EFFECT OF DATA HOMOGENIZATION ON DETERMINATION OF TEMPERATURE TRENDS OVER IRAN

[1]ZOHREH JAVANSHIRI, [2]MORTEZA PAKDAMAN, [3]YASHAR FALAMARZI, [4]SHARARE MALBUSI, [5]MANSOURE KUHI

[1,5]Applied Climatology Division, Climatological Research Institute (CRI), Mashhad, Iran
[2,4] Climatology of Atmospheric Disasters Division, Climatological Research Institute (CRI), Mashhad, Iran
[3] Climate Change Division, Climatological Research Institute (CRI), Mashhad, Iran
E-mail: [1]Javanshirizohreh@gmail.com, [2]Pakdaman.m@gmail.com, [3]Yashar.Fa@gmail.com, [4]Malbousi_434@yahoo.com, [5] Man_koohi@yahoo.com

Abstract – The daily minimum, maximum and mean temperature data at 37 weather stations in Iran from1960 to 2018 are analyzed for homogeneity and trend. Only 12 stations passed the homogeneity test successfully without any break point or outlier**.** Approximately 86%of the breaks could be explained by the station relocations. Annual anomalies of homogenized series were calculated using as reference the 30-years period 1961-1990. The regional trend of temperature is estimated using mean annual anomalies from stations with similar variability. The minimum temperature have increased significantly in all regions at rate of 0.35-0.63° C/decade. The maximum temperature have positive trend over most regions with the rate of change varying from 0.14 to 0.29 °C/decade.

Keywords - Homogeneity, Iran, Temperature, Trend.

I. INTRODUCTION

It is certain that global mean surface temperature has risensince 1970 and maximum and minimum temperatures over land haveincreased since 1950, according to Fifth Assessment Report (AR5[18]).Despite the robust significant warming trend, there are variability in the rate of warming in different periods, seasons and regions.

Climate change usually have strong effects in people and their behavior, as well as on agricultural resources and availability of water, and is especially important in regions in which its economic activity is depend on agriculture such as most part of Iran (Ghasemi [14]).

Many climate change researches, on the in-situ data by focusing on temperature, has been done(Moberg and Alexandersson [2], Vincent and Gullett [16], Begret et al. [5], Brunetti et al.[7], Brunet et al.[6], Alexander et al. [2], Caesar et al. [9], Collins et al. [11], Syrakova and Stefanova [36], Vincent et al.[41]).

The temperature variability was also investigated by several Iranian studies. Rahimzadeh and Asghari ([30], [31])analyzed 11 climatic elements including minimum andmaximum temperatures for 33 synoptic stations duringthe period 1951–1997. The highest trend were found in minimum temperatures, except the few stations like Orumiyeh located in the Northwest of the country.Shirgholami and Ghahraman [14]studied 34 synoptic stations in different climates of Iran, and showed 59% of stations had a statistically significant positive trend for mean annual temperature. Masoudian [22] found positive and negative trends in temperature time series for the period 1951–2000.

Kousari and Asadi Zarch [19] showed that minimum and mean temperatures have significantly positive trend, especially during the last few years up to the year 2000, in arid and semi-arid areas of Iran.Rahimzade et al.[29] studied the minimum and maximum temperature in 32 stations for the period 1960-2010. The country was dividedinto 10 regions in term of trends and variability of temperature. Also, the minimum and maximum temperature have increased almost in all regions at rate of 0.4-0.5 and 0.2-0.3 (° C/decade), respectively.Ghasemi [14] studied the maximum, minimum and mean temperature in 38 stations in during 1961-2010 and reported that the annual trends were 0.34 and 0.15° C/decade for minimum and maximum temperature, respectively.

Forasmuch as for detecting accurate long-term climatic trend, using homogenized data is necessary, the general objective of this work is to provide a dataset of homogenized daily maximum, minimum and mean temperatures for 37 stations across Iran for the period 1960-2018. Also, determining the regional temperature trend over the period 1961–2018, in order to accurately represent local climate diversities, by these homogenized series.

This article is organized as follows: First, it presents a very short review about geographical characteristics and climate of Iran, the dataset of Iranian synoptic stations and available metadata in Section 2. Section 3 is dedicated to the use of homogeneity and adjustment methods. Analysis procedure and an examplefor one region, with similar minimum, maximum and mean variability and with nearly equal trends, are presented. Regional trends of annual minimum, maximum and mean temperature are discussed in Section 4.

II. MATERIALS

A. Study Area

Iran is located in the Middle East zone and borders the Caspian Sea, Persian Gulf, and Gulf of Omanwith an area of 1 648 000 km^2extending from 25º 00ʻto 39º 47ʻN and 44º 02ʻto 63º20ʻE (Fig.1). The main mountain chain in Iranis Zagros Mountainsconsists a

series of parallel ridges from northwest to southeast. Alborz Mountains is the other one which is narrow but height,rimming the Caspian Sea littoral in the North. There are several closed basin in center of Iran that named Central Plateau. The Dasht-e Kavir and the Dasht-e Lut are salt deserts which located in the east of the plateau.

This varied topography of Iran, rugged and mountainous rims surrounding high interior basins, give rise to various regional climates.

B. Database

The density of synoptic stations is not uniform across Iran. Northeast and Northwest of Iran, with better water resources, more facilities for agriculture, industry and so on higher population, have more dense network to compare the central deserts of Iran. Also, the record lengthis not same for all stations, the longest one is from 1951. The number of stations across Iran during the period from 1951 to 2018 are shown in Fig.2. Because of inaccurate and incomplete data in the period of 1951-1960, this period was removed in our study.

The number of operating stations in the period of 1960-2018 is 34 stations (Fig.2). The Qom station have 19-year data gaps, so it was excluded. The missing values for 33 remaining stations are less than 14%, which are estimated using the neighboring stations using the CLIMATOL method (Guijarro [15]). The stations of Saqqez, Dezful, Zabol and Chabahar were added to the list of our studied stations,considering that these stations have lack of data only for

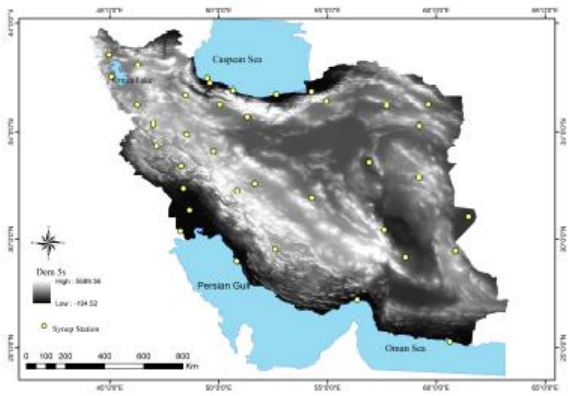


Fig.1. Topography of I. R. of Iran

1-3 years at the start of the period, estimated using neighboring stations.

C. Metadata

The metadata come from I.R. of Iran Meteorological Organization. Unfortunately, the available metadata is low, and does not cover all of non-climatic reasons for non-homogeneities. Ithas only information about changes in observing site, not instruments, observing schedule, observing habit and micro-environment around the observational grounds.Also, there is major challengesin detection of accurate time of relocations like; not access to accurate information for some stations, non-consistency between metadata and recorded data, no record of month of relocation at stations, frequent relocation of some stations.

III. METHODS

A. Data Quality and Homogeneity

The quality and homogeneity of long term time series of climate observations is of major importance. A homogeneous climate time series is defined as one where variations are caused only by variations in climate (Conrad and Pollak [12]; Aguilar et al. [1]). Other unnatural variations like; changes in location of the stations, instruments, observing practices and station environment, which can lead to erroneous interpretations of the studied climate, are called in-homogeneities. Unfortunately, few long term climate time series are free of irregularities (Auer et al. [3]). Therefore, before using climatological data in any kind of study, especially in climate change studies, a quality control and homogeneity assessment of data set is necessary (Peterson et al. **Error! Reference source not found.**).

Several methods have been developed for detection of non-climatic inhomogeneity and adjustment. Reviews of these techniques (e.g. Panofsky and Brier [24], Kobysheva and Naumova [21], Potter [26], Alexandersson [2], Jones et al. [20], Quayle et al. [27], Gullett et al. [16], Caussinus and Mestre [10], Szentimrey [36, 37, 38], Free et al. [13]) can be seen in the works by Peterson et al. **Error! Reference source not found.**, Aguilar et al. [1] and Beaulieu et al. [4].

There are a large number of software packages thatimplement these techniques (http://www.climatol.eu/tt-hom/index.html). The European Science Foundation funded the Action ES0601 («HOME», Advances in Homogenization

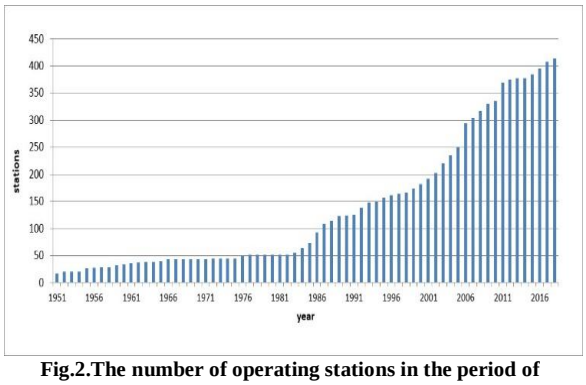


Fig.2.The number of operating stations in the period of 1960-2018

Methods of Climate Series: An Integrated Approach) that enabled to compare many of them (Venema et al.[39]). The MULTITEST project is other one comparesthe updated methods that could be executed in fully automatic mode

(http://www.climatol.eu/MULTITEST/). These homogenization efforts had been 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 [14].This methodology involves five steps;

- Estimate data; normalize seriesandestimate them fromthe weighted average oftheir neighbors by type II regression [34]. 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 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, comute series of anomalies (differences between the normalized original and estimated data). Standardized anomalies greater than prescribed threshold will result in the deletion of their corresponding original data.
- In-homogeneity detection; The Standard Normal Homogeneity Test (SNHT, [2]) is applied to the anomaly series in two stages; i) On windows of 120 terms moved forward in steps of 60 terms (for monthly data). ii) 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 data before the breakare transferred to a new series with the same coordinates. This procedure is done iteratively, until no series is found inhomogeneous.
- Correction; infill all missing data in all homogeneous series and sub-series with the same data estimation procedure using only the reference of their own other fragments.

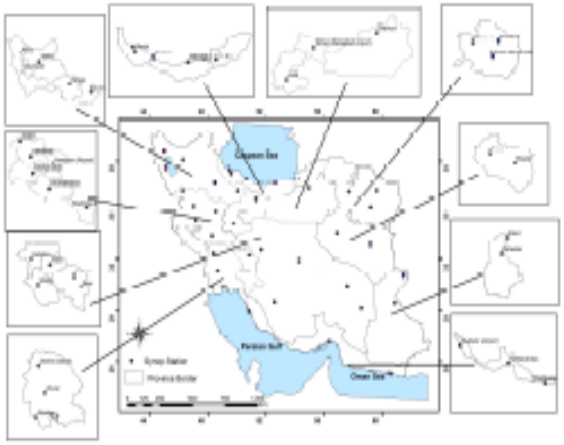


Fig.3. Climatic regions and locations of weather stations used in this study

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

B. Analysis procedures

Iran has different regional climates because of its size and varied topography.According to variability of minimum and maximum temperature, Iran was divided into 10 sub-regions [29].

The areas were 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 Persian Gulf, the central area, and also the Northwest, Northeast, East, Southeast, and Southwest.Climatic regions are presented in Fig.3. The following homogenization procedure was applied separately on the datasets of each climatic region.

- Detection outliers; we did two steps for this purpose.First comparing series with neighbors, histogram of standardized anomalies was plotted by the CLIMATOL method and thresholds for detection outliers were determined.Original data corresponding to standardized anomalies that are greater than prescribed thresholds detected as outliers. Second, detected outliers in first step werecompared with the values of the days before and after.If they differ significantly, accepted as outliers and deleted.

- Detection in-homogeneity for monthly series; First, the monthly time series were calculated from daily series. The WMO's recommendation (WMO [42]) about calculation of monthly valueswas followed.Second, abrupt discontinuities were detected by CLIMATOL method. Third, the pairwise detection provided by HOMER was applied. Finally, if break points in the secondstep confirmed by metadata or pairwise detection, accepted as non-climatic breaks.

- The monthly and daily seriesadjusted with the monthly break-point by CLIMATOL method.
- Anomaly time series was created by subtracting the mean of period 1961–1990 from each of the time series.
- The anomalies are averaged, and regional trend for maximum, minimum and mean temperature were computed by Mann-kendall and Sen' Slop methods for the period 1960–2018.

C. Example

The analysis procedure of Costal area across Caspian Sea and specially Gorgan stationfor minimum temperature is presented to show details of approach.

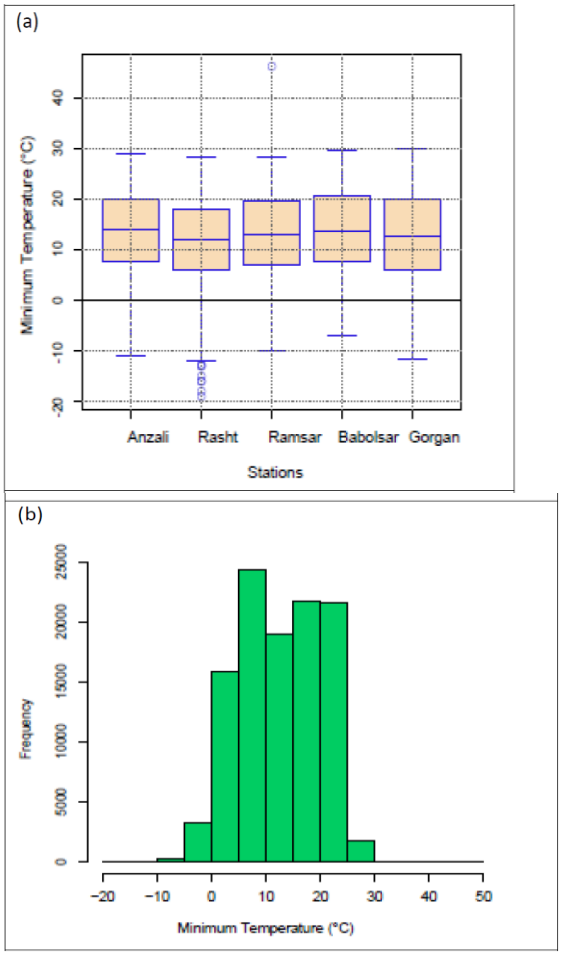
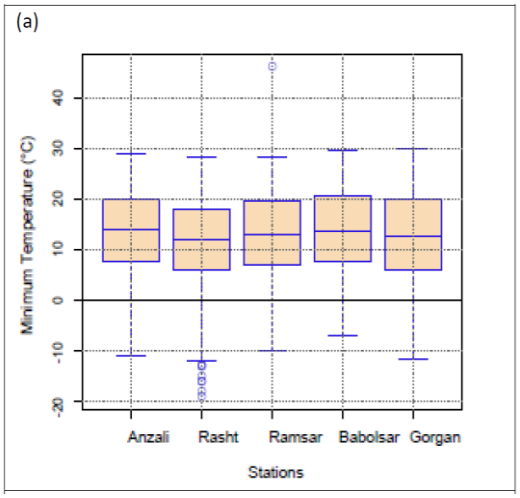


Fig. 4 **shows box-plots of the data at every station and a histogram of all data in Caspian Sea region.**

The frequency histogram shows the probability distribution is near normal. Also, the presence of very anomalous values in Rasht and Ramsar stations is evident in box-plots. For further investigation, the histogram of standardized anomalies is plotted. Fig. 5shows this histogram and as can be seen it is much skewed to the right. The data withabsoluteanomalies greater than 8 standard deviations, were



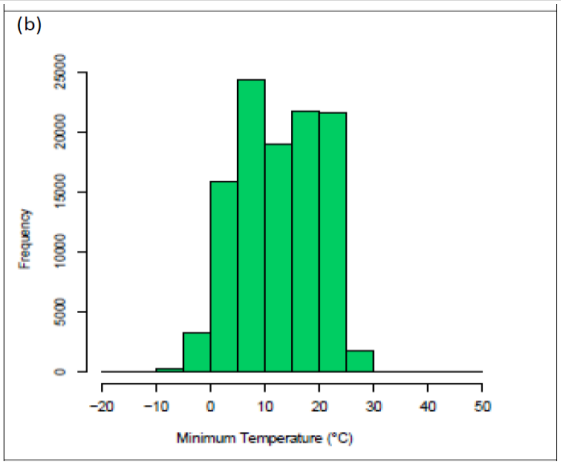


Fig. 4. (a) Box-plots of the data at every station. (b) Histogram of all data.

considered as outliers.These outliers along with date were presented in Table 1.

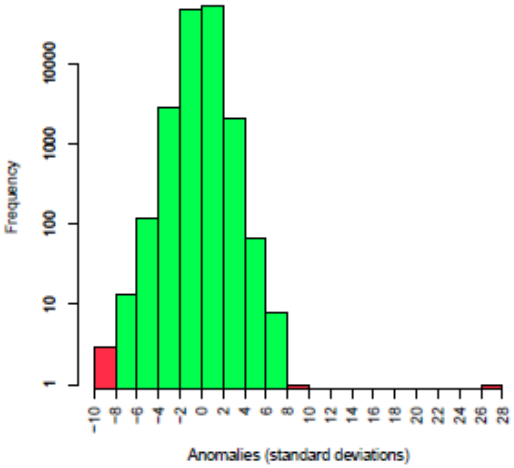


Fig. 5. Histogram of anomalies.

station	date	observed	Anomaly
Rasht	12/2/1978	-7	-9.4
Rasht	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 1. Outliers for minimum temperature in Caspian Sea region (step 1)

For confirming these outliers has been correctly identified, their valueswould be compared with the values of the days before and after. According to Table 2, the detected outliers in Rasht and Ramsar stations were confirmed and deleted from original data.

The time series of standardized anomalies for Gorgan station was plotted to get preliminary understanding (Fig.6). It is clearly inhomogeneous. The homogeneity test on the monthly series by CLIMATOL algorithm shows break points in 1984 and 2007. Also the result of pairwise detection by HOMER software is provided in

Fig.7; break points in 1984 and 2007 is evident. Comparing the identical change points with metadata

information from the station, showed that the Gorgan station had significant relocation in 1984 and 2006. Therefore these points were accepted as non-climatic abrupt and the data were adjusted by CLIMATOL method. Fig.8 shows series before and after adjustment with along linear trend.

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

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

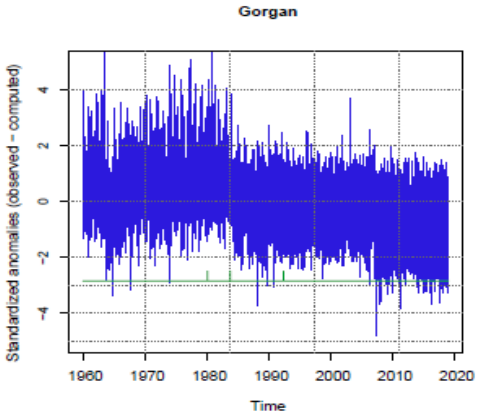


Fig.6. Standardized anomalies for minimum temperature of Gorgan station

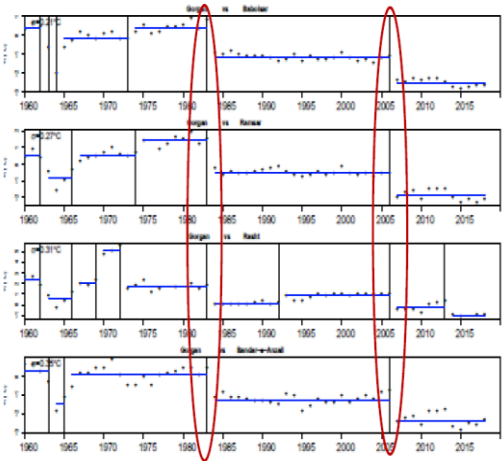


Fig.7. Pairwise compression between the Gorgan station and its neighboring stations in the Caspian Sea region, bold vertical lines denote the year of probable break points, σ is the standard deviation of noise.

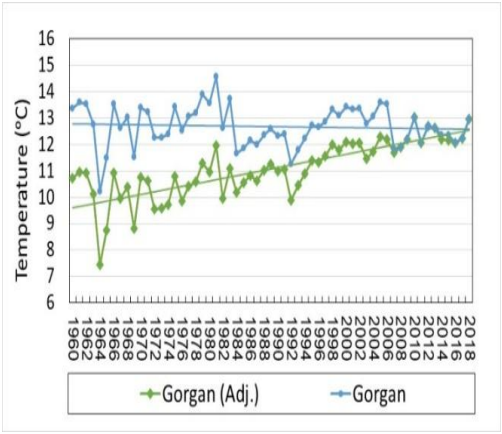


Fig.8. The annual mean minimum temperature of original and adjusted data series at Gorgan station during 1960-2018.

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

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

Table 3 gives the result of Mann-Kendall test, and Sen' Slope. The results show that there is no statistically significant trend before adjustment, while there is the statistically significant positive one after that. Fig.9 shows the variability of the time series of minimum temperature after removing non-climatic discontinuities for the Costal area across Caspian Sea. As can be seen the variability of time series are so near and the trend of their mean can representative the trend of the whole area for the period 1960-2018. Average of anomaly time series (means of period 1961-1990 were subtracted) across Anzali, Rasht, Ramsar, Babolsar and Gorgan stations were calculated and its trend were considered as representative of the Caspian Sea Area (Fig.10). According to the result of the Mann-Kendall test and Sen' Slop, the annual minimum temperature in Caspian Sea region has significantly increased at a rate 0.46 °C/decade.

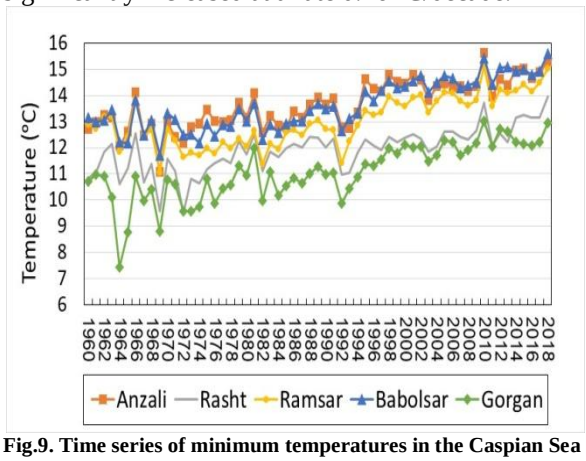


Fig.9. Time series of minimum temperatures in the Caspian Sea region after removing discontinuities.

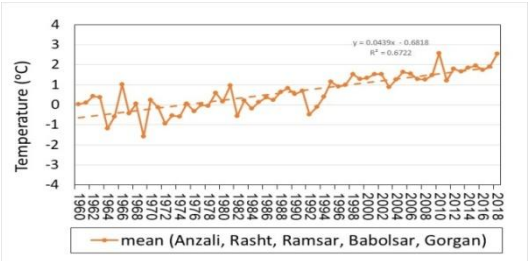


Fig.10. Anual minimum temparture anomalies for the period 1960-2018, expressed as departures from 1961 to 1990 average for Caspian Sea region.

IV. RESULTS

The result of homogeneity assessment for each station is provided in Table 4. Analyzing all minimum, maximum and mean temperature series, after removing all non-homogeneities, showed the temperature variations are similar in each of the 10 regions that identified by Rahimzade and Zavareh [29]. Table 5Table 5 shows the regional trends of annual minimum, maximum and mean temperature with respect to 1961-1990. According to these results, there is a statistically significant positive linear trend in annual minimum temperature at level 1% in all regions (varying from 0.35° to 0.63° C/decade). The annual maximum temperature has increased significantly at level 1% in all regions (at rate of 0.14-0.29 °C/decade) except Costal area across Caspian Sea and East which does not have a significant trend. On the subject of mean annual temperature, Central area, Northeast, east and Southeast show positive significant trends (varying from 0.16 to 0.4 ° C/decade). The greatest increase in temperature is in the central area. Also, minimum temperature increase about twice as fast as maximum temperature.

Region	Stations	Break Points	Causes
Northwest	Qazvin	1974	Relocation
	Khoy	-	-
	Orumiyeh	2003	Relocation
	Tabriz	1971	-
	Zanjan	1984 2014	Relocation -
Zagros Mountain	Kermanshah	-	-
	Khorramabad	1980	Relocation
	Sanandaj	1974	Relocation
	Shahr-e Kord	2003	Relocation
	Hamadan	-	-
	Saqqez	1987	-
Coastal area across Caspian Sea	Bandar-e Anzali	1983	Relocation
	Babolsar	-	-
	Gorgan	1984 2007	Relocation Relocation
	Ramsar	-	-
	Rasht	1969 1973	Relocation
Central area	Bam	-	-
	Isfahan	1994	Relocation
	Kerman	-	-
	Shiraz	2004	Relocation
	Yazd	-	-
Northeast	Mashhad	1982	Relocation
	Sabzevar	1965 1972 2004 2008	Relocation Relocation Relocation Relocation
	Torbat e Heydariyyeh	1985	Relocation
East	Birjand	1978	Relocation
	Tabas	-	-
Southeast	Zahedan	1985	Relocation
	Zabol	-	-
	Tehran	-	-
	Arak	1981	Relocation
	Shahrud	1965 1982	Relocation Relocation

Coastal area across Persian Gulf	Bandar Abbas	1971	Relocation
	Bushehr	-	-
	Chabahar	-	-
	Dezful	-	-
Southwest	Ahvaz	-	-
	Abadan	1981	Relocation

Table 4. Result from homogeneity tests for the selected stations cover the period 1960-2018.

Region	T_{min}		T_{max}		T_{mean}	
	p-value	Slop	p-value	Slop	p-value	Slop
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	0.09	0.00	0.23
East	0.00	0.45	0.09	0.29	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 5. Annual minimum, maximum and mean temperature for the period 1960-2018 expressed as °C/decade.

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