Research Article **Open Access**

Trends and Anomalies in Daily Climate Extremes over Iran during 1961–2010

Fatemeh Parak [1,*], Ahmad Roshani[2], Javad Bodagh Jamali[2]

[1] Department of Climatology, Faculty of Geography, Kharazmi University, Tehran, Iran
[2] Atmospheric Science and Meteorological Research Center (ASMERC), Tehran, Iran

Article History

Received
December 10, 2014

Revised
January 25, 2015

Accepted
January 29, 2015

Published Online
February 15, 2015

Keywords:
Climate change,
Climatic extremes,
Climatic variability,
Extreme temperature,
Extreme precipitation
Iran

Abstract: The analysis of the spatiotemporal trends of temperature and precipitation are important for the policy guidelines of future development and sustainable management of a country. This study presents spatiotemporal variations in temperature and precipitation indices to elucidate climatic change over Iran during last five decades i.e., 1961 -2010 by examining data obtained from30 synoptic stations across the country. Results indicate significant and spatially coherent rising trends in temperature indices. From the results it is clear that the majority of the trends in the annual means of daily maximum temperature, daily minimum temperature, tropical nights, warm nights and warm spell duration index showed strongly positive tendency during the last decades, while the increasing trends in the Central region of Iran was stronger than this in the other areas. Decreasing trends have been found in the diurnal temperature range, Cold spell duration index and Cool nights were found over most regions of Iran and positive trends were found for Growing season length and Warm days over other regions of the country. Cooling trends were found for the southern half of the Zagros Mountain and Shahrekord station. Among the precipitation indices we found positive trends in daily intensity index, heavy precipitation and extreme wet days over most of the country and a significant increase in the heavy precipitation series was observed mostly in Southwestern regions of Iran, as well as along the coasts of the Persian Gulf. We can conclude that the average amount of wet day precipitation has significantly increased across Iran. Overall, these trends were statistically significant mostly over the central areas of the country and there was strong climatic variability in the rest of country, especially arid and semi-arid regions. The northwest region was only region with weak anomalies in studies indices.

***Corresponding authors:** Fatemeh Parak; **Email**: f.parak@yahoo.com

Cite this article as: Parak et al., 2015. **Trends and anomalies in daily climate extremes over Iran during 1961–2010.** *Journal of Environmental & Agricultural Sciences*. 2:11.

1. Introduction

The subject of climate change is gaining importance due to increasing frequency, duration and intensity of extreme climate events, such as drought, flood, heat wave and cold waves. Extreme heat events includes record breaking summer heat waves of 2003 and 2010 hampered various aspects of life due to intensity, duration and frequency of high temperature in different parts of the world (García-Herrera et al., 2010; Barriopedro et al.,2011; Coumou and Rahmstorf, 2012). Numerous studies using a long term dataset showed that global warming, as a result of greenhouse effect, has very likely increased temperature variability in Europe, as a result more frequent and severe warm extremes were recorded while there was an attenuation of cold events (Keggenhoff et al., 2006; Fischer and Schär, 2010; Trenberth and Fasullo, 2012; Krueger et al., 2015). The study of these events and their frequency is very important in order to understand causes and to decipher certain signs or particular pattern of their occurrence. Moreover, this kind of research is important for the assessment of their impacts on human beings, agriculture and industries.

IPCC (2007) described 0.74 °C rise in global mean surface temperature from1906 to 2005. This increase in temperature was more significant during1910 to 1945 and 1970 to 2005. Other studies found consistent increase in temperature since 1980s. The analysis of temperature during last 50 years showed that the warming occurred at the rate of 0.13°C per decade, which is almost double than the centennial average of warming at the rate of 0.07°C per decade over the last 100 years. Moreover it was observed that, between 1950s and 1990s northern hemisphere was warmer than any other 50-year period in the last five centuries. It is reported that a reduction in consecutive dry days (CDD) and warm nights were observed. Asymmetric rise in temperature is the prominent feature, where minimum temperature is increasing faster than the maximum temperature, resulting in the decreased diurnal temperature range (DTR) at the rate of -0.07°C per decade since 1950s, (Boccolari and Malmusi, 2012).

Most of the studies had analyzed the long term climatology data with the focus on mean values, neglecting extreme climatic events. This was mainly due to unavailability of high quality meteorological data which is usually prerequisite for monitoring, detection and attribution of anomalies in climate extreme (Zhang et al., 2005). Recently Rahimzade et al., (2009) analyzed meteorological data of Iran using 27 different indices of temperature and precipitation, as indicator of climatic anomalies to determine recent climate change. They found fairly negative trends for low temperature or winter indices like cool days and nights, frost and ice days, and DTR. However positive trends were found for warm days, summer days, and tropical nights over most region of Iran.

In addition, the analysis conducted by different researchers in different countries may not perfectly merge to form a global map as they might have investigated different indices (Bonsal et al., 2007) and potentially using different range of thresholds. However, anomalies and trends in climatic extremes and extreme events have shown more sensitivity to climate change as compared to the means values. Extreme events have more serious implications than average trends therefore they have received more attention from scientific community (You et al, 2010a, 2010b). Throughout the 20th century anomalies in climatic extremes had been significant across the globe. Among these extremes rising temperature was pronounced and precipitation indices showed a tendency toward wetter conditions particularly in the last few decades. (Frich et al., 2002; Alexander et al., 2006; Coesar et al., 2006).

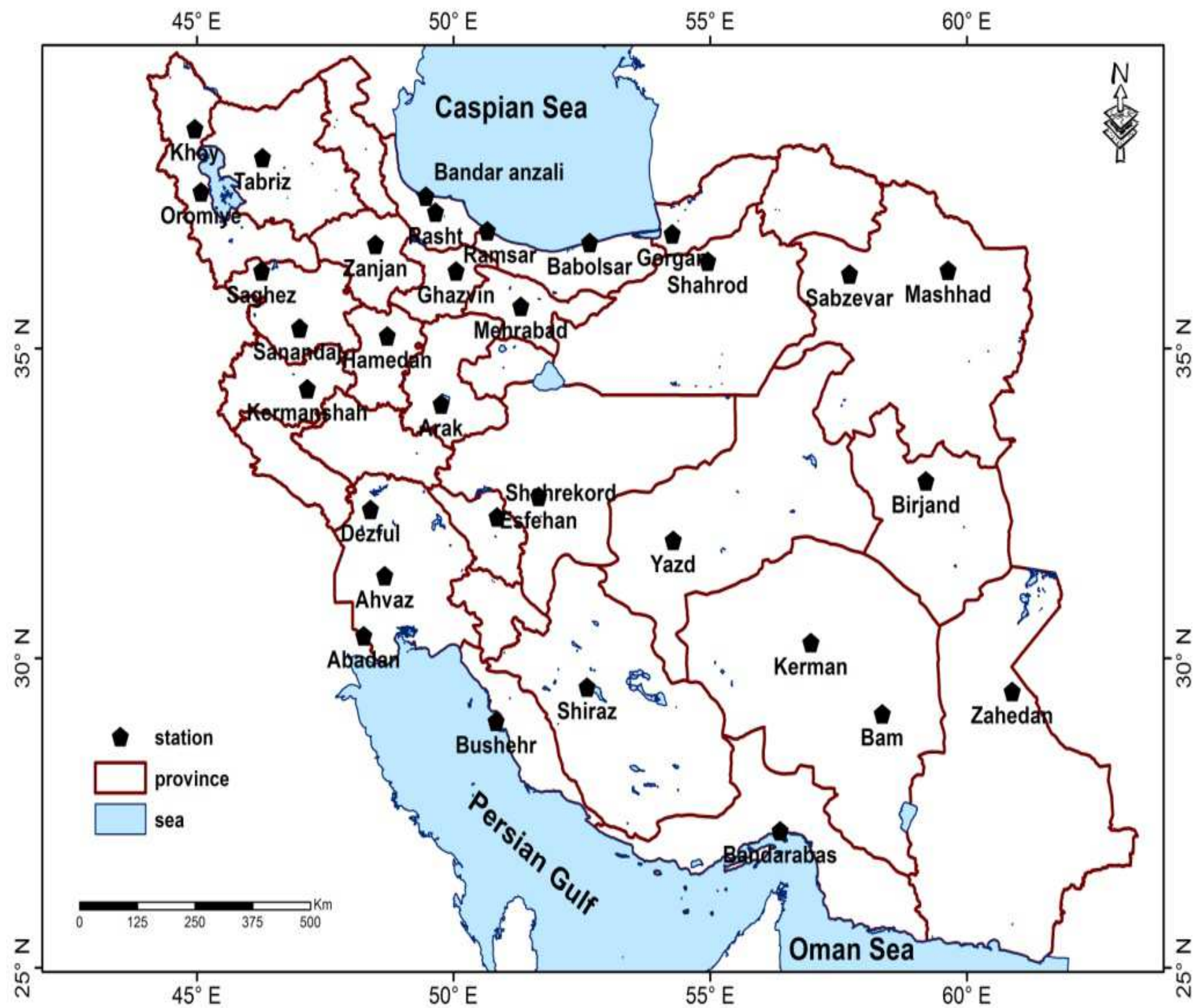


Fig. 1. Spatial distribution of the synoptic stations in Islamic Republic of Iran map.

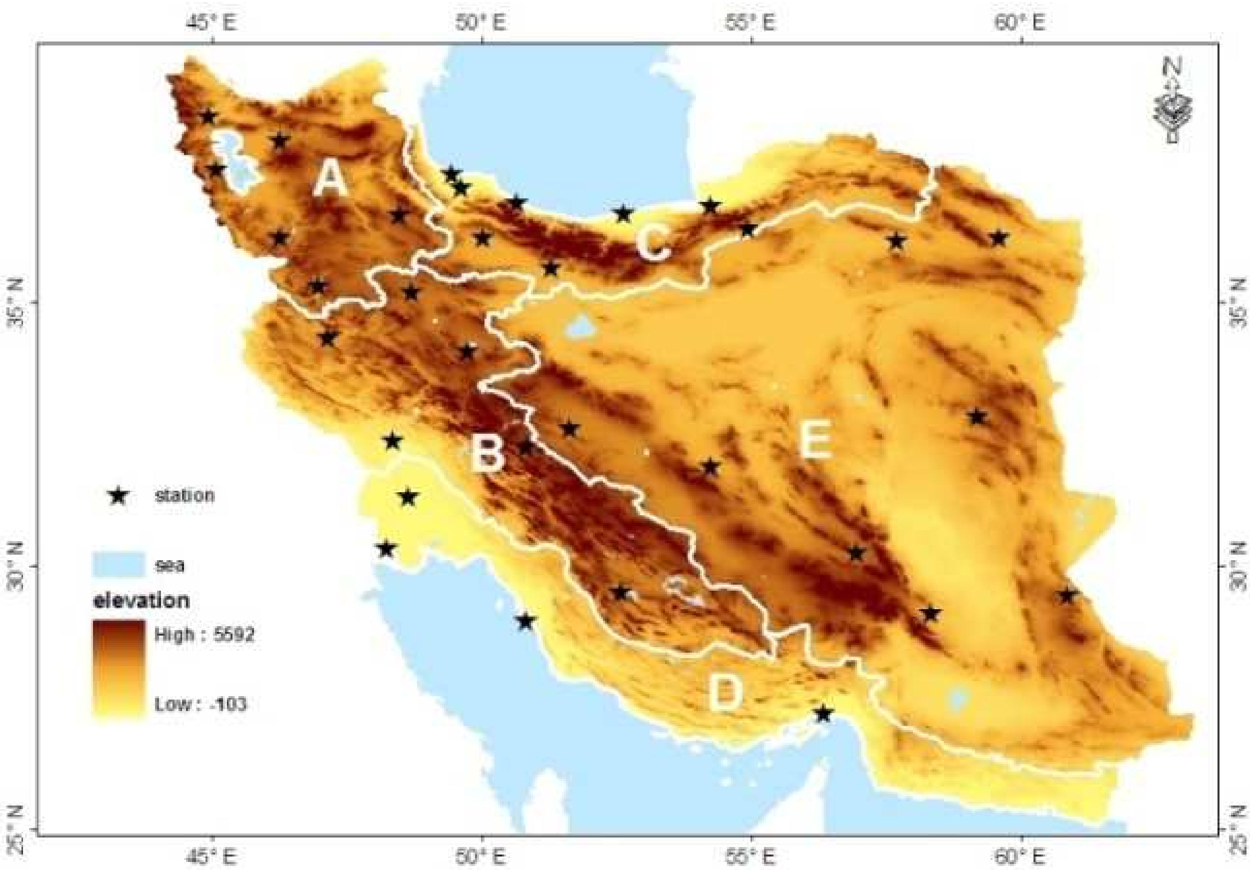


Fig. 2. Five regions including: Azarbaijan (A), Zagros (B) and Alborz (C) mountain ranges, Caspian Sea cost (D) and central part (E) of Islamic Republic of Iran.

Both temperature and precipitation extremes have teleconnections with each other's (Krishnamurti et al., 2015). Pakistan flood and Russian heatwave of 2010 are recent example of teleconnection between hydrometeorological extremes (Lau and Kim, 2012) Studies have shown a significant widespread changes in temperature extremes are associated with global warming. Changes in precipitation extremes exhibit much less spatial coherence than those of temperature extremes, making it different to detect regional trends (Haylock et al, 2006; Klein Tank et al, 2006; Trenberth and Fasullo, 2012).

This study was aimed to provide a better understanding of the anomalies and changing trends in duration, frequency and intensity of climatic extremes by examining temperature and precipitation indices over Iran during 1961-2010.

2. Material and Methods

2.1. Data

The study area i.e., Iran, lies approximately between 25 ^{o}N and 40 ^{o}N in latitude and between 44 ^{o}E and 64 ^{o}E in longitude (Fig.1). Based on the Koppen climate classification, most parts of Iran are categorized under arid (BW) and semi-arid (BS) climates. Alborz and Zagros are the important mountains of Iran, which play an important role in non- uniform spatiotemporal distribution of temperature and precipitation in Iran (Dinpashoh, 2006).

Examination of climate changes needs long and high quality records of climatic variables. In the present study, dataset of daily maximum, minimum and mean air temperatures and precipitation (P) for the period 1961-2010 from 30 synoptic stations from different geographic locations of Iran (Fig.1) were collected from the Islamic Republic of Iran Meteorological Organization (IRIMO) and were analyzed. Homogeneity of the dataset was assessed and approved by IRIMO previously. Most of the regions were covered by the corresponding data and the geographical location of the stations.

2.2. Regional categorization

To provide an overall picture of climate variation in the Iran, we also computed regional averages for every index. We divided total area of Iran into five climatic regions based on the climatic variation and geographic locations i.e., distance from sea, mountains and central land. These regions includes mountain ranges Azerbaijan (A), Zagros (B) and Alborz (C), coastal areas of Caspian Sea (D) and central part of country (E) (Fig. 2). The regional averaged indices are computed as the mean of the indices at individual stations relative to their climatology.

2.3. Data analysis techniques

In the study a linear trend was computed from the indices series using a least squares fitting. The Mann–Kendall statistic tests were applied to detect and describe significant trends in the climatic variables. In addition, the magnitude of the decadal trends was derived from the Durbin–Watson test.

Table1. List of 29 ETCCDMI Core Indices for the analysis of extreme precipitation and temperature.

ID	Indicator Name	Definitions	Unit
TXMean	Annual maximum temperature	Annual mean of daily maximum temperature	°C
TNMean	Annual minimum temperature	Annual mean of daily minimum temperature	°C
FD0	frost days	Frost days: Annual count when TN (daily minimum) < 0°C	Day
SU25	summer days	Summer days: Annual count when TX (daily maximum) >25°C	Day
ID0	ice days	Ice days: Annual count when TX (daily maximum) <0°C	Day
TR20	tropical nights	Tropical nights: Annual count when TN (daily minimum) >20°C	Day
GSL	growing season length	Growing season length: Annual (1 Jan–31 Dec in Northern Hemisphere) count between first span of at least 6 days with daily mean temperature T>5°C.	Day
TXx	max Tmax	Max Tmax: Monthly maximum value of daily maximum temperature	°C
TXn	min Tmax	Min Tmax: Monthly minimum value of daily maximum temperature	°C
TNx	max Tmin	Max Tmin: Monthly maximum value of daily minimum temperature	°C
TNn	min Tmin	Min Tmin: Monthly minimum value of daily minimum temperature	°C
TN10p	cool nights	Cool nights: Percentage of days when TN < 10th percentile	Days
TX10p	cool days	Cool days: Percentage of days when TX < 10th percentile	Days
TN90p	warm nights	Warm nights: Percentage of days when TN > 90th percentile	Days
TX90p	warm days	Warm days: Percentage of days when TX > 90th percentile	Days
WSDI	warm spell duration indicator	Warm spell duration indicator: Annual count of days with at least 6 consecutive days when TX > 90th percentile	Days
CSDI	cold spell duration indicator	Cold spell duration indicator: Annual count of days with at least 6 consecutive days when TN < 10th percentile	Days
DTR	diurnal temperature range	Diurnal temperature range: Monthly mean difference between TX and TN	°C
CDD	consecutive dry days	Consecutive dry days: Maximum number of consecutive days with precipitation < 1mm	Days
CWD	consecutive wet days	Consecutive wet days: Maximum number of consecutive days with precipitation ≥1mm	Days
PRCPTOT	annual total wet day precipitation	Wet days precipitation: Annual total precipitation in wet days with precipitation ≥1mm	Mm
R10mm	number of heavy precipitation days	Heavy precipitation days: Number of days with precipitation ≥10 mm	Days
R20mm	number of heavy precipitation days	Very heavy precipitation days: number of days with precipitation ≥20 mm	Days
R25mm	number of heavy precipitation days	Very heavy precipitation days: Number of days with precipitation ≥25 mm	Days
Rx1DAY	number of heavy precipitation days	Max 1-day precipitation: Monthly maximum 1 day precipitation	Mm
Rx5DAY	max 5 days precipitation amount	Max 5-day precipitation: Monthly maximum consecutive 5 days precipitation	Mm
SDII	simple daily intensity index	Simple daily intensity index: Annual total precipitation on wet days divided by number of these days with precipitation ≥1mm	mm/ day
R95p	very wet days	Very wet days: Fraction of annual total precipitation exceeding the 1961–1990; 95th percentile	%
R99p	extremely wet days	Extremely wet days: Fraction of annual total precipitation exceeding the 1961–1990; 99th percentile	%

The brief descriptions of the used statistical methods are as follows:

2.3.1. Mann– Kendall test

The Mann– Kendall test is one of the widely used non- parametric tests to detect significant trends in hydrological and meteorological time series data (Modarres and da Silva, 2007; Partal and Kahya, 2006).The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). Mann (1945) originally used this test and Kendall (1975) subsequently derived the test statistic distribution. The test is suitable for data that do not follow a normal distribution, and supports multiple observations per time series (Kampata et al., 2008). The Mann– Kendall test is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\left(x_j - x_k\right) \qquad (1)$$

$$sign\left(x_j - x_k\right) = \begin{cases} +1 \; if \; \left(x_j - x_k\right) > 0 \\ 0 \;\; if \; \left(x_j - x_k\right) = 0 \\ -1 \; if \; \left(x_j - x_k\right) < 0 \end{cases} \qquad (2)$$

$$Var(S) = \frac{[n(n-1)(2n+5)] - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \qquad (3)$$

Where n is the number of data points, t is the number of ties for i value and m is the number of tied values. Then equations (1) and (3) were used to compute the test statistic Z from the following equation:

$$Z_{MK} = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} if S > 0 \\ 0 \qquad\quad if S = 0 \\ \dfrac{S-1}{\sqrt{VAR(S)}} if S < 0 \end{cases} \qquad (4)$$

A positive value of Z indicates an increasing trend and a negative value indicates a decreasing trend. The null hypothesis H_0 that there were no trends in the records is either accepted or rejected depending if the computed Z statistics is less than or more than the critical value of Z-statistics obtained from the normal distribution table at the 5% significance level (Kampata et al., 2008).

2.3.2. Durbin–Watson test

This test is based on the first order autoregressive error model $\varepsilon_t = \varphi\varepsilon_{t-1} + u_t$ Where φ is the autocorrelation parameter and the u_t, are independently normally distributed with zero mean and variance σ^2. When one is concerned with positive autocorrelation the alternatives are given as follows:

$$H_0 : \varphi \le 0 \quad H_1 : \varphi > 0 \qquad (5)$$

Here H_0implies that error terms are uncorrelated or negatively correlated, while H_1implies that they are positively auto-correlated. This test is based on the difference between adjacent residuals $\varepsilon_t - \varepsilon_{t-1}$and is given by

$$d = \frac{\sum_{t=2}^{n}\left(e_t - e_{t-1}\right)^2}{\sum_{t=1}^{n} e_t^2} \qquad (6)$$

Where e_t is the regression residual for period t, and n is the number of time periods used in fitting the regression model (Kanji, 2006).

2.3.3. Selected indices

The ETCCDMI recommended a total of 29 core indices with primary focuses on extremes to be derived from station daily data (Table 1). We compute these indices using RClimDex, an R-based software package developed at the Climate Research Branch of Meteorological Service of Canada on behalf of the ETCCDMI.

3. Results and Discussion

3.1. Extreme Temperature

The results highlighted that the annual means of daily maximum temperature (TX), minimum temperature (TN), summer days (SU25), tropical nights (TR20), highest daily minimum temperature (TNx), highest daily maximum temperature (TXx), lowest daily maximum temperature (TXn), lowest daily minimum temperature (TNn), warm days, warm nights, duration of warm spell and growing season length showed increasing trend in most parts of the country (Fig.4 and Fig.6).

The positive trend of annual means of TX and TN especially since 1970s is an important indicator of warming trend in the country (Fig. 4). These findings are in good agreement with the results obtained from other studies in the Iran (Tabari et al., 2011).

Significant positive trends of TR20 and summer days (SU25) for mountainous and arid and semi-arid climatic regions were recognized. The largest positive trends of summer days (SU25) about 1.6 and 1.5 day per decade occurred in Babolsar (Fig.3A) and Sabzevar stations. But the largest negative trend for this index of −2.09 and -1.01 days per decade occurred in Anzali and Saghez stations.

These findings support results of Zhang et al. (2005). 21 stations in the southern and central regions have experienced positive trends for tropical nights (TR20), especially after 1980s. Ahvaz (+1.5 days per decade) (Fig.3B) and Ghazvin (−1.3 days per decade) showed higher anomalies.

The rate of the positive trends in TXx (Fig. 4) and TNx (Fig.6) were obtained in this study was weaker than that reported by Zhang and et al (2005). Most of the studied stations i.e., 18 of 30 stations, 18 of 30

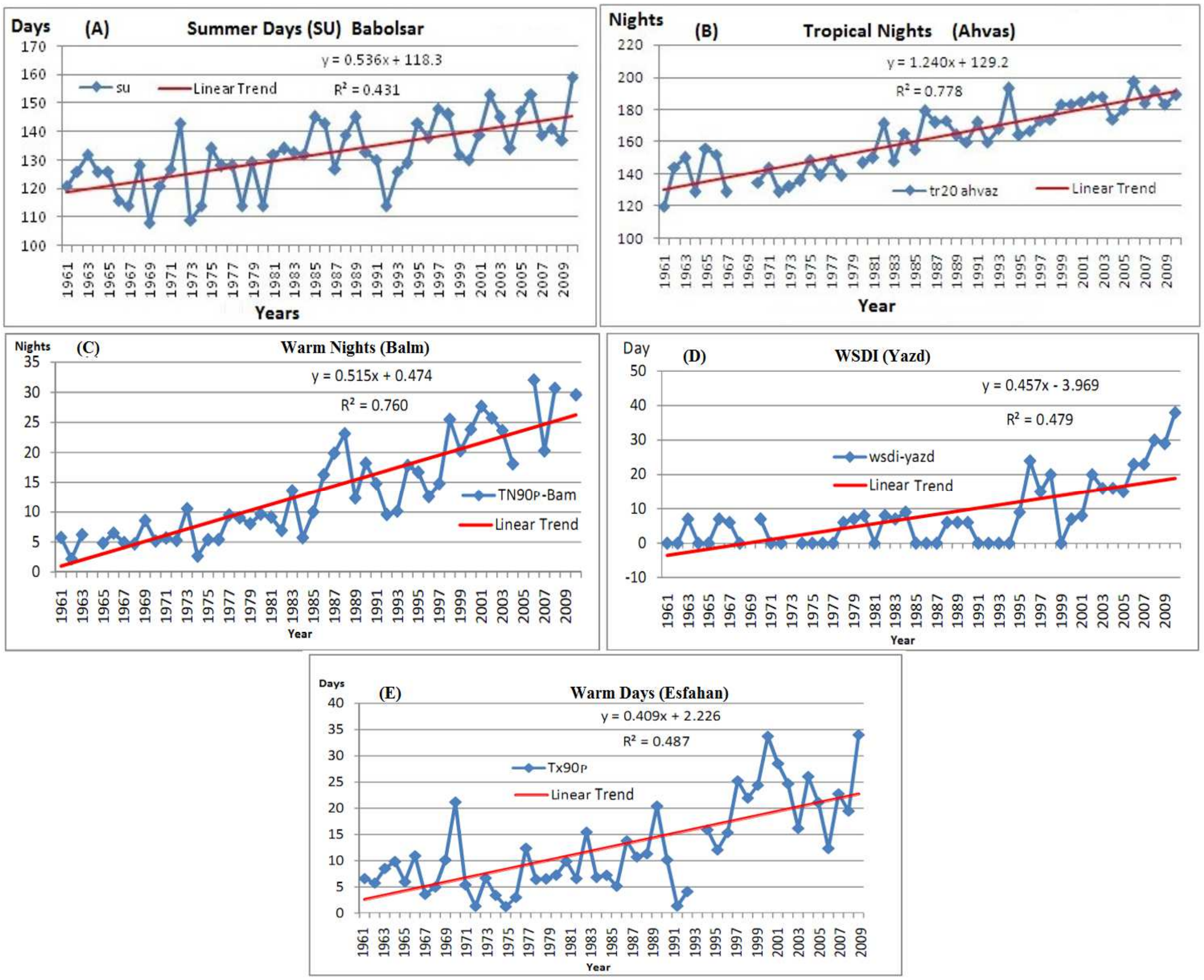


Fig. 3. Time series of temperature extreme of five different stations as representatives of different geographic locations.

stations, showed a positive trends of TNx. The largest positive trend of 1.6 ˚C per decade was observed in Anzali followed by Shahrood, The statistical tests detected a warming trend in the TXx at more stations such as in southern region. But negative trends were overall occurred in Zagros Mountain. Generally Iran experienced a positive trend for TXn (Fig.4) and TNn (Fig.6). Especially, most of the stations show positive trends for TNn, which lies approximately between 29^{0}N and 33 ^{0}N and over 36 ^{0}N in latitude. The strongest positive trends for these daily temperature extremes have been found in Ahvaz and Babolsar with trends of 2.1 and 1.9˚C per decade, respectively. The significant negative slopes of linear trends for this index were −1.5 ˚C per decade in Bandar Abbas and -2.3 ˚C per decade in Birjand. In regions such as the Zagros Mountain, the negative trends obtained are not so strong.

Any substantial differences were not found between the TN90p and TX90p indices and many stations show significant positive trends (fig.5). These results are more consistent with the findings of Zhang et al. (2005) and there is a strong evidence for globally increasing tendency of warm nights both in terms of their number and intensity (Christidis et al., 2005).

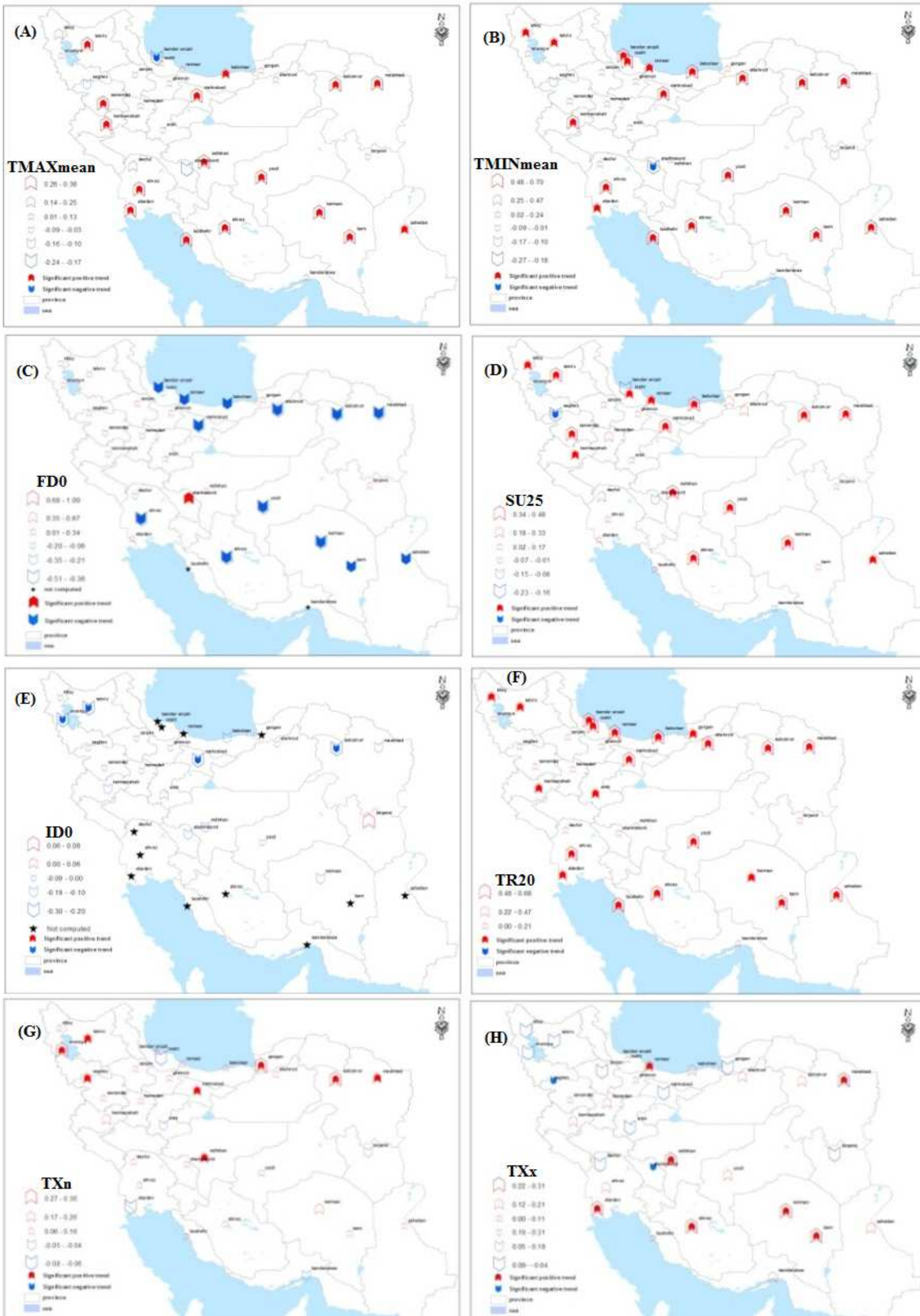


Figure 4. Trends in averages of TXmean, TNmean, FD0, SU25, ID0, TR20, TXn, TXx over Iran.

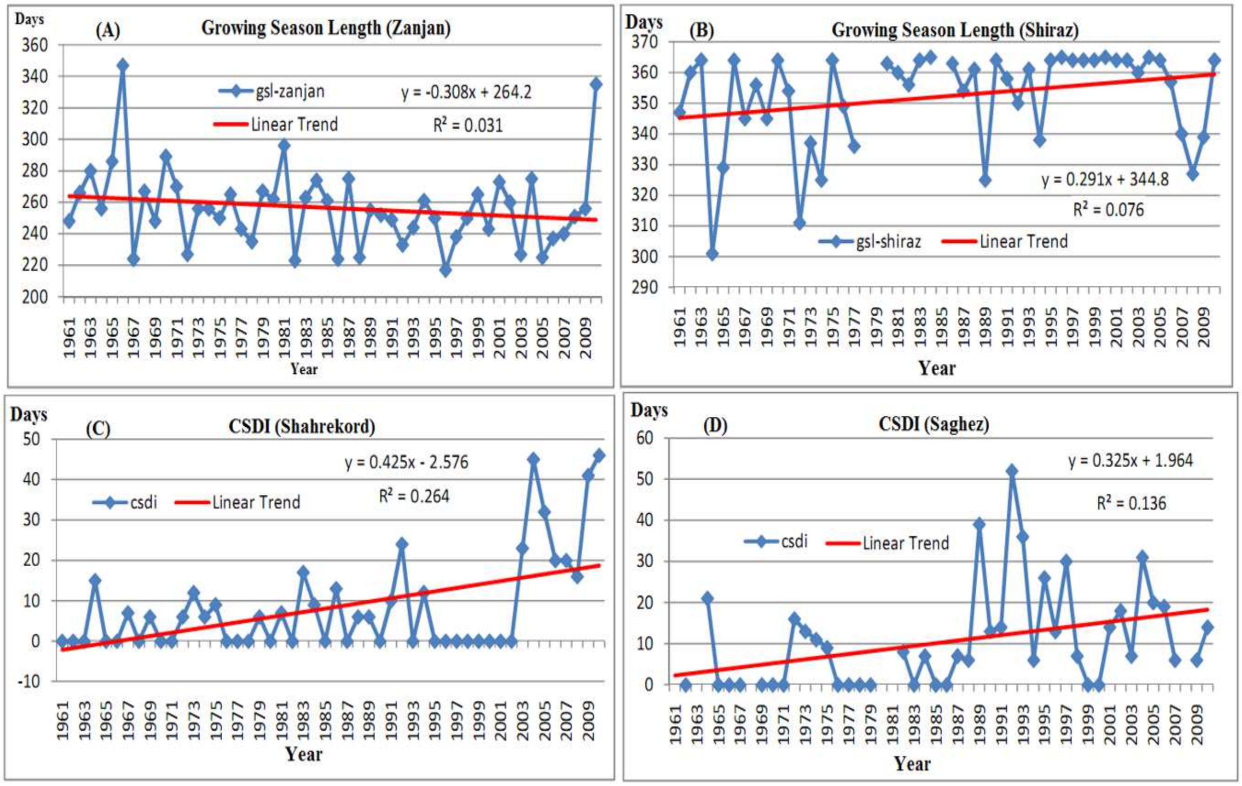


Fig.5. Comparison between time series of GSL for Zanjan (A), Shiraz (B) and CSDI for Shahrekord (C), Saghez (D).

The patterns for both daily temperature extremes i.e., TN and TX at 90^{th} percentile (TN90p and TX90p) indices are quite similar and positive trends at most of the weather stations are statistically significant. Trends in the TN90p and TX90p were larger than those in the TN10p and TX10p. This Similar trends of these indices were also reported for the Middle East regions (Zhang *et al.*, 2005). A similar pattern for TR20 was also found over the country (fig.3).

The highest numbers of TX90p and TN90p have also occurred after 1980s, coinciding very well with the result of Zhang et al. (2005). We cannot found significant negative trends for TN90p over the whole country. More than 22 stations have experienced positive trends, the strongest being in Bam with 0.99 percent in decade (Fig.3C). The result shows the decreasing and increasing trends of warm days for the Esfahan and Shahrekord stations, respectively. The number of warm days at the Shahrekord station had a decrease over the study period of approximately -1.33 percent per decade while the Esfahan station had an increase of 1.01 percent per decade.

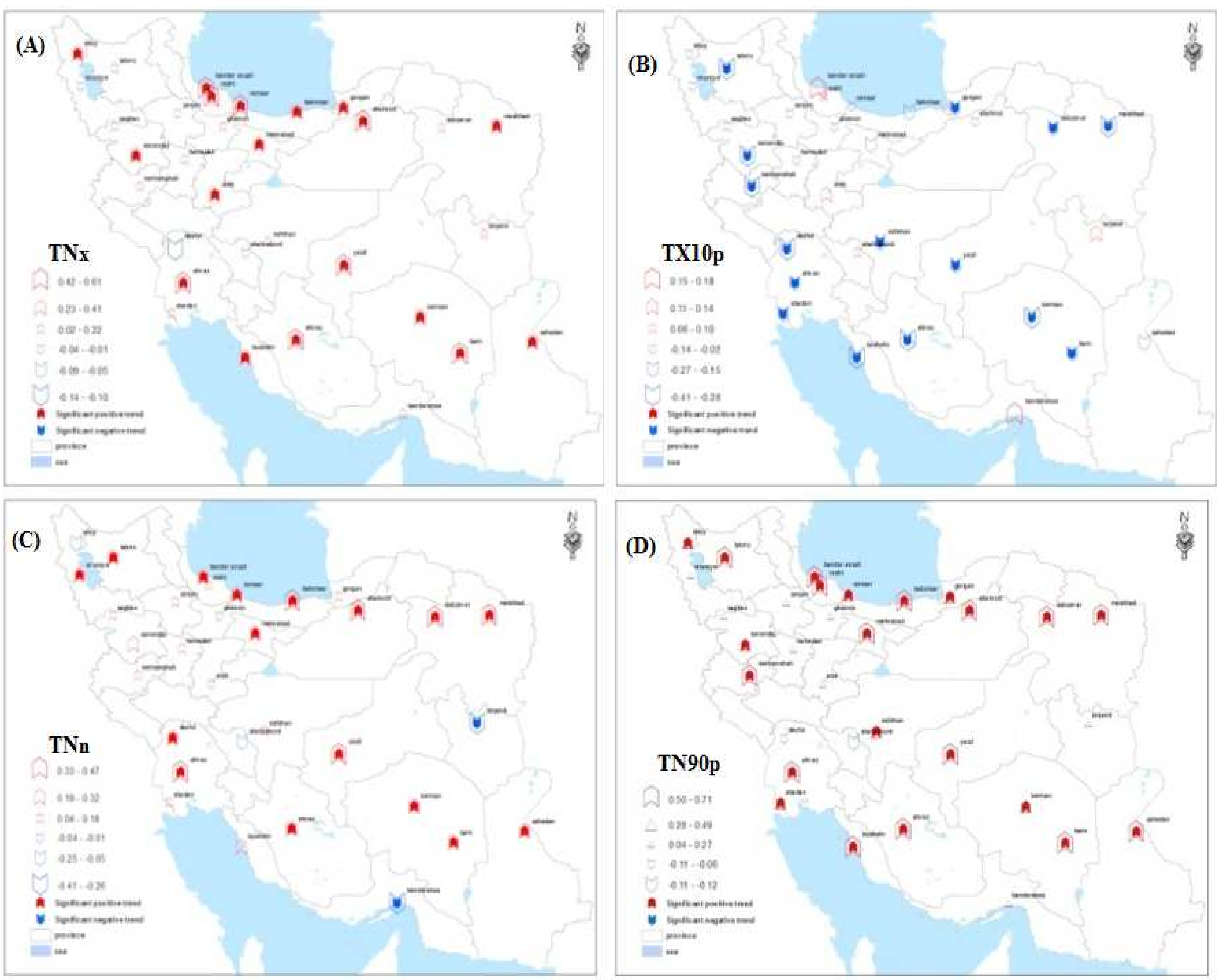
The positive trends for the warm spell duration index (WSDI) were found in most parts of the country however this was prominent for Yazd with 1.37 days per decade (Fig.3D). The rate of the positive trend in WSDI obtained for this study is very smaller than that (9 day per decade) reported by Rahimzade et al (2009). Negative but weak and non-significant trends of WSDI were observed for Anzali and Shahrekord stations. The trends of growing season length (GSL) were not meaningful for the weather stations located at the southern parts of the country. However negative trend of GSL was significant for Zanjan (Fig. 5A) and Saghez.

On the other hand, Frost days, Ice days, Cold nights, Cold days, Cold spell duration and Diurnal temperature range decreasing in most parts of the country. Excluding of the southern region, negative trends in FD according to global decrease trend (Zhang et al. 2005; Frich et al. 2002) were observed from 1980s for other areas of the country. In some regions such as Southern Zagros (west) and Central and Eastern Alborz (north), negative trends were significant for the number of FD. Large significant negative trends in this indices were found in Yazd, Kerman, Sabzevar and Shahroud stations located in the arid regions of the country imply that frost days have decreased by about respectively 1.5, 1.5, 1.2 and 1.1 days $decade^{-1}$

The rate of the negative trend in FD obtained in this study for Sabzevar station (-1.2 day per decade) is very smaller than that (− 9.9 day per decade) reported by Rahimzade et al. (2009). On the contrary, the magnitude of the positive trend in FD0 found in this study only for Shahrekord station is 1.2 day per decade. The mountainous region of the country more experienced a maximum temperature below 0°C. In the mountainous region in the west and north i.e., Zagros and Alborz, contrasting trends for the number of FD0 were observed, positive for Zargos, while negative for Alborz (Fig.4).

Countrywide significant negative trends for TN10p and TX10p indices were observed. This result is more consistent with the studies by Zhang *et al.* (2005) and Rahimzade et al. (2009). Negative trend rates in cooling night lay in the range of -1.98 percent decade^{-1} (Ahvaz station) to -1.4 percent decade^{-1} (Bushehr station), while decreasing trend in cooling day was in the range of 1.28 percent decade^{-1} at Kermanshah station. On the contrary, the magnitude of the positive trend found in this study for Shahrekord station (0.93 percent decade^{-1}) and Saghez station (0.8 percent decade^{-1}).

In case of cold spell duration indicator (CSDI) most of the stations showed negative trends for and more of them are statistically significant (Fig.6). Saghez showed a negative trend for WSDI and significant positive trend for CSDI about 1.4 days per decade (Fig.5D). Although the slope of CSDI trend at Sharekord is about 1.13 days per decade (Fig.5C), while this station showed a negative trend for Warm spell duration indicator (WSDI). Most of the stations show negative trends for diurnal temperature range (DTR) due to decrease for monthly mean difference between daily temperature extremes i.e., TX and TN. The largest negative trend of -1.1, -1.03 and -0.95ºC per decade occurred in Ramsar, Shiraz and Bam (Fig.7), however some of the stations show non-significant positive trends for this index.



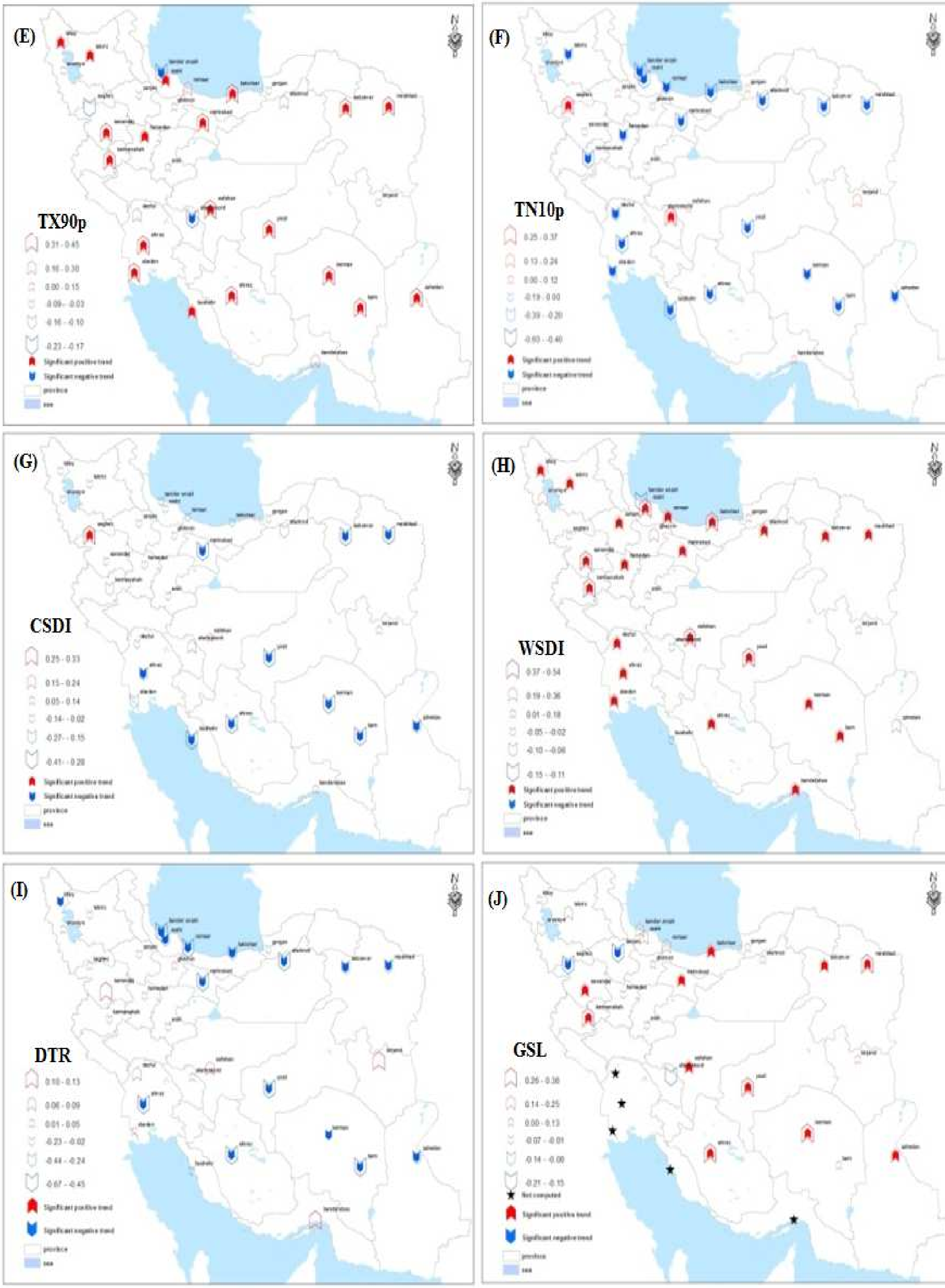


Figure 6. Trends of TNn, TNx, TN10p, TX10p, TX90p, TN90p, CSDI, WSDI, DTR and GSL over Iran

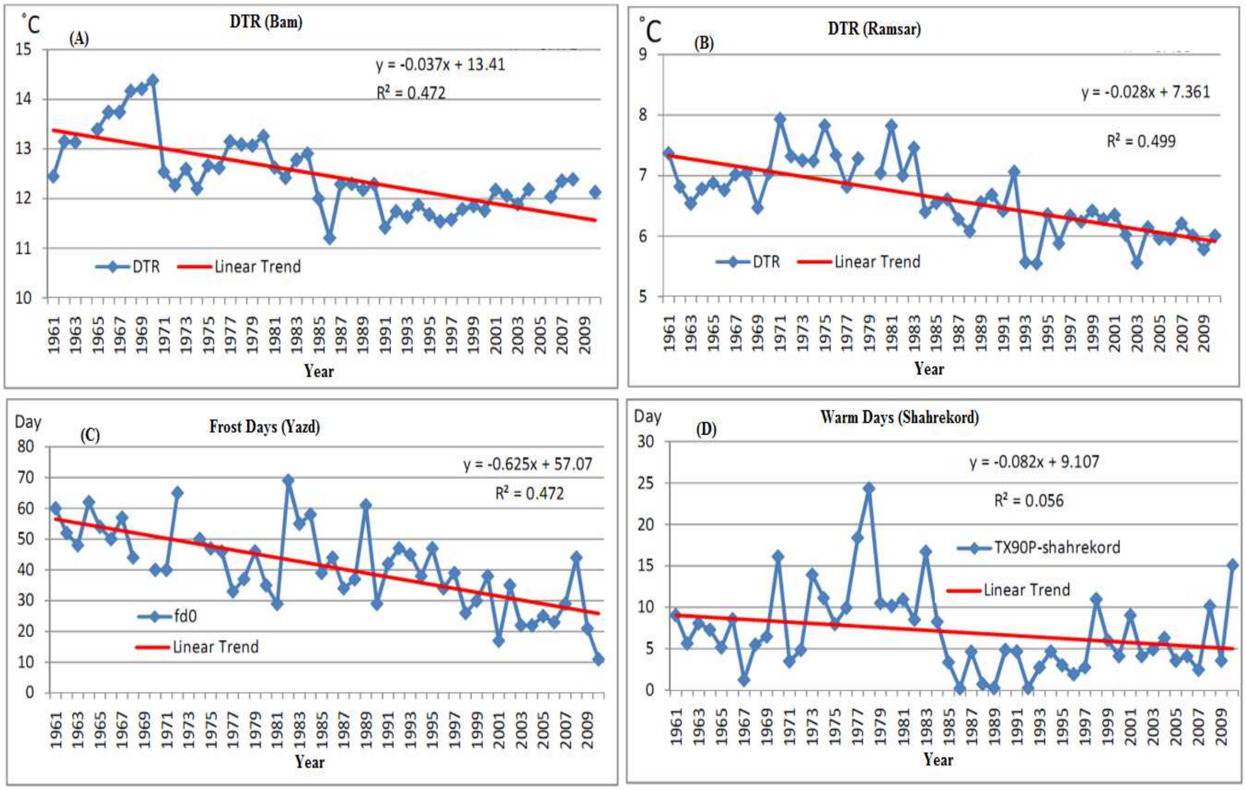


Figure 7. Time series of negative trends for four temperature extremes in different stations.

The increasing trends in temperature extremes i.e., Tmax and Tmin were found in this study are in accordance with the results of Tabari et al. (2011). But trends were overall stronger in the minimum temperature. Also, Marked significant trends for indices like Warm spell duration (WSDI), Cold spell duration (CSDI) and Growing season length (GSL) were found over most regions of Iran are in accordance with the results of Zhang et al. (2005)

3.2. Extreme precipitations

Positive trends were found for wet-days precipitation (PRCPTOT), extremely wet days (R99p), very wet days (R95p) and simple daily intensity index (SDII), and over most regions of the country. Among the studied 30 stations majority of stations showed positive trends and the 10 stations showed significant trends for SDII. The results highlighted that annually occurrence of very wet days (R95p) during the studied period in stations located at the Caspian Sea shore.

Positive trends in R95p at stations from arid and semi-arid climate regions of Iran, in addition verify the presence of the more extreme precipitation events. The largest significant positive trends occurred in Esfahan (1.7 percent decade^{-1}) and Tehran (2.57 percent decade^{-1}) respectively (Fig.9 A, B). The western regions of the country experienced a positive trend for extremely wet days (R99p), but significant trend only occurred in Abadan. Also, negative trends in R99P were found at the majority of the stations in the western, eastern and arid and semi-arid regions. The strongest negative trends were also found in Bam and Tabriz. The amounts of annual total precipitation and annual total precipitation from wet days (PRCPTOT) are very similar and substantial change of such wet days occurred in 1970.

The significant negative trends for this index were found in the northwest and southeast regions of the country and southeast of the Caspian Sea, and significant positive trends in the north and southwest regions. In addition, the strongest positive trends in Babolsar and Abadan with trends of 2.2 and 2.1 mm per decade. On the contrary, the largest negative trend found in this study for Tabriz station (1.85 mm per decade).

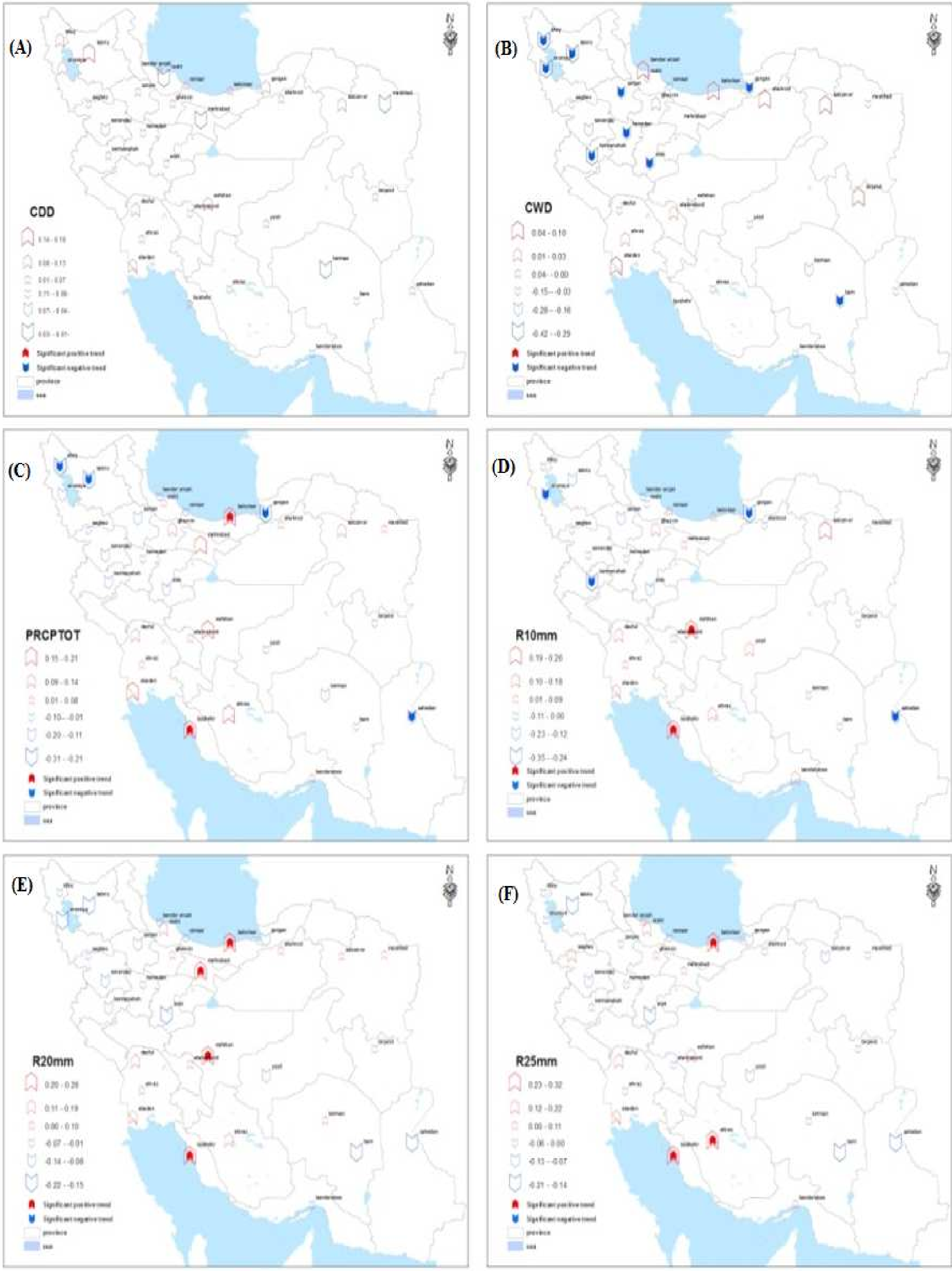


Fig. 8. Trends in CDD, CWD, PRCPTOT, R10mm, R20mm, R25mm

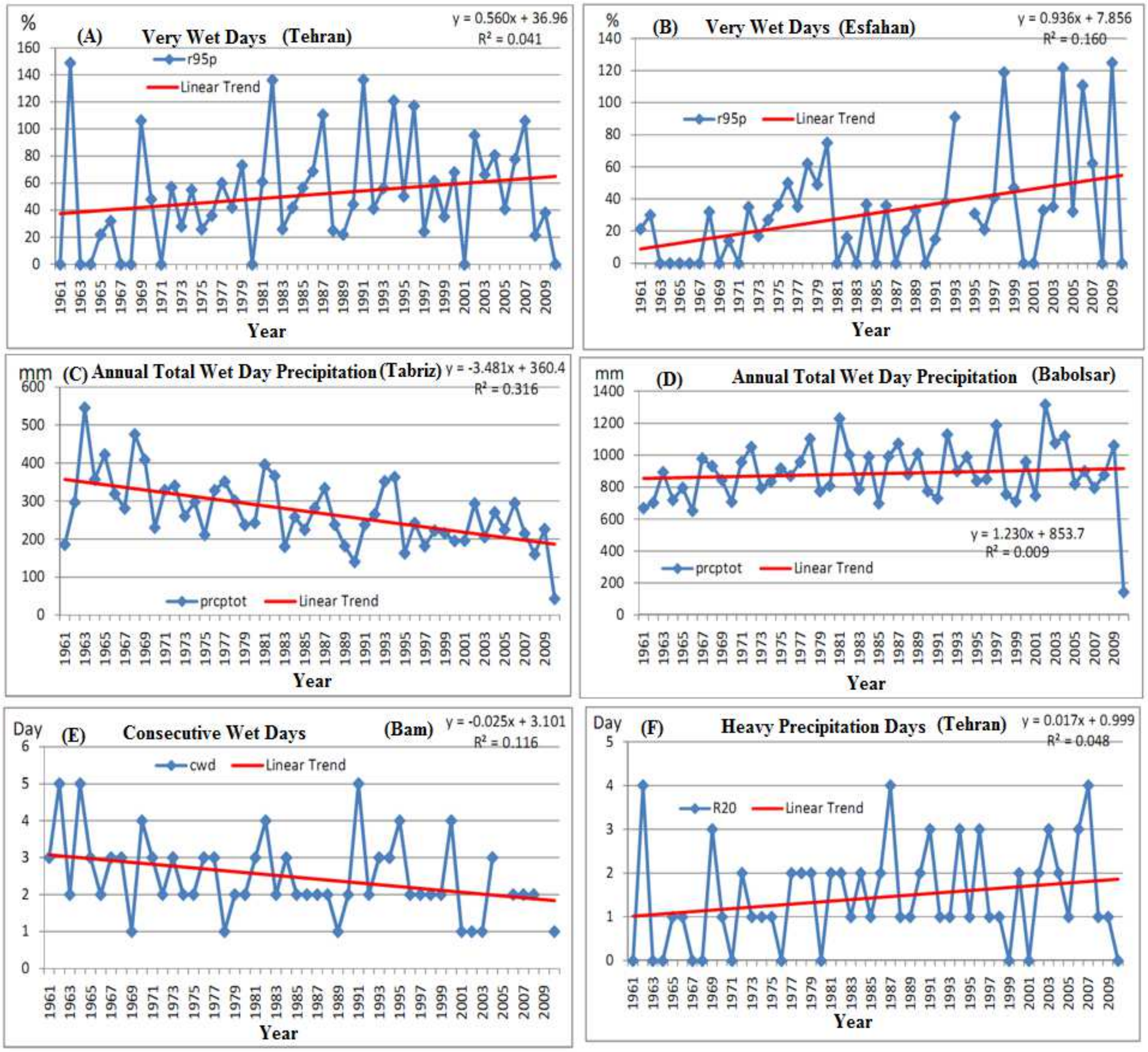


Figure 9. Time series of positive (negative) trends of four precipitation extremes in different stations with different climates.

In many regions of the country, including regions in the northwest and west of the country, we were found negative trends in the consecutive wet days (CWD) index. The strongest significant negative trends were found in the stations of Gorgan (Caspian Sea) and Bam (arid and semiarid regions). In other regions, time series of the index show very weak positive trends were statistically non- significant. Almost every station in the west, north and middle of the country, especially in the west of Zagros Mountain and both side of Alborz Mountain, experienced very weak positive trends in the Consecutive Dry Days (CDD) index. In other words, there are not any significant trend and regular dispersal of CDD in these areas. The analysis indicated that the more stations in the south and southwest of the country experienced days with heavy precipitation in each year and positive trends for heavy precipitation were observed in these regions. There are a negative trend of heavy precipitation days (R10mm) in the Northwestern, north and southeastern regions of the country. Furthermore, the highest number of heavy precipitation (R10mm) was totally found at Tehran station in 1982.

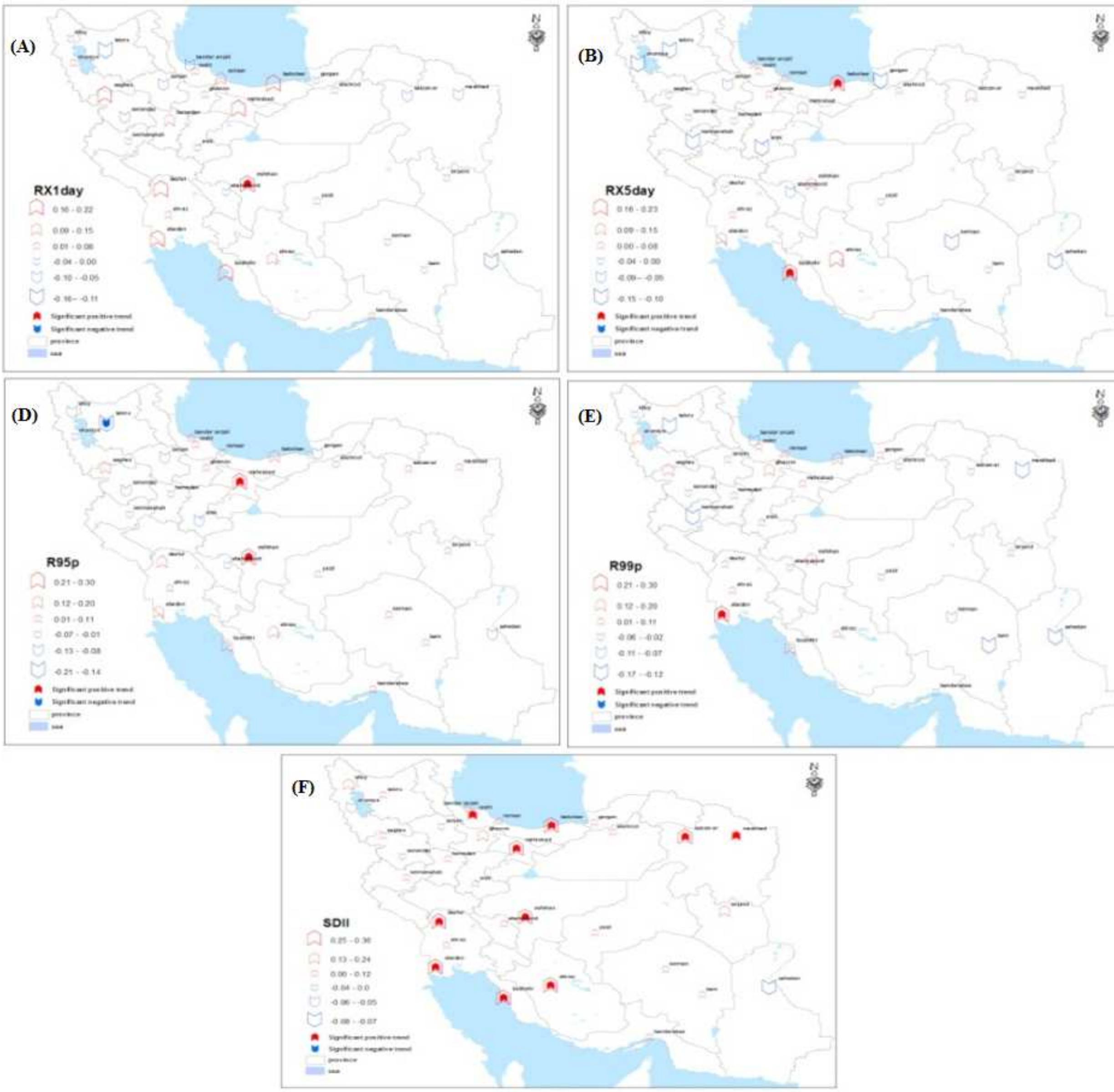


Figure 10. Time series of positive (negative) trends of four precipitation extremes in different stations with different climates.

The mega cities of the study area such as Tehran are different in many ways from other cities. The largest positive trends in R20mm have been found in Tehran station (2.44 days decade^{-1}). Possible reasons for having such patterns might be due to urbanization and/or increase of aerosols. In addition factors such as the local and regional air pollution and different urbanization characteristics may influence the nature and magnitude of the climatic trends in different ways.It is noteworthy that we observed significant positive trends in R10mm, R20mm and R25mm, in the Bushehr station. This result suggests a more activity of rainfall systems such as Sudani cyclonic systems over these regions in recent years (Fig.8).

It is important that the arid and semi-arid regions have experienced positive trends for maximum 1-day precipitation (Rx1DAY) and this pattern might be due to drought several times especially in recent years.

Positive trends for the Rx1DAY index were observed in a vast area located in the north and west of the country (Fig.10). The highest positive and significant trend was recorded in Esfahan (1.88 mm per decade) located in the semi-arid region. The positive trends for maximum 5-day precipitation (Rx5DAY) were found in Caspian Sea region and southern parts of the Alborz Mountain and southwest of the country. We found the steepest positive trends in Babolsar and Bushehr with slopes of 2.3 and 1.7 mm per decade, respectively. On the other hand, negative trends for this index were found in the northwest and southeast regions of the country.

3.3. Regional Extremes

The regional averaged indices were computed as the mean of the indices at individual stations relative to their climatology. The significant trends in 18 indices found in central part of the country (E region) are in accordance with the results of Evans et al. (2010) and the highest Variability of extreme temperature and precipitation was also found in this region. In the next stage, the largest variability occurred in Alborz and Zagros Mountain ranges and Azarbaijan respectively. Marked positive trends for indices like Warm nights (TN90p), tropical nights (TR20) and Warm Spell Duration Index (WSDI) were found over most regions of Iran. The largest negative trend of Warm nights (TN90p) of 1 percent per decade occurred in most regions of the country. In some regions like Azarbaijan and central part of the country time series of this index show the strongest positive trends. Generally, in parallel with Zhang *et al*. (2005) findings, on average, the Tropical nights (TR20) increased by 1 day per decade for the whole country. The strongest positive trends for this index have been found in central part of country and Zagros with trends of 1.82 and 0.85 day per decade, respectively. The whole country, on average, experienced an increasing trend of 1 day per decade for the Warm spell duration indicator (WSDI).

We also found positive trends of GSL for the majority of the country, with the strongest in Zagros and Alborz Mountains and arid regions, showing an increase of 1.5 days per decade. The whole country, except some small areas in the Azarbaijan region, experienced a positive trend for Simple daily intensity index (SDII) and showed a trend of 2 mm per decade and is in accordance with the results of ShiftehSomee et al., (2012).We found positive trends of 1.1 days per decade for TMIN mean over the whole country except in Azarbaijan. In addition, the significant decrease of cool nights (TN10P) was obtained over central parts and Alborz and southern regions respectively, at the rate of 1.2 percent per decade. On the contrary, the magnitude of the positive trend in warm days (TX90P) found in this study for Zagros Mountain range (1.7 percent per decade), central parts and southern regions. The positive trends for TNx have been found in Zagros and Alborz mountain ranges and central parts with trend of 1.9 ºC per decade.

There were some areas in Zagros, Alborz and central part of the country that showed negative trends for diurnal temperature range (DTR). Maximum decrease in DTR was found in Zagros at the rate of 2.07 ºC per decade. This decrease in DTR can be attributed to asymmetric rise in daily temperature extremes, i.e., TN is rising faster than the TX. Decreasing DTR found in Iran is consistent with the trend observed in different countries and at global scale (Karl et al., 1991. Decreasing DTR is related to fall in crop yield and therefore have severe implications for food production and food security both at regional and global scale (Peng et al., 2004; Peng et al., 2013; Rehmani et al., 2014).

We observed a negative trend in CSDI over the Alborz mountain ranges and central parts, and negative trend in CWD over the Azarbaijan and Western regions of the country, although a clear negative trend was observed for ID0 and TX10P over central parts of the country. A positive trend was observed for the Alborz mountain ranges and central parts of the country for summer days (SU25) and a negative trend was observed for PRCPTOT over Azarbaijan regions. We found positive trends in TXmean for the central parts of the country. The results showed that most of the trends in the other indices were not significant over the whole country.

4. Conclusions

This study investigated long-term trends in the time series of the temperature and precipitation extreme indices at 30 synoptic stations in Iran on the daily timescales for the period 1961–2006. In this paper, the Mann-Kendall and the Durbin Watson tests were used to investigate the spatiotemporal trends. The findings of this study confirmed the results of previous investigation and present the new results for extreme temperature and precipitation in Iran. The positive trends in the temperature series is more consistent with the global warming events and have a significant effect on trends of extreme temperature events in recent years. The distribution of the trends for minimum temperature trends indicated that the negative trends mainly occurred in the most parts of Iran except in northwest part. On the contrary, positive trends were detected in more stations and in some areas, for example, from the central regions of the country. No substantial differences were found in case of annual total precipitation and annual total precipitation from wet days (PRCPTOT), however substantial anomaly of such wet days occurred in 1970. There are a large number and significant trends of heavy precipitation days in the south and southwest of the Iran. This result suggests a more increase of rainfall storms over south, southwest and central regions of the country. However, more statistically significant cases were found only at central part of the country and the highest number of stations with significant trends was also found in this region. Almost every station in the Azarbaijan region experienced less variability at regional scales. Further studies aimed to compare the trends found in our study at different spatiotemporal scales will be of great scientific interest. The results also suggest the need for further investigation on local anthropogenic intervention in the environment, which could be one of the major causes of climate change.

Acknowledgement

The authors are grateful to the Islamic Republic of Iran Meteorological Organization (IRIMO) for providing the requisite meteorological data. We wish to express our gratitude to the anonymous reviewers whose suggestions and remarks have greatly helped us to improve the quality of the manuscript

Competing Interest

Authors declare that they have no competing interest.

References

Alexander, L.V., X. Zhang, T.C. Peterson, J. Caesar, B. Gleason, A.M.G. Klein Tank, D. Collins, B. Trewin, F. Rahimzadeh, A. Tagipour, K. R. Kumar et al. 2006. Global observed changes in daily climate extremes of temperature and precipitation. J. Geophys. Res. 111:D05109–D05109.

Alexander, L., T. Peterson, T. Wallis. 2005. Trends in Middle East climate extremes indices during 1930–2003. J. Geophys. Res. 110:D22104.

Amengual, A., V. Homar, R. Romero, H.E. Brooks, C. Ramis, M. Gordaliza and S. Alonso. 2014. Projections of heat waves with high impact on human health in Europe. Global Planetary Change. 119: 71-84.

Barriopedro, D., E. Fischer, J. Luterbacher, R. Trigo and R. García-Herrera. 2011.The hot summer of 2010: redrawing the temperature record map of Europe. Science.332:220−224.

Boccolari, M. and S. Malmusi. 2012. Changes in temperature and precipitation extremes observed in Modena, Italy. Atmos. Res. 122:16-31.

Bonsal, B.R., X. Zhang, and L.A. Vincent. 2001. Characteristics of daily and extreme temperatures over Canada. J. Climate.14:1959–1976.

Caesar, J. and L. Alexander. 2006. Large-scale changes in observed daily maximum and minimum temperatures: Creation and analysis of a new gridded data set. J. Geophys. Res. 111:D05101.

Christidis, N., P.A. Stott, S. Brown, G.C. Hegerl and J. Caesar. 2005. Detection of changes in temperature extremes during the second half of the 20th century. Geophys. Res. Lett. 32: L20716.

Coumou, D. and S. Rahmstorf. 2012. A decade of weather extremes. Nature Clim. Change. 2: 491–496.

Dinpashoh, Y. 2006. Study of reference crop evapotranspiration in I. R. of Iran. Agric. Water Manag. 84:123–129.

Dole, R., M. Hoerling, J. Perlwitz, J. Eischeid, P. Pegion, T. Zhang, X.-W. Quan, T. Xu, and D. Murray. 2011. Was there a basis for anticipating the 2010 Russian heat wave? Geophys. Res. Lett. 38:L06702.

Evans, J.P. 2010. Global warming impact on the dominant precipitation processes in the Middle East. Theor. Appl. Climatol. 99:389–402.

Fischer, E.M. and C. Schär. 2010. Consistent geographical patterns of changes in high-impact European heat waves. Nature Geosci. 3: 398–403.

Frich P., L. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A.M.G. Klein Tank and T.C. Peterson. 2002. Global changes in climatic extremes during the second half of the 20th century. Clim. Res.19: 193–212.

García-Herrera, R., J. Díaz, R.M. Trigo, J. Luterbacher, and E.M. Fischer. 2010. A review of the European summer heat wave of 2003. Crit. Rev. Env. Sci. Tech. 40: 267–306.

Gilbert, R.O. 1987. Statistical methods for environmental pollution monitoring. Van Nostr and Reinhold, New York.

Haylock M.R., T.C. Peterson, L.M. Alves, T. Ambrizzi, Y.M.T. Anunciacao, J. Baez, V.R. Barros, M.A. Berlato, M. Bidegain, G. Coronel, et al. 2006. Trends in total and extreme South American rainfall 1960–2000. J. Climate. 19: 1490–1512.

IPCC. 2007. Climate Change- the scientific basis. Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge.

Jaagus, J. 2006. Climatic changes in Estonia during the second half of the 20th century in relationship with changes in large-scale atmospheric circulation. Theor. Appl. Climatol. 83: 77 –88.

Kampata, J.M., B.P. Parida and D.B. Moalafhi. 2008. Trend analysis of rainfall in the headstreams of the Zambezi River Basin in Zambi. Phys. Chem. Earth.33: 621–625.

Kanji, G.K. 2006. 100 Statistical Tests (3rd Edition). London: SAGE Publications Ltd.

Karl, T.R., G. Kukla, V.N. Razuvayev, M.J. Changery, R.G. Quayle, R.R. Heim, D.R. Easterling and C.B. Fu. 1991. Global warming: evidence for asymmetric diurnal temperature change. Geophys. Res. Lett. 18:2253–2256.

Keggenhoff. I, M. Elizbarashvili, A. Amiri-Farahani and L. King. 2014. Trends in daily temperature and precipitation extremes over Georgia, 1971–2010. Weather Clim. Extremes.4: 75–85.

Kendall, M. 1975. Rank Correlation Methods. London: Griffin.

Klein-Tank, A.M.G., T.C. Peterson, D.A. Quadir, S. Dorji, X. Zou, H. Tang, K. Santhosh, U.R. Joshi, A.K. Jaswal, R.K. Kolli, et al. 2006. Changes in daily temperature and precipitation extremes in Central and South Asia. J. Geophys. Res. 111: D16105.

Krishnamurti, T. N., R. Krishnamurti, S. Das, V. Kumar, A. Jayakumar, and A. Simon, 2015: A pathway connecting the monsoonal heating to the rapid Arctic ice melt. J. Atmos. Sci. 72: 5–34.

Krueger, O., G.C. Hegerl and S.F.B. Tett. 2015. Evaluation of mechanisms of hot and cold days in climate models over Central Europe. Environ. Res. Lett. 10: 014002

Lau, W. K. M. and K. Kim.2012. The 2010 Pakistan flood and Russian heat wave: Teleconnection of hydro meteorological extremes. J. Hydrometeor. 13: 392–403.

Mann, H. 1945. Nonparametric tests against trend. Econometrica. 13: 245-259.

Modarres, R. and V.P.R. da Silva. 2007. Rainfall trends in arid and semi-arid regions of Iran. J. Arid Environ.70: 344-355.

Otto, F.E.L., N. Massey, G.J. van Oldenborgh, R.G. Jones and M.R. Allen. 2012. Reconciling two approaches to attribution of the 2010 Russian heat wave. Geophys. Res. Lett. 39: L04702

Pall, P., T. Aina, D.A. Stone, P.A. Stott, T. Nozawa, A. G.J. Hilberts, D. Lohmann and M.R. Allen. 2011. Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. Nature. 470: 382–386.

Partal, T. and E. Kahya. 2006. Trend analysis in Turkish precipitation data. Hydrol. Process. 20: 2011–2026.

Peng S., J. Huang, J.E. Sheehy, R.C. Laza, R.M. Visperas, X. Zhong, G.S. Centeno, G.S. Khush and K.G. Cassman. 2004. Rice yields decline with higher night temperature from global warming. Proc. Nat. Acad. Sci. USA. 101: 9971–9975.

Rahimzadeh, F., A. Asgari and E. Fattahi. 2009. Variability of extreme temperature and precipitation in Iran during recent decades. Int. J. Climatol. 29: 329–343.

Rahmstorf, S. and D. Coumou. 2011. Increase of extreme events in a warming world, Proc. Natl. Acad. Sci. U. S. A. 108(44): 17905–17909.

ShiftehSomee, B., A. Ezani and H. Tabari. 2012. Spatiotemporal trends and change point of precipitation in Iran. 10.1016/j.atmosres.04.016.

Tabari, H., B. ShiftehSomee and M. RezaeianZadeh. 2011. Testing for long-term trends in climatic variables in Iran. Atmosph. Res. 100:132 –140.

Tencer, B., A. Weaver and F. Zwiers. 2014. Joint occurrence of daily temperature and precipitation extreme events over Canada. J. Appl. Meteor. Climatol. 53: 2148-2162.

Trenberth, K.E. and J.T. Fasullo. 2012. Climate extremes and climate change: The Russian heat wave and other climate extremes of 2010. J. Geophys Res.117:D17103.

Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, et al. 2007. Observation: surface and atmospheric climate change. Climate Change 2007: The physical science basis. Contribution of working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge university press: UK, New York.

You, Q., S.C. Kang, E. Aguilar, N. Pepin, Flügel, Wolfgang-Albert, Y.P. Yan, Y.W. Xu, Y.J. Zhang and J. Huang. 2010a. Changes in daily climate extremes in China and their connection to the large scale atmospheric circulation during 1961–2003. Clim.Dyn.36:2399-2417.

You, Q., S.C. Kang, N. Pepin, Flügel, Wolfgang-Albert,Y.P. Yan, Behrawan, Houshang and J. Huang. 2010b. Relationship between temperature trend magnitude, elevationand mean temperature in the Tibetan Plateau from homogenized surface stations and reanalysis data. Global Planet. Change 71, 124–133.

Zhang X., E.Aguilar, S. Sensoy, H. Melkonyan, U. Tagiyeva, N. Ahmed, N. Kutaladze, F. Rahimzadeh, A. Taghipour, T.H. Hantosh, et al. 2005. Trends in Middle East climate extremes indices during 1930–2003. J. Geophys. Res. 110 (D22): 104.