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ORIGINAL PAPER

Homogenization and trend detection of temperature in Iran for the period 1960–2018

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Abstract
The daily minimum, maximum and mean temperature data at 37 weather stations in Iran from 1960 to 2018 were analyzed for their homogeneity and trend. Of these, only 10 stations passed the homogeneity test successfully without any break point or outlier. Approximately 75% of the breaks could be explained by the station relocation. Annual and seasonal anomalies of the homogenized series were calculated using the 30-year period of 1961–1990 as the reference. The regional trend of temperature was estimated using the mean annual and seasonal anomalies from stations that showed similar variability. The mean temperatures showed a positive trend over most of the 10 regions in Iran, with the rate of change varying from 0.1 to 0.4° C/decade. The minimum temperatures increased significantly in all the regions at the rate of 0.35– 0.63° C/decade, with the highest warming occurring over the central area of Iran in autumn. The maximum temperatures showed a positive trend over all the 10 regions with the exception of the east area. The associated rate of change varied from 0.14 to 0.29° C/decade. The highest increase occurred over the Northeastern area during spring.

1 Introduction

According to the Fifth Assessment Report (AR5; IPCC 2013), global mean surface temperatures have risen since 1970 and maximum and minimum temperatures over land have increased since 1950. However, despite the robust significant warming trend, there is variability in the rate of warming over different periods, seasons and regions. Climate change has strong effects on people and their behavior, as well as on agricultural resources and the availability of water. This is all the more significant in regions where the economic growth is highly dependent on agriculture, such as in most parts of Iran (Ghasemi 2015). Many studies of climate change that focus on the in-situ temperature data, have been pursued (e.g., Moberg and Alexandersson 1997; Vincent and Gullett 1999; Begret et al. 2005; Brunetti et al. 2006; Brunet et al. 2006; Alexander et al. 1986; Caesar et al. 2006; Collins et al. 2009; Syrakova and Stefanova 2009; Vincent et al. 2002; Dong et al. 2015; Toreti and Desiato 2008; Mondal et al. 2015; Sayemuzzaman et al. 2015; Lakhraj-Govender and Grab 2019).

The temperature variability was also investigated in several Iranian studies. Rahimzadeh and Asghari (2003, 2005) analyzed 11 climatic elements including the minimum and maximum temperatures for 33 synoptic stations during the period 1951–1997. The highest trends were found in minimum temperatures, except at few stations such as Orumiyeh located in the northwest of the country. Shirgholami and Ghahraman (2005) studied 34 synoptic stations over the different climates of Iran, and showed that 59% of the stations had a statistically significant positive trend for the mean annual temperature. Masoudian (2006) found positive and negative trends in the temperature time series for the period 1951–2000. Kousari and Asadi Zarch (2011) showed that minimum and mean temperatures have a significant positive trend in the arid and semi-arid areas of Iran, especially during the last few years up to the year

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2000. Rahimzadeh and Nassaji Zavareh (2014) studied the minimum and maximum temperatures at 32 stations for the period 1960–2010. The temperature time series in Qazvin, Khoy, Orumiyeh, Zanjan, Khorramabad, Sanandaj, Shahre Kord, Bandare Anzali, Gorgan, Rasht, Esfahan, Kerman, Shiraz, Mashhad, Torbat-e Heydariyyeh, Birjand, Arak, Semnan, Bandar Abbas and Bushehr stations were found to be inhomogeneous.They also showed that the minimum and maximum temperatures increased almost in all the regions at the rate of 0.4–0.5 °C/decade and 0.2–0.3 °C/decade, respectively. Ghasemi (2015) studied the maximum, minimum and mean temperatures at 38 stations during 1960-2010 and reported that the annual trends increase were respectively 0.34 °C C/decade and 0.15 °C/decade for the minimum and maximum temperature. Rafati and Karimi (2018) assessed the homogenization of mean monthly temperature for 33 synoptic stations during 1960–2014 using the PMFred algorithm and obtained linear trend estimates. They found that mean monthly temperature series were inhomogeneous at the Zanjan, Saqqez, Sanandaj, Kermanshah, Khorramabad, Shahr-e Kord, Ahvaz, Abadan, Yazd, Bandar Abbas, Bam, Kerman, Zahedan, Zabol, Mashhad, Torbat-e Heydariyyeh, Gorgan, Ramsar, Rasht, Qazvin, Birjand and Arak stations. They reported that mean monthly temperatures significantly increased at most of Iran's stations, with the exception of the northwest of Iran and at the Sabzevar, Shahroud, Kerman, Bam and Bandar Abbas stations. Fallah-Ghalhari et al. (2019) studied the trends of minimum and maximum temperatures in Iran using time series of daily minimum and maximum temperatures of 45 meteorological stations from 1976 to 2005. They found that the maximum and minimum temperatures increased significantly at the rates of 0.23 and 0.39 °C/decade, respectively. Tehrani et al. (2019) evaluated annual, seasonal, and monthly trends of temperature, precipitation and stream-flow for the Neka basin in the north of Iran over a 44-year period (1972–2015). The temperature trend in the Neka basin was found to be significantly upward for most months.

For detecting the accurate long-term climatic trend, the use of homogenized data is absolutely necessary. Previous works had focused on homogenizing monthly series while the study of the variability of indices and extreme values depends on daily series. Therefore, the primary objective of our investigation was to provide a data set of homogenized daily maximum, minimum and mean temperature series. The specific objective was to evaluate the regional temperature trend over the period 1960–2018 of Iran in order to accurately represent local climate diversities.

This paper is organized in the following manner: Sect. 2 presents a short review of the geographical characteristics and climate of Iran and the database of Iranian synoptic stations. The homogeneity and adjustment methods are given in Sect. 3. Regional trends of seasonal and annual minimum, maximum and mean temperature are discussed in Sect. 4. Finally, the conclusions are given in Sect. 5.

2 Materials

2.1 Study area

Iran is located in the Middle East zone and borders the Caspian Sea, the Persian Gulf, and the Gulf of Oman with an area of 1,648,000 km^2 extending from 25 °C 00′ to 39 °C 47′N and 44 °C 02′ to 63 °C 20′E (Fig. 1). The main mountain chain in Iran is the Zagros Mountains consisting of a series of parallel ridges running in the northwest to the southeast direction. The Alborz Mountains is the other mountain range which is narrow but high, rimming the Caspian Sea littoral in the North. There are several closed basins in the center of Iran named the Central Plateau. The Dashte Kavir and the Dashte Lut are salt deserts located in the eastern part of the plateau. This varied topography of Iran, and the rugged and mountainous rims surrounding high interior basins, give rise to various regional climates.

2.2 Database

The density of synoptic stations is not uniform across Iran. The northeast and the northwest of Iran, with better water resources, more facilities for agriculture, industry, a higher population and so on, have a denser network of stations compared to the central deserts of Iran. Also, the record length is not the same for all the stations, the longest one being since 1951. The number of stations across Iran during the period of 1951–2018 is shown in Fig. 2. Due to inaccurate and incomplete data for 1951–1959, this period was removed from the study. The number of operating stations in the period of 1960–2018 is 34 stations (Fig. 2). The Qom station has a 19-year data gaps, and thus was excluded. The missing values for the 33 remaining stations are less than 14% and these data were subsequently estimated with the data of the neighboring stations, using the CLIMATOL method (Guijarro 2018). The stations at Saqqez, Dezful, Zabol and Chabahar were added to the list of stations, considering that these stations lack the data of only one to three years at the start of the period.

2.3 Metadata

The metadata came from the Islamic Republic of Iran Meteorological Organization (IRIMO). Unfortunately, the available metadata is low which do not cover all of the non-climatic reasons for non-homogeneity. It only contains information about changes at the observing sites,

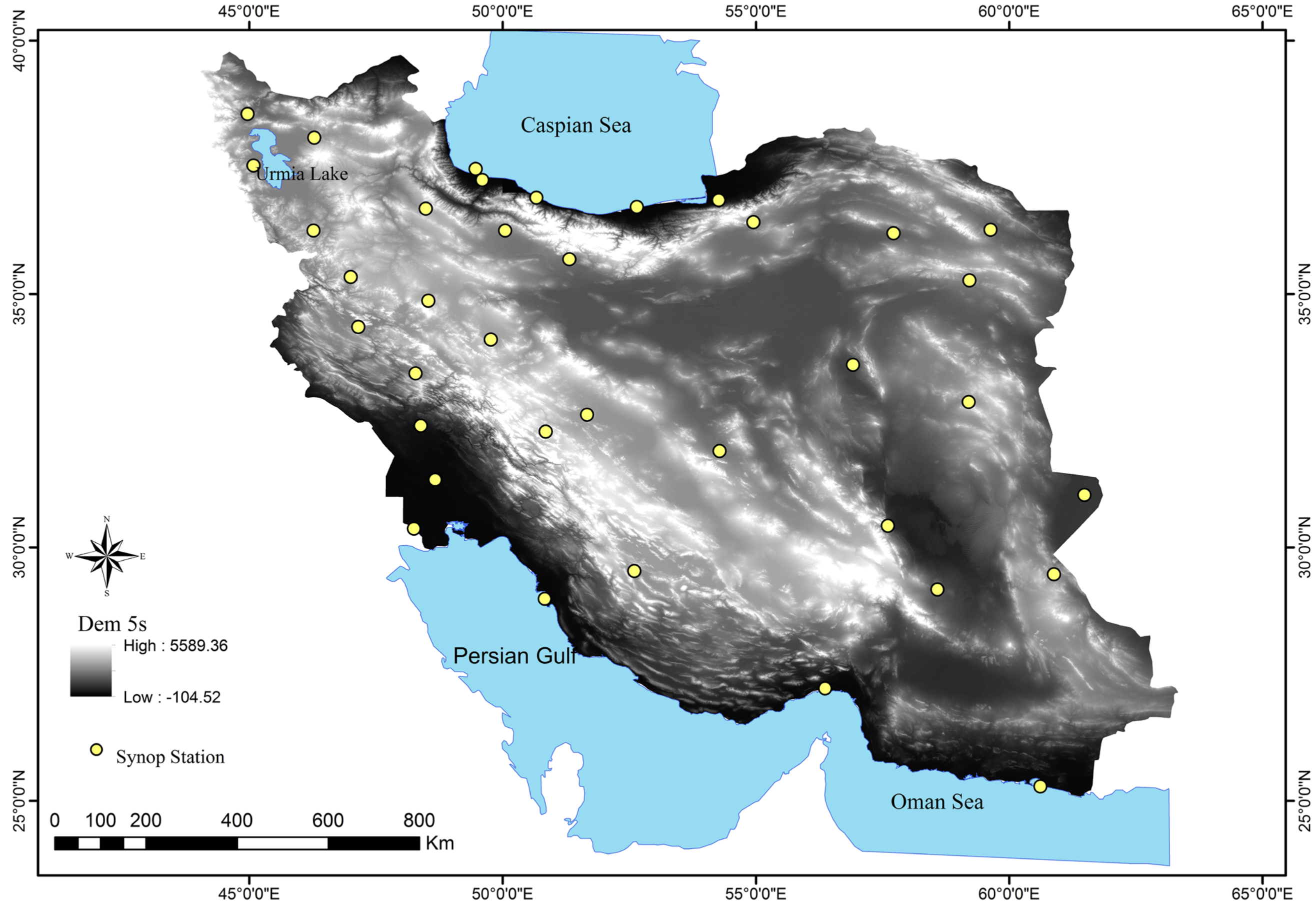
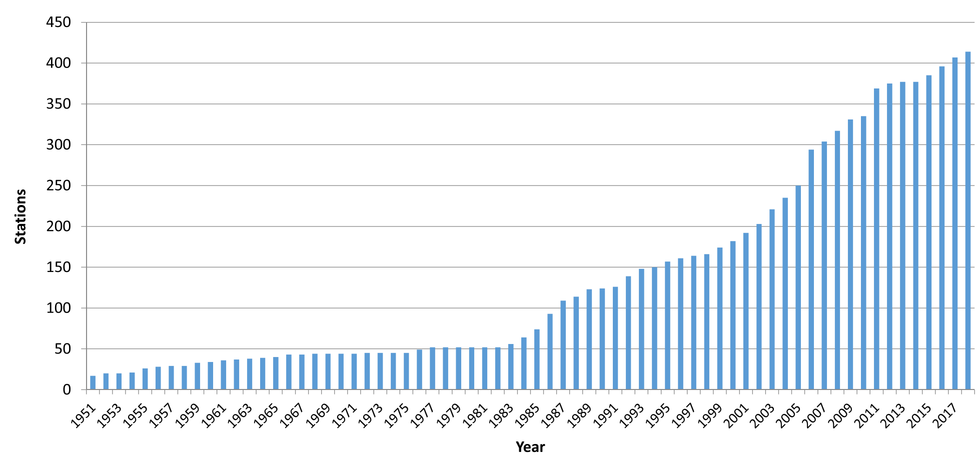


Fig. 1 Digital elevation model (DEM) of I. R. of Iran

Fig. 2 The number of operating synoptic stations in the period of 1951–2018



but not on the instruments, observing schedule, observing habit and micro-environment around the observational grounds. There are major challenges to the detection of the accurate time of re-locations such as; not being accessible to accurate information for some stations, non-consistency between the metadata and recorded data, no record of the month of relocation at stations, and frequent relocation of some stations.

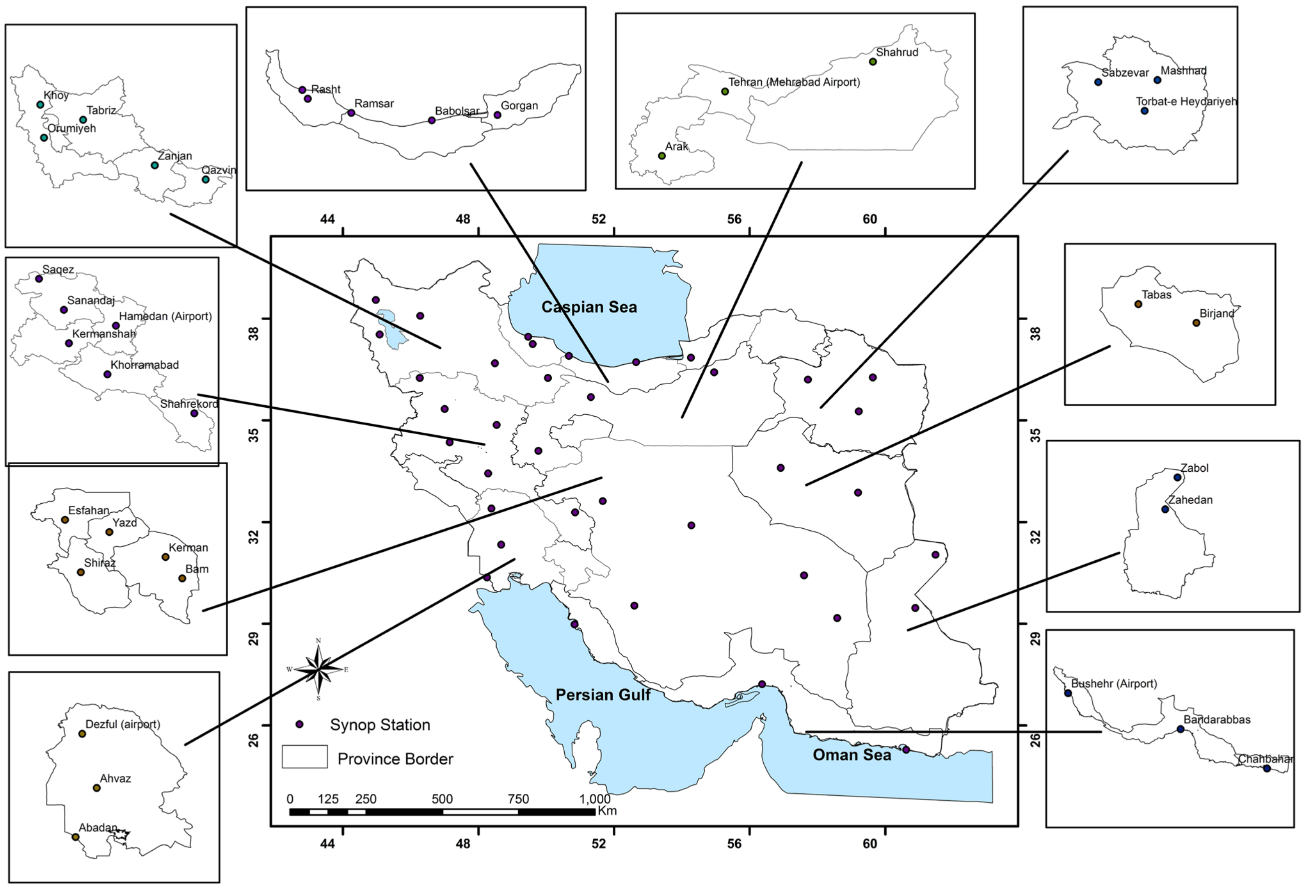


Fig. 3 Climatic regions and locations of synoptic weather stations used in this study

3 Methods

3.1 Data quality and homogeneity

The quality and homogeneity of long-term time series of climate observations are of major importance for any research work. A homogeneous climate time series is defined as one where variations are caused only by variations in climate (Conrad and Pollak 1950; Aguilar et al. 2003). Other unnatural variations such as changes in the location of the stations, instruments, observing practices and station environment, which can lead to erroneous interpretations of the studied climate, are called inhomogeneities. Unfortunately, few long-term climate time series are free of irregularities (Auer et al. 2004). Therefore, before using climate data in any kind of study, especially in climate change studies, quality control and homogeneity assessment of the data set are necessary (Peterson et al. 1998).

Several methods have been developed for the detection of non-climatic in-homogeneity and adjustment. Reviews of these techniques (e.g., Panofsky and Brier 1968, Kobysheva and Naumova 1979, Potter 1981, Alexandersson 1986, Jones et al. 1986, Quayle et al. 1991, Gullett et al.1991, Caussinus and Mestre 1996, Szentimrey 1999, Free et al. 2001, Buishand 1982) can be found in the works of Peterson et al. (1998), Aguilar et al. (2003) and Beaulieu et al. (2008). There are a large number of software packages that implement these techniques (http://www.climatol.eu/tt-hom/index.html). The European Science Foundation funded Action ES0601 (HOME, Advances in Homogenization Methods of Climate Series: An Integrated Approach) that enabled the comparison of many of these methods (Venema et al. 2012). The MULTITEST project also compares the updated methods that could be executed in the fully automatic mode (http://www.climatol.eu/MULTITEST/). These homogenization efforts focused on monthly and annual series. For quality control and homogenization of daily, monthly and annual series, the R package CLIMATOL (https://CRAN.R-project.org/package=climatol), was presented by Guijarro (2018). This methodology involves the following five steps;

– *Estimating data* normalize series and estimate them from the weighted average of their neighbours by type

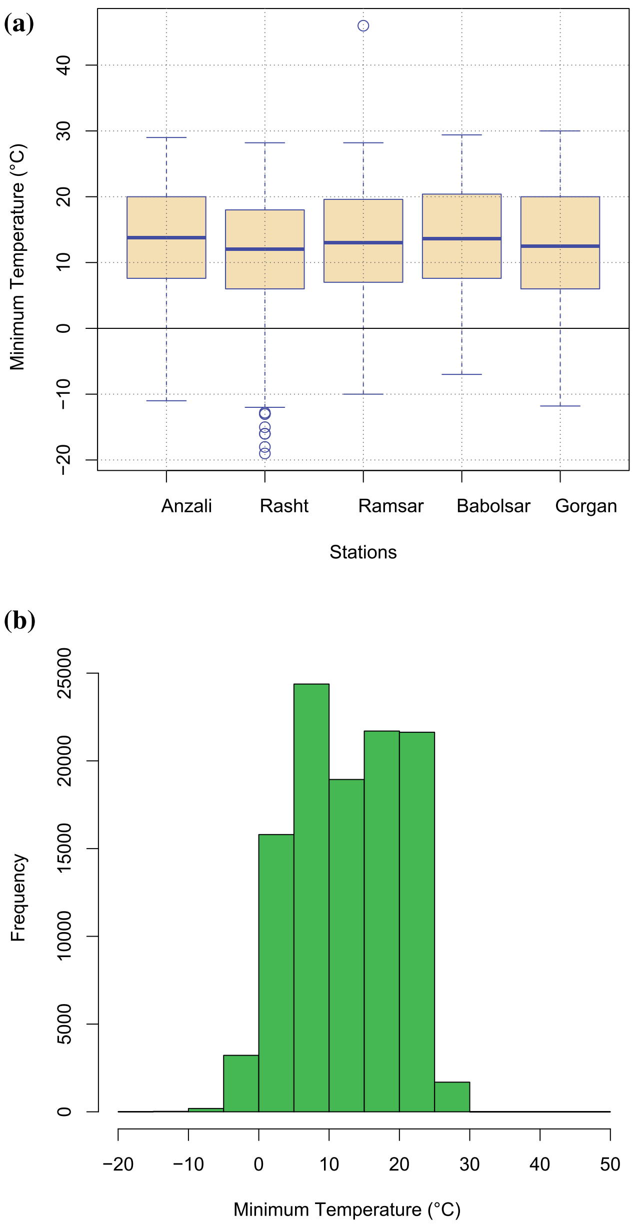


Fig. 4 **a** Box-plots of the data at every station. **b** Histogram of all data

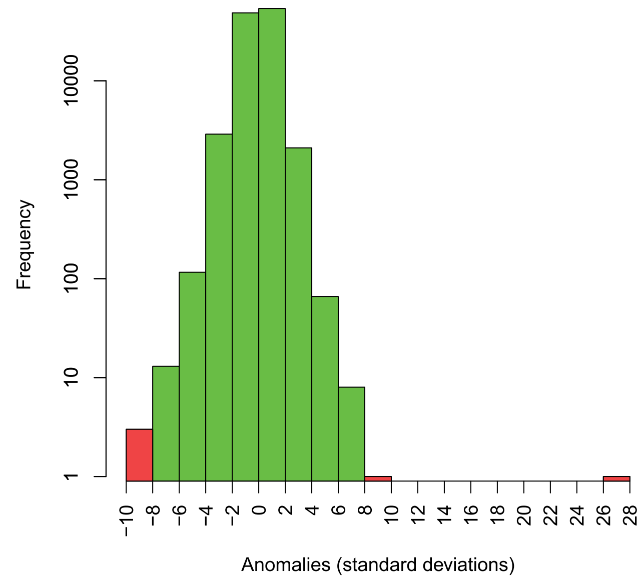


Fig. 5 Histogram of anomalies

Table 1 Outliers for minimum temperature in the Caspian Sea region (step 1)

Station	Date	Observed (°C)	Anomaly (°C)
Rasht	12-2-1978	− 7	− 9.4
Rash	12-10-1978	− 9	− 9.43
Rasht	1-19-2016	20.2	8.34
Ramsar	11-24-1976	46	26.8
Babolsar	11-24-1976	6	− 9.81

Table 2 Comparison of outlier data for the minimum temperature parameter in the coastal area across Caspian Sea with the data of 2 days before and 2 days after (step 2)

Station	Rasht	Rasht	Rasht	Ramsar	Babolsar
2 days ago	5	10	4	8	4
1 day ago	3	10	2	5	5
Date	**− 7**	**− 9**	**20.2**	**46**	**6**
1 day later	10	6	13	7	10
2 days later	8	7	8	11	9

II regression (Sokal et al. 1969). The weights of the reference series can be all the same or be computed as an inverse function of the distance between the observing sites.

- *Filling missing values* compute the means and standard deviations of available data in each series, use the estimated series (after undoing normalization) to fill the missing data and compute new means and standard deviations. This process is repeated until the maximum change in a mean is less than a chosen small amount.
- *Outliers* for every original series, determine the series of anomalies (differences between the normalized original and estimated data). Standardized anomalies greater than the prescribed threshold will result in the deletion of their corresponding original data.
- *In-homogeneity detection* The Standard Normal Homogeneity Test (SNHT; Alexandersson 1986) is applied to the anomaly series in two stages: (1) On windows of 120 months moved forward in steps of 60 months, (2) On the whole series. At each stage, the series with the maximum SNHT statistics greater than a prescribed threshold, is split at the point of maximum SNHT and all the data

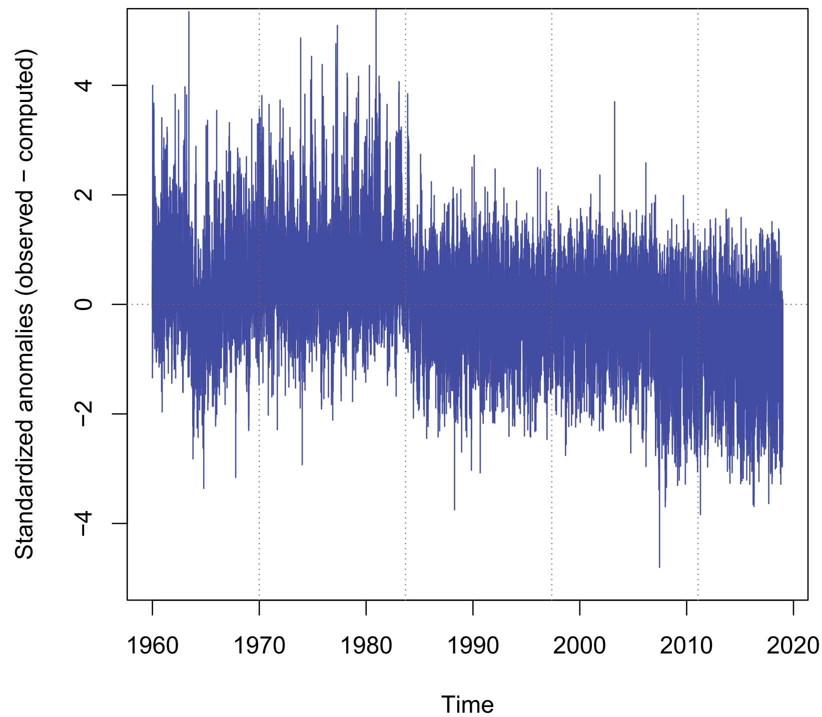


Fig. 6 Standardized anomalies for minimum temperature of Gorgan station

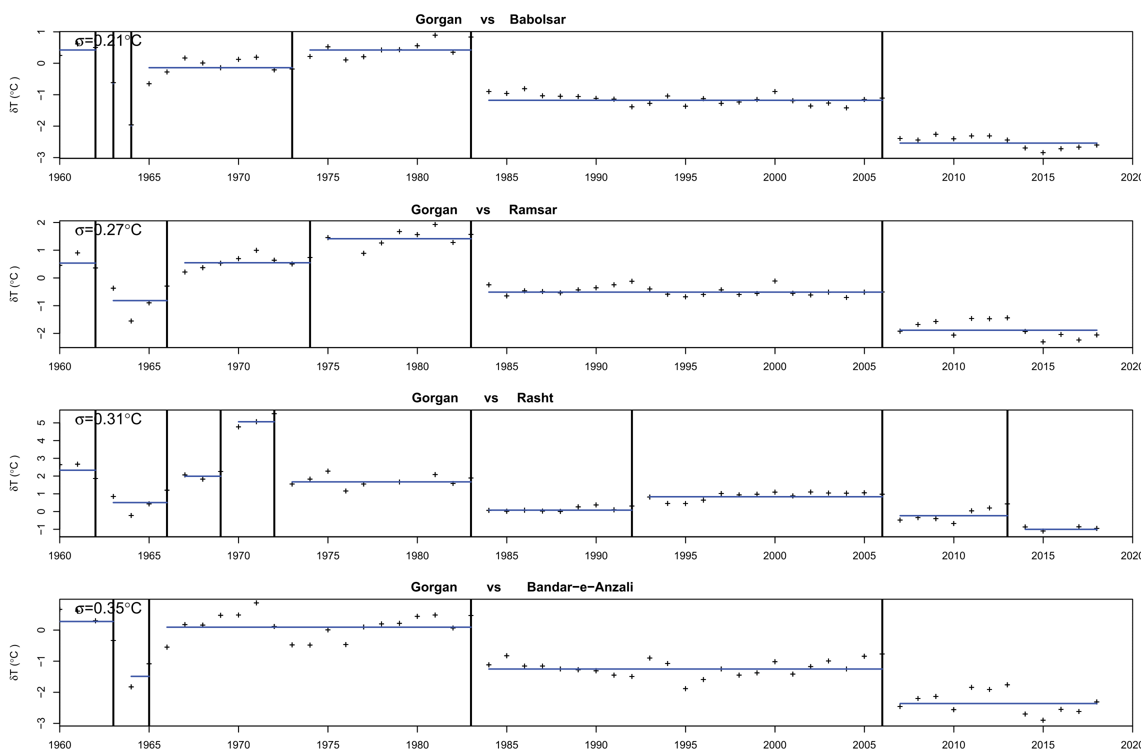


Fig. 7 Pairwise comparison between the Gorgan station and the stations in the Caspian Sea region; bold vertical lines denote the year of probable break points, σ is the standard deviation of noise

before the break are transferred to a new series with the same coordinates. This procedure is done iteratively, until no series is found to be in-homogeneous.

– *Correction* infill all the missing data in all homogeneous series and sub-series with the same data estimation

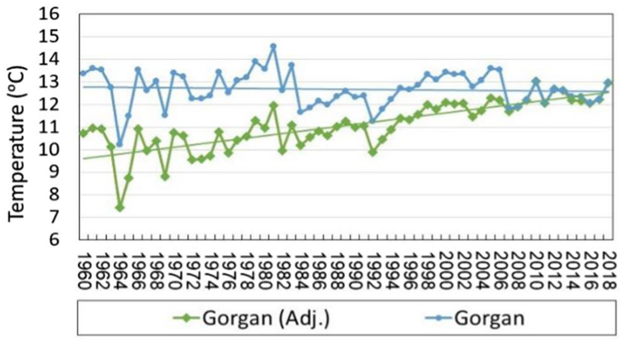


Fig. 8 The annual minimum temperature of original and adjusted data series at Gorgan station during 1960–2018

Table 3 Annual minimum temperature trends of the Gorgan station for the data series before and after adjustment

	Before adjustment	After adjustment
Mann-Kendall (*p*-value)	0.35	0.00
Sen' slope	− 0.005	0.05

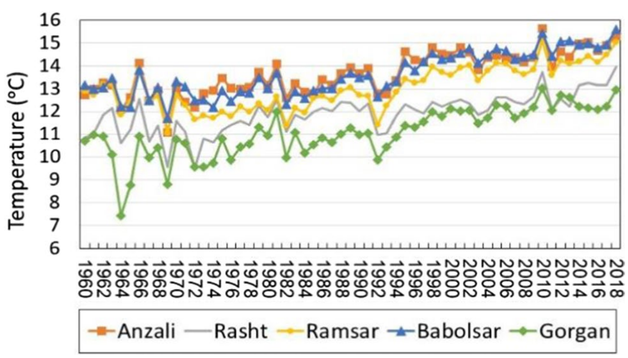


Fig. 9 Time series of minimum temperatures in the Caspian Sea region after removing discontinuities

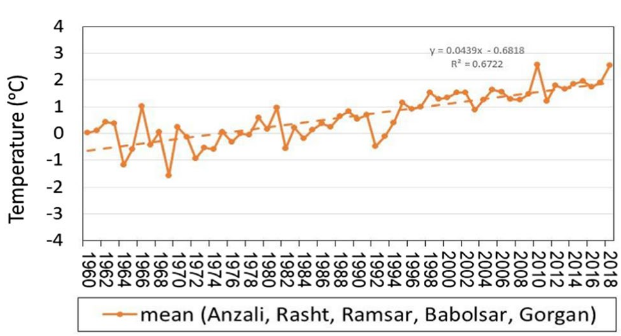


Fig. 10 Annual minimum temperature anomalies for the period 1960–2018, expressed as departures from 1961 to 1990 average for the Caspian Sea region

procedure using only the reference of their own other fragments.

In order to detect and adjust for possible multiple change points or shifts that could exist in the series, the R-package CLIMATOL was used. For detecting non-climatic discontinuous, in addition to the metadata, the paired comparison method from the HOMER software was also utilized.

3.2 Analysis procedure

Iran has different regional climates because of its size and varied topography. According to the variability of minimum and maximum temperature, Iran was divided into 10 sub-regions (Rahimzadeh and Nassaji Zavareh 2014). The areas are the Zagros Mountains, the coastal area across the Caspian Sea, the south side of the Alborz mountains, the coastal area across the Oman Sea and the Persian Gulf, the central area, and the northwest, northeast, east, southeast, and the southwest. The climatic regions are presented in Fig. 3. The following homogenization procedure was applied separately on the data sets of each climatic region.

- *Detecting outliers* Two steps were followed for this purpose. Firstly, to compare the series with neighbors, the histogram of standardized anomalies by the CLIMATOL method was plotted and thresholds for detection outliers were determined. Original data corresponding to standardized anomalies that were greater than the prescribed thresholds, were detected as outliers. Secondly, detected outliers in the first step were compared with the values of the days before and after. If they differed significantly, they would be accepted as outliers and deleted.
- *Detection of in-homogeneity for monthly series* Firstly, the monthly time series were calculated from the daily series. Based on WMO's recommendation (WMO 2011), a monthly value should not be calculated if more than 10 daily values are missing or five or more consecutive daily values are missing. Secondly, abrupt discontinuities were detected with the CLIMATOL method. Thirdly, the pairwise detection provided by the HOMER software was applied. Finally, if break points in the second step were confirmed by metadata or pairwise detection, they would then be accepted as non-climatic breaks.
- The monthly and daily series were adjusted with the monthly break-point by the CLIMATOL method.
- The annual series were calculated by averaging temperature series from January to December and the seasonal series from December to January (DJF), March to May (MAM), June to August (JJA) and September to November (SON) as the winter, spring, summer and autumn series respectively.

Table 4 Result of the homogeneity tests for the selected stations over the period 1960-2018

Region	Stations	Break Points	Causes
Northwest	Qazvin	1974	Relocation
	Khoy	–	–
	Orumiyeh	2003	Relocation
	Tabriz	–	–
	Zanjan	1984	Relocation
		2014	–
Zagros Mountain	Kermanshah	–	–
	Khorramabad	1980	Relocation
	Sanandaj	1974	Relocation
	Shahr-e Kord	2003	Relocation
		1984	–
	Hamadan	–	–
	Saqqez	1987	–
Coastal area across Caspian Sea	Bandar-e Anzali	1983	Relocation
	Babolsar	–	–
	Gorgan	1984	Relocation
		2007	Relocation
	Ramsar	–	–
	Rasht	1969	Reconstruction in 1970–1973
		1973	Reconstruction in 1970–1973
		1993	Relocation
Central area	Bam	1969	–
	Isfahan	1994	Relocation
	Kerman	1966	–
		1977	–
	Shiraz	2004	Relocation
		1984	Relocation
	Yazd	1969	–
Northeast	Mashhad	1986	Relocation
		1969	Relocation
	Sabzevar	1972	Relocation
		2004	Relocation
		2008	Relocation
	Torbat_e Heydariyyeh	1985	Relocation
East	Birjand	1978	Relocation
	Tabas	–	–
Southeast	Zahedan	–	–
	Zabol	1987	–
South side of the Alborz mountains	Tehran	–	–
	Arak	1981	Relocation
	Shahrud	1965	Relocation
		1982	Relocation
Coastal area across Persian Gulf	Bandar Abbas	1971	Relocation
	Bushehr	1963	Relocation
		1971	Relocation
		2002	–
	Chabahar	1985	–
Southwest	Ahvaz	1983	Relocation
	Abadan	1981	Relocation
	Dezful	–	–

Table 5 The differences between the results of our work and those of previous work on the homogenization of temperature data

Stations	Our work	Rahimzade and Zavareh (2014)	Rafati and Karimi (2018)	Metadata
Qazvin	1974	1974	1971	Relocation in 1974
	–	–	1981	–
Orumiyeh	–	1984	–	Relocation in 1984
	2003	2003	–	Relocation in 2002
Kermanshah	–	–	1971	Relocation in 1986
Khorramabad	1980	–	1979	Relocation in 1980
Sanandaj	1974	1974	–	Relocation in 1974
	–	–	1984	Relocation in 1988
Saqqez	1987	–	1987	–
Bandar-e Anzali	1983	1983	–	Relocation in 1983
Gorgan	–	–	1976	-
	2007	2007	–	Relocation in 2006
Ramsar	–	–	1968	–
Rasht	1969	–	1971	Reconstruction in 1970–1973
	1973	–	1981	Reconstruction in 1970–1973
Bam	1969	–	1969	–
Esfahan	1994	1994	–	Relocation in 1994
Kerman	1966	-	1965	-
	–	–	1969	–
	1977	–	1976	–
	–	1984	1977	Relocation in 1985
Shiraz	1984	1985	–	Relocation in 1985
	2004	2003	–	Relocation in 2003
Yazd	1969	–	1969	–
	–	–	1971	–
Mashhad	1986	1986	–	Relocation in 1985
Sabzevar	1972	–	–	Relocation in 1970
	2004	–	–	Relocation in 2004
	2008	–	–	Relocation in 2008
Birjand	1978	1977	1982	Relocation in 1978
Zahedan	–	–	1961	Relocation in 1984
Zabol	1984	–	1986	Reconstruction in 1960–1962
Shahrud	1965	–	–	Relocation in 1965
	1982	–	–	Relocation in 1983
Bushehr	1963	1963	–	Relocation in 1963
	1971	1970	–	Relocation in 1963
	2002	–	–	–

- The anomaly time series was created by subtracting the mean of period 1961–1990 from each of the time series.
- The anomalies were averaged, and the regional trend for maximum, minimum and mean temperature was computed by Mann-Kendall and Sen' slope methods for the period 1960–2018. The significance level of the the Mann-Kendal test was 99%.

3.3 Example

The analysis procedure of the coastal area across the Caspian Sea and, especially, at the Gorgan station for minimum temperature is presented to show the details of the approach. Figure 4 displays the box-plots of the data at every station and a histogram of all the data in the Caspian Sea region. The frequency histogram shows the probability distribution is near normal. Also, the presence of very anomalous values at the Rasht and Ramsar stations is evident from the box-plots. For further investigation, the histogram of

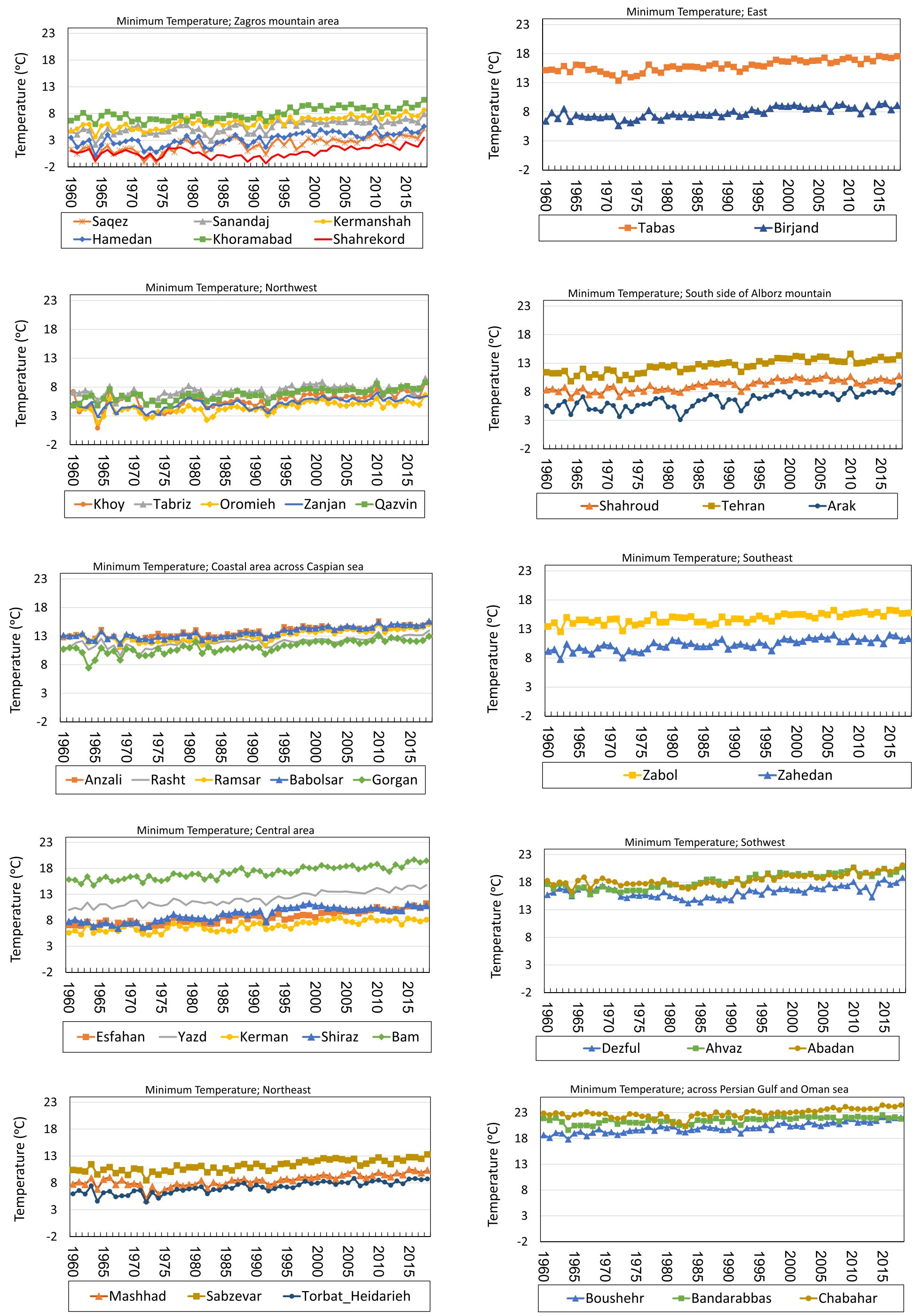


Fig. 11 Time series of minimum temperature in the stations of the 10 regions after homogenization

standardized anomalies is plotted. Figure 5 shows this histogram, evidently, it is much skewed to the right. The data with absolute anomalies greater than 8 standard deviations were considered as outliers. These outliers along with the dates are presented in Table 1. For confirming that these outliers have been correctly identified, their values were compared with the values of the days before and after. According to Table 2, the detected outliers at the Rasht and Ramsar stations were confirmed and deleted from the original data. The time series of standardized anomalies for the Gorgan station was plotted to obtain a preliminary understanding (Fig. 6). It is clearly an in-homogeneous case. The homogeneity test on the monthly series by CLIMATOL algorithm shows break points in 1984 and 2007. Furthermore, the result of pairwise detection by the HOMER software is provided in Fig. 7. It shows obvious break points in 1984 and 2007. Comparing the identical change points with metadata information from the station, it indicated that the Gorgan station had

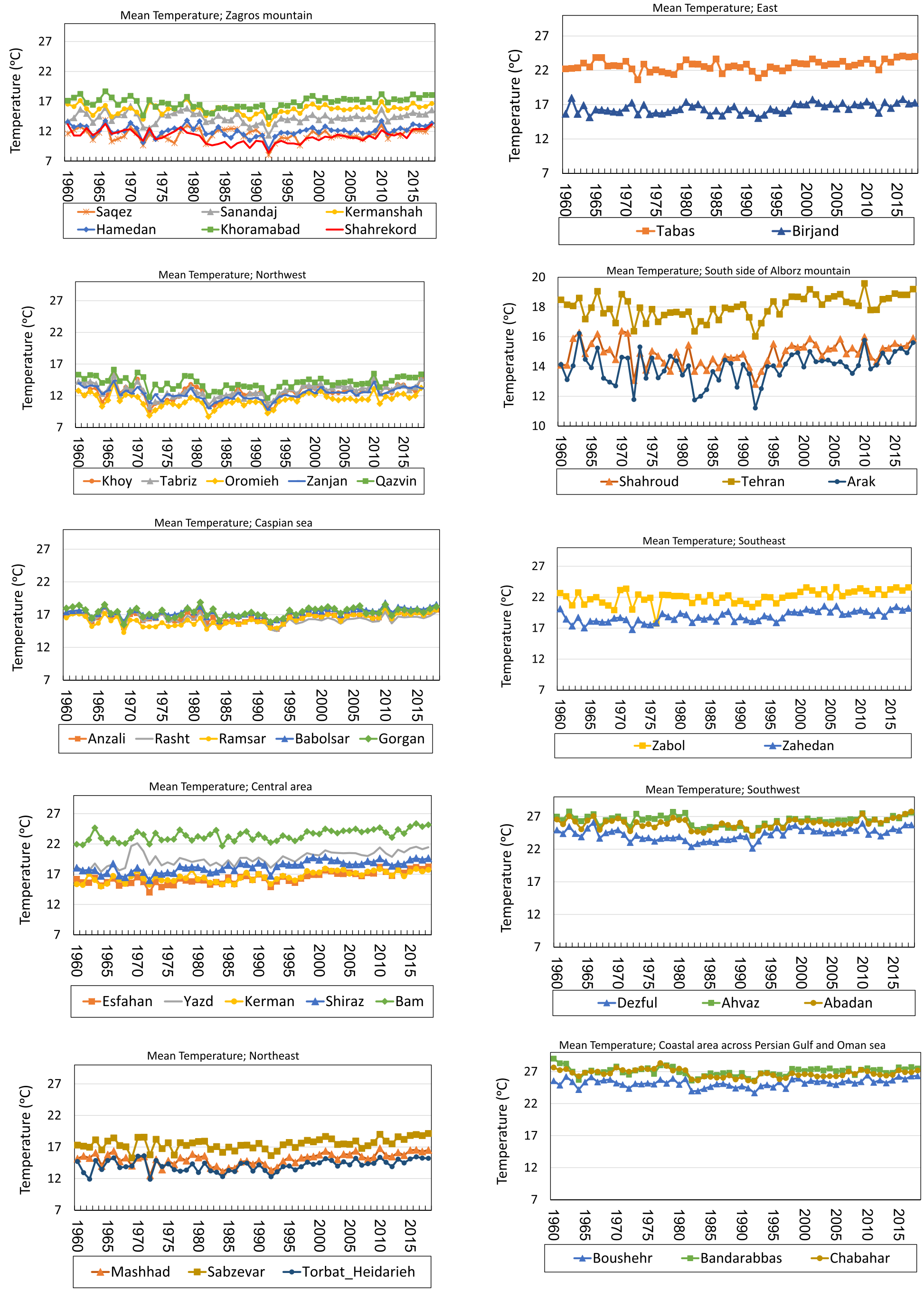


Fig. 12 Time series of mean temperature in the stations of the 10 regions after homogenization

significant re-locations in 1984 and 2006. Therefore, these points were accepted as non-climatic abrupt and the data were adjusted by CLIMATOL method. Figure 8 depicts the series before and after adjustment along with the linear trend.

Table 3 gives the result of the Mann-Kendall test, and Sen' slope. The results show that there is no statistically significant trend before adjustment, while there is a statistically significant positive trend after adjustment. Figure 9 shows the variability of the time series of minimum temperature after removing non-climatic discontinuities for the coastal area across the Caspian Sea. As can be seen, the variability of time series is similar and the trend of their mean can be representative of the trend of the whole area for the period 1960–2018. The average of the anomaly time series (the means of period 1961-1990 were subtracted) across the Anzali, Rasht, Ramsar, Babolsar and Gorgan stations was calculated, and its trend was considered as representative of the Caspian Sea area (Fig. 10). According to the results of the Mann-Kendall

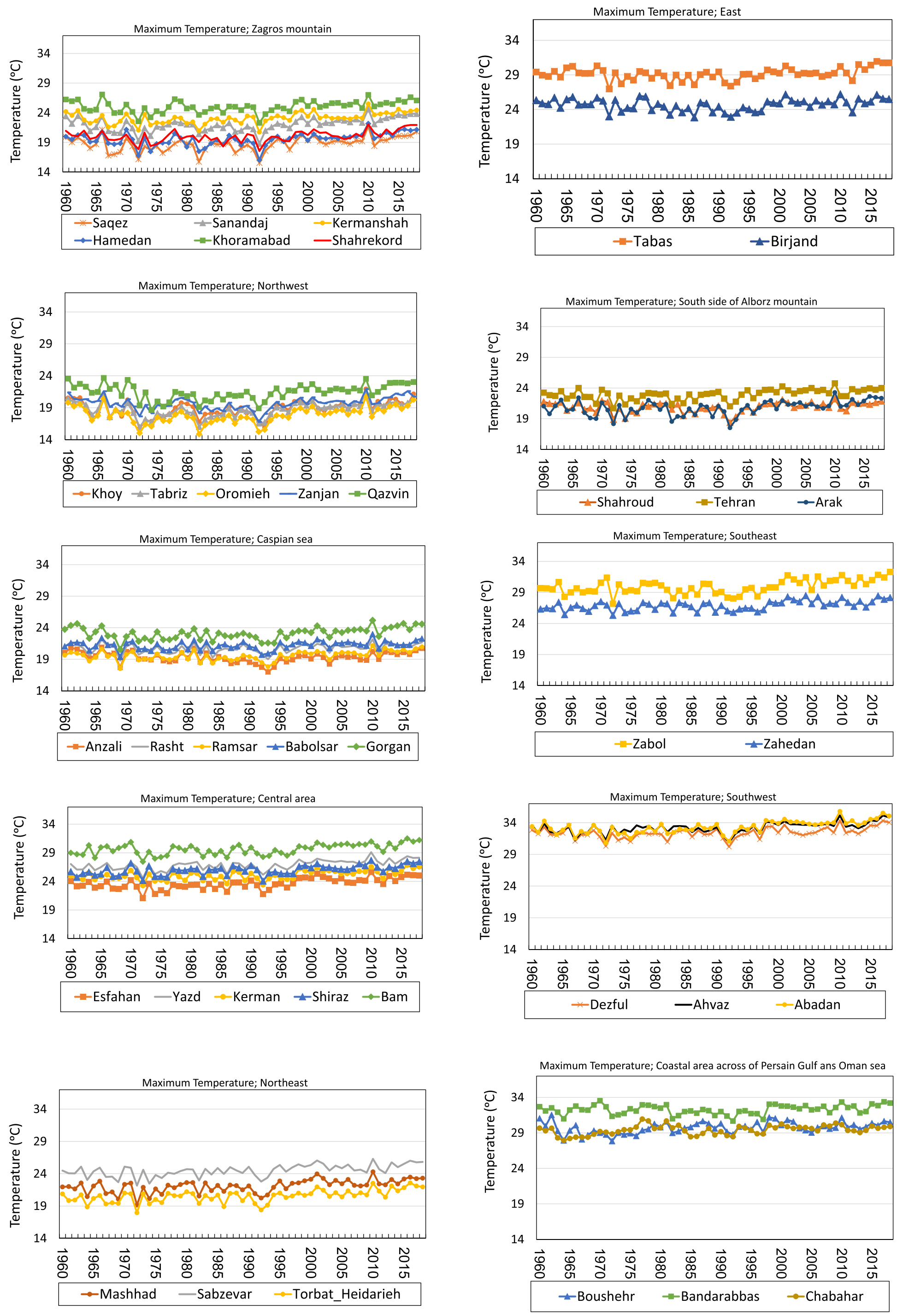


Fig. 13 Time series of maximum temperature in stations of each 10 regions after homogenization

test and Sen' slope, the annual minimum temperature in the Caspian Sea region has significantly increased at a rate of 0.460 °C/decade.

4 Results and discussion

The result of the homogeneity assessment for each station is provided in Table 4. The results obtained are different from those of Rahimzadeh and Nassaji Zavareh (2014) and Rafati and Karimi (2018) for some stations. These

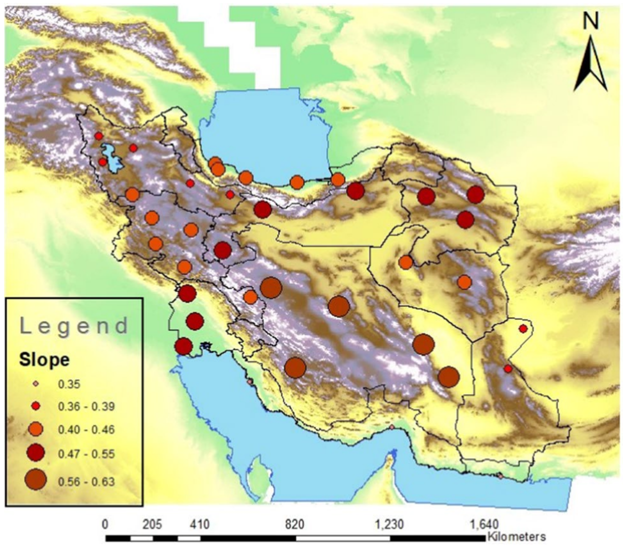


Fig. 14 Annual trend of minimum temperature anomalies for the period 1960–2018 (°C), expressed as departures from 1960 to 1990

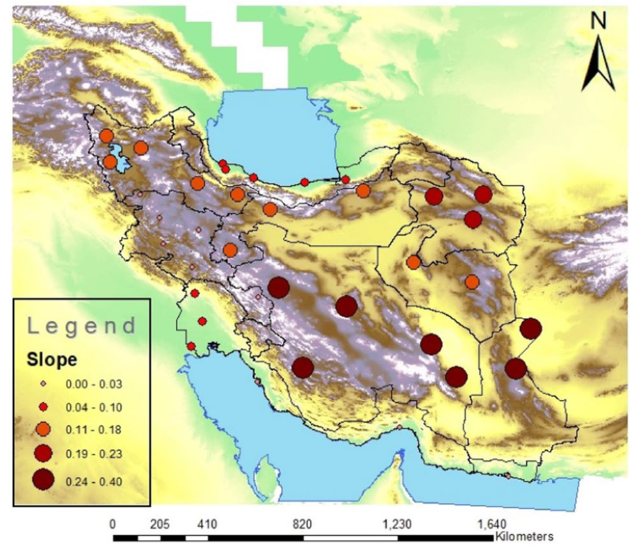


Fig. 16 Annual trend of mean temperature anomalies for the period 1960–2018 (°C), expressed as departures from 1960 to 1990

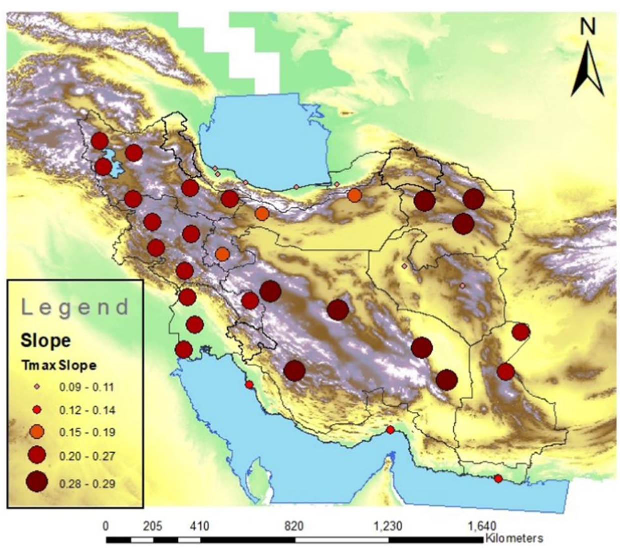


Fig. 15 Annual trend of maximum temperature anomalies for the period 1960–2018 (°C), expressed as departures from 1960 to 1990

differences with the corresponding metadata are presented in Table 5. Our results are more reliable, because they are confirmed by the findings of Rahimzadeh and Nassaji Zavareh (2014) or Rafati and Karimi (2018) for most of the stations.

The analysis of the temperature time series, after removing all non-homogeneities, showed that the temperature variations are similar at each of the 10 regions identified by Rahimzadeh and Nassaji Zavareh (2014). Figures 11, 12 and 13 show the variability of the minimum, mean and maximum temperature after homogenization for the stations in the regions, respectively. The similar variability and strong correlation of the series in the regions are obvious. Also, these figures show that the minimum temperature was lowest in the Zagros mountain and the northwest. Southwest and the area across the Persian Gulf experienced the warmest days. All the regions except for the central area were subjected to a cool period (negative trend) from 1960 to 1975. Iran experienced a warming period from 1975 to 2018 with brief periods of cooling during 1981–1985, 1990–1994 and 2010–2014.

Figures 14, 15 and 16 give the spatial distribution of annual trends for minimum, mean and maximum temperature with respect to 1961-1990, respectively. Table 6 presents the result of the Mann-Kendall test and Sen' slope for the regional annual trends. According to these results, there is a statistically significant positive linear trend in annual minimum temperature at level 1% in all the regions (varying from 0.35 °C to 0.63 °C/decade). The annual maximum temperature has increased significantly at level 1% in all the regions (at a rate of 0.14–0.29 °C/decade) except for the Coastal area across the Caspian Sea and the east which do not have a significant trend. On the subject of annual mean temperature, the central area, northeast, east, the southern side of Alborz mountain, and the southeast show positive significant trends (varying from 0.16 to 0.4 °C/decade). The greatest increase in mean temperatures is in the central area. Also, minimum temperatures increase about twice as fast as maximum temperatures.

Table 7 gives a comparison of our results with those of Rahimzadeh and Nassaji Zavareh (2014), Ghasemi (2015) and Fallah-Ghalhari et al. (2019). The trends found in our work is consistent with those of Rahimzadeh and Nassaji

Table 6 Trend of annual minimum, maximum and mean temperature for the period 1960–2018 expressed as °C/decade

Region	T_min		T_max		T_mean	
	p-value	slope	p-value	slope	*p*-value	slope
Northwest	0.00	0.38	0.00	0.26	0.05	0.13
Zagros Mountain	0.00	0.45	0.00	0.27	0.62	0.03
Coastal area across Caspian Sea	0.00	0.46	0.05	0.11	0.04	0.10
Central area	0.00	0.63	0.00	0.29	0.00	0.40
Northeast	0.00	0.5	0.00	0.29	0.00	0.23
East	0.00	0.45	0.09	0.09	0.00	0.18
Southeast	0.00	0.39	0.00	0.27	0.00	0.34
South side of Alborz mountain	0.00	0.55	0.00	0.19	0.00	0.16
Coastal area across Persian Golf	0.00	0.35	0.00	0.14	0.96	0.00
Southwest	0.00	0.5	0.00	0.27	0.15	0.08

Table 7 The comparison of our results and those of previous works on the maximum and minimum temperature trends

	Period	Number of Stations	T_min	T_max
Our work	1960–2018	37	0.22	0.47
Rahimzadeh and Nassaji Zavareh (2014)	1960–2010	32	0.21	0.48
Ghasemi (2015)	1961–2010	38	0.15	0.34
Fallah-Ghalhari et al. (2019)	1976–2005	45	0.23	0.39

Zavareh (2014), but different from the finiding of Ghasemi (2015) and Fallah-Ghalhari et al. (2019). The reason for the difference with Ghasemi (2015)' results could be that Ghasemi (2015) used non-homogeneous series to estimate the trends and, therefore, the results were biased. The trend of minimum temperature found by Fallah-Ghalhari et al. (2019) was smaller than our work, while, according to their study period 1976–2005, it was expected to be higher. As mentioned earlier, all the regions except for the central area experienced a cool period (negative trend) from 1960 to 1975. A more detailed evaluation of the result of Fallah-Ghalhari et al. (2019) revealed that they found negative trends for Isfahan, Gorgan, Saqqez, Shahr_e Kord and Torbat_e Heydariyyeh stations contradicting our results. We found the non-climatic break points in this series, most of which confirmed by the available metadata, and the adjusted series were used for estimating trends. In fact, the trend of this series before homogenization was negative, which is not reliable (e.g., Gorgan station, explained in Sect. 3.3). It seems that Fallah-Ghalhari et al. (2019) have not identified these non-climatic break points and have estimated the trends from non-homogeneous series.

Upon comparing the regional trends of the period 1960–2018 (Table 6) and the period 1960–2010 (Rahimzadeh and Nassaji Zavareh 2014), it is concluded that the rate of increase at a maximum temperature in the last decade was higher than the previous five decades in the Zagros and southwest regions, while it has been lower in the Persian Gulf and Oman sea region. Also, the rate of increase at a minimum temperature in the last decade has been lower than the previous five decades in the southern side of Alborz mountain.

Figure 17 gives the spatial distribution of seasonal trends for minimum, maximum and mean temperature with respect to 1961–1990, respectively. Table 8 presents the regional seasonal trend for minimum, mean and maximum temperature for the period of 1960–2018, expressed as °C/decade. The minimum temperatures had a positive trend in all seasons, with the greatest warming in autumn for the central area. The maximum temperatures increased significantly in the spring and summer for most of the regions, with the greatest increases in spring for the northeast.

5 Conclusions

The CLIMATOL methodology was applied for quality control and homogenization of minimum, maximum and mean temperature series of 37 synoptic weather stations of Iran for the period 1960–2018. Pairwise detection from the HOMER software and metadata information were used for segmenting climatic and non-climatic breaks. Approximately 72% of the series suffered from in-homogeneities (breaks and outliers). In 10 stations, neither breaks nor outliers were detected, and the metadata could explain about 75% of the total breaks. After adjusting the series, annual and seasonal anomalies of homogenized series were calculated using as reference the 30-years period of 1961–1990. The regional trends of

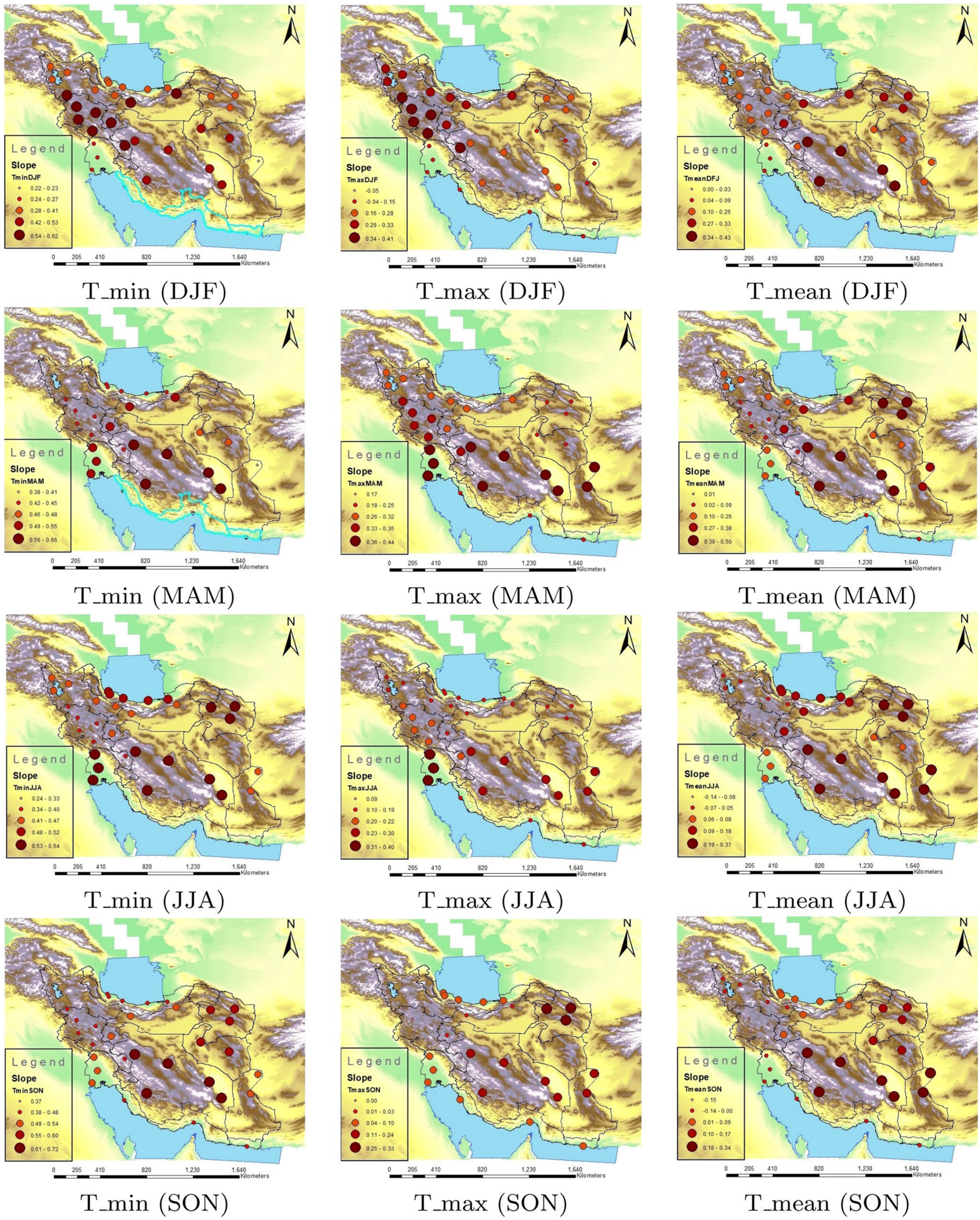


Fig. 17 Seasonal trend of maximum, minimum and mean temperature anomalies for the period 1960–2018 (°C), expressed as departures from 1960 to 1990

Table 8 Trend of seasonal minimum, maximum and mean temperature for the period 1960–2018 expressed as °C/decade

Parameter	Regions	DJF *p*-value (slope)	MAM *p*-value (slope)	JJA *p*-value (slope)	SON *p*-value (slope)
T_min	Northwest	0.02 (0.35)	0.00 (0.41)	0.00 (0.45)	0.00 (0.37)
	Zagros mountain	0.00 (0.62)	0.00 (0.43)	0.00 (0.40)	0.00 (0.48)
	Coastal area across Caspian sea	0.00 (0.40)	0.00 (0.45)	0.00 (0.52)	0.00 (0.44)
	Central area	0.00 (0.53)	0.00 (0.66)	0.00 (0.62)	0.00 (0.72)
	Northeast	0.00 (0.41)	0.00 (0.40)	0.00 (0.58)	0.00 (0.59)
	East	0.00 (0.49)	0.00 (0.48)	0.00 (0.24)	0.00 (0.60)
	Southeast	0.02 (0.22)	0.00 (0.38)	0.00 (0.44)	0.00 (0.54)
	Southside of Alborz mountain	0.00 (0.62)	0.00 (0.55)	0.00 (0.47)	0.00 (0.52)
	Coastal area across Persian Gulf and Oman sea	0.00 (0.23)	0.00 (0.44)	0.00 (0.33)	0.00 (0.43)
	Southwest	0.00 (0.27)	0.00 (0.54)	0.00 (0.64)	0.00 (0.52)
T_mean	Northwest	0.18 (0.22)	0.04 (0.19)	0.63 (0.05)	0.44 (– 0.06)
	Zagros mountain	0.07 (0.26)	0.31 (0.09)	0.05 (– 0.14)	0.01 (-0.15)
	Coastal area across Caspian sea	0.90 (0.00)	0.22 (0.10)	0.00 (0.18)	0.18 (0.09)
	Central area	0.00 (0.43)	0.00 (0.50)	0.00 (0.27)	0.00 (0.33)
	Northeast	0.04 (0.28)	0.03 (0.23	0.01 (0.19)	0.07 (0.13)
	East	0.08 (0.18)	0.01 (0.26)	0.19 (0.08)	0.01 (0.17)
	Southeast	0.01 (0.23)	0.00 (0.38)	0.00 (0.37)	0.00 (0.34)
	Southside of Alborz mountain	0.15 (0.19)	0.04 (0.20)	0.04 (0.13)	0.39 (0.05)
	Coastal area across Persian Gulf and Oman sea	0.56 (0.03)	0.14 (0.09)	0.07 (– 0.08)	0.68 (0.00)
	Southwest	0.34 (0.09)	0.01 (0.21)	0.34 (0.07)	0.54 (– 0.04)
T_max	Northwest	0.10 (0.33)	0.00 (0.30)	0.05 (0.18)	0.89 (0.00)
	Zagros mountain	0.01 (0.41)	0.00 (0.35)	0.00 (0.22)	0.82 (0.00)
	Coastal area across Caspian sea	0.70 (– 0.05)	0.08 (0.17)	0.01 (0.18)	0.16 (0.1)
	Central area	0.05 (0.25)	0.00 (0.43)	0.00 (0.26)	0.00 (0.20)
	Northeast	0.04 (0.33)	0.00 (0.46)	0.00 (0.28)	0.05 (0.17)
	East	0.78 (0.04)	0.05 (0.24)	0.19 (0.09)	0.99 (0.00)
	Southeast	0.29 (0.13)	0.00 (0.43)	0.00 (0.30)	0.00(0.24)
	Southside of Alborz mountain	0.09 (0.30)	0.00 (0.32)	0.01 (0.18)	0.59 (0.03)
	Coastal area across Persian Gulf and Oman sea	0.43 (0.05)	0.00 (0.25)	0.00 (0.16)	0.05 (0.09)
	Southwest	0.12 (0.15)	0.00 (0.44)	0.00 (0.40)	0.13 (0.10)

temperature were estimated using the mean annual and seasonal anomalies from the stations located in the region with similar variability. The major results are as follows:

- To detect an accurate long-term climatic trend, quality control and homogenization of series with reliable methods are necessary. Not adjusting in-homogeneities can lead to unreliable results such as the negative trend of minimum temperature for the case of the Gorgan station (Fig. 8).
- Over the period of 1960–2018, the annual minimum temperature in Iran increased by 0.35–0.63 °C/decade; 0.14–

0.29 °C/decade for the annual maximum temperature, and 0.1–0.4 °C/decade for the annual mean temperature.
– The minimum temperatures had a positive trend in all seasons, whereas the maximum temperatures often increased significantly in the spring and summer.
– All regions except for the central area went through intermittent cool periods from 1960 to 1975, and the country experienced a warming period from 1975 to 2018 with brief periods of cooling during 1981–1985, 1990–1994, and 2010–2014.

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