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ORIGINAL PAPER

Detection of trends in days with extreme temperatures in Iran from 1961 to 2010

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Abstract Human health and comfort, crop productivity, water resource availability, as well as other critical hydrological, climatological, and ecological parameters are heavily influenced by trends in daily temperature maxima and minima ($T_{d\max}$, $T_{d\min}$, respectively). Using Mann–Kendall and sequential Mann–Kendall tests, trends in the number of days when $T_{d\max}$≥30 °C or $T_{d\min}$≤0 °C, over the period of 1961 to 2010, were examined for 30 synoptic meteorological stations in Iran. For 67 % of stations, days when $T_{d\min}$≤0 °C showed a significant negative trend, while only 40 % of stations showed a significant positive trend in days when $T_{d\max}$≥ 30 °C. The upward trend in $T_{d\max}$ became significant between 1967 and 1975, according to the station, while the downward trend in $T_{d\min}$ became significant between 1962 and 1974 for the same stations. Changes in precipitation type across most parts of the country show a high correlation with these temperature trends, especially with the negative trend in $T_{d\min}$. This suggests that future climatological and hydrological alterations within the country, along with ensuing climatic issues (e.g., change in precipitation, drought, etc.) will require a great deal more attention.

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1 Introduction

The rise in greenhouse gas emissions arising from increased industrialization and urbanization has, in recent years, contributed significantly to global warming, which has, in turn, led to shifts in global climate parameters (e.g., changes in the quantity, temporal pattern and areal distribution of precipitation, shifts in temperature (Richardson et al. 2011)). The Fifth Report of the Intergovernmental Panel on Climate Change notes that by-and-large all portions of the globe (except a small region in the North Atlantic) have experienced a rise in temperature over the last century (IPCC 2013). Such upward increments in temperature have major effects on losses of water resources, rising crop evapotranspiration as well as many other climatological and hydrological factors which ultimately have an impact on human and ecosystems (Henderson-Sellers and McGuffie 2012; USDA 2013; Dinar and Mendelsohn 2011). The potentially dire consequences of climate change have led, in recent years, to a worldwide upsurge in research in this field. Trend analysis of climatological parameters, especially temperature, is one of the major methods for detecting changes in climate. An analysis of monthly mean temperatures from 473 stations in Spain between 1961 and 2006, showed temperature to have generally increased during all months and seasons of the year over the study period (del Río et al. 2011). Using Mann–Kendall (MK), Sen's slope, and sequential MK methods to detect trends in air temperature in Romania, Croitoru et al. (2012) showed most of the country to have experienced a positive increase in temperature. Monthly mean temperature in Malta rose by an average of 1.1 °C between 1951 and 2010, with the largest changes occurring during the months of June, August, and October (Galdies 2012). While mean temperatures across India rose by 0.24 °C per decade between 1971 and 2009 (Bapuji Rao et al. 2014), in contrast, at certain locations in the country (e.g., Pune), mean temperature declined significantly between 1901 and 2000 (Gadgil and Dhorde 2005). Near surface temperatures in Armenia increased significantly between 1979 and 2012, surpassing the rate of increase between 1961 and 1994 (Gevorgyan 2014). Applying the MK test to temperature readings from 80 spatially-distributed weather stations in Sicily, Italy, Viola et al. (2014) found there to be a general warming trend in Sicily over the period of 1924 to 2006. Studying temperature parameters for 35 synoptic stations in Iran using an MK test revealed that most of the stations, particularly those in the eastern and western parts of the country showed significant positive trends, especially in the summer (Saboohi et al. 2012). Applying the MK test and wavelet transforms to a high resolution air temperature gridded data file for a period from 1956 to 2010, Araghi et al. (2015) showed that all regions of Iran showed positive temperature trends over this period, and that these were particularly strong in the warmer seasons. Given the effects of extreme temperatures on agriculture, ecosystems, human society, and other biological systems, especially in arid and semi-arid regions prone to water crises, this study analyzed the trend in the number of days with extreme temperatures occurring in Iran over the past five decades. It must be noted that most of the previous studies for temperature trends in Iran have focused on monthly (e.g., average, maximum, or minimum) temperatures (Tabari and Hosseinzadeh Talaee 2011; Tabari and Talaee 2011; Saboohi et al. 2012; Kousari et al. 2013), while this study is focused on extreme daily temperatures with specified criteria (e.g., more than 30 °C and less than 0 °C). These extreme thermal data are very important factors in ecology, agriculture, and also in some hydrological applications and processes. For example, many plants and biological systems are unable to function properly in temperatures of more than 30° to 35° C, while some other plants need under zero temperature periods for their biological growth (Connor et al. 2011). Precipitation type, snow melting rate, topsoil water availability, evapotranspiration, etc. are some of the issues that are strongly affected by extreme daily temperatures (Karamouz et al. 2013).

2 Data and methods

Approximately 1.65×10^6 km^2 in area, Iran is situated between 25°N to 38°39′N latitude and 44°E and 63°25′E longitude in south west Asia. Based on the Köppen method, most regions of Iran have an arid to semi-arid climate (Dinpashoh et al. 2011; Ahrens 2011; Saadat et al. 2011). Less than a third of global mean precipitation of 830 mm year^{-1}, the roughly 250 mm year^{-1} in mean precipitation across Iran shows great spatiotemporal variability (Modarres and de Paulo Rodrigues da Silva 2007; Tabari et al. 2012). It is well-known that as the record length increases, the validity of the results increases accordingly. There are more than 200 synoptic stations in Iran, but most of these stations do not have sufficient data record length. To analyze trends in the number of days with extreme temperatures, daily temperature maxima and minima ($T_{d\max}$, $T_{d\min}$, respectively) between 1961 and 2010 were collected from 30 synoptic meteorological stations (Table 1, Fig. 1) spread across all of Iran and free of data lacunae. The selected stations have the best quality and longest record datasets among all of the synoptic stations in Iran and for this reason, most of the previous studies on climatic variables in this country were focused on these stations as well (Saboohi et al. 2012; Shifteh Some'e et al. 2013; Tabari and Hosseinzadeh Talaee 2011; Tabari et al. 2011b; Tabari and Talaee 2011). In addition, the central part of Iran has a very arid climate with very little precipitation. So these parts of Iran (that are called the Central Desert and Lut Desert) have very little human

Table 1 Identification of 30 synoptic stations which were used in this study

Station name	Longitude (°E)	Latitude (°N)	Elevation (m)	Climate
Abadan	48.25	30.37	6.6	Arid
Ahvaz	48.67	31.33	22.5	Arid
Arak	49.77	34.1	1,708	Semi-arid
Babolsar	52.65	36.72	−21	Humid
Bam	58.35	29.1	1,066.9	Hyper-arid
Bandar Abbas	56.37	27.22	98	Arid
Birjand	59.2	32.87	1,491	Arid
Bushehr	50.83	28.98	196	Arid
Esfahan	51.67	32.62	1,550.4	Arid
Ghazvin	50.05	36.25	1,279.2	Semi-arid
Gorgan	54.27	36.85	133	Sub-humid
Hamedan	48.72	35.2	1,679.7	Semi-arid
Kerman	56.97	30.25	1,753	Arid
Kermanshah	47.15	34.35	1,318.6	Semi-arid
Khorramabad	48.28	33.43	1,147.8	Semi-arid
Khoy	44.97	38.55	1,103	Semi-arid
Mashhad	59.63	36.27	999.2	Semi-arid
Ramsar	50.67	36.9	−20	Humid
Rasht	49.6	37.25	−6.9	Humid
Sabzevar	57.72	36.2	977.6	Arid
Sanandaj	47	35.33	1,373.4	Semi-arid
Shahrekord	50.85	32.28	2,048.9	Semi-arid
Shahroud	54.95	36.42	1,345.3	Arid
Shiraz	52.6	29.53	1,484	Semi-arid
Tabriz	46.28	38.08	1,361	Arid
Tehran	51.32	35.68	1,190.8	Semi-arid
Torbat Heydarieh	59.22	35.27	1,450.8	Semi-arid
Yazd	54.28	31.9	1,237.2	Arid
Zahedan	60.88	29.47	1,370	Arid
Zanjan	48.48	36.68	1,663	Semi-arid

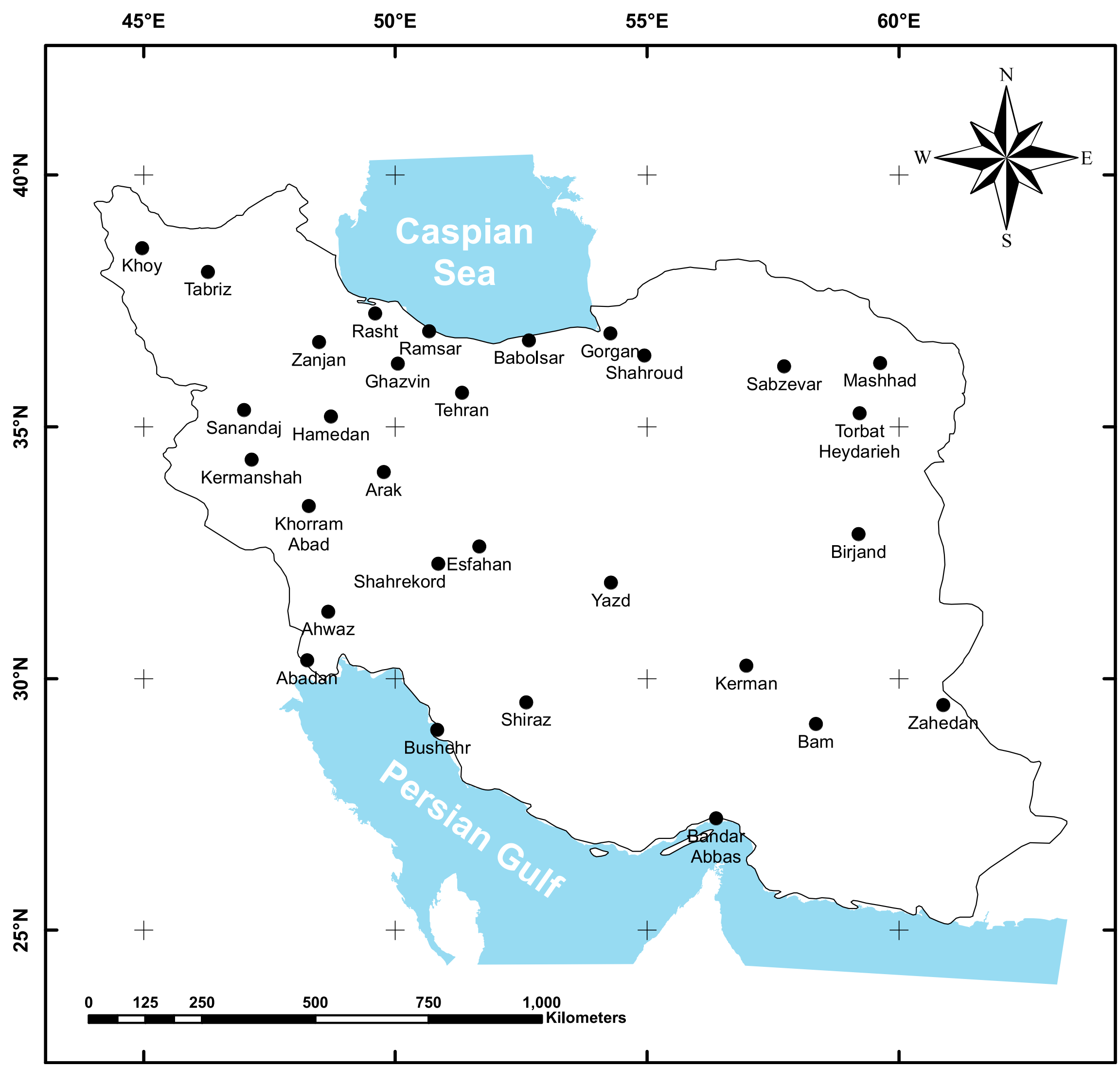

Fig. 1 Location of the synoptic stations used in this study

habitation, and as such there are not many synoptic stations in the central parts of the country. As such, the stations in these regions with the best quality data (e.g., Bam, Esfahan, Kerman, Yazd, etc.) were selected for this research. For each year, the number of days when $T_{d\max}\geq 30$ °C or $T_{d\min}\leq 0$ °C were counted. Descriptive statistics and boxplots of the datasets were developed (Tables 2 and 3, Fig. 2). It must be noted that since the studied data in this research were counted event time series, the length of data is more critical, because estimating the missing values in a time series will increase the uncertainty in the results of the analysis. The selected stations do not have any gaps in data for the number of days when $T_{d\max}\geq 30$ °C or $T_{d\min}\leq 0$ °C.

2.1 Test of homogeneity

When variations in a climatic variable are caused only by natural fluctuations in weather conditions, that variable has homogeneity. In other cases, especially when the location of a station is changed, the climatic variables in that station will be changed accordingly. Analysis of homogeneity in any studied data is a very important step in climatological research, especially when trend analysis is the main purpose of the study. In this research, Levene's test was employed to examine the homogeneity in the studied data. This test is an alternative to the Bartlett test (Storch and Zwiers 1999; Brown and Forsythe 1974); the Levene test is less sensitive to the normal distribution of samples. The Levene test is defined as follows:

$$\begin{aligned} H_0 &: \sigma_1^2 = \sigma_2^2 = \cdots = \sigma_k^2 \\ H_a &: \sigma_i^2 \neq \sigma_j^2 \end{aligned}$$

$$W = \frac{(N-k)}{(k-1)} \frac{\sum_{i=1}^{k} N_i \left(\overline{Z}_{i.} - \overline{Z}_{..}\right)^2}{\sum_{i=1}^{k} \sum_{j=1}^{N_i} \left(Z_{ij} - \overline{Z}_{i.}\right)^2} \tag{1}$$

$$Z_{ij} = \left| Y_{ij} - \overline{Y}_{i.} \right| \tag{2}$$

Table 2 Descriptive statistics for number of days with $T_{d\max} \geq$ 30 °C in the selected stations during the period of 1961 to 2010

Station name	Mean	S.D.	Min.	Max.	Range	Skewness	Kurtosis
Abadan	217.3	9.9	200	247	47	0.64	0.05
Ahvaz	215.2	9.9	200	245	45	0.38	−0.13
Arak	110.7	12.2	72	135	63	−0.43	0.69
Babolsar	60.5	16.5	28	102	74	0.30	−0.42
Bam	194.3	13.8	169	226	57	0.28	−0.83
Bandar Abbas	234.5	13.8	197	266	69	−0.03	0.49
Birjand	141.9	14.0	110	167	57	−0.16	−0.66
Bushehr	200.6	9.5	171	220	49	−0.73	0.56
Esfahan	127.9	10.8	105	153	48	−0.01	−0.34
Ghazvin	112.7	12.1	77	134	57	−0.33	−0.20
Gorgan	106.6	14.3	77	137	60	−0.06	−0.88
Hamedan	99.0	9.8	75	124	49	−0.07	−0.16
Kerman	137.7	12.2	110	166	56	0.00	−0.45
Kermanshah	127.5	9.5	105	147	42	−0.03	−0.51
Khorramabad	146.5	10.7	121	177	56	0.03	0.23
Khoy	78.8	16.0	36	108	72	−0.52	−0.03
Mashhad	109.3	12.7	66	135	69	−0.54	1.20
Ramsar	25.5	15.1	1	72	71	0.72	0.37
Rasht	62.8	14.1	32	97	65	0.44	−0.14
Sabzevar	146.0	10.7	123	168	45	0.08	−0.51
Sanandaj	117.2	9.6	90	135	45	−0.54	0.28
Shahrekord	97.3	16.3	54	128	74	−0.32	0.07
Shahroud	96.5	12.9	53	120	67	−0.74	0.79
Shiraz	152.1	10.6	129	177	48	−0.04	−0.31
Tabriz	79.0	11.8	51	103	52	−0.24	−0.09
Tehran	126.2	9.2	100	146	46	−0.22	0.15
Torbat Heydarieh	104.0	18.5	56	146	90	−0.24	−0.36
Yazd	162.4	11.8	132	189	57	0.03	−0.12
Zahedan	164.8	13.0	136	198	62	0.23	0.03
Zanjan	70.5	11.5	38	103	65	−0.23	0.88

where $\overline{Z}_{i.}$ and $\overline{Z}_{..}$ are the groups and overall means, respectively, N is the size of total dataset and N_i is the size of ith subgroup, and k is the number of subgroups. The Levene test rejects the H_0 when $W > F_{\propto,k-1,N-k}$ where $F_{\propto,k-1,N-k}$ is the upper critical value of F distribution with $k-1$ and $N-k$ degree of freedom and significance level of α. Homogeneity will not be present in data when H_0 is rejected in the Levene test.

2.2 Mann–Kendall (MK) trend test

The Mann–Kendall (MK) test is a non-parametric trend test which is very popular in climatology and hydrology studies (Yue et al. 2002; Gadgil and Dhorde 2005; Partal and Kahya 2006; Partal and Küçük 2006; Modarres and de Paulo Rodrigues da Silva 2007; Adamowski et al. 2009, 2010; del Río et al. 2011; Dinpashoh et al. 2011; Tabari and Hosseinzadeh Talaee 2011; Tabari et al. 2011a; Nalley et al. 2012, 2013; Shadmani et al. 2012; Wang et al. 2012a, b; Yang et al. 2012; Duhan and Pandey 2013; Safeeq et al. 2013; Shi et al. 2013; Nsubuga et al. 2014; Pingale et al. 2014; Araghi et al. 2015). By applying this test on a time series, one can detect the existence and significance of any trend in the data. The original version of the MK test entails calculating S, the number of positive differences minus the number of negative differences (Wilks 2011):

$$S = \sum_{i=1}^{n-1} \text{sign}(x_{i+1} - x_i) = \sum_{i=1}^{n-1} \text{sign}(\Delta x) \quad (3)$$

$$\text{Sign}(\Delta x) = \begin{cases} +1, & \Delta x > 0 \\ 0\,, & \Delta x = 0 \\ -1, & \Delta x < 0 \end{cases} \quad (4)$$

where, x_i is the ith ranked data in the time series and n is the length of the data records. The variance of this distribution, var(S), depends on whether all data in the time series are distinct, or whether some are repeated values. If there are no ties, the variance of the sampling distribution of S is calculated

Table 3 Descriptive statistics for number of days with $T_{d\min} \leq 0$ °C in the selected stations during the period of 1961 to 2010

Station name	Mean	S.D.	Min.	Max.	Range	Skewness	Kurtosis
Abadan	1.3	2.6	0	15	15	3.32	13.08
Ahvaz	1.2	2.6	0	14	14	3.18	10.84
Arak	89.9	16.1	53	124	71	0.14	−0.61
Babolsar	6.9	8.6	0	42	42	1.88	4.16
Bam	8.5	8.4	0	40	40	1.70	3.25
Bandar Abbas	0.0	0.0	0	0	0	–	–
Birjand	76.0	11.2	54	97	43	−0.04	−0.99
Bushehr	0.0	0.0	0	0	0	–	–
Esfahan	70.5	12.3	48	92	44	0.08	−1.10
Ghazvin	87.6	17.3	45	134	89	0.05	0.46
Gorgan	15.7	11.0	0	47	47	0.96	0.77
Hamedan	140.4	14.3	115	177	62	0.33	−0.42
Kerman	90.7	15.2	55	122	67	0.25	−0.38
Kermanshah	88.6	13.5	65	118	53	0.49	−0.57
Khorramabad	49.2	20.1	0	91	91	−0.12	−0.68
Khoy	109.5	18.7	67	142	75	0.00	−0.57
Mashhad	84.4	23.0	39	138	99	0.06	−0.73
Ramsar	9.5	10.1	0	50	50	1.56	3.22
Rasht	22.5	17.7	0	99	99	1.92	5.25
Sabzevar	55.3	20.8	16	93	77	0.12	−1.12
Sanandaj	103.5	17.6	72	142	70	0.17	−0.93
Shahrekord	125.2	12.1	103	151	48	0.16	−0.94
Shahroud	78.6	19.7	43	118	75	0.06	−1.14
Shiraz	46.5	18.5	6	82	76	−0.11	−0.54
Tabriz	98.1	15.3	63	135	72	0.28	0.25
Tehran	41.5	20.6	5	86	81	0.30	−0.70
Torbat Heydarieh	93.8	12.2	68	117	49	−0.16	−0.91
Yazd	49.6	16.6	12	78	66	−0.19	−0.90
Zahedan	53.3	14.1	26	87	61	0.30	−0.42
Zanjan	119.4	13.9	92	146	54	−0.15	−0.89

as:

$$\mathrm{var}(S) = \frac{1}{18} \cdot [n(n-1)(2n+5)] \quad (5)$$

whereas, if there are ties the variance is calculated as:

$$\mathrm{var}(S) = \frac{1}{18} \cdot \left[[n(n-1)(2n=5)] - \sum_{j=1}^{J} t_j(t_j-1)(2t_j+5) \right] \quad (6)$$

The MK statistic, Z, is then given by:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{var}(S)}}, & S > 0 \\ 0 \quad , & S = 0 \\ \frac{S+1}{\sqrt{\mathrm{var}(S)}}, & S < 0 \end{cases} \quad (7)$$

where, J indicates the number of groups of repeated values, and t_j is the number of repeated values in the jth group (Wilks 2011). Previous studies have shown that the existence of a seasonality pattern or serial correlation in any time series can affect the results of the MK test (Hirsch and Slack 1984; Hamed and Ramachandra Rao 1998; Yue et al. 2002). It has therefore been recommended that before applying the MK test on a dataset, one calculates autocorrelations to detect the seasonality pattern and any serial correlation in time series. The lag-k autocorrelation coefficient, r_k, can be calculated as (Wilks 2011):

$$r_k = \frac{\sum_{i=1}^{n-k} [(x_i - \overline{x}_-)(x_{i+k} - \overline{x}_+)]}{\left[\sum_{i=1}^{n-k} (x_i - \overline{x}_-)^2\right]^{1/2} \left[\sum_{i=k+1}^{n} (x_i - \overline{x}_+)^2\right]^{1/2}} \quad (8)$$

where the subscripts "−" and "+" indicate sample means over the first and last n-k data values, respectively. Equation (6) is valid for $0 \leq k \leq n-1$, a condition applicable to most time series.

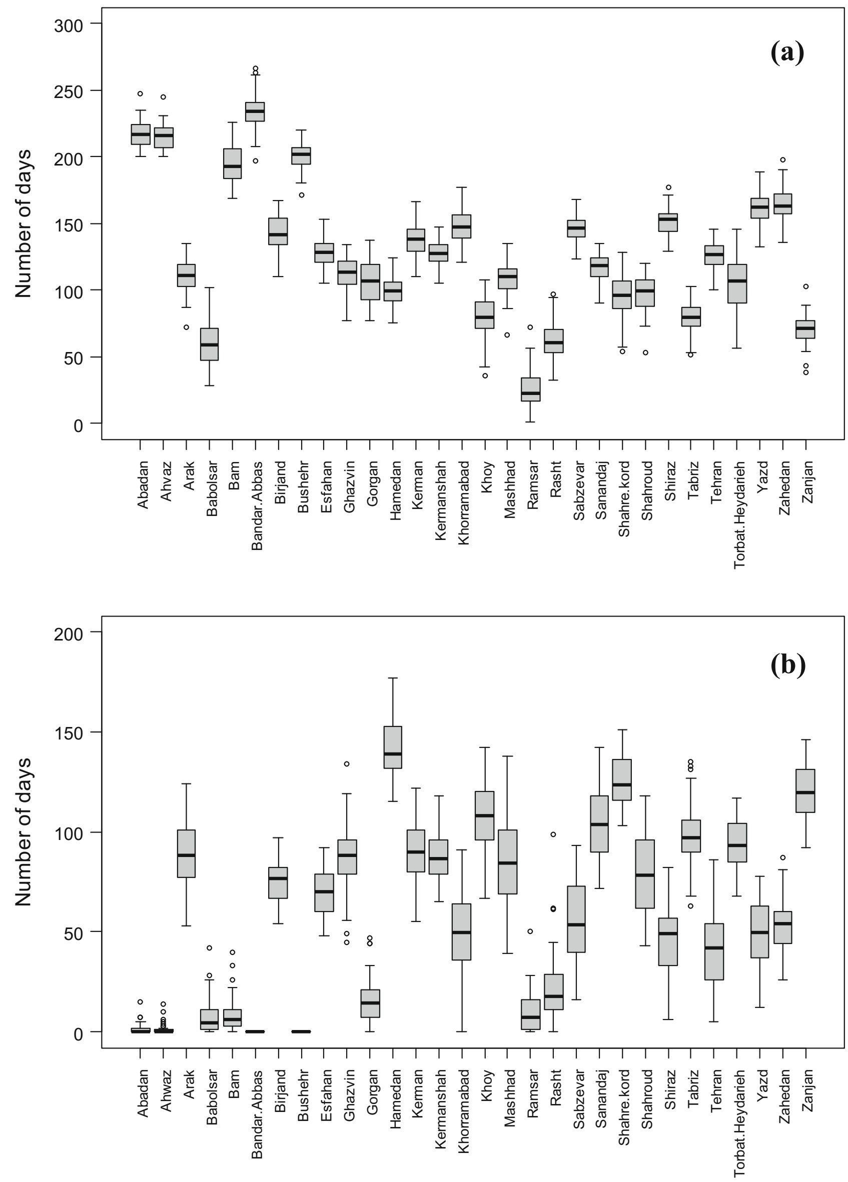

Fig. 2 Boxplots for number of days when $T_{d\max} \geq 30$ °C (**a**) and the number of days when $T_{d\min} \leq 0$ °C (**b**) in the studied synoptic stations

The collection of autocorrelations computed for various lags are called the autocorrelation function. Often autocorrelation functions are displayed graphically, with the autocorrelations plotted as a function of lag (Wilks 2011). To judge if observed sample data are serially correlated, the significance of the lag-1 serial correlation at a significance level of α=0.10 of the two-tailed test is assessed using the following approximation:

$$\frac{-1-1.645\sqrt{n-2}}{n-1} \leq r_k \leq \frac{-1+1.645\sqrt{n-2}}{n-1} \quad (9)$$

Hamed and Ramachandra Rao (1998) showed that when positive (negative) autocorrelation exists in times series, the estimation of variance will be less (more) than the actual value and this will in turn erroneously increase (decrease) the MK Z-value. The modified version of the MK test which must be used in such cases is as follows (Hamed and Ramachandra Rao 1998; Yue et al. 2002):

$$\mathrm{var}\left(S'\right) = \frac{1}{18}\cdot[n(n-1)(2n+5)]\left[\frac{n}{n_e^*}\right] \quad (10)$$

$$\frac{n}{n_e^*} = 1 + \left(\frac{2}{n^3-3n^2+2n}\right)\sum_{f=1}^{n-1}(n-f)(n-f-1)(n-f-2)\rho_e(f) \quad (11)$$

$$\rho(f) = 2\sin\left[\frac{\pi}{6}\rho_e(f)\right] \quad (12)$$

where n^* is the effective sample size required to account for the autocorrelation factor in the data. $\rho_e(f)$ is the autocorrelation function between the ranks of the observations and is calculated as the inverse of Eq. 10.

2.3 Sequential MK test

The sequential MK test has been recommended by the World Meteorological Organization (WMO) as an appropriate method for analyzing progressive trends and especially for detecting the onset year(s) of a trend in meteorological times series (Sneyers 1990; Partal and Kahya 2006). This test considers the relative values of all terms in a time series ($x_1, x_2, \ldots, x_n$) and the following steps have to be performed:

1. The magnitudes of x_j annual mean time series, ($j=1, \ldots, n$) are compared with those of x_k ($k=1, \ldots, j-1$). At each comparison, the number of cases where $x_j > x_k$ is counted and recorded in n_j.
2. The statistic t_j, as well as its mean, $E(t_j)$, and variance, $var(t_j)$, are calculated as:

$$t_j = \sum_{j=1}^{j=n} n_j \tag{13}$$

$$E(t_j) = \frac{n(n-1)}{4} \tag{14}$$

$$\mathrm{var}(t_j) = \frac{j(j-1)(2j+5)}{72} \tag{15}$$

3. The sequential values of the statistic $u(t)$ are then calculated as:

$$u(t) = \frac{t_j - E(t_j)}{\sqrt{\mathrm{var}(t_j)}} \tag{16}$$

where, $u(t)$ is a standardized variable with a mean of zero and standard deviation of one, which fluctuates around zero as the time series progresses. When $u(t)$ is plotted against time, significant variations in trend are found when the $u(t)$ curve crosses the upper or lower 95 % confidence limits (e.g., +1.96 and −1.96 for an α=5 % significance level). In such a case, the trend can be said to have changed significantly at that point. Likewise, the $u'(t)$ values are computed backward, starting from the end of the series. When $u(t)$ and $u'(t)$ lines cross each other and then continue at different slopes, the point represents the onset of a trend in the time series.

3 Results and discussions

As mentioned in Section 2.1, for Leven's homogeneity test, the time series in each of the datasets and for any of the stations was divided into five subgroups consisting of 1961–1970, 1971–1980, 1981–1990, 1991–2000, and 2001–2010. The critical value of $F_{0.05,\ 4,\ 45}$ was approximately equal to 2.6. Results of Levene's test for the series of $T_{d\max} \geq 30$ °C and $T_{d\min} \leq 0$ °C are presented in Table 4. The results show that data in all of the stations have homogeneity since the Levene's statistic is not greater than the critical value and the p-value is not less than α=0.05. It must be noted that counting time series which are published by the Iranian Meteorological Organization have generally been tested for homogeneity and the data have been homogenized if necessary.

In most stations the series for the number of days *per annum* when $T_{d\min} \leq 0$ °C series showed a greater range of variation than the $T_{d\max} \geq 30$ °C series (Table 2,

Table 4 Levene's test statistics for (a) number of days with $T_{d\max} \geq$ 30 °C and (b) number of days with $T_{d\min} \leq 0$ °C

Station name	$T_{d\max} \geq 30$ °C		$T_{d\min} \leq 0$ °C	
	Levene's Statistic	*p* value	Levene's Statistic	*p* value
Abadan	1.24	0.308	1.28	0.292
Ahvaz	0.42	0.793	2.13	0.091
Arak	1.11	0.363	0.93	0.455
Babolsar	1.63	0.184	2.14	0.091
Bam	1.56	0.201	0.85	0.499
Bandar Abbas	0.53	0.711	–	–
Birjand	1.12	0.360	0.72	0.580
Bushehr	0.58	0.680	–	–
Esfahan	1.13	0.354	0.89	0.480
Ghazvin	0.87	0.488	1.37	0.259
Gorgan	0.08	0.987	1.17	0.335
Hamedan	0.42	0.791	0.51	0.732
Kerman	0.47	0.761	2.23	0.082
Kermanshah	1.22	0.314	1.25	0.304
Khorramabad	0.90	0.472	1.05	0.394
Khoy	0.24	0.913	2.18	0.088
Mashhad	0.73	0.576	1.56	0.200
Ramsar	1.07	0.384	1.14	0.349
Rasht	0.54	0.707	1.78	0.150
Sabzevar	1.70	0.167	0.82	0.517
Sanandaj	2.14	0.091	1.83	0.142
Shahrekord	2.22	0.082	0.36	0.835
Shahroud	1.53	0.211	0.83	0514
Shiraz	0.44	0.776	0.37	0.827
Tabriz	0.57	0.683	0.56	0.690
Tehran	1.15	0.348	0.98	0.430
Torbat Heydarieh	1.49	0.221	0.26	0.903
Yazd	1.45	0.233	1.04	0.396
Zahedan	2.16	0.089	0.64	0.637
Zanjan	0.27	0.893	1.13	0.356

Table 5 Lag-1 autocorrelation coefficients and MK *Z* values for (a) number of days with $T_{d\max}\geq$ 30 °C and (b) number of days with $T_{d\min}\leq 0$ °C (significant ACFs and MK *Z* value at α=5 % are bolded)

Station name	$T_{\mathrm{dmax}}\geq 30$ °C			$T_{\mathrm{dmin}}\leq 0$ °C		
	ACF	MK *Z* value	Onset of trend	ACF	MK *Z* value	Onset of trend
Abadan	0.02	1.90	–	0.08	−1.04	–
Ahvaz	0.13	**2.04**	1972	0.17	**−2.82**	1962
Arak	**0.39**	−1.44	–	**0.37**	0.29	–
Babolsar	0.06	**2.48**	1975	0.22	**−3.91**	1963
Bam	**0.46**	**2.39**	1973	0.22	**−3.62**	1962
Bandar Abbas	**0.34**	0.59	–	–	0.00	–
Birjand	0.23	−1.00	–	**0.33**	0.12	–
Bushehr	0.21	**3.12**	1967	–	0.00	–
Esfahan	0.18	**2.15**	1974	0.18	−1.49	–
Ghazvin	**0.45**	−0.56	–	0.26	−1.65	–
Gorgan	0.24	0.33	–	0.14	0.74	–
Hamedan	−0.03	1.12	–	**0.33**	**−2.24**	1970
Kerman	0.27	**3.09**	1974	**0.58**	**−5.30**	1971
Kermanshah	**0.46**	**1.96**	1971	0.23	**−4.70**	1969
Khorramabad	**0.48**	−1.42	–	**0.69**	**4.29**	1972
Khoy	**0.31**	0.89	–	**0.31**	**−2.18**	1968
Mashhad	**0.28**	**2.51**	1974	**0.72**	**−5.90**	1968
Ramsar	0.19	1.00	–	0.19	**−2.94**	1962
Rasht	0.01	−0.70	–	**0.48**	**−3.64**	1962
Sabzevar	0.22	**2.32**	1970	**0.67**	**−4.03**	1969
Sanandaj	0.27	**2.58**	1972	**0.59**	**−3.81**	1970
Shahrekord	**0.58**	**−2.76**		0.20	1.93	–
Shahroud	0.14	0.44	–	**0.67**	**−5.56**	1964
Shiraz	0.26	**2.40**	1968	**0.75**	**−4.55**	1968
Tabriz	**0.29**	**2.93**	1967	0.16	**−3.01**	1962
Tehran	0.13	1.54	–	**0.55**	**−4.77**	1972
Torbat Heydarieh	**0.66**	**−4.56**	1967	0.21	**−2.77**	1964
Yazd	**0.34**	**3.27**	1974	**0.61**	**−6.35**	1972
Zahedan	0.22	1.55	–	**0.31**	**−4.05**	1974
Zanjan	0.24	−1.36	–	0.17	**−2.54**	1972

Fig. 2). As expected, given humidity's major role in moderating air temperature (Shelton 2009; Barry and Chorley 2009), the humid stations (Babolsar, Rasht and Ramsar) had somewhat lower values in both $T_{d\min}\leq 0$ °C and $T_{d\max}\geq 30$ °C series than other stations studied. Stations located in the warmer humid regions (Abadan, Ahwaz, Bandar Abbas and Bushehr) showed small to zero $T_{d\min}\leq 0$ °C series values that proved generally lower than those at other stations.

Correlograms generated to detect seasonality patterns and serial correlation in each station's time series, showed that while these series did not exhibit a seasonality pattern, there were correlations in some stations' data. Figure 3 shows correlograms for the Sabzevar and Tehran synoptic stations. Table 5 shows the lag-1 autocorrelation coefficients (ACFs) and either standard MK *Z*-values (Eq. 5, ACF not significant), or MK *Z* values adjusted to account for significant ACF values (Eqs. 8–10) for all the time series investigated. The MK test showed trends in series of number of days when $T_{d\min}\leq 0$ °C to be significant for most stations, whereas the series for $T_{d\max}\geq 30$ °C were significant for fewer stations. The fact that most stations showed a negative trend in $T_{d\min}\leq 0$ °C time series (Table 5), suggests that the occurrence of extreme minimum temperatures in the country will decline. This roughly concurs with previous temperature trend studies in Iran, which have shown minimum temperatures to generally increase at a higher rate than maximum temperatures (Tabari and Talaee 2011; Kousari et al. 2013). Roughly two thirds of stations have experienced a significant negative trend in $T_{d\min}\leq 0$ °C series, indicating that extreme winters will be

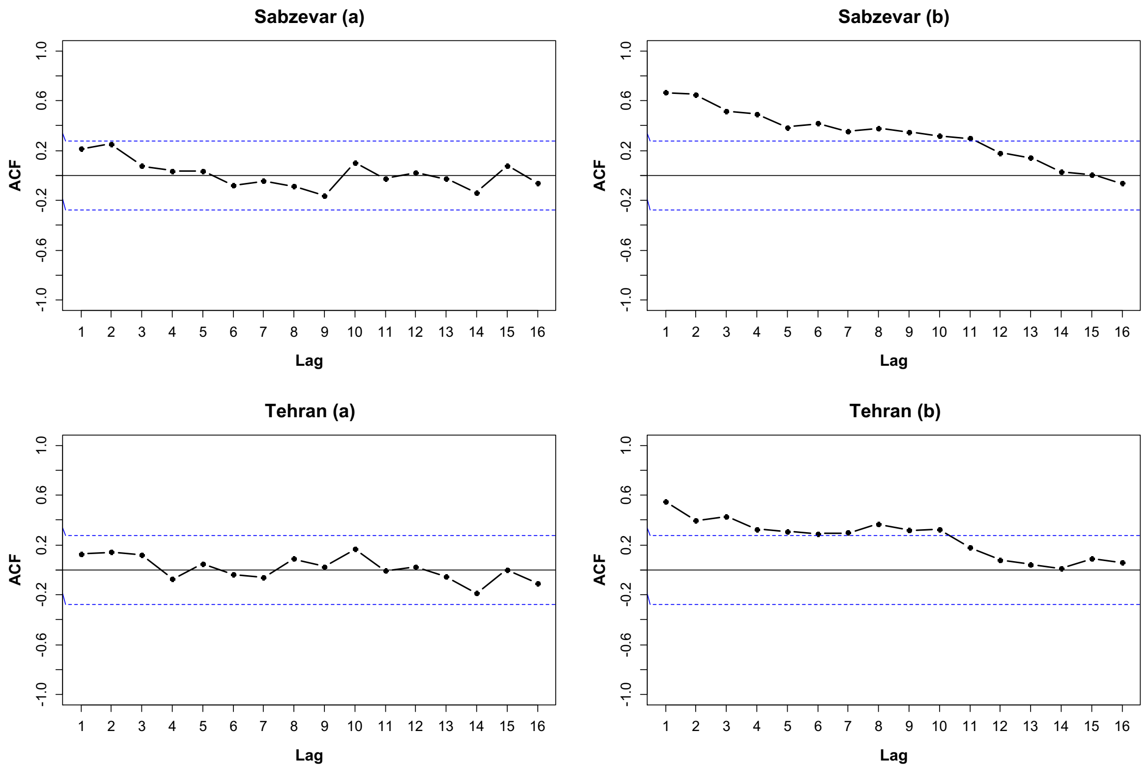

Fig. 3 Correlograms for Sabzevar and Tehran synoptic stations for number of days when $T_{d\max} \geq 30$ °C (**a**) and the number of days when $T_{d\min} \leq 0$ °C (**b**). *Dotted lines* indicate the confidence limits at $\alpha = 5\%$

less common in the future. On the other hand, the trend for the $T_{d\max} \geq 30$ °C time series is positive and significant for only 40 % of all stations. For these stations, the trend indicates that extreme high temperature events will occur with greater frequency in coming years. Returning drought conditions in most portions of the country in recent years, especially from the end of spring through the middle of autumn, concur with the present trend analysis. Given their preexisting water resource deficits, regions currently categorized as arid will suffer more from the occurrence of extreme high temperature. Clearly, this issue is a current problem in some regions in Iran (e.g., Kerman, Mashhad, Sabzevar, Shiraz, Yazd, etc.). While one might expect humid regions (e.g., Babolsar, Ramsar and Rasht stations) to have lesser variation in their temperature over time than other regions, significant positive trends were noted in humid station $T_{d\min}$ series, and a significant positive trend was found in the $T_{d\max} \geq$ 30 °C series of the Babolsar humid region station. For the Bandar Abbas and Bushehr stations, $T_{d\min}$ remained at or above 0 °C, so no ACFs or MK Z-values could be calculated for their $T_{d\min} \leq 0$ °C series. Another noticeable point in this table is that the stations Shahrekord and Torbat Heydarieh were the only stations to show significant negative trends in their $T_{d\max} \geq 30$ °C series, with the Torbat Heydarieh station also showing a significant negative trend in its $T_{d\min} \leq 0$ °C series. This concurs with the results of previous studies regarding temperatures at the Torbat Heydarieh station (Kousari et al. 2013; Tabari and Hosseinzadeh Talaee 2011). It suggests that extreme temperature conditions will lessen at this station, which is confirmed by observations from this station in recent years.

In the analysis of general trends in a climatological time series, and particularly in the case of climate change studies, it is important to establish the onset of any temporal trend in time series. To find these points, the sequential MK test was performed for both the number of days when $T_{d\max} \geq 30$ °C and the number of days when $T_{d\min} \leq 0$ °C time series, for all selected synoptic stations. Sequential MK plots for the Bam and Sanandaj stations, illustrative of different trend onsets are presented in Fig. 4. Based on the sequential MK test the onsets of $T_{d\max} \geq 30$ °C trends for the different stations occurred between 1967 and 1975, whereas for $T_{d\min} \leq 0$ °C series the onset occurred earlier, between 1962 and 1974 (Table 5). This indicates that the increment in $T_{d\min}$ occurred earlier than that in $T_{d\max}$ and that evidence of climate change was more obvious at lower temperatures. The changing of precipitation type from snow to rain is one of the major consequences of the minimum temperature trends which have occurred in

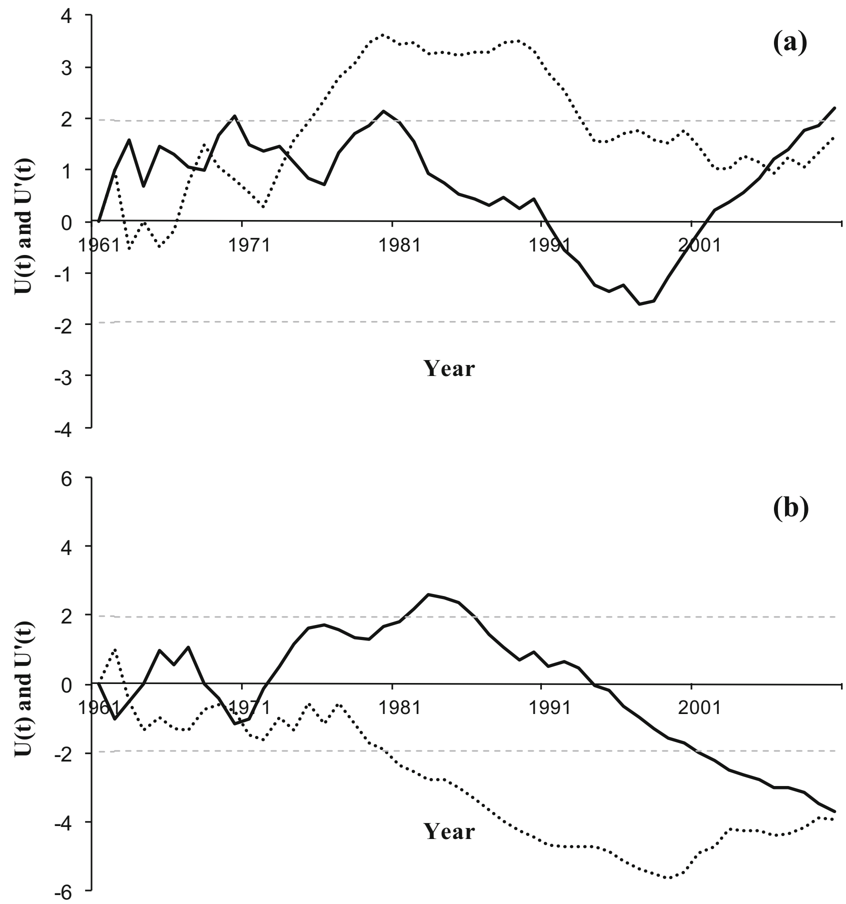

Fig. 4 *U(t)* and *U'(t)* plots for (**a**) station of Bam (for the number of days when $T_{d\max}$≥30 °C) and (**b**) station of Sanandaj (for the number of days when $T_{d\min}$≤ 0 °C). (Note: *U(t)* and *U'(t)* are sequentially illustrated by *solid* and *dotted line*)

Iran, even in the regions with colder climate (e.g., Tabriz, Sanandaj, etc.). This issue has been discussed in a number of recent studies (Zarenistanak et al. 2014; Farajzadeh and Karimi 2014). While changes in precipitation type are not only influenced by variations in $T_{d\min}$, but also by many other factors (Raziei et al. 2012, 2013; Ghasemi and Khalili 2006), the important role of changes in $T_{d\min}$ in altering precipitation type is a foundational concept in meteorology (Ahrens 2009; Lutgens and Tarbuck 2013) as has been confirmed by previous studies in Iran (Rahimzadeh et al. 2009). Because of the natural complexity in precipitation formation, changes in precipitation are expected to begin later than changes in temperature. This is confirmed by previous studies showing the onset of changes in precipitation in different locations in Iran to have occurred between 1979 and 1992 (Shifteh Some'e et al. 2012), compared to 1975, the latest onset of changes in temperature determined in the present study. As can be seen in this figure, approximately most parts (67 % of stations) of Iran have experienced a significant negative trend in the number of days where $T_{d\min}$≤0 °C, while a significant positive trend in the number of days where $T_{d\max}$≥30 °C was only apparent in 40 % of all stations (Fig. 5). This indicates that at present climate change has had greater effects on the minimum temperature in Iran and is expected to influence maximum extreme temperatures to a greater extent in coming years.

4 Conclusions

The number of days when extreme temperature conditions occurred in 30 synoptic stations in Iran during the period of 1961 to 2010 was examined. First, the MK test was used to determine trends in the time series and the sequential MK was then employed to detect the onset of the existing trends. The fact that the number of days when $T_{d\min}$≤0 °C showed a significant negative trend in 67 % of all stations studied, while the number of days when $T_{d\max}$≥30 °C showed a significant positive trend in only 40 % of the stations, indicates that the $T_{d\min}$ ≤ 0°C decreased at a greater rate than the increase $T_{d\max}$≥ 30°C within the country. This suggests that a hydrological crisis (e.g., droughts, dry spells, etc.) is likely to develop in coming years, particularly since the precipitation type is likely to be affected. A change in precipitation type and repetitive droughts are two major consequences which

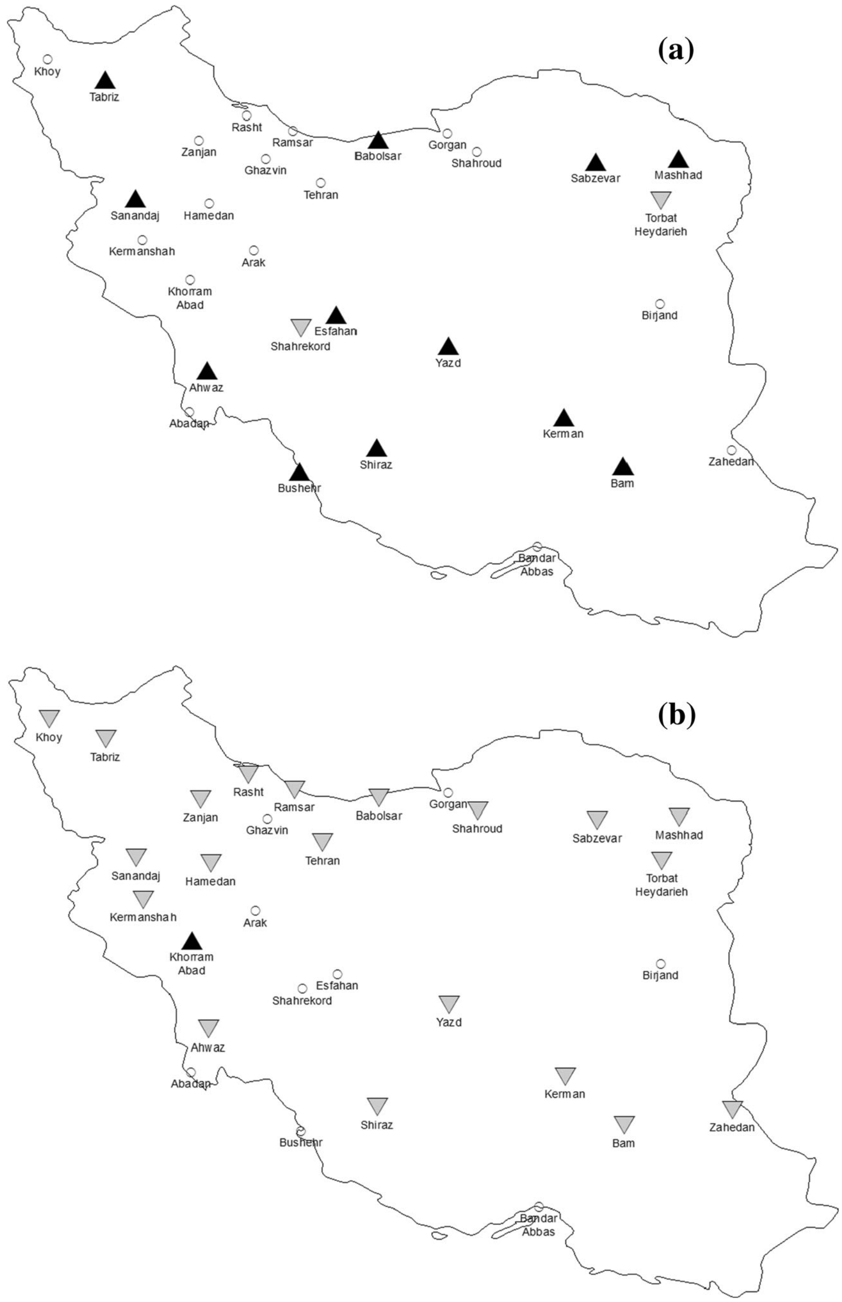

Fig. 5 Significant trends for series (**a**) the number of days when $T_{d\max}\geq 30$ °C and series (**b**) the number of days when $T_{d\min}\leq 0$ °C. (Note: *black* (*gray*) *triangles* indicate positive (negative) trend and circles show non-significant trends)

have already been observed in Iran, especially in the last two decades. Results of the sequential MK test show that the trend in the number of days when $T_{d\max}\geq 30$ °C time series began between 1967 and 1975, whereas the equivalent trend for $T_{d\min}\leq 0$ °C began earlier, between 1962 and 1974. This suggests that in the future, problems created by extreme maximum temperatures will increase. The important effects of temperature patterns (especially minimum temperature) on water demands will be one of the critical subjects of future studies in this field, because when precipitation type is permanently altered, stored water will be lost faster and water demands will rise accordingly. Such studies are important to facilitate the transition to more integrated and adaptive forms of water resources management (Halbe et al. 2013, 2014) in the arid and semi-arid regions of the world, where limited water resources are a critical issue.

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