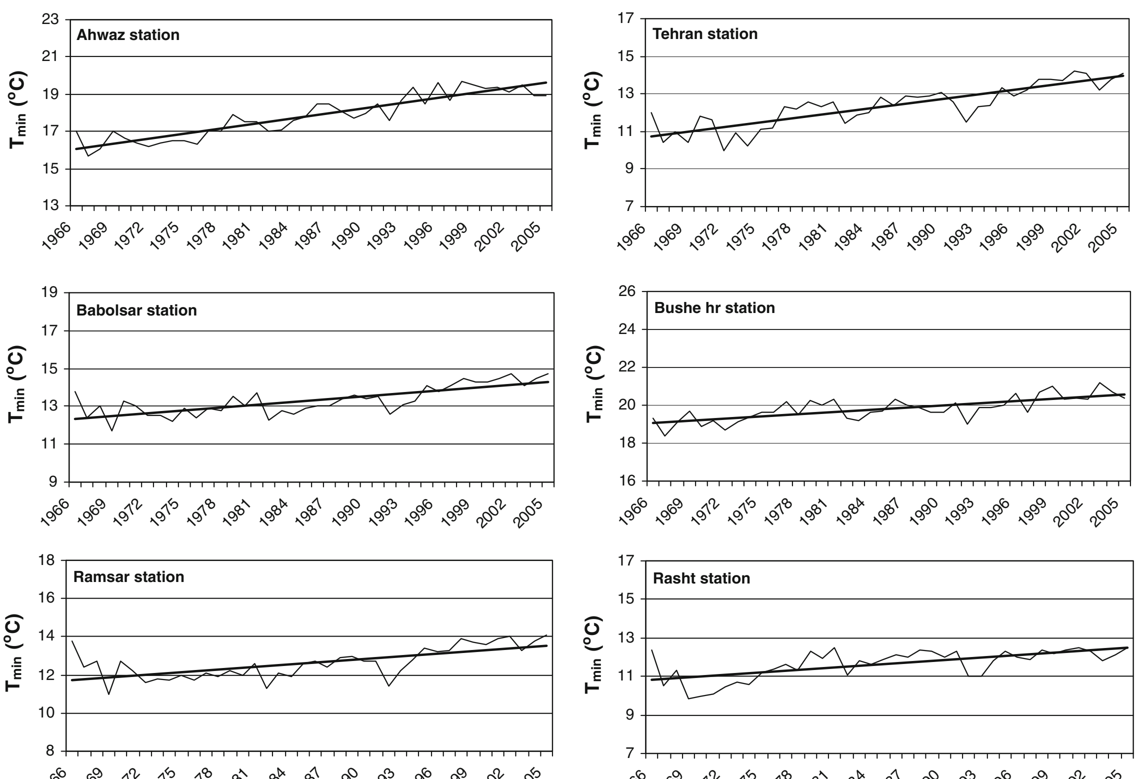


Fig. 4 Time series and linear trends of T_{min} at the stations with the most significant trends

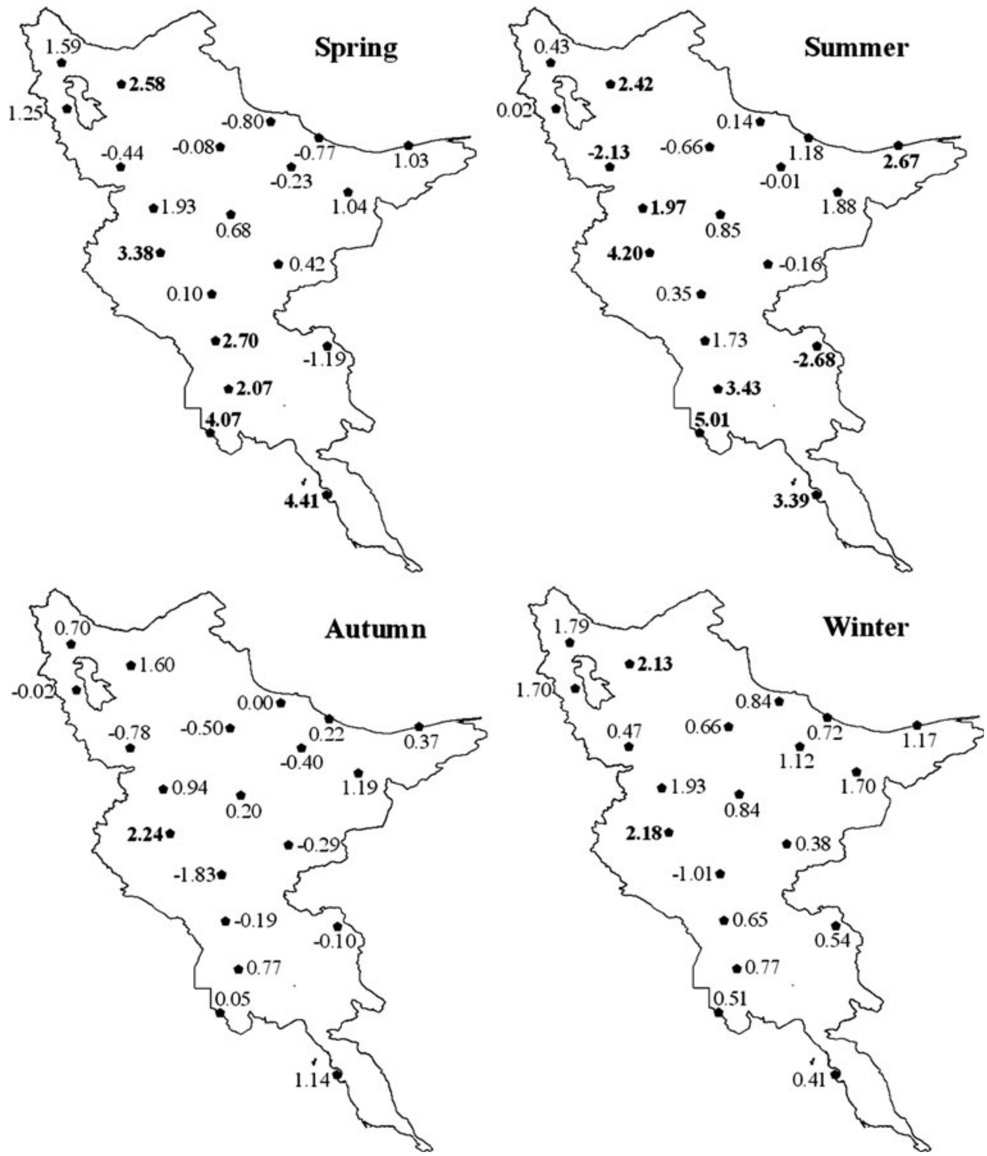


Fig. 5 Values of the statistics *Z* of the Mann–Kendall test for the seasonal means of T_{max} during 1966–2005 (*bold values* indicate significant trends)

Khorram-Abad and Shahrekord stations, while the negative T_{max} trends were entirely insignificant. According to the linear regression method, the magnitudes of the significant increasing trends in annual T_{max} varied from (+)0.213°C/decade at Babolsar station to (+)0.597°C/decade at Kermanshah station. In addition, the rates of annual T_{min} increased from (+)0.334°C/decade at Abadan station to (+)0.911°C/decade at Ahwaz station. On the other hand, the rates of the significant decreasing trends in annual T_{min} were (−)0.291 and (−)0.577°C/decade at Shahrekord and Khorram-Abad stations, respectively. The time series and linear trends of T_{max} and T_{min} at the stations with the most significant trends are shown in Figs. 3 and 4, respectively.

The results of the Mann–Kendall test on the seasonal and monthly T_{max} and T_{min} series are shown in Figs. 5, 6, 7, 8. Based on the results of the three methods, the increasing T_{max} trends were observed in spring and summer seasons at 12 stations and in autumn and winter seasons at 9 and 19 stations, respectively. The increasing T_{max} trends were significant at the 95 and 99% confidence levels in spring, summer, autumn and winter seasons at six, seven, one and two stations, respectively. In addition, 15 stations showed positive trends in spring and summer T_{min} data, followed by 14 in autumn and winter. One can see that about 9, 11 and 10 stations showed a significant increase in spring, summer and autumn T_{min}, respectively, while only six in winter. According to the linear regression method, the significant increasing T_{max} trends varied between (+)0.256°C/decade in summer season at Sanandaj station and (+)0.753°C/decade in summer season at Abadan station. Furthermore, the significant increasing T_{min} trends ranged from (+)0.282°C/decade in summer at Arak station to (+)1.107°C/decade in summer at Ahwaz station. On the contrary, the highest significant decreases of T_{max} and T_{min}

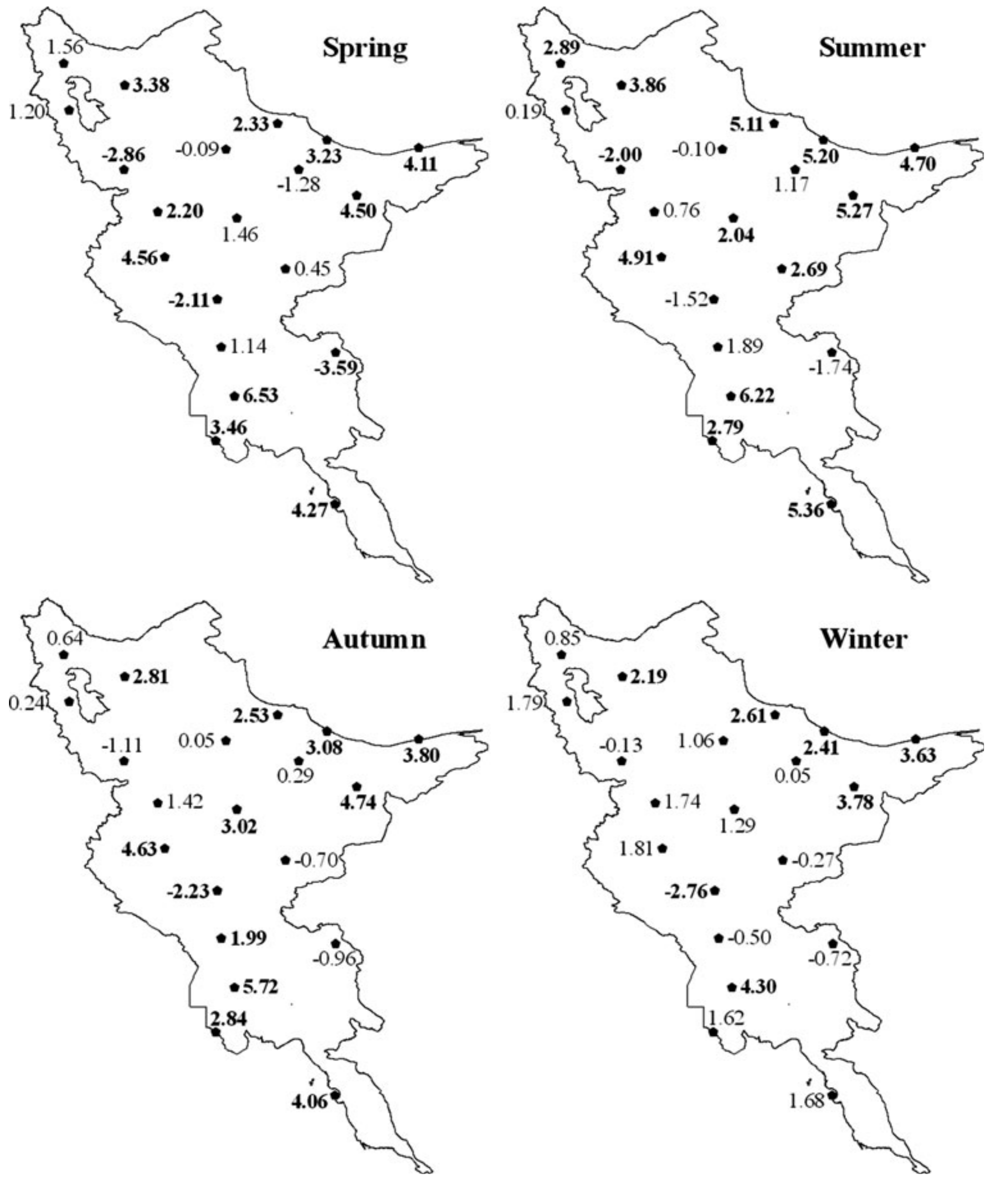


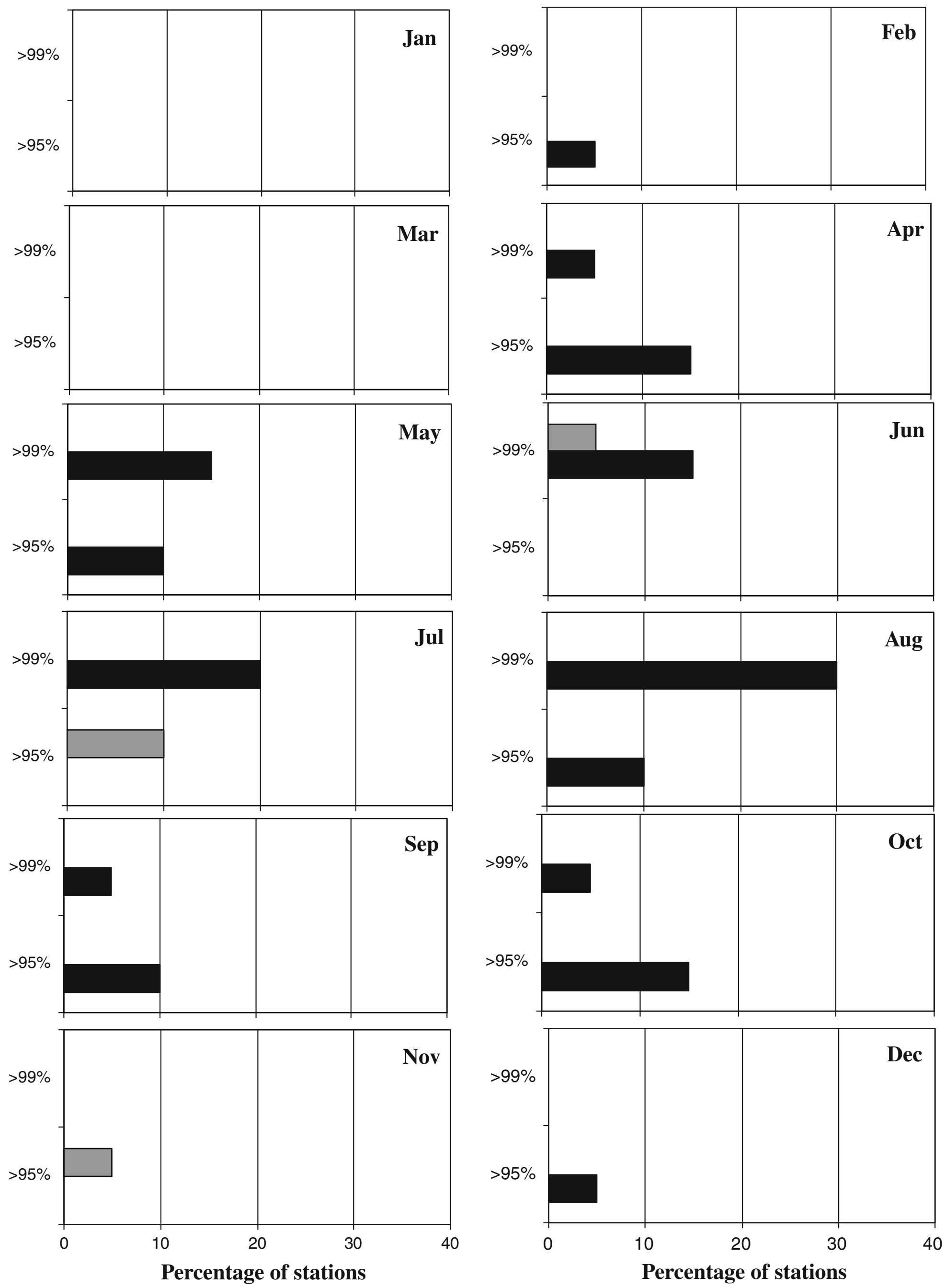
Fig. 6 Values of the statistics *Z* of the Mann–Kendall test for the seasonal means of T_{min} during 1966–2005 (*bold values* indicate significant trends)

values were obtained over Shahrekord in summer at the rate of (−)0.508°C/decade and over Saghez in spring at the rate of (−)0.794°C/decade, respectively.

Similar to the annual and seasonal series, the monthly T_{max} and T_{min} series showed both increasing and decreasing trends depending on the station. The significant increasing T_{max} and T_{min} trends were larger than the significant decreasing ones at the stations. The highest numbers of stations with significant positive trends of T_{max} and T_{min} occurred in August, accounting for 40 and 60% of the total stations for the T_{max} and T_{min} series, respectively. In contrast, the lowest numbers of stations with significant positive trends of T_{max} and T_{min} were observed between November and March. These results are in agreement with the seasonal analysis. On the contrary, the major number of significant negative trends in the T_{max} and T_{min} series took place in July and May, respectively. Khorram-Abad, Saghez and Shahrekord stations showed significant negative trend in both monthly T_{max} and T_{min} series, and Gazvin station in only T_{min} data. All of the monthly T_{min} time series were significant positive at Ahwaz, Babolsar and Tehran stations, whereas the highest significant trends in the monthly T_{max} series were found at Kermanshah, Abadan and Bushehr stations. In addition, Abadan, Bushehr, Kermanshah, Rasht and Tabriz stations showed statistically significant positive trends in the monthly T_{min} series in almost all the months of spring and summer and some months of autumn.

No significant positive or negative trends were detected by the trend tests in the monthly T_{max} and T_{min} series at Zanjan station. Furthermore, monthly T_{max} did not indicate any significant trends at Arak, Ghazvin, Hamedan, Ramsar,

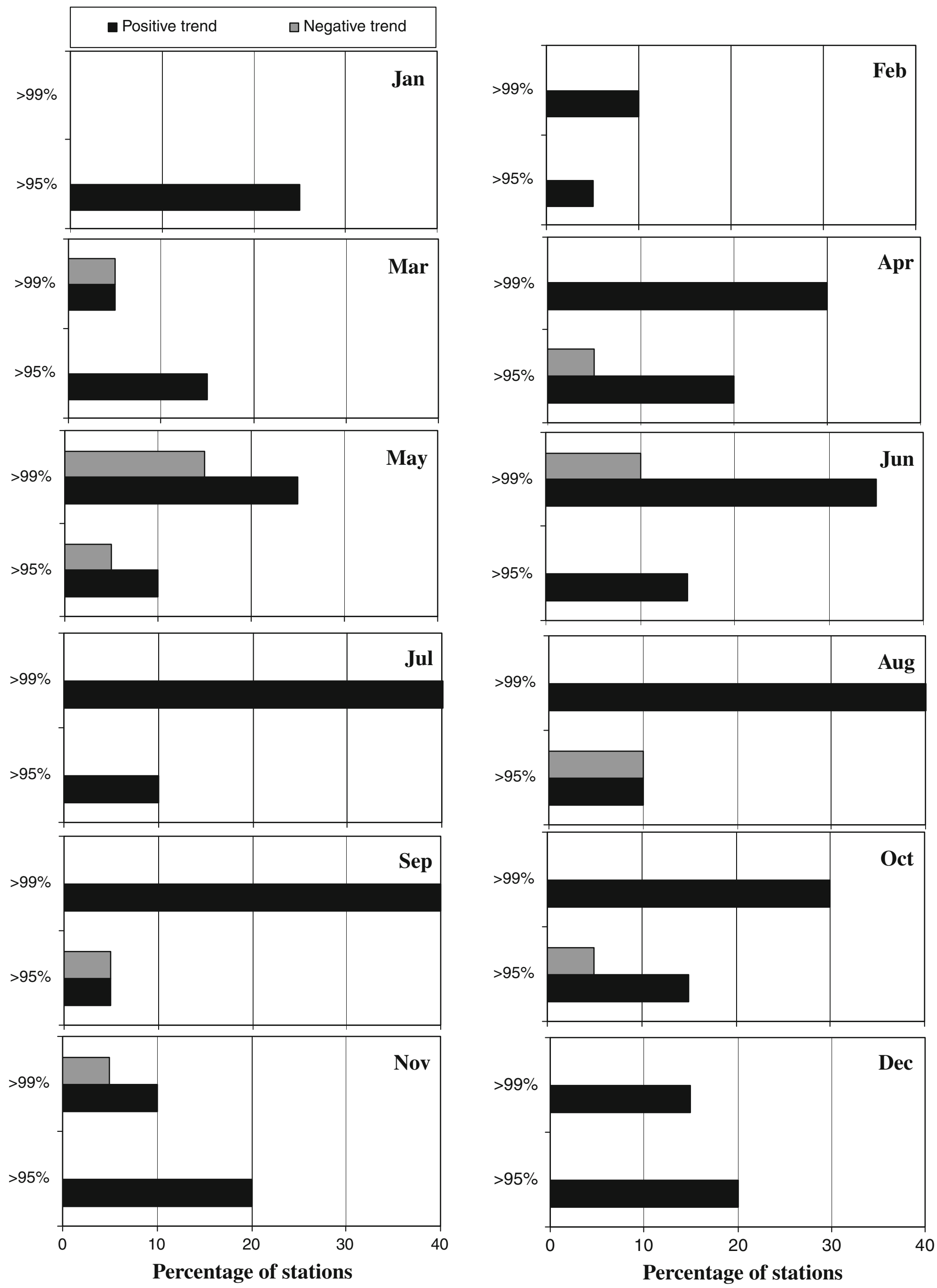
Fig. 7 The percentage of stations with significant trends in the monthly T_{max} series by the Mann–Kendall test at the 95 and 99% confidence levels



Rasht stations. According to the linear regression method, the significant increasing T_{max} trends varied from (+)0.298°C/decade in September to (+)1.01°C/decade in August at Abadan station. In addition, the significant increasing T_{min} trends ranged between (+)0.300°C/decade in April at Hamedan station and (+)1.204°C/decade in July at Ahwaz station. On the other hand, the highest decreases in the monthly T_{max} and T_{min} values were found over Khorram-Abad in November at the rate of (−)0.661°C/decade and over Saghez in May at the rate of (−)0.991°C/decade, respectively.

The previous study on mean air temperature (Ghahraman 2006) indicated that mean temperature at the majority of the stations in Iran increased in recent decades. Tabari et al. (2010) also found an increasing trend in mean air temperature in 70% of the stations located in the western half of Iran using the Mann–Kendall test. However, Soltani and Soltani (2008) indicated a mix of positive and negative trends in T_{max} and T_{min} data in the northeast of Iran. The warming trends of T_{min} and T_{max} found in this study are in accordance with the results obtained by Smadi (2006) in Jordan.

Fig. 8 The percentage of stations with significant trends in the monthly T_{min} series by the Mann–Kendall test at the 95 and 99% confidence levels



The analysis showed that T_{min} increased at a higher rate than T_{max} in the study period. These findings are in good agreement with the results of Turkes and Sumer (2004) in Turkey. The results of this study indicated that the observed warming trend during the past decades occurred mainly due to the increase in T_{min} rather than T_{max}. The increase in T_{min} might be related to several factors such as global warming, increased concentrations of anthropogenic greenhouse gases, aerosols which exert cooling effects on the climate, increased cloud cover and urbanization.

Overall, warming trends were found in the T_{max} and T_{min} series in the study area during the last decades. According to Soltani and Soltani (2008), positive trend in temperature might be due to greenhouse effects, while other probable reasons are: (1) an increase in natural and anthropogenic clouds, (2) haze from cities, factories and burning fields and forests, (3) vapor trials of high altitude aircraft, (4) irrigation that keeps the soil surface warmer at night, (5) anthropogenic greenhouse gases and (6) warming of the urban zones, which keeps the night temperature high.

4 Conclusions

In this study, the trends of the annual, seasonal and monthly T_{max} and T_{min} time series were examined for 20 stations in the western half of Iran for the period 1966–2005. The similarity was very large between the results from the three statistical methods on the temperature data. The results indicated similar positive trends for the variables studied, although T_{min} generally increased at a higher rate than T_{max} in most of months and seasons. The annual T_{max} and T_{min} series showed a positive trend in 85% of the stations and a negative trend in 15% of the stations (Khorram-Abad, Saghez, Shahrekord) in the study region. Analysis of the linear regression method indicated that the rate of increasing trends in annual T_{max} ranged between (+)0.213°C/decade at Babolsar station and (+)0.597°C/decade at Kermanshah station. In addition, the rates of annual T_{min} increased from (+)0.334°C/decade at Abadan station to (+)0.911°C/decade at Ahwaz station.

The percentage of stations characterized by significant increasing trends of T_{max} was 30% for spring, 35% for summer, 5% for autumn, 10% for winter. Furthermore, the significant increasing trends of T_{min} were observed in 50, 55, 50 and 30% of the stations for spring, summer, autumn and winter seasons, respectively. Therefore, stronger increasing trends were identified in T_{max} and T_{min} data in spring and summer compared with those in autumn and winter. On the monthly scale, the major number of significant positive trends of T_{max} and T_{min} occurred in August, accounting for 40 and 60% of the total stations for the T_{max} and T_{min} series, respectively. In contrast, the lowest numbers of stations with significant positive trends of T_{max} and T_{min} were observed between November and March. All of the monthly T_{min} time series were significant increasing at Ahwaz, Babolsar and Tehran stations, whereas the highest significant trends in the monthly T_{max} series were found at Kermanshah, Abadan and Bushehr stations. On the contrary, no significant positive or negative trends were detected in the monthly T_{max} and T_{min} series at Zanjan station.

Vast urbanization and industrialization during the past decades can be considered as a reason of positive trend in the air temperature. The urbanization process is a very important factor in climate warming. The urbanization processes in Iran started in the 1960s and 1970s due to land reforms from the 1960's when the government started to subsidize agriculture, commercializing farming and outsourcing many of the existing agrarian communities. The government's decision to promote industrial development and establishment of factories and industries around big cities led to an influx of urban population thereby construction of high-rise buildings and large housing estates in the 1970s.

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