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Trends of Extreme Temperature Over the Lake Urmia Basin, Iran, During 1987-2014

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Abstract

The variability of temperature extremes has been the focus of attention during the past several decades and had a great influence on the hydrologic cycle. A long-term, high-quality daily maximum (TX) and minimum temperature (TN) of seven stations was used to determine the spatial and temporal characteristics of extreme temperature events in Lake Urmia Basin in Iran during 1987 to 2014. The RClimdex was used to calculate 16 extreme temperature indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI) for this study and the Mann-Kendall test was employed to assess the trend. All the temperature-based indices show patterns consistent with a general warming trend. The results revealed statistically significant changes in important temperature indices over the study area during the past three decades. On the whole, cold indices, including cool days, cool nights, ice days, frost days and cold spell duration index significantly decreased by -3.07, -2.27, -1.8, -1.53 and -0.16 days/decade, respectively. In contrast, warm indices such as warm days, warm nights, summer days, tropical nights, warm spell duration index, and growing season length significantly increased by 2.99, 3.34, 3.3, 3.06, 2.63 and 1.79 days/decade. Minimum TX, maximum TX, Minimum TN and maximum TN increased significantly by 1.00, 1.76, 0.36 and 1.01 °C/decade. Furthermore, the magnitudes of the trends in cold/warm days are larger than those in cold/warm nights, which indicate that the trends in minimum temperature extremes are more rapid than in maximum temperature extremes. Strong relationships between the annual mean temperature and the extreme temperature indices were detected in this study.

Keywords: Temperature extremes, Trends, Mann-Kendall test, Lake Urmia Basin.

1. Introduction

It has been proved that the enhanced atmospheric greenhouse gases contributed to an increase in global mean temperature. The globally averaged temperature data shows a linear warming trend of 0.85 °C (0.65 to 1.06 °C) during 1880– 2012. The total increase between the mean of the 1850–1900 and the 2003–2012 is 0.78 °C (0.72 to 0.85 °C), based on the single longest dataset available (IPCC, 2013). Human activities and the environment are affected by extreme climatic events, such as heat waves, droughts and floods (Moberg and Jones, 2005). According to the Inter-government Panel on Climate Change (IPCC), increasing evidence indicates that the global warming has resulted in a growing frequency and severity of extreme climate events in the past decades, such as high temperature, heat wave and multi-region heavy rainfall and flood. (http://www.ipcc.ch/meeting_documentation/meeting_documentation.shtml).

On a global scale, temperature indices demonstrate significant warming during the 20th century, citing the highest trends for the most recent periods and for minimum temperature indices. However, trends in extreme precipitation illustrate a much lower spatial coherence, yet on a global scale a significant wetting trend could be detected, whereas the number of consecutive dry days shows very different regional changes (Alexander et al., 2006). Recently, climate extremes have been studied in many regions around the world, for improving our understanding of changes in the extremes in these regions and establishing a network for scientists working on climate change. Studies include the Asia-Pacific Network region (Choi et al., 2009, Caesar et al., 2011; Revadekar et al., 2012), the western Indian Ocean (Vincent et al., 2011), Asia (Klein Tank et al., 2006; You et al., 2011), Africa (New et al., 2006; Aguilar et al., 2009), the

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Caribbean (Peterson et al., 2002), the Middle East (Zhang et al., 2005), South America (Aguilar et al., 2005; Vincent et al., 2005; Haylock et al., 2006; Marengo, J.A., 2009; Skansi et al., 2013), North America (Peterson et al., 2008), Europe (Griffiths et al., 2005; Moberg and Jones, 2005; Gilles et al., 2006; Nikulin et al., 2011; Fernandez-Montes and Rodrigo, 2011), and China (Fan et al., 2012; Wang et al., 2013; Guan et al., 2015). The results show that the changes in extreme temperature events have occurred coherently at many weather stations, with a decrease in cold extremes and increases in warm extremes over the past 50 years.

In Iran, there are numerous regional studies of recent trends and variability in the monthly climate over Iran. However, there has been little work on temperature extremes (Taghavi and Mohammadi, 2007; Alijani, 2011; Masoodian and Darand, 2012; Alijani and Farajzadeh, 2015; Alizadeh-Choobari et al., 2016b). Alijani (2007) analyzed a time series of extreme events in Tehran from 1961 to 2004. Results of this research indicated that all indices had positive trends. Sohrabi et al., (2009) detected noticeable changes in temperature and precipitation extremes that can lead to warmer and dryer climate in Semnan province in Iran. Rahimzadeh et al. (2009) examined the extreme temperature and precipitation to determine recent climatic changes over Iran. They found negative trends for indices representing cold maximum and minimum temperature extremes, i.e. frost days (FD), ice days (ID), cool days (TX10p), cool nights (TN10p) and diurnal temperature range (DTR), and conversely, positive trends for indices representing warm maximum and minimum temperature extremes, i.e. summer days (SU25), warm days (TX90p) and tropical nights (TR20) over most regions of the country. Taghavi (2010) investigated the linkage between climate change and extreme events in Iran. The results of this study showed that the number of very warm days has increased while the number of very cool days has decreased. Marofi et al. (2011) investigated to detect probable trends and effects of climatic extreme events of precipitation and temperature on the northern and southern coastlines of Iran. The results indicate that minimum temperature had a higher increase than the maximum temperature. Diurnal temperature ranges have experienced dramatic declines. Sohrabi et al. (2013) computed and utilized Eighteen climate indices to demonstrate the spatial and temporal variations of climatic crisis, including amount, frequency, and intensity of various climatic events over the mountainous region in Iran. The results of their research indicated that the temperature extremes showed consistent warming patterns over most of the study region. Molanejad et al. (2014) analyzed the spatial and temporal patterns of changes in the precipitation extremes indices and their associations with climate change at twenty meteorological stations in northwest Iran. The results showed a decreasing trend in the amount, frequency and intensity of precipitation in most stations. Alizadeh-Choobari et al. (2016a) investigated the climate change and anthropogenic impacts on the rapid shrinkage of Lake Urmia. Their results revealed that over the past few decades, a warming trend of the order 0.18 °C decade^{-1} has been identified, while precipitation has been decreasing by approximately 9 mm decade^{-1} over the basin. Alizadeh-Choobari and Najafi (2017) investigated the climate change and its impact on some weather extremes in Iran. The results showed that Iran has warmed by nearly 1.3 °C during the period 1951-2013, with an increase of the minimum temperature at a rate two times that of the maximum. They observed an increase in the frequency of heat extremes and a decrease in the frequency of cold extremes.

The Lake Urmia, as one of the largest saltwater lakes on earth and a highly endangered ecosystem, has been shrinking rapidly (AghaKouchak et al., 2015b; Alizadeh-Choobari et al., 2016a). Changing hydrologic patterns due to the climatic changes and the increase in the frequency and intensity of droughts are important factors that can affect the variability of the lake's surface (Delju et al., 2013; Tabari et al., 2014). It is acknowledged that a warming climate can intensify the effect of droughts (AghaKouchak et al., 2014). As well, under the continued warming caused by increases in the greenhouse gases, the dryness of the lake can be exacerbated. However, the human activities should also not be ignored. The contribution of human activities in creation of extreme climate/environmental conditions is fully discussed by AghaKouchak et al. (2015a).

To date, the trends and variability in temperature extremes have not been investigated systematically and deeply in the Lake Urmia Basin. One shortcoming comes from that most previous studies focused on either mean temperature changes (Delju et al., 2013; Fathian et al., 2015), or northwest of Iran that Lake Urmia Basin is located there (Molanejad et al., 2014). Another shortcoming is the use of inappropriate trend computation methods. Some studies (Sohrabi et al., 2009) used the ordinary least squares to detect trends, but this method is sensitive to outliers or extremes that often occur in extreme events (Vincent et al., 2005; Vincent and Mekis, 2006).

To overcome the above shortcomings, the main objectives of this study are: (1) to analyze the trends in statistical parameters of daily minimum and maximum temperature use Mann-Kendal test for the entire Lake Urmia Basin; (2) to explore the temporal changes of extreme temperature indices during 1987–2014; (3) to investigate the spatial distribution of temperature extremes in Lake Urmia Basin during 1987–2014 based on 16 climate indices proposed by the Expert Team on Climate Change Detection and Indices. This information can help the government policy makers and urban planners to establish and improve the risk management systems to effectively mitigate the adverse impacts of climate extremes.

2. Study area

The Lake Urmia Basin is located between 37°4′ to 38°17′ latitude and 45°13′ to 46° longitude in northwest Iran and covers an area of 51,800 km^2, which composes 3.15 % of the entire country and includes 7 % of the total surface water in Iran (Figure 1). The Lake Urmia is the largest lake in the country and is also the second hyper saline lake (before September 2010) in the world. The lake basin includes 14 main sub basins that surround the lake with the areas varying from 431 to 11,759 km^2. The most important rivers in this basin are Zarrineh Rud, Simineh Rud, and Aji Chai (Fathian et al., 2015). Climate in the Urmia Lake Basin is continental, affected mainly by the mountains surrounding the lake (Delju et al., 2013).

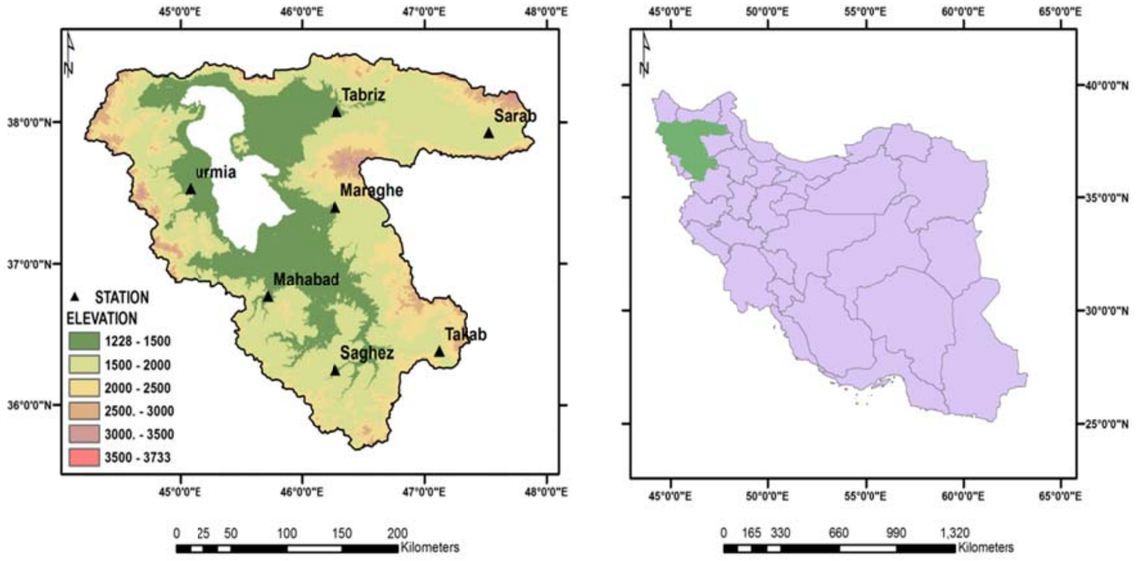

Figure 1. Geographic locations of the Lake Urmia Basin and location of meteorological stations.

3. Data and methods

3.1. Dataset

In this study, seven weather stations listed in Table 1 are selected to provide a broad range of coverage in the region in terms of data length, homogeneity, and geographical distribution. For this study, data was obtained from the database of the Islamic Republic of Iran Meteorological Organization (IRIMO), and daily minimum and maximum temperature were used to compute climate indices. Study Period for temporal trend and spatial distribution is 1987 to 2014.

Data quality control plays a pivotal role in calculating the indices and their trends. It is a necessary step before the analysis of precipitation variation, because erroneous outliers can impact the trends seriously. Simple data quality control of the indices in this study is performed using the computer program RClimDex (developed by Zhang and Feng, 2004) at the Climate Research Branch of Meteorological Service of Canada) whose software and documentation are available online for downloading (http://cccma.seos.uvic.ca /ET CCDI/). The program can identify all missing or unreasonable values, such as precipitation values below 0 mm. Additional execution involves identification of potential outliers, which have to be manually checked, validated, corrected or removed (Zhang et al., 2005; You et al., 2008, 2011). For precipitation, data plots permitted visual inspection to reveal more outliers, as well as problems that cause changes in the seasonal cycle or variance of the data (Aguilar et al., 2005; New et al., 2006). The homogenization of the datasets was performed using the software RHtestV4 (available online at http://etccdi.pacificclimate.org/software.shtml). This software employs a two-phase regression model to identify the multiple change points in the time series (Wang and Feng, 2013). After data quality control and homogeneity assessment, RClimDex was used to calculate climate indices from the daily data.

3.2. Definition of extreme indices

The Expert Team on Climate Change Detection and Indices (ETCCDI) has been coordinating an international effort to develop, calculate and analyze a suite of 11 precipitation and 16 temperature indices adopted by the Fourth Assessment Report of IPCC (AR4). This suite of indices has been widely used to examine the changes in extremes in many parts of the world during the last several years (Zhang et al., 2005; Vincent and Mekis, 2006; You et al., 2008; Rahimzadeh et al, 2009; Wang et al., 2013; Keggenhoff et al., 2014; Wu et al., 2014; Yan et al., 2015; Yu and Li, 2015; Dashkhuu et al., 2015; Guan et al., 2015).

Indices irrelevant to the study were omitted, leading to a final selection of 16 temperature indices (Table 2). These indices were chosen to reflect different aspects in climate extremes, e.g., frequency, intensity and duration. It can be divided into five different categories (Alexander et al., 2006): absolute indices including Minimum TX (TXn), Maximum TX (TXx), Minimum TN (TNn) and Maximum TN (TNx); percentile indices including cool days (TX10), warm days (TX90), cool nights (TN10) and warm nights (TN90); threshold indices including frost days (FD), ice days (ID), tropical nights (TR20) and summer days (SU25); duration indices including growing season length (GSL); cold spell duration index (CSDI) and warm spell duration index (WSDI) and range indices including diurnal temperature range (DTR). These indices were calculated on an annual basis.

Table 1. List of stations with latitude, longitude, altitude and time period in the study area.

Station	Longitude (E)	Latitude (N)	Altitude(m)	Period
Mahabad	45° 43′	36° 46′	1500	1985-2014
Maragheh	46° 16′	37° 24′	1477.7	1985-2014
Urmia	45° 05′	37° 32′	1316	1951-2014
Saghez	46° 16′	36° 14′	1552.8	1962-2014
Sarab	47° 32′	37° 56′	1682	1987-2014
Tabriz	46° 17′	38° 05′	1361	1951-2014
Takab	47° 7′	36° 23′	1765	1986-2014

Table 2. Definitions of temperature indices used in this study.

ID	Descriptive name	Definition	Units
Absolute indices			
TXn	Min Tmax	Monthly minimum value of daily maximum temperature	°C
TXx	Max Tmax	Monthly maximum value of daily maximum temperature	
TNn	Min Tmin	Monthly minimum value of daily minimum temperature	
TNx	Max Tmin	Monthly maximum value of daily minimum temperature	
Percentile indices			
TX10	Cool days	Percentage of days when TX < 10th percentile	Days
TX90	Warm days	Percentage of days when TX > 90th percentile	Days
TN10	Cool nights	Percentage of days when TN < 10th percentile	Days
TN90	Warm nights	Percentage of days when TN > 90th percentile	Days
Threshold indices			
FD	Frost days	Annual count when TN (daily minimum) < 0 _C	Days
ID	Ice days	Annual count when TX (daily maximum) < 0 _C	Days
TR20	Tropical nights	Annual count when TN (daily minimum) > 20 _C	Days
SU25	Summer days	Annual count when TX (daily maximum) > 25 _C	Days
Duration indices			
GSL	Growing season Length	Annual count between first span of at least 6 days with TG > 5 _C and the first occurrence after 1st July of at least 6 consecutive days with TG < 5 _C	Days
CSDI	Cold spell duration index	Annual count of days with at least 6 consecutive days when TN[10th percentile during 1962–2008	
WSDI	Warm spell duration index	Annual count of days with at least 6 consecutive days when TX[90th percentile during 1962–2008	
Range indices			
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	

3.3. Mann–Kendall test

The Mann–Kendall (M–K) trend test (Mann, 1945; Kendall, 1962) recommended by the World Meteorological Organization (WMO) is an effective tool to assess the significance of monotonic trends in hydro-meteorological series. The test is a non-parametric test, which is suitable for data that do not follow a normal distribution and less sensitive to outliers (Vincent and Mekis, 2006; Tabari and Talaee, 2011). This method has been widely used to detect trends in meteorological and hydrological time series (Zhang et al., 2000; Li et al., 2010; You et al., 2011; Wang et al., 2013). According to this test, the null hypothesis H_0 states that the data (x_1, …, x_n) is a sample of n independent and identically distributed random variables. The alternative hypothesis H_1 of a two-sided test is that the distributions of x_k and x_j are not identical for all $k, j \leq n$ with $k \neq j$. The test statistic S, which has mean zero and a variance computed by Equation (2), is calculated using Equation (1), and is asymptotically normal (Tabari and Talaee, 2011):

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

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

where n is the number of data points, m is the number of tied groups (a tied group is a set of sample data having the same value), and t_i is the number of data points in the i^{th} group. In cases where the sample size $n > 10$, the standard normal variable Z is computed by using Equation 3 (Tabari and Talaee, 2011).

$$Z = \begin{cases} \frac{s-1}{\sqrt{Var(s)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{s+1}{\sqrt{Var(s)}} & if \quad S < 0 \end{cases} \qquad (3)$$

Positive values of Z indicate increasing trends while negative Z shows decreasing trends. When testing either increasing or decreasing monotonic trends at the α significance level, the null hypothesis was rejected for an absolute value of Z greater than $Z_{1-a/2}$, obtained from the standard normal cumulative distribution tables (Partal and Kahya, 2006; Modarres and Silva, 2007;Tabari and Talaee, 2011). In this research, significance levels of a = 0.01 and 0.05 were applied.

To determine the direction and time of

change in annual temperature, the sequential Mann-Kendall test (Sneyers, 1990) was used. Time-series plots were prepared for all indices with smoothed values and the *u(t)* and *u'(t)* values derived from the sequential analysis of the Mann–Kendall test (Lana et al., 2004). Pearson's correlation was used to detect and estimate the correlation coefficient among indices. For spatial differences of the climate extreme events, the spatial distribution maps were drawn by Kriging method in ArcGIS 10.

4. Results

4.1. Trends in Absolute indices

Table 3 shows the regional increasing (I) decreasing (D) trend and the percentage of stations with positive (significant at the 0.05 level), no trend and negative trends (significant at the 0.05 level) in extreme temperature indices. Figure 2 shows the anomaly time series curves of absolute indices and Figure 3 shows the spatial distribution pattern of the temporal trends in absolute extremes for the seven meteorological stations in Lake Urmia basin during 1987-2014. All absolute indices demonstrated an increasing trend. However, all the linear trends for each index were not statistically significant. The regional trends for TXn, TNn are 1.00 and 0.36 °C/decade, respectively. The variations in TXn are more moderate than those in TNn. The regional trends for TXx, TNx are equivalent to 1.76 and 1.01 C°/decade.

For monthly minimum value of daily maximum temperature (TXn) and monthly maximum value of daily maximum temperature (TXx), 100% of stations showed increasing trends in the data series. The proportions of stations with statistically significant trends for TXx were 29% at the 5% significance level. As for the monthly minimum value of daily minimum temperature (TNn) and monthly maximum value of daily minimum temperature (TNx), approximately 71% and 86% of the stations had increasing trends with fluctuations, but only 14% of stations were statistically significant in TNx.

The spatial distributions for absolute temperature indices exhibited an increasing trend in most parts of the study region. The spatial change of the TXx and TXn had increasing trends in whole regions, and Maragheh and Takab showed significant trends in maximum TX. The stations with increasing trends for TNn were mainly distributed in central and eastern LUB. Urmia and Mahabad have a decreasing trend. These stations due to their placement behind the Mediterranean trough, which has been strengthened in recent years, have faced with intensifying downfall cold air of high latitudes during the cold seasons. For this reason, the minimum TN has been reduced.

The spatial distribution for TNx exhibited a declining trend in southwest and the other parts showed increasing trends. However, Mahabad had significant increasing and Takab had decreasing trends. Takab has a lower heat capacity due to its high altitude and lake of water resources and, therefore, has recorded the lower TNx.

Table 3. Percentage of stations with positive, no trend, and negative (significant at the 0.05 level) trends for the temperature indices.

Index	Trend	Positive	No trend	Negative
TXn	I	100%	0	0
TXx	I	100% (29%)	0	0
TNn	I	71%	0	29%
TNx	I	86% (14%)	0	14%
TX10	D	0	0	100% (86%)
TX90	I	100% (71%)	0	0
TN10	D	0	0	100% (71%)
TN90	I	100% (100%)	0	0
FD	D	0	0	100% (29%)
ID	D	0	0	100% (14%)
SU25	I	100% (86%)	0	0
TR20	I	71% (57%)	0	29%
GSL	I	100% (43%)	0	0
CSDI	D	43%	0	57% (43%)
WSDI	I	100% (86%)	0	0
DTR	I	86% (43%)	14%	0

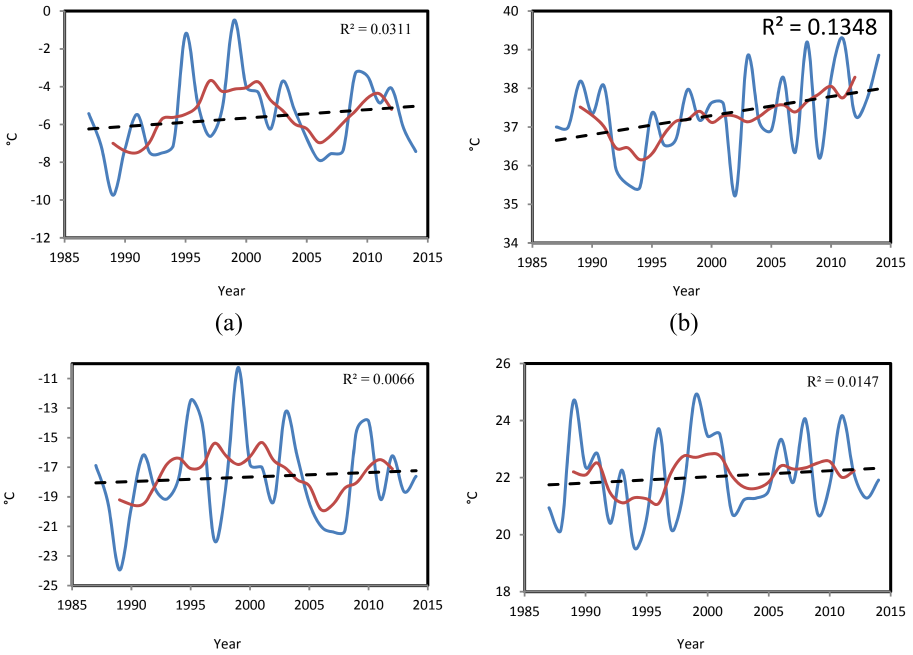

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Figure 2. Inter- annual variation of absolute temperature indices in the LUB. The dashed line is the linear trend; the red line is the five-year smoothing average and R is its correlation coefficient.

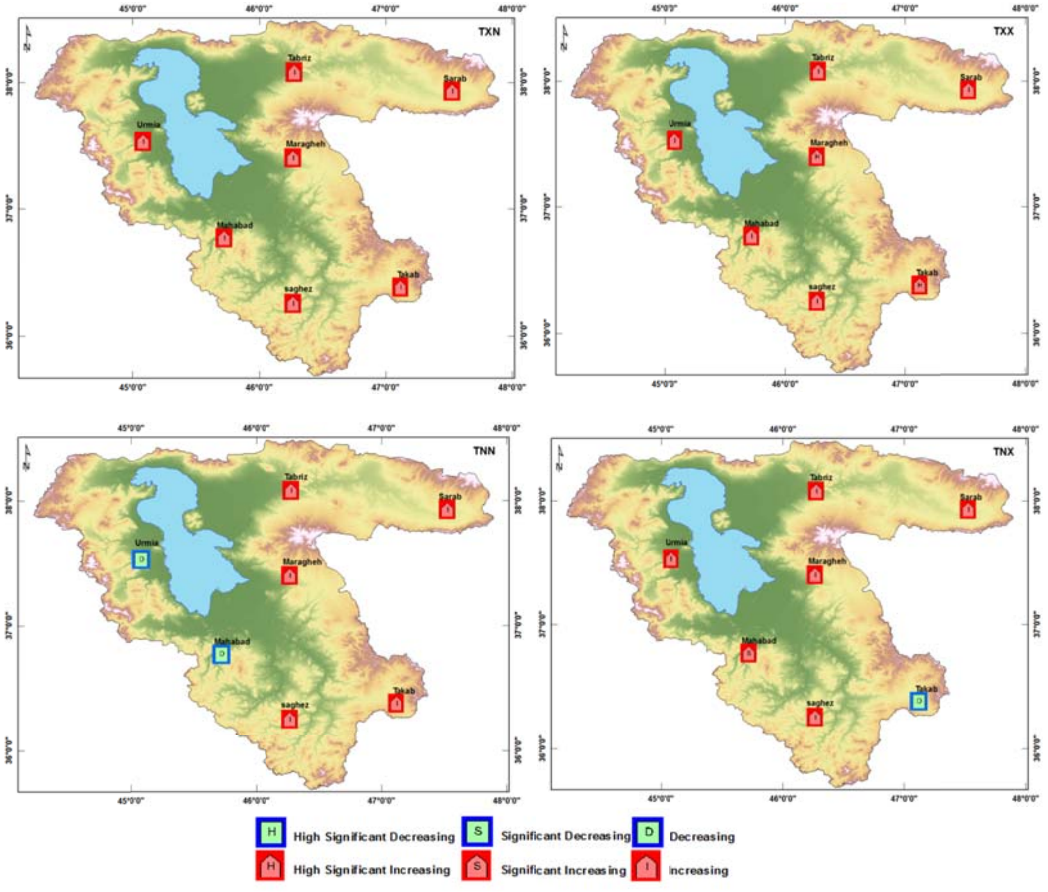

Figure 3. Spatial distributions of absolute temperature indices in the Lake Urmia Basin.

4.2. Percentile indices

The annual series of percentile indices over Lake Urmia Basin are shown in Figure 4. Over the 1987-2014, cool days (TX10p) and cool nights (TN10p) significantly decrease with a trend of -3.07 and -2.27 days/decade, respectively. However, warm days (TX90p) and warm nights (TN90p) significantly increase at the rate of 2.99 and 3.34 days/decade, respectively. Table 2 shows the proportion of stations where trends in indices are of a particular relative magnitude. Decreased frequency of TX10 and TN10 has occurred at 100% of the stations and statistically significant trends are found at about 86% in TX10 and 71% in TN10. Similarly, the temperatures recorded in TX90 and TN90 have also increased at 100% of stations and 71% and 100% of stations were statistically significant, respectively.

The Mann-Kendal sequential test is carried out on the extreme temperature for the recent 28 years. TX10 and TN10 have an abrupt change around 1994; and increased after 2000. The abrupt change test discloses that TX90 and TN90 had an abrupt change in 1998 (Figure 5).

More detailed information of how the magnitude of rates of change in extreme climate events varies from one weather station to another is demonstrated by spatial distribution maps of trends in these four indices at the individual stations (Figure 6). For TX10 and TN10, all of the stations presented a decreasing trend and more than half of them have a significant trend at the 1% significance level. The spatial distribution for TX90 and TN90 exhibited an increasing trend in all parts of the study region.

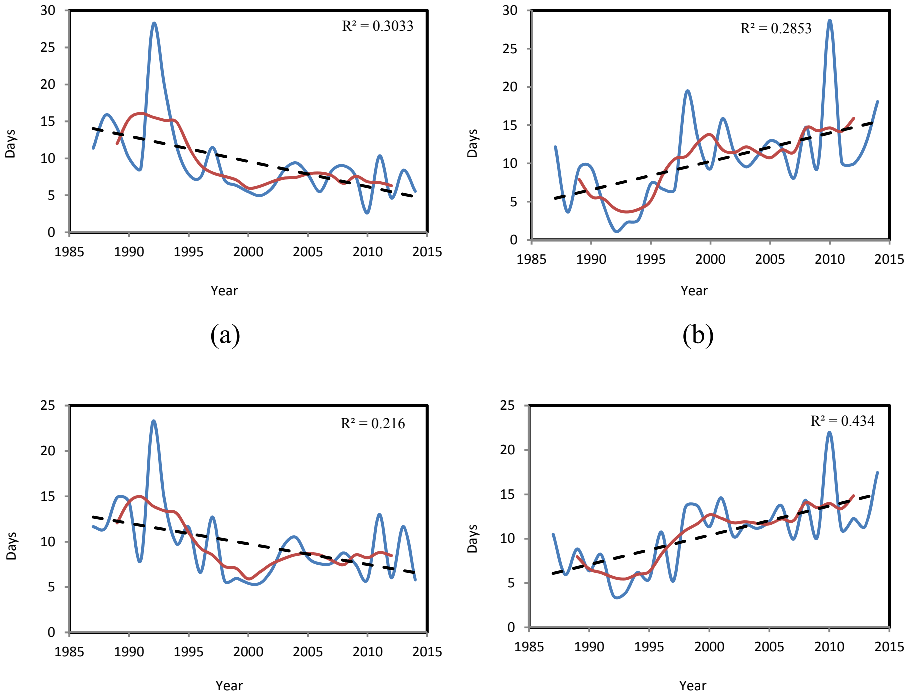

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Figure 4. Inter- annual variation of percentile temperature indices in the LUB. The dashed line is the linear trend; the red line is the five-year smoothing average and R is its correlation coefficient.

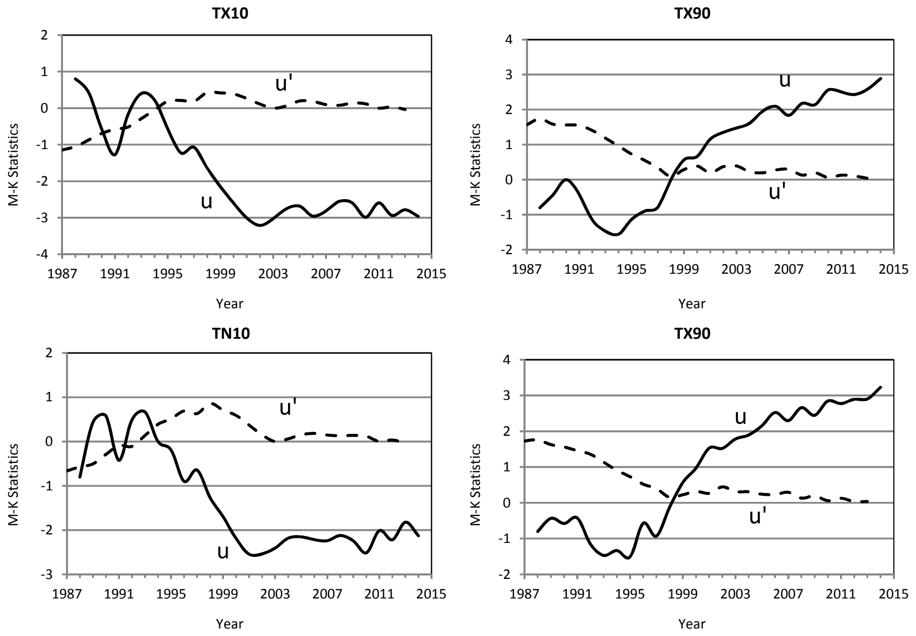


Figure 5. Mann- Kendall sequential test of the annual number for percentile indices over LUB.

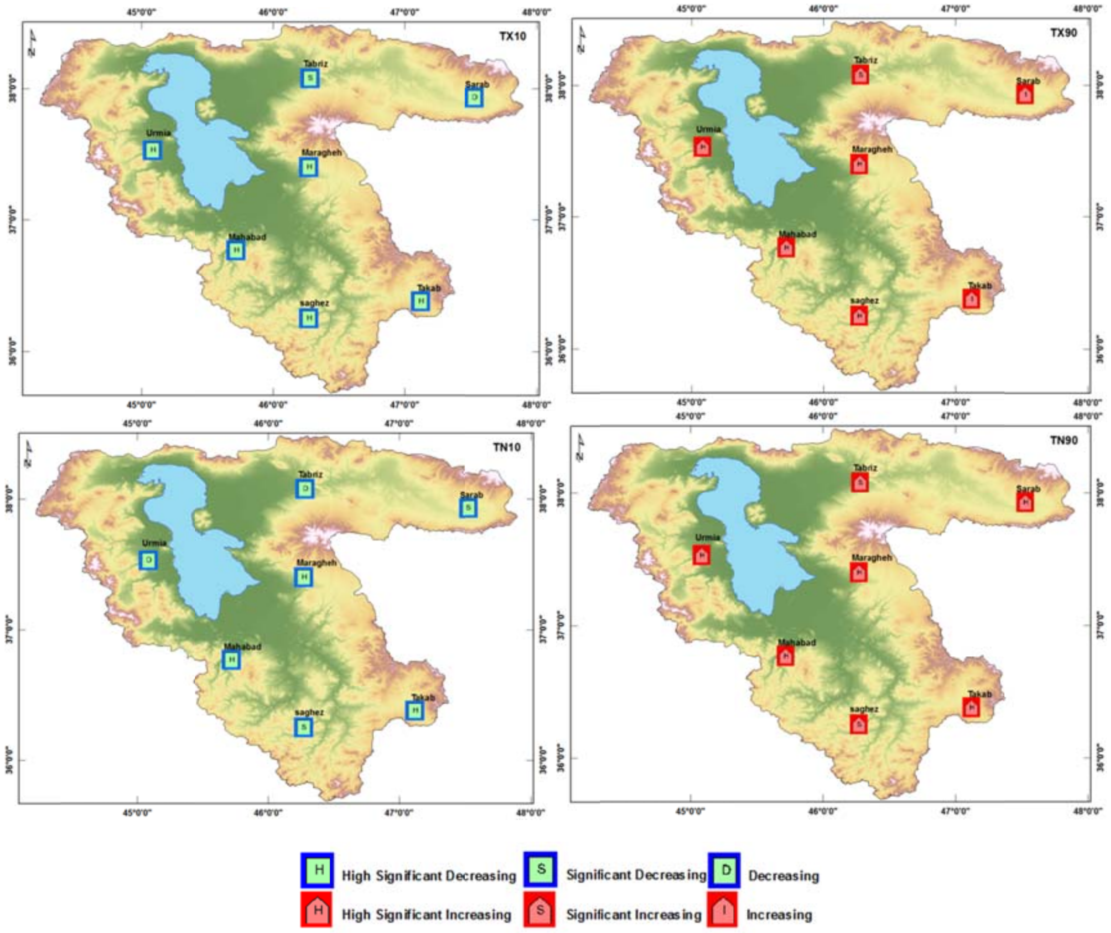
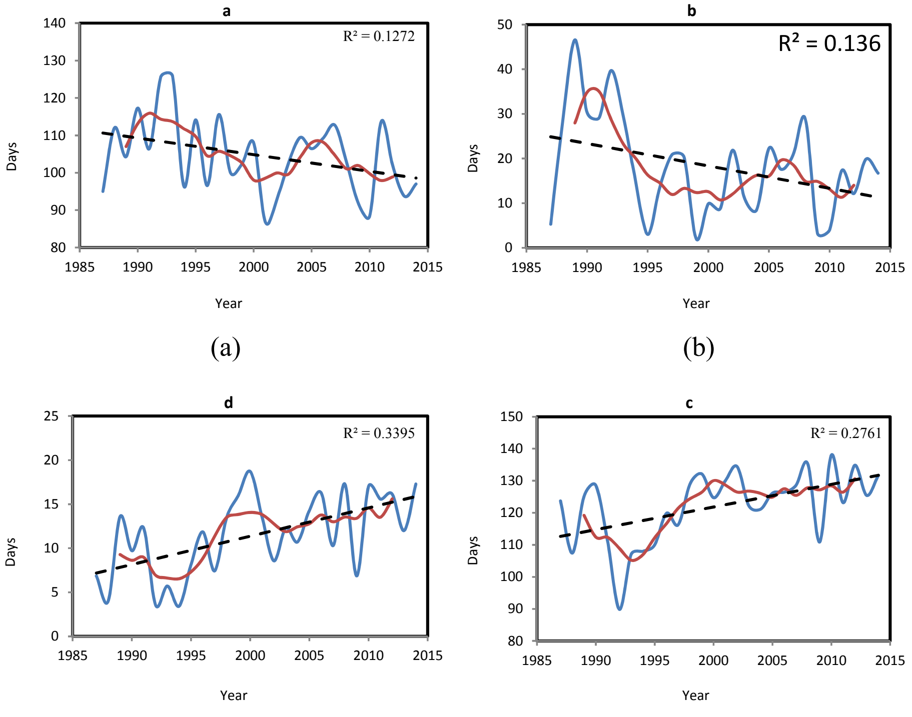


Figure 6. Spatial distributions of percentile temperature indices in the Lake Urmia Basin.

4.3. Threshold indices

Figure 7 demonstrates the regional annual series for threshold indices. The frequency of frost days (FD) has decreased by 1.53 days/decade, whereas tropical nights (TR20) have increased in frequency by 3.06 days/decade. Consistent with these trends, ice days (ID) have decreased in frequency by 1.8 days/decade, whereas summer days (SU25) have increased in frequency by 3.3 days/decade. Decreased frequency of frost days (FD) and ice days (ID) has occurred at 100% of the stations and statistically significant trends are found at about 29% and 14% of stations, respectively. The numbers of summer days (SU25) have increased at 100% of stations and 86% of them were statistically significant (Table 3). As for the tropical nights (TR20), approximately 71% of the stations had increasing trends with fluctuations, but only 57% of them were statistically significant.

The spatial variability in threshold indices is demonstrated in Figure 8. The number of frost days (FD) decreased in all parts of the study area and Sarab and Takab had significant decreasing trend. On the contrary, the number of summer days (SU25) presented an increasing trend and more than half of the stations have a significant trend at the 1% significance level. The spatial change of ice days (ID) had decreasing trends in whole regions and Maragheh showed significant trends. Tropical nights (TR20) have significantly increased at approximately 50% of stations and the stations with larger trend magnitudes are distributed in the central regions. Sarab and Takab in northeast and southeast had decreasing trend. In these stations, due to their mountainous nature and high altitudes as in other mountainous regions, the number of tropical nights (TR20) has declined.



(a) (b)

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Figure 7. Inter- annual variation of threshold temperature indices in the LUB. The dashed line is the linear trend; the red line is the five-year smoothing average and R is its correlation coefficient.

4.4. Duration indices and Range indices

The annual series of duration indices and range indices are shown in Figure 9. During the research period, the most indices demonstrated increasing trends. The growing season (GSL) in the Lake Urmia Basin was lengthened at a rate of 1.79 days/decade (Figure 9a). For GSL, 100% of stations had increasing trends, but only 43% of them had significant positive trends and mainly increased between 2 and 4 days/decade. The cold spell duration index (CSDI) has decreased by 0.16 days/decade, but it did not change significantly at the 0.05 level (Figure 9b). Decreased frequency of CSDI has occurred at 57% of the stations and statistically significant trends are found at about 43% of stations. The warm spell duration index (WSDI) has increased in frequency by 2.63 days/decade, and increasing trend has occurred at 100% of the stations. The proportion of stations with statistically significant positive trends for WSDI was 86%. The average regional diurnal temperature range (DTR) increased at a rate of 2.52 °C /decade. About 14% of stations in DTR show no trends; however, most of stations (86%) on the Lake Urmia Basin in DTR increased. Nevertheless, statistically significant trends are found at about 43%.

In Figure 10, the spatial variability in Duration indices and range indices is demonstrated. The Growing Season Length (GSL) increased in all parts of the study area, and Maragheh, Mahabad and Takab had significant increasing trend. The Cold Spell Duration Index (CSDI) has significantly decreased at approximately 50% of stations and the stations with larger trend magnitudes are distributed in the central regions. These stations due to their placement in the warm front of Mediterranean trough, which has been strengthened in recent years, have experienced a decline in the duration of cold spells. The spatial distribution for warm spell duration index (WSDI) exhibited an increasing trend in all parts of the study area. As for Diurnal Temperature Range (DTR), the stations showing increasing trends were centered in all parts of the region. Most of the stations with significant positive trends were mainly located in the north regions of the basin.

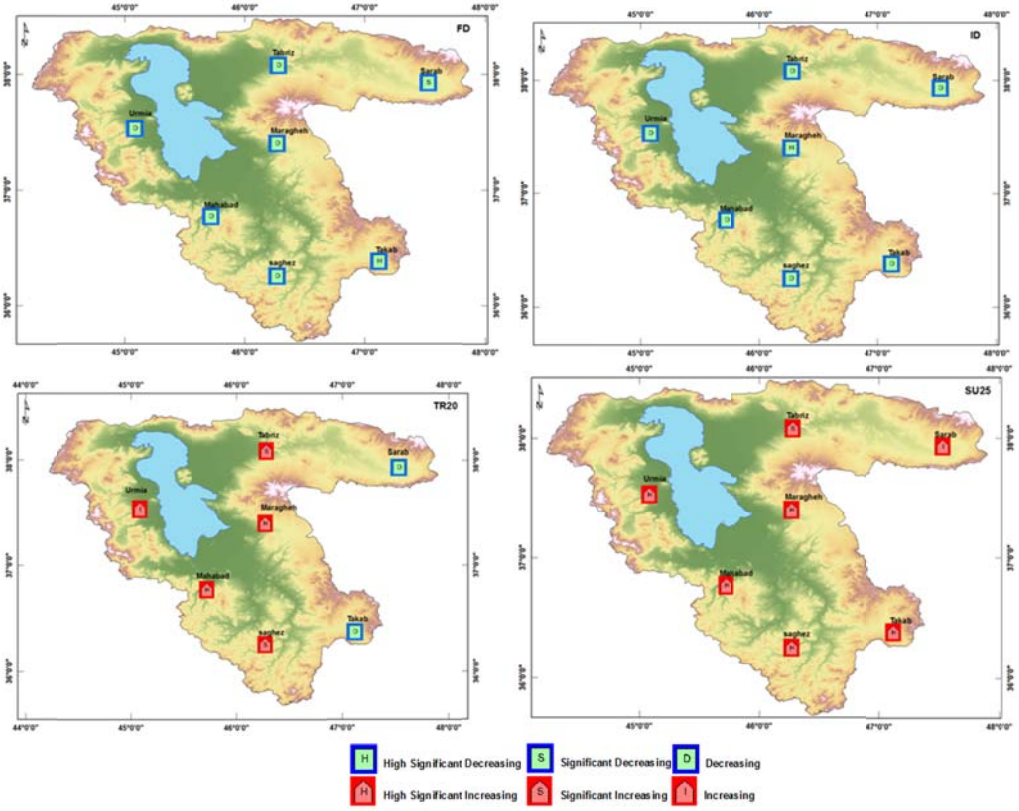

Figure 8. Spatial distributions of threshold temperature indices in the Lake Urmia Basin.

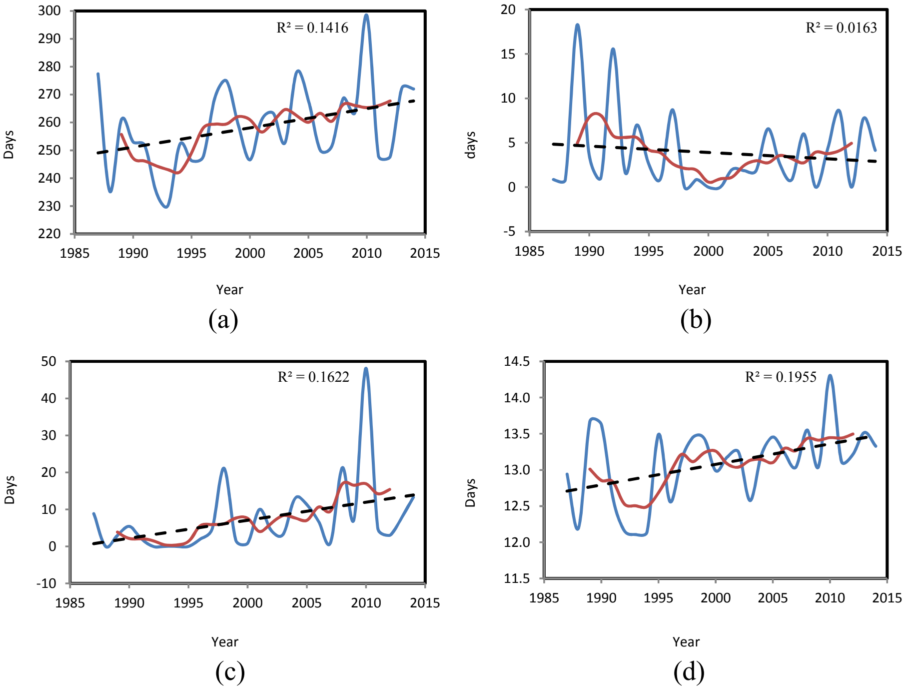

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Figure 9. Inter- annual variation of duration and range indices in the LUB. The dashed line is the linear trend; the red line is the five-year smoothing average and R is its correlation coefficient.

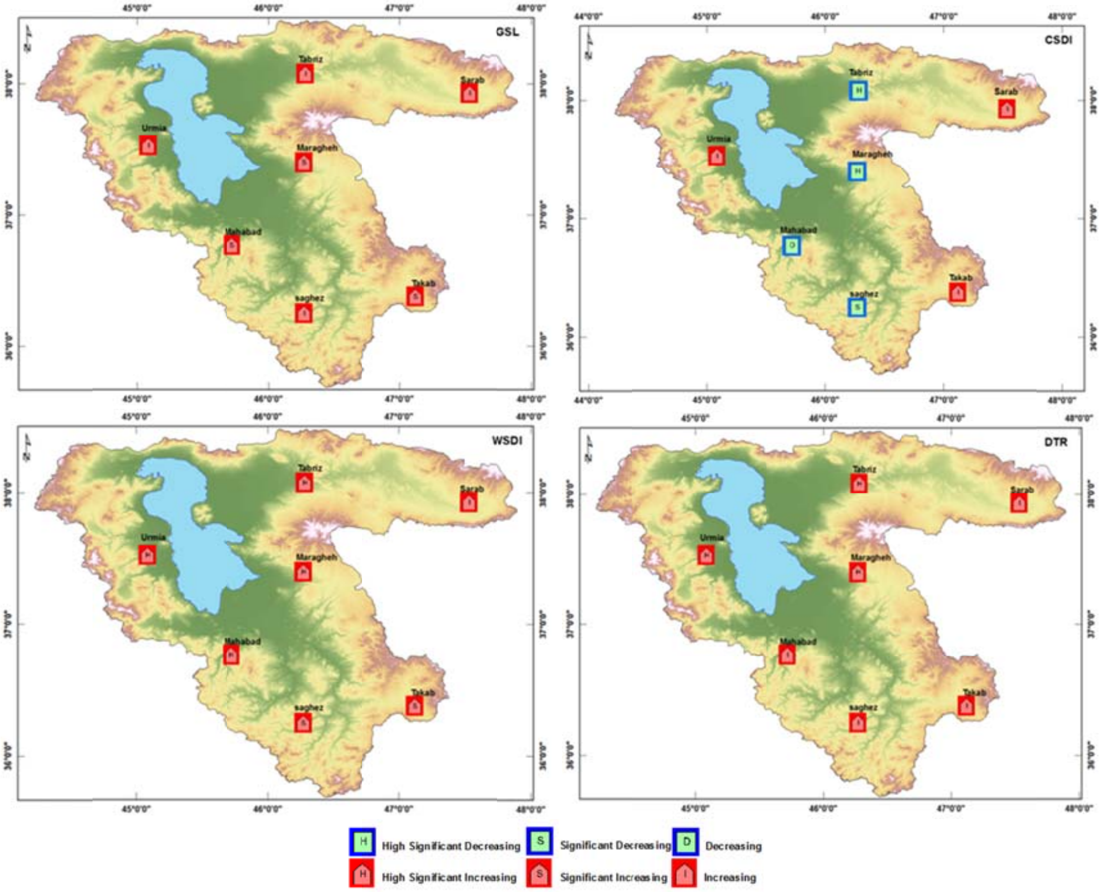

Figure 10. Spatial distributions of duration indices and range indices in the Lake Urmia Basin.

4.5. Analysis of correlations of temperature indices

In order to further investigate whether the temperature extreme indices are indicative to mean temperature and explore the correlations among the extreme temperature indices, correlation coefficients were calculated. Table 4 and 5 show that both warm and cold extremes except for monthly maximum value of daily minimum temperature (TNx) have high correlations with the mean annual temperature, with correlation coefficients over 0.4 (p/0.05), indicating that changes in temperature extremes can reflect general warming over the Lake Urmia Basin. Comparing the behavior of different warm indices, warm nights (TN90) and warm days (TX90) have the strongest correlations with mean temperature, and their coefficients are 0.895 and 0.825, respectively. Negative correlations are also significant between mean temperature and cold indices, and the maximum value of correlation coefficients is 0.921 and 0.855 for cool days (TX10) and cool nights (TN10), indicating the decrease of extreme cold events. The indices chosen in this study can have better indicative functions to climate warming over Lake Urmia Basin. In addition, there are high correlations among warm indices and among cold ones, respectively.

Table 4. Correlation coefficients of temperature indices for warm extremes in the Lake Urmia Basin.

	Tmean	TXx	TNx	TX90	TN90	SU25	TR20	GSL	WSDI
Tmean	1								
TXx	0.423^{*}	1							
TNx	0.271	0.500^{**}	1						
TX90	0.825^{**}	0.526^{**}	0.217	1					
TN90	0.895^{**}	0.569^{**}	0.362	0.911^{**}	1				
SU25	0.791^{**}	0.451^{**}	0.450^{*}	0.775^{**}	0.781^{**}	1			
TR20	0.690^{**}	0.732^{**}	0.707^{**}	0.658^{**}	0.786^{**}	0.759^{**}	1		
GSL	0.662^{**}	0.309	-0.61	0.820^{**}	0.681^{**}	0.587^{**}	0.356	1	
WSDI	0.590^{**}	0.402^{*}	0.029	0.873^{**}	0.750^{**}	0.509^{**}	0.426^{*}	0.799^{**}	1

Table 5. Correlation coefficients of temperature indices for cold extreme in the Lake Urmia Basin.

	Tmean	TXn	TNn	TX10	TN10	FD	ID	CSDI
Tmean	1							
TXn	0.501^{**}	1						
TNn	0.411^{*}	0.899^{**}	1					
TX10	-0.921^{**}	-0.461^{*}	-0.322	1				
TN10	-0.855^{**}	-0.417^{*}	-0.350	0.890^{**}	1			
FD	-0.780^{**}	-0.295	-0.309	0.664^{**}	0.664^{**}	1		
ID	-0.694^{**}	-0.814^{**}	-0.748^{**}	0.632^{**}	0.593^{**}	0.489^{**}	1	
CSDI	-0.493^{**}	-0.513^{**}	-0.509^{**}	0.562^{**}	0.714^{**}	0.304	0.635^{**}	1

5. Conclusions

In this study, 16 extreme temperature indices over the Lake Urmia Basin were analyzed to investigate the temporal and spatial changes from 1987 to 2014. The following conclusions were drawn:

All of the temperature-based indices showed consistent warming trends. The cold indices, including cool days (TX10), cool nights (TN10), ice days (ID), frost days (FD) and cold spell duration index (CSDI) decreased in the Lake Urmia Basin during the past three decades. Over the same period, the warm indices, including warm days (TX90), warm nights (TN90), summer days (SU25), tropical nights (TR20), warm spell duration index (WSDI), and growing season length (GSL), significantly increased. Furthermore, the magnitudes of the trends in the warm extremes are larger than those in the cold extremes. Extreme warm events in most regions tended to increase, while extreme cold events tended to decrease in the Lake Urmia Basin. With the exception of the monthly maximum value of daily minimum temperature (TNx), the indices strongly correlate with the annual mean temperature. In addition, there are high correlations among warm indices and among cold ones, respectively.

The main findings of this study suggest that the regional temperature trends over the Lake Urmia Basin are similar to those calculated for global and regional scales; the climate has become warmer in the past several decades. These findings are in agreement with those extracted by Alijani and Farajzadeh (2015); Alizadeh-Choobari et al. (2016a). All the temperature-based indices show patterns consistent with a general warming trend, and these changes are consistent with previous studies in other parts of the world (Zhang et al., 2005; Alexander et al., 2006; Brown et al., 2008; You et al., 2011; Wang et al., 2013; Yu and Li, 2015; Alizadeh-Choobari and Najafi, 2017).

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