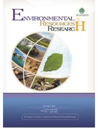

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Temporal and spatial distribution of extreme precipitation indices over the lake Urmia Basin, Iran

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Abstract

Climate extremes have more direct and significant impact than average state on social and ecological systems. In this study temporal and spatial distribution of extreme precipitation events were analyzed based on the daily precipitation data of seven meteorological stations in the Lake Urmia Basin in Iran from 1987 to 2014. Eleven indices of precipitation extremes were selected and calculated using the RClimDex software. The Mann-Kendall test was employed to assess trend in extreme precipitation indices, and the Sen's Estimator test was used to determine the slope of the significant trends. Results demonstrate that consecutive dry days (CDD) exhibit an increasing trend. The other indices of precipitation extremes, Consecutive wet days (CWD), heavy precipitation days (R10mm), heavier precipitation days (R20mm), heaviest precipitation days (R25mm), maximum 1-day precipitation (RX1day), maximum 5-day precipitation (RX5day), very wet day precipitation (R95), extremely wet day precipitation (R99), simple daily intensity index (SDII), and wet-day precipitation (PRCPTOT) show decreasing trend and time of change in most indices starting from 1995-1996. However, all the linear trends for each index are not statistically significant. Decreasing trends in precipitation days were greater than those in precipitation indices. The slope of trends in extreme precipitation indices showed that the highest slope of the decreasing trend occurred in wet-day precipitation, consecutive dry days and very wet day precipitation. Spatial distribution for precipitation extremes exhibited a declining trend in most regions in the Lake Urmia Basin. Furthermore, the extreme precipitation indexes had positive correlations with the annual total precipitation, and their correlation coefficients were statistically significant at the 1% significance level, except for consecutive dry days.

Keywords: Precipitation extremes, Spatial and temporal distribution, Mann-Kendall test, Sen's Estimator test, Lake Urmia Basin.

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Introduction

The Inter Governmental Panel on Climate Change (IPCC) (2012) stated that there are high economic losses from weather and climate related disasters which have increased during the last 60 years and will have greater impacts on sectors with closer links to climate, such as water, agriculture and food security; while the highest fatality rates and economic losses caused by hydro-meteorological induced disasters are registered in developing countries. Variations and trends in extreme climate events are more sensitive to climate changes than to the mean values. According to theIPCC, increasing evidence indicates that global warming has resulted in a growing frequency and aggravated severity of extreme climate events in the past decades, such as heat wave, high temperature, and multi-region heavy rainfall and flood (http://www.ipcc.ch/meeting_documentation/meeting_documentation.shtml).

The variability of the daily temperature and precipitation extremes are considered as a signature of climate change in a region (IPCC, 2007; Zhang et al., 2011, and references cited therein). A subset of extreme climate indices is characterized by using the shapes of lower and upper tails of the probability distribution functions (PDFs), even though the entire PDF has relevance for the climate change signals (Zhang et al., 2011). Another subset is based on defining a fixed threshold; the thresholds for the extreme climate indices are region dependent (Alexander et al., 2006). The threshold based extreme climate indices have explicit relevance for the climate impact based studies (see, for instance, Zhai and Pan, 2003).

Extreme precipitation events have been increasing since the late 20th century in the mid-latitude and high-latitude land areas of the Northern Hemisphere (IPCC, 2007). Climatic precipitation extremes aggravate the frequency, intensity, and duration of disasters, such as droughts and floods, and cause catastrophic damage to agriculture, ecology and life (You et al., 2008; Penalba and Robledo, 2010; Fu et al., 2013). Extreme precipitation events have received worldwide attention due to their large-scale impacts and have been studied in many regions of the world (Zhai and Pan, 2003; Zhang, 2005; Alexander et al., 2006; Goswami et al., 2006; Deque, 2007; Aguilar et al., 2009; Fu et al., 2010; Vincent et al., 2011; Zhang et al., 2011; Caesar et al., 2011; Wang et al., 2013; Liu et al., 2013; Boccolari and Malmusi, 2013; Wu et al., 2014: Deng et al., 2014; Song et al., 2015; Yan et al., 2015).

In Iran, trends in extreme precipitation have been documented in several studies (Asgari et ai., 2008; montazeri, 2009; Alijani, 2011; Asakere et al., 2012; Masoudian and Darand, 2013; Roordeh et al., 2014; BabaiFini et al., 2014). For example, Alijani (2007) analyzed a time series of daily rainfall variability and extreme events at Tehran station from 1961 to 2004. In his study, the frequency and intensity of these extreme events were investigated utilizing indices, such as annual rain levels, rain days, maximum 1-day precipitation, the frequency of rain days exceeding the 75th, 90th, 95th, and 99th percentiles, and the amount of rainfall. Findings of this research indicated that all the 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 of Iran. 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, while changes in total and extreme precipitation indices varied, depending upon geographic location. Marofi et al. (2011) investigated the probable trends and effects of climatic extreme events of precipitation and temperature in the northern and southern coastlines of Iran. The results showed that precipitation indices indicate few significant trends over the studied period. The results emphasized that the water resources in the studied area would face problems. 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 of Iran. The results of their research indicated that the variation of precipitation patterns also exhibited noticeable changes as altitude increases in the northwest of Iran. 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.

The Lake Urmia Basin (LUB), which is located in northwest of Iran, is part of Iran's six major river basins. Similar to other regions of Iran, the northwest of the country has experienced frequent dry periods in recent decades. This basin is one of the prominent agricultural areas and a mountainous region, where fluctuations of various parameters of climate are ordinary. Therefore, this region is sensitive to global climate change; however, the changes with regard to extreme climate are not clear. Regional assessments on various climates and geographic regions are needed for understanding uncertainties in extreme events' responses to global warming. The purpose of this study was to assess recent trends in 11 extreme precipitation indices in Lake Urmia Basin from 1987 to 2014. In addition, spatial and temporal variability of changes in these indices at all stations are discussed. It is hoped that this study will provide valuable information to policymakers and researchers and play a role in assessing and predicting the influence of extreme precipitation events influencing floods and droughts in Lake Urmia Basin.

Data and methods

Study area

The Lake Urmia Basin is located between 37°4′ to 38°17′ latitudes and 45°13′ to 46° longitudes in northwest of 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 (Fig. 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 and is an important natural asset with considerable cultural, economic, aesthetic, recreational, scientific, conservation and ecological value. The lake basin includes 14 main sub basins that surround the lake with areas varying from 431 to 11,759 km^2. The most important rivers are ZarrinehRoud, SiminehRoud, and Aji Chai (fathian et al., 2015). Climate in the Urmia Lake Basin is harsh and continental, affected mainly by the mountains surrounding the lake (Delju et al., 2013).

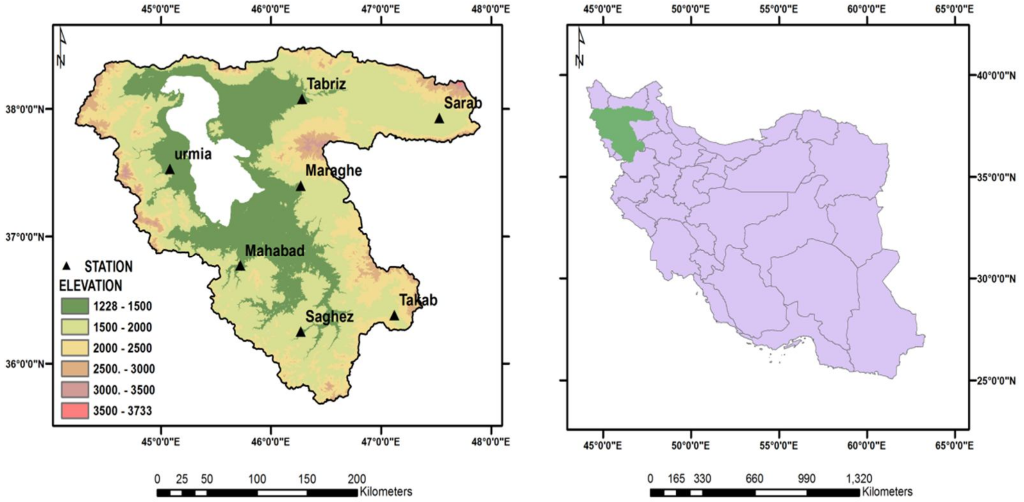


Figure 1. Geographic locations of the Lake Urmia Basin and location of meteorological stations

Data

In this study, seven weather stations listed in Table 1 were 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 precipitation data were used to compute climate indices. The study period for time series is 1987 to 2014 and its spatial distribution is shown in Table 1.

Data quality control plays a fundamental 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 was performed using the computer program RClimDex (developed by Zhang and Feng, 2004) at the Climate Research Branch of Meteorological Service of Canada) available online for downloading (http://cccma.seos.uvic.ca/ETCCDI/). 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.

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	1987-2014
Maragheh	46° 16′	37° 24′	1477.7	1987-2014
Urmia	45° 05′	37° 32′	1316	1987-2014
Saghez	46° 16′	36° 14′	1552.8	1987-2014
Sarab	47° 32′	37° 56′	1682	1987-2014
Tabriz	46° 17′	38° 05′	1361	1987-2014
Takab	47° 7′	36° 23′	1765	1987-2014

Methods

Definition of extreme precipitation 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 precipitationand 16 temperature indicesadopted by the Fourth Assessment Report of IPCC (AR4). The precipitation indices (table 2) have been widely used to assess changes in extreme precipitation events because they are representative approaches that have relatively low noise, weak extremes, and strong significance (Klein Tank et al., 2006; Caesar et al., 2011). The extreme precipitation indices used can be divided into two types (Liu et al., 2013; Wang et al., 2013): precipitation indices (PRCPTOT, RX1day, RX5day, R95, R99 and SDII); and number of precipitation days (R10mm, R20mm, R25mm, CWD, and CDD).

Table 2. Definitionsof theusedprecipitation indices.

Index	Descriptive name	Definition	Units
PRCPTOT	Wet-day precipitation	Annual total precipitation based on wet days	mm
RX1day	Maximum 1-day precipitation	Annual maximum 1-day precipitation	Mm
RX5day	Maximum 5-day precipitation	Annual and monthly maximum 5-day precipitation	mm
R95	Very wet day	Annual total precipitation when RR N95th percentile of the 1982–2012 daily precipitation	Mm
R99	Extreme very-wet day	Annual total precipitation when RR N99th percentile of the 1982–2012 daily precipitation	mm
SDII	Simple daily intensity index	Average precipitation on wet days	mm/d
R10mm	Number of heavy precipitation days	Annual count of days when RR ≥ 10 mm	day
R20mm	Number of very heavy precipitation days	Annual count of days when RR ≥ 20 mm	day
R25mm	Number of heaviest precipitation days	Annual count of days when RRS 25 mm	day
CWD	Consecutive wet days	Maximum number of consecutive wet days	day
CDD	Consecutive dry days	Maximum number of consecutive dry days	day

Mann–Kendall Test

The Mann–Kendall (M–K) trend test (Mann, 1945; Kendall, 1975) recommended by the World Meteorological Organization (WMO) is an effective tool to assess the significance of monotonic trends in hydrometeorological 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; Cannarozzo et al., 2006; Su et al., 2008; Kampata et al., 2008; Li et al., 2010; You *et al.*, 2011; Some'e et al., 2012; Wang et al., 2013). According to this test, the null hypothesis H_0 states that the de-seasonalized data (x_1, …, xn) 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 ≤ n with k ≠ j. The test statistic S, which has zero mean and a variance computed by Eq. 3, is calculated using Eqs. 1 and 2, and is asymptotically normal (Tabari and Talaee, 2011):

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

$$sgn(x_j - x_k) = \begin{cases} +1 & if \quad (x_j - x_k) > 0 \\ 0 & if \quad (x_j - x_k) = 0 \\ -1 & if \quad (x_j - x_k) < 0 \end{cases} \qquad (2)$$

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

Where *n* is the number of data points, *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 computedusing Eq. 4 (Tabari and Talaee, 2011).

$$Z = \begin{cases} \frac{s-1}{\sqrt{Var(s)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{s+1}{\sqrt{Var(s)}} & if \quad S < 0 \end{cases} \qquad (4)$$

Positive values of *Z* indicate increasing trends while negative *Z* show decreasing trends. When testing either increasing or decreasingmonotonic trends at the α significance level, the null hypothesiswas 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, the Mann-Kendalsequential test 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).

Sen's estimator

If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated using a simple nonparametric procedure developed by Sen (1968). The slope estimates of N pairs of data are first computed by Eq. (5):

$$Q_i = \frac{x_j - x_k}{j-k} \text{ for } i=1, \ldots, N \quad (5)$$

where x_j and x_k are data values at times j and $k(j > k)$, respectively. The median of these N values of Q_i is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by Eq. (6):

$$Q_{med} = Q_{[(N+1)/2]} \quad (6)$$

If N is even, then Sen's estimator is computed by Eq. (7):

$$Q_{med} = \frac{1}{2}\left(Q_{[N/2]} + Q_{[(N+2)/2]}\right) \quad (7)$$

Finally, Q_{med} is tested with a two-sided test at the 100(1-α) % confidence interval and the true slope can be obtained with the nonparametric test (Partal and Kahya, 2006). In this work, the confidence interval was computed at two different confidence levels ($\alpha = 0.01$and $\alpha = 0.05$) as follows:

$$C_\alpha = Z_{1-\alpha/2}\sqrt{Var(s)} \quad (8)$$

where $Var(S)$ has been defined in Eq. (3), and $Z_{1-a/2}$ is obtained from the standard normal distribution.Then, $M_1 = (N-C_\alpha)/2$ and $M_2 = (N + C_\alpha)/2$ are computed. The lower and upper limits of the confidence interval, Q_{min} and Q_{max}, are the M_1th largest and the $(M_2 + 1)^{th}$ largest of the N ordered slope estimates Q_i. If M_1 is not a whole number, the lower limit is interpolated. In the same vein, if M_2 is not a whole number the upper limit is interpolated (Salmi et al., 2002).

Results and discussion

Temporal trends of precipitation extremes indices

Temporal trends of precipitation index

The mean values of precipitation extremes in Lake Urmia basin in 1987-2014 are shown in Fig. 2 a-f and Table 3. Most indices demonstrated decreasing trend and time of change in most indices started from 1995-1996. However, all the linear trends for each index were not statistically significant. As for themaximum 1-day precipitation (RX1day), maximum 5-day precipitation (RX5day) and Wet-day precipitation (PRCPTOT), 86% of stations showed decreasing trends with fluctuations. The proportions of stations with statistically significant trends for RX5day and PRCPTOT were respectively 29% and 14% at the 5% significance level. The RX1day and RX5day showed slight decreasing trends at the rate of 8.7 and 7.5 mm/decade, while The PRCPTOT had increased at a rate of 12.4 mm/decade (Fig. 2a, b and f). Similarly, considering very wet day precipitation (R95), extremely wet day precipitation (R99) and simple daily intensity index (SDII), approximately 71% of the stations had decreasing trends. The proportions of stations with statistically significant trends for R99 and SDII were respectively 29% and 14%. The regional trends of R95, SDII and R99 were 7.8, 9.6 and 14.9 mm/decade from 1987 to 2014, respectively (Figure 2c, d and e).

Table 3. Percentage of stations with positive, non-trend, and negative (significant at the 0.05 level) trends for the precipitation indices

Index	Trend	positive	Non- trend	negative	Change time
CDD	I	71%	0	29%	1998
CWD	D	14%	0	86% (29%)	1997
R10	D	14%	0	86% (43%)	1995
R20	D	0	0	100% (43%)	1995
R25	D	14%	0	86% (43%)	1995
RX1day	D	14%	0	86%	1995
RX5day	D	14%	0	86% (29%)	1995
R95	D	29%	0	71%	1996
R99	D	29%	0	71% (29%)	1996
SDII	D	29%	0	71% (14%)	1996
PRCPTOT	D	14%	0	86% (14%)	1995

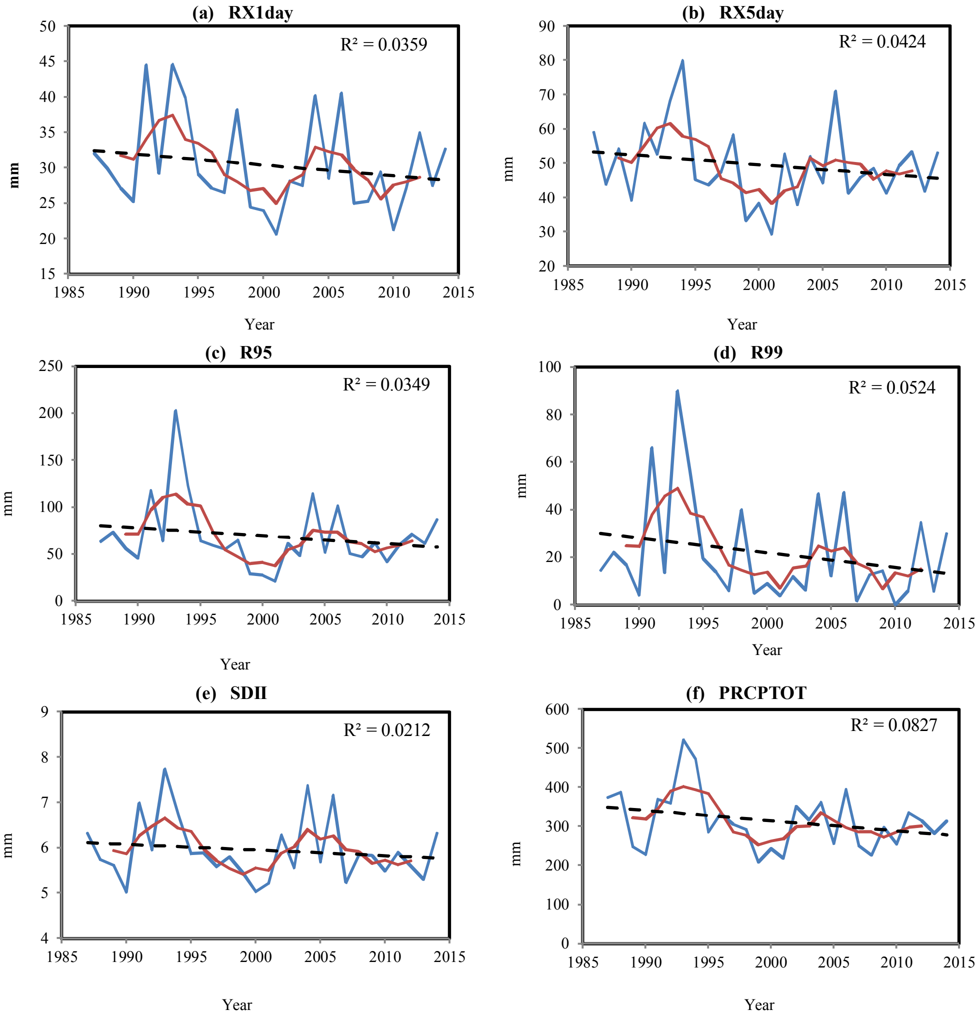


Figure 2. Inter-annual variation of precipitation indices in the LUB from 1987 to 2014. The dashed line is the linear trend; the red line is the five-year smoothing average. R^2 is its coefficient of determination.

Temporal trends of precipitation days

In Lake Urmia Basin, in a majority of cases, most precipitation indices suggested that the amount and intensity of rainfall are decreasing. During the research period, the indices of the precipitation days demonstrated decreasing trends (Fig. 3a-e and Table 3). Also, the time of change in most indices started from 1995. Similarly, all the linear trends for each index were not statistically significant. For consecutive dry days (CDD), respectively 71% and 29% of the stations showed a positive and negative trend from 1987 to 2014 (Fig. 3a). As for the consecutive wet days (CWD), heavy precipitation days (R10 mm) and heaviest precipitation days (R25mm), approximately 86% and 14% of the stations had decreasing and increasing trends. For CWD 29% of stations were statistically significant but for R10 and R25 mm, 43% of stations had statistically significant decreased trend. Considering heavier precipitation days (R20 mm) 100% of stations showed decreasing trends in the data series (Fig. 3.d) The proportions of stations with statistically significant trends for R20 mm was 43% at the 5% significance level.

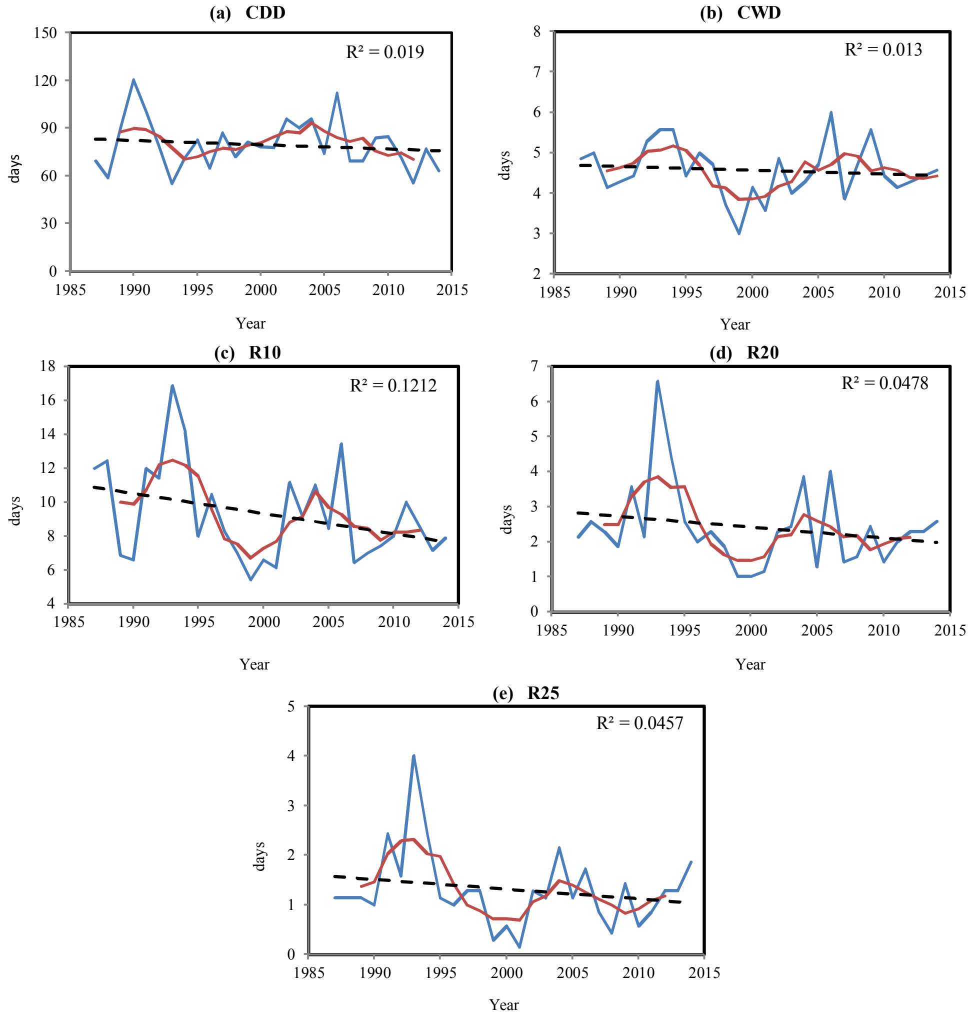


Figure 3. Inter-annual variation of precipitation days in the LUB from 1987 to 2014. The dashed line is the linear trend; the red line is the five-year smoothing average. R^2 is its coefficient of determination.

Spatial distributions of precipitation extreme indices

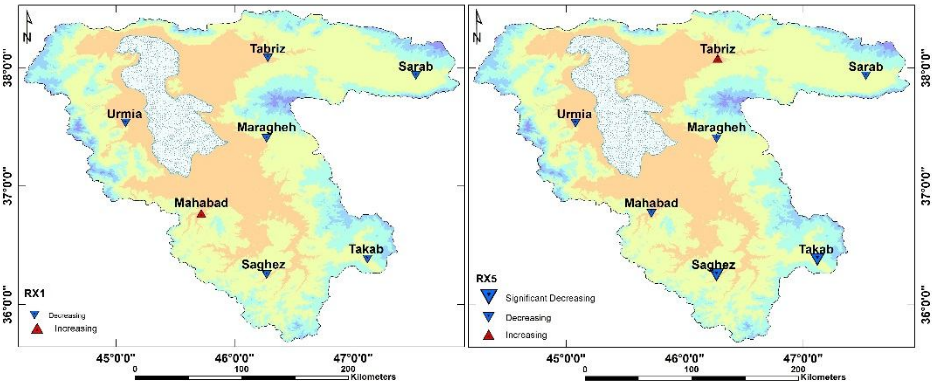
Spatial distributions of precipitation index

After calculating the extreme precipitation indices, the Mann-Kendall test was calculated for extreme precipitation indices time series and the significance of Z at the 5% and 1% significance level was studied (table 4). As noted in this table, the extreme precipitation indices show decreasing trend in most of the stations. After determining the amounts and direction of trends, the slope of trends in extreme precipitation indices was calculated using the Sen's Estimator method, as shown in Table 4. The highest slope of the decreasing trend in extreme precipitation indices occurred in PRCPTOT (Maragheh and Takab) and CDD (Mahabad) (with a slope of 6.32, 2.35 and 1.15 respectively) and its highest slope of increasing trend occurred in PRCPTOT (Sarab), CDD (Takab) and RX1day (Mahabad) (with a slope of 1.43, 0.31 and 0.24 respectively).

To explore the spatial distribution of trends on precipitation extremes over the Lake Urmia Basin, the Mann-Kendall trend was interpolated based on each station's trend value for the entire study period. It provides more detailed information of how the magnitudes of rates vary in precipitation extremes among the seven weather stations. Fig. 4 shows the spatial distribution of precipitation indices. The spatial distributions for precipitation extremes exhibited a declining trend in most parts of the study region. The stations with decreasing trends for RX1day were mainly distributed in central and eastern LUB, and the Mahabad station represented increasing trend in the west of the study area. Stations with decreasing trends for RX5day were centered in all parts of the region except North. Saghez and Takab stations in this region showed significant trends at the 5% significance level. As for R95, the stations showing decreasing trends were centered in all parts of the region except the North and Northeast. The stations with decreasing trends for R99 were mainly distributed in eastern part of Lake Urmia Basin, and the Saghez and Takab station represented increasing trend in the south of the study area. The decrease of SDII was mainly in central and western LUB. Only Maragheh station in this district was significant at the 1% significance level. The spatial change of PRCPTOT had decreasing trends in the whole region but only Northeast and Maragheh were significant.

Table 4. Mann-Kendall Statistic (Z) for extreme precipitation indices in Lake Urmia Basin

Index	Station	Mahabad	maragheh	Urmia	Saghez	Sarab	Tabriz	Takab
CDD	Z	-1.84	0.56	0.24	0.47	-0.38	0.69	0.57
	Q_{med}	-1.15	-0.36	0.19	0.25	-0.11	-0.39	0.31
CWD	Z	-1.62	-1.50	-0.09	-3.34^{**}	0.94	-0.06	-6.93^{**}
	Q_{med}	0.00	0.00	0.00	0.00	0.00	0.00	-0.06
R10	Z	-2.65^{**}	-3.58^{**}	-0.92	-1.50	1.20	-1.52	-2.01^{*}
	Q_{med}	-0.12	-0.30	-0.04	-0.12	0.00	0.00	-0.15
R20	Z	-0.64	-2.77^{**}	-1.49	-0.74	-4.21^{**}	-3.28^{**}	-1.11
	Q_{med}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R25	Z	-0.58	-0.36	-0.02	-2.35^{*}	-4.33^{**}	0.43	-2.15^{*}
	Q_{med}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RX1day	Z	1.01	-1.03	-0.16	-1.80	-0.49	-1.46	-0.50
	Q_{med}	0.24	-0.09	-0.05	-0.50	-0.09	-0.18	-0.19
RX5day	Z	-0.36	-0.07	-0.14	-2.25^{*}	-0.08	0.47	-2.38^{*}
	Q_{med}	-0.10	-0.01	-0.06	-0.88	-0.01	0.11	-0.80
R95	Z	-0.25	-1.23	-0.19	-0.58	0.04	0.28	-0.51
	Q_{med}	-0.38	-0.67	0.00	-1.12	0.00	0.09	-1.08
R99	Z	0.75	-0.58	0.53	-2.23^{*}	-1.75	-0.08	-2.57^{*}
	Q_{med}	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SDII	Z	-0.36	-2.84^{**}	-0.36	-0.93	0.88	-0.83	0.18
	Q_{med}	-0.01	-0.05	-0.01	-0.03	0.02	-0.01	0.00
prcptot	Z	-0.61	-3.31^{**}	-0.14	-1.38	1.03	-0.83	-1.22
	Q_{med}	-1.61	-6.32	-0.27	-4.31	1.43	-1.11	-2.35



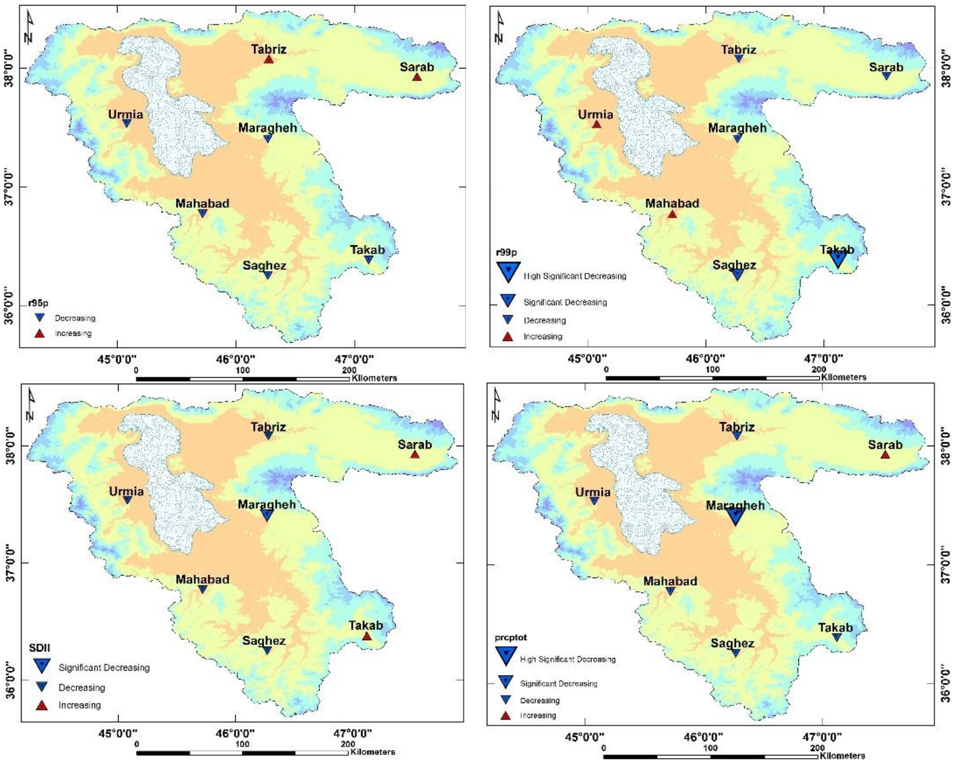
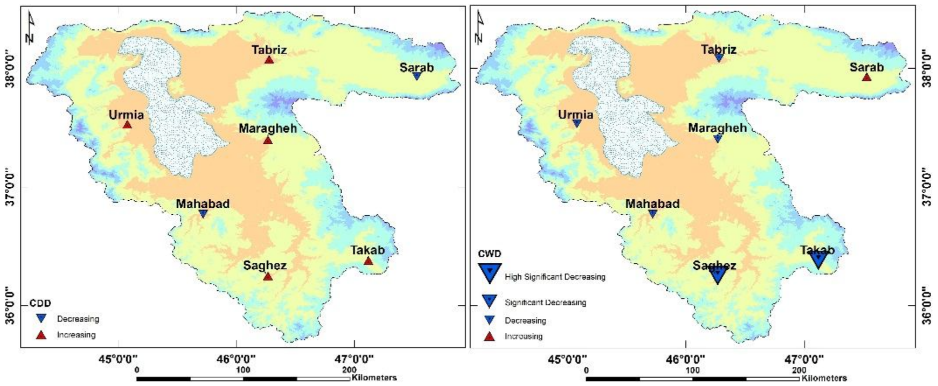


Figure 4. Spatial distributions of precipitation indices in the Lake Urmia Basin

Spatial distributions of precipitation days

The spatial distributions of the change trends for the numberdays of precipitation are shown in Fig. 5. The spatial distribution for CDD exhibited an increasing trend from southeast to northwest over the study region.The spatial change of the CWD and R10 mm had decreasing trends in most areas of the regions. The stations with increasing trend for CWD and R10 mm were centered in the Northeast. For CWD, Saghez and Takab stations represented significant decreasing trend in the south of the study area. However, nearly half of the stations showed a significant decreasing trend at the 1% significance level for R10 mm. The spatial change of the R20 mm had decreasing trends in the whole region and nearly half of the stations presented a significant decreasing trend at the 1% significance level. Stations with decreasing trends for R25 were centered in all parts of the region except North. Sarab, Saghez and Takab stations in this region showed significant trends at the 1% and 5% significance level.



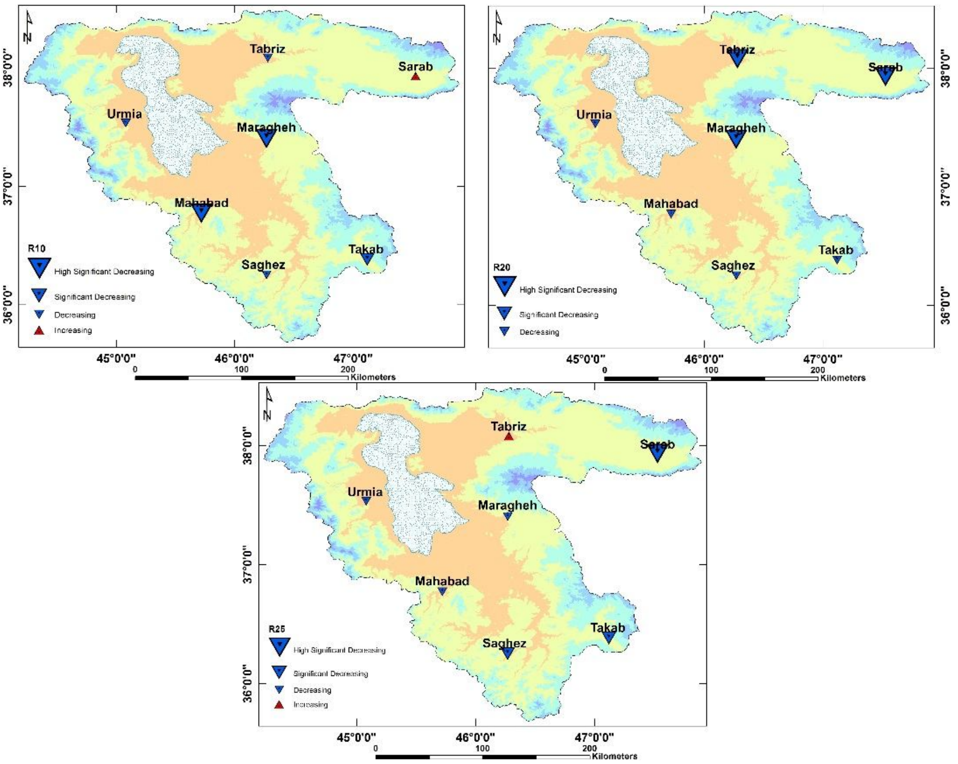


Figure 5. Spatial distributions of precipitation days in the Lake Urmia Basin

Precipitation extremes correlated with annual total precipitation

In order to verify whether the extreme precipitation indices have a relationship with the change of annual total precipitation, the correlation coefficients between annual total precipitation and extreme precipitation indices were calculated (Table 5). Except for CDD, the other extreme precipitation indices had positive correlations with the annual total precipitation and their correlation coefficients were statistically significant at the 1% significance level. The correlation coefficients between total precipitation and precipitation indices, including R10 mm, R20 mm, and PRCPTOT, exceeded 0.9, and the others exceeded 0.64, which indicated that the total annual precipitation is correlated with extreme precipitation. Furthermore, Table 5 also shows statistically significant correlations among the precipitation indices.

Table 5. Correlation coefficients between annual total precipitation and extreme precipitation indices

	ATP	CDD	CDW	R10	R20	R25	R95	R99	RX1day	RX5day	SDII	prcptot
ATP	1											
CDD	-0.209	1										
CDW	0.647**	-.149	1									
R10	0.956**	-.108	.621**	1								
R20	0.822**	-.043	.511**	.818**	1							
R25	.811**	-.059	.511**	.788**	.856**	1						
R95	.855**	-.145	.531**	.836**	.963**	.911**	1					
R99	.748**	-.114	.420*	.745**	.902**	.806**	.928**	1				
RX1day	.758**	-.012	.408*	.735**	.839**	.767**	.876**	.945**	1			
RX5day	.791**	-.035	.628**	.760**	.718**	.700**	.774**	.789**	.839**	1		
SDII	.813**	.038	.528**	.828**	.868**	.781**	.881**	.849**	.861**	.780**	1	
prcptot	.994**	-.203	.651**	.962**	.835**	.816**	.868**	.767**	.776**	.797**	.815**	1

Note: ATP stands for annual total precipitation. ** significant at the 1% significance level; * significant at the 5% significance level.

Conclusion

This study was based on meteorological date from seven stationsin the Lake Urmia Basin during 1987 to 2014, and 11 indices of extreme precipitation calculated using RClimDex software were employed to analyze the temporal and spatial distribution characteristicsof climate extremes. For the temporal variation features in precipitation extremes, all indices demonstrated decreasing trend except CDD and time of change in most indices started from 1995-1996. However, all the linear trends for each index were not statistically significant. As for RX1day, RX5day and PRCPTOT, 86% of the stations had decreasing trends with fluctuations. RX1day and RX5day showed slight decreasing trends at the rate of 8.7 and 7.5 mm/decade, while The PRCPTOT increased at a rate of 12.4 mm/decade. For R95, R99 and SDII, 71% of the stations showed decreasing trends. The regional trends of R95, SDII and R99 were 7.8, 9.6 and 14.9 mm/decade from 1987 to 2014, respectively. For CDD, 86% and 14% of the stations showed respectively a positive and negative trend. As for CWD, R10 mm and R25 mm, 86% of the stations had decreasing trends. Considering R20 mm, 100% of stations showed decreasing trends in the data series. The proportions of stations with statistically significant trends for R20mm were 43% at the 5% significance level. The spatial distribution for precipitation extremes exhibited a declining trend in most regions in the Lake Urmia Basin. The stations with decreasing trends for RX1day were mainly distributed in central and eastern LUB. Stations with decreasing trends for RX5day were centered in all parts of the region except north. As for R95, the stations showing decreasing trends were centered in all parts of the region except North and Northeast. The stations with decreasing trends for R99 were mainly distributed in eastern part of Lake Urmia Basin. The decrease of SDII was mainly in central and western LUB. The spatial change of PRCPTOT had decreasing trends in the whole region except northeast. The spatial distribution for CDD exhibited an increasing trend from southeast to northwest over the study region.The spatial change of the CWD and R10 mm had decreasing trends in most regions. The station with increasing trend for CWD and R10 mm were centered in the northeast. The spatial change of the R20 mm had decreasing trends in whole regions. Stations with decreasing trends for R25 were centered in all parts of the region except north. Moreover, the extreme precipitation indices had positive correlations with the annual total precipitation, and their correlation coefficients were statistically significant at the 1% significance level, except for CDD.

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