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Toward coupling hydrological and meteorological drought characteristics in Lake Urmia Basin, Iran

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Abstract

Investigation of precipitation characteristics on daily, monthly, and annual time scales can contribute to gaining important information related to temporal and spatial distribution of precipitation or even flow rate challenges (e.g., hydrological droughts). The low levels of long-term precipitation and high variability in different time scales are considered the main inherent characteristics of climate in Iran. Due to the direct effects of precipitation on water resources, especially on the river flow rate, it is necessary to assess the efficient indices to visualize the variations in the components of water resources. One of the main indices is the precipitation concentration index (PCI) which is known as a strong indicator of the precipitation distribution generally used on annual and seasonal scales. In this study, drought analysis in the Lake Urmia Basin (LUB) located in northwest of Iran was performed with the daily river flow rate and monthly precipitation values within the period of 1984–2013. The results of changes in precipitation indicated that the irregularity of precipitation distribution had grown in spring months. Also, due to the diminishing precipitation trend on the annual time scale, PCI index also increased. It is concluded that LUB detected a significant descending trend on the annual, spring, and winter time scales in the last 30 years. The PCI values were proved high irregularity in summer with PCI amount of 20.1 and most regularity in winter with PCI amount of 10.4. This paper also aims to assess the effects of PCI on the river flow rate along with the flow shortness volume values using hydrometric and rain gauge stations within LUB. The results obtained from the changes in river flow rate and flow shortness volume revealed that the river flow rate has mostly a falling trend. Finally, it was observed that the time when the river flow rate data changed happened after beginning of changes in the precipitation data. A decrease in inflow from 900 million cubic meters up to 14 billion cubic meters with high flow shortness volume may happen in worst conditions. These results highlighted the importance of applying water resources management in LUB.

Keywords Flow shortness volume · Lake Urmia · Meteorological drought · Precipitation concentration index · Time of change point

1 Introduction

Climate change and global warming have led to the high prevalence of droughts and intensified their duration. This change causes uneven precipitation distribution and affects water resources. Climate change is predicted to result in major changes in water availability across the globe and would add considerable stress to water resources and to the environment. The global change has impacted the water cycle and led to more hydrological extreme events such as heavy rainfalls, floods, and droughts. One of the most important aspects of climate change is how it influences the temporal distribution of precipitation and river flow rates. Due to the impact of precipitation on water availability, many indices such as standardized precipitation index (SPI) have been developed to understand its historical changes and determinant role. Among other indices, the precipitation concentration index (PCI) is able to provide information on long-term variability in precipitation levels. PCI is part of the Fournier index which has a strong background in drought analysis. The results obtained from PCI can be used to plan water resources management and can also be employed as a tool to support preparation in the face of flood or erosion warning (Adegun et al. 2012). This

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concept can also be used in irrigation scheduling and design of new irrigation systems. An unbalanced precipitation distribution could diminish crop performance with reduction of both the moisture stored in the soil and irrigation intervals simultaneously. This disturbance may lead to drought and causes occurrence of dangerous flood through rainfalls with even lower than the mean long-term level.

PCI has been applied extensively in many pieces of research (Martin-Vide 2004; Zhang et al. 2009; Adegun et al. 2012; Valli et al. 2013; Khalili et al. 2016; Zamani et al. 2018). For example, Raziei et al. (2014) studied the homogeneity of precipitation in Iran by employing PCI. The results indicated a strong regular distribution or low concentration throughout the year in the northern parts of the country. Luis et al. (2011) studied the variability in precipitation database using PCI in Spain. They found that the changes in PCI are complex and appear to be related to global atmospheric features as well as synoptic and local factors affecting precipitation trends. Also Khalili et al. (2016) conducted a study about spatial variations of monthly and annual precipitation in Iran during the last half century in two 25-year sub-periods. Zamani et al. (2018) analyzed the PCI on daily, seasonal, and annual time scales within the period from 1971 to 2011 over the Jharkhand state, India. The results revealed a highly irregular and non-uniform distribution on the annual scale.

Changes in the precipitation pattern leads to reduced water storage and flow rates in rivers. Hydrological drought, which means dryness or river flow shortage, is mainly affected by climate change and human activities (Harding et al. 2014; Van Loon 2015; Gan et al. 2016). Therefore, it is essential to assess the hydrological drought as an outcome of meteorological drought considering the new identified indices. In this context, Shiau and Shen (2001) calculated the frequency, probability, and duration of hydrological drought using the frequency functions in northern Taiwan. Nützmann and Mey (2007) estimated the runoff changes in Germany and reported that the river baseflow and hydrological drought are mainly controlled by diminished groundwater levels. Pandey et al. (2008) developed an index based on flow shortage to analyze the streamflow drought for Betwa River basin in India. They found that the drought is more severe from August to November as compared with the other months. Modarres and Sarhadi (2009) studied the driest hydrological periods, drought risk, and return periods in the Halilrud basin in southeast of Iran. Tabari et al. (2013) focused on the stream flow drought index (SDI) at 14 hydrometric stations over the period 1975–2009 in the northwest of Iran. The results revealed increasing drought severity and return periods in their study region. Besharat et al. (2014) studied the statistical distribution functions to estimate the hydrological drought in the Lake Urmia Basin (LUB). They calculated daily streamflow drought states using log-Pearson III

distribution function from 65 distribution functions to evaluate the return period of hydrological drought in LUB.

Khajeh et al. (2017) examined the impact of climate change on hydrological droughts in Zarinehrud River. They employed downscaled data to predict the drought severity in this river within the period of 2011–2040. Lin et al. (2017) explored the relationship between hydrological drought, reservoir operation, and land cover in southern China. They indicated that hydrological drought responds significantly to the fluctuations of El-Nino Southern Oscillation.

Over the last 30 years, there have been dramatic changes in the distribution and concentration of precipitation, which has been mentioned in various studies. Changes in quantities and distribution of precipitation in the LUB have had significant negative impacts on river flow rate and Lake Urmia water level. Changes in the level of precipitation in the basin area have led to reduced baseflow of the rivers and loss of permanent rivers in the LUB. Alterations of the precipitation concentration have also contributed to disturbing the rain balance and extreme flood events in the LUB. Most studies related to the meteorological and hydrological drought have assessed drought indices, but they have not studied the amount and duration of precipitation as well as flow shortness volume. However, the majority of studies on these issues have overlooked precipitation patterns and its impact on the river drought phenomenon. Also, only a few studies have investigated the trends in precipitation indices and hydrological drought. Since the impact of a drought depends mostly on the severity, frequency, duration, and area which are essential for spatiotemporal analysis, thus, the aim of this study is to evaluate some well-known indices involved with the meteorological and hydrological drought in LUB as the second largest saline lake in the world based on the monthly and annual precipitation of rain gauge stations along with the hydrometric stations within the basin.

2 Methodology

2.1 Case study

Lake Urmia which is a hub for accumulation of water flow of all the rivers in the Urmia basin, with an area of approximately 5750 km^2 and a mean altitude of 1276 m above mean sea level, and is located in the north middle of LUB. Around Lake Urmia, there are 16 wetlands with areas between 5 and 120 ha (of which some have dried up) with a valuable ecosystem. LUB is situated between the eastern longitude coordinates of 44° 14′ and 47° 53′ and the northern latitudes of 35° 40′ and 38° 30′. The precipitation changes in LUB vary from 220 to 900 mm and the mean precipitation is 363 mm, where the amount of precipitation grows from the central parts of the basin toward the surrounding highlands. The location, the

studied rain gauge, and hydrometric stations in LUB are demonstrated in Fig. 1, and the main characteristics of these stations are presented in Table 1.

2.2 Precipitation concentration index

PCI index has been proposed as an indicator of concentration and distribution of the precipitation. The seasonal and annual scales of this index have been calculated as Eqs. 1 and 2, respectively (Oliver 1980).

$$PCI_{Seasonal} = \frac{\sum\limits_{i=1}^{3} p_i^2}{\left(\sum\limits_{i=1}^{3} p_i\right)^2} \times 25 \tag{1}$$

$$PCI_{Annual} = \frac{\sum\limits_{i=1}^{12} p_i^2}{\left(\sum\limits_{i=1}^{12} p_i\right)^2} \times 100 \tag{2}$$

where p_i is the monthly precipitation in ith month. The number 3 in Eq. 1 indicates the number of months in a season. According to the initial results and suggestions of Oliver (1980), the theoretical minimum PCI is 8.3, which showed a completely uniform distribution of precipitation (meaning that the same amount of precipitation occurs each month). He also suggested that the PCI values less than 10 may be inferred as the uniform distribution of precipitation. PCI values from 11 to 15 represent average precipitation, and amounts of 16 to 20 of this index reflect the distribution of their downpours. The value of 16.7 specifies that the total precipitation is concentrated in half of the period.

According to this study, the quantities larger than 20 for the PCI index represent a highly irregular distribution of precipitation (Luis et al. 2011). For example, the value of 25 for this indicator indicates that precipitation occurred in the 1/3 period (this means that the total precipitation occurred in 4 months).

The results of applying this index across different climates of the world such as Spain, Nigeria, and India showed that PCI index can be useful to examine the precipitation concentration distribution (Luis et al. 2011; Adegun et al. 2012; Valli et al. 2013; Khalili et al. 2016; Zamani et al. 2018).

2.3 Dryness volume shortage index

2.3.1 Extracting the flow shortness volume from daily river flow rate

Dryness period is defined as a time interval (a month or more consecutive months) where the river flow rate is less than the
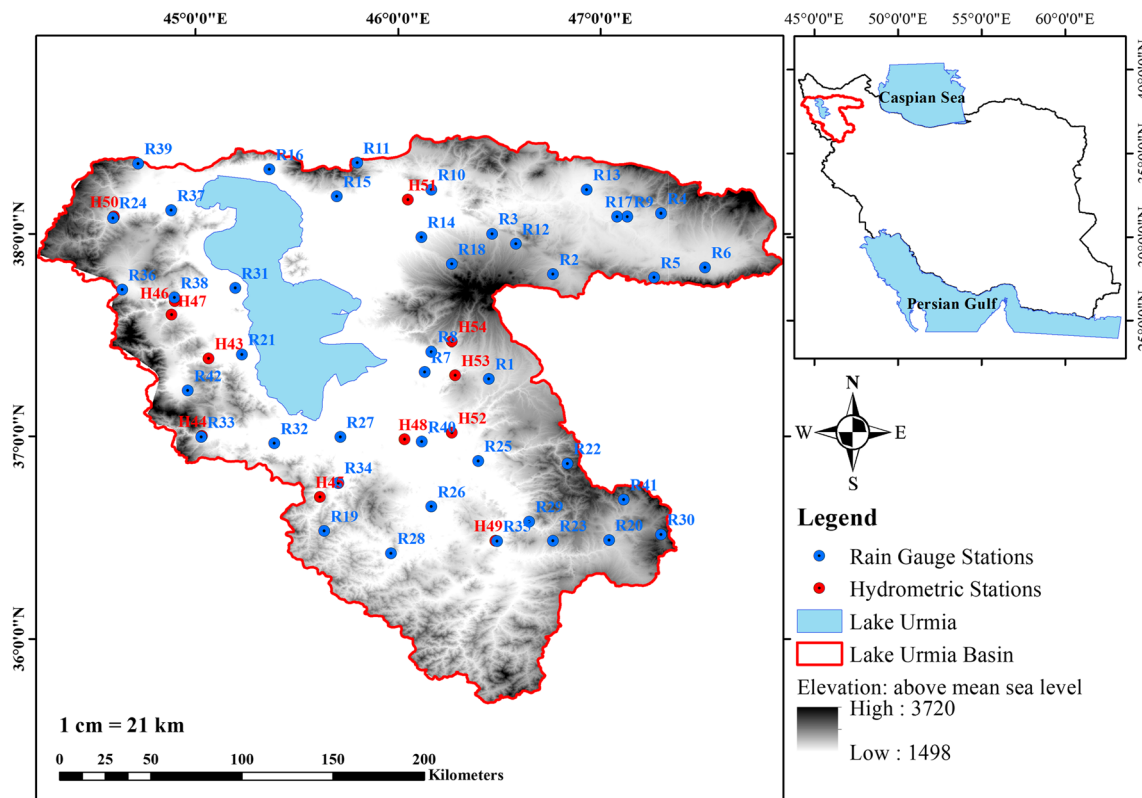

Fig. 1. Location of the selected rain gauge and hydrometric stations in LUB

Table 1. Basic characteristics of the stations used in this study within the period of 1984–2013 (station name which starts with R represents rain gauge and those beginning with H represent hydrometric station)

No.	Station name	Elevation (m)	Mean annual precipitation (mm)	No.	Station name	Elevation (m)	Mean annual precipitation (mm)	No.	Station name	Elevation (m)	Mean annual precipitation (mm) and mean annual river flow rate (m³/s)
R1	Agchekol	1710	424	R19	Afan	1620	579	R37	Tamar	1387	213
R2	Bashsizojan	1850	353	R20	Alasagel	1700	393	R38	Tapik	1398	369
R3	Basmanj	1700	172	R21	Babarood	1282	343	R39	Urban	1840	1840
R4	Ghezelche	1844	329	R22	Badamloo	2119	638	R40	Zarineh	1390	1390
R5	Ghoshchi	1980	768	RR23	Bagch	1898	348	R41	Zereshoran	2100	2100
R6	Haris	1690	464	R24	Chehreq	1611	366	R42	Zharabad	1569	542
R7	Khoshehmehr	1320	309	R25	Chobchole	1361	306	H43	Sari Ghame-sh	1391	48.7
R8	Khormazard	1556	398	R26	Dashband	1318	397	H44	Kutar	1380	7.8
R9	Mehraban	1608	327	R27	Gerdeyaghob	1280	269	H45	Kalhor	1500	1.1
R10	Pardel	1415	238	R28	Ghezel Gonbad	1374	402	H46	Pey Ghala	1500	8.7
R11	Payam	1790	458	R29	Ghezel-Ghaber	1657	323	H47	Tapik	1450	12.2
R12	Saeedabad	1950	381	R30	Ghoshkhana	2260	380	H48	Dizag	1320	7.9
R13	Saray	1545	288	R31	Moshabad	1281	248	H49	Tazakand Simineh	1290	4.1
R14	Isfahlan	1400	273	R32	Naqade	1306	323	H50	Chehreq	1600	3.9
R15	Shabestar	1400	297	R33	Pey Ghala	1306	486	H51	Akhola	1310	10.4
R16	Tasoj	1390	372	R34	Pole sorkhe	1350	356	H52	Tazekand Sofi	1260	3.9
R17	Zarnaq	1600	298	R35	Sari Ghamesh	1391	322	H53	Shirinkand	1380	1.9
R18	Zenjanab	2110	323	R36	Sero	1628	361	H54	Geshlaq Amir	1450	2.0

mean long-term period of the river flow rate (Besharat et al. 2014). The mean individual daily long-term period (MIDLP) of the river flow rate extracted for all 365 days was used to calculate the dryness volume shortage index (DVSI) (Eq. 3).

$$MIDLP = \frac{\text{River flow rate of } 1^{th} \text{Oct of } 1983 + ... + \text{River flow rate of } 1^{th} \text{Oct of } 2013}{\text{Number of years}} \tag{3}$$

Accordingly, 365 MIDLPs of river flow rates have been calculated for each river in the first step. Then daily time series data of flow rate were subtracted from their own MIDLPs to calculate the new data abbreviated by ND. For example, the daily river flow rate data for the 1st of October 1983 were deduced from the MIDLP of first of October. In this way, this new data set (ND) equal to the number of time series of interest was created. The least value of the year was known as the flow shortness volume with 1-day duration. Similarly, the minimum amount obtained from summing the values of the flow shortness volume through two successive days extracted from ND data was regarded as the 2-day flow shortage volume. This procedure continued until reaching the duration

when the river flow rates were less than the mean. Since this study aimed to reach to the consecutive drought periods 1 to n days (here maximum to 60 days), and it may be faced several gaps, therefore, the filling of these gaps may be carried out using a simple linear regression method (Besharat et al. 2014).

2.4 Trend analysis

Mann-Kendall (MK) test (Mann 1945; Kendall 1948) as one of the most well-known nonparametric tests aims to specify whether an ascending or a descending trend exists in data series, since parametric tests have some assumptions including normality, stability, and independence of variables.

However, most of these assumptions cannot be applied to hydrologic variables; instead, the nonparametric methods are more preferred in meteorological and hydrological studies. The nonparametric methods are less sensitive to extreme values compared to parametric tests when examining the trends. Nonparametric tests can also be utilized for data time series regardless of linearity or nonlinearity of the trend (Hamed and Rao 1998; Delju et al. 2013; Khalili et al. 2014; Fathian et al. 2015).

The main assumption of Mann-Kendall test is that the sample data has no significant autocorrelation. However, some hydrological series might have a significant autocorrelation coefficient (Dinpashoh et al. 2013). When a series has an autocorrelation coefficient, there is an increased chance for Mann-Kendall test to reveal existence of a trend in this series. In this case, the null hypothesis, i.e., lack of trend, is rejected, yet this hypothesis should not actually be rejected (Dinpashoh et al. 2013). The Modified Mann-Kendall (MMK) test was first presented by Hamed and Rao (1998) and was later used by Kumar et al. (2009) for analyzing the trend of Indian rivers. Overall, this test has four revisions as described by Dinpashoh et al. (2013). In the present study, the third revision was performed which completely removes the autocorrelation effect of time series. Specifically, in this method, the effect of all significant autocorrelation coefficients is removed from the time series and is applied to series whose autocorrelation coefficients are significant in one or more cases.

2.4.1 Sen's slope estimator

This estimator is a useful indicator in Mann-Kendall test or so-called Sen's slop which represents the extent of trend uniformity. This test was first presented by Thiel (1950) and was later developed by Sen (1968). Meanwhile, in this research, the Pettitt test developed by Pettitt (1979) was employed to evaluate the time of change point for the precipitation, flow rate, and flow shortness volume (Thiel 1950; Sen 1968; Pettitt 1979).

The flowchart of the proposed methodology, including pre-processing of original data, extraction of MIDLP and ND, PCI values, and evaluating the trend of data, is demonstrated in Fig. 2.

3 Results and Discussion

3.1 The results of evaluation of the PCI data in LUB

Using monthly and annual precipitation data of the selected rain gauge stations in LUB from 1984 to 2013 and employing Eqs .1 and 2, PCI values were calculated on annual and seasonal scales with the mean results presented in Table 2. LUB has a regular precipitation distribution pattern on seasonal scale and in spring (Table 2). In spring and fall, irregular distributions of precipitation were observed for all stations. In terms of precipitation distribution, the condition of LUB was irregular and highly irregular in summer, which is not unexpected given the four-season climate of Iran. In winter, the condition over LUB is satisfactory (Table 2).

The results of investigating precipitation concentration of LUB indicated that none of the rain gauge stations had a regular concentration (PCI < 10) on the annual scale, with the rain gauge stations R2, R3, R4, R11, R18, R22, and R24 having a moderate precipitation concentration and distribution. Further at this scale, the rain gauge stations R1, R10, R8, R19, R20, R21, R23, R25, R27, R29, R34, R36, R40, R41, and R42 had irregular concentrations for monthly precipitation in more than 50% of the studied years, suggesting that the precipitation distribution was irregular in 12 months of a year over the studied years. Highly irregular precipitation is visible at stations R38, R31, R27, and R26 at the annual scale. In order to calculate the precipitation concentration index over

Fig. 2 Flowchart of the proposed methodology

Preparing the monthly precipitation data
↓
Extracting PCI values on monthly and annual scales using Equations 1 and 2
↓
Evaluating the trend of data using Mann-Kendall test
↓
Evaluating the time of changing point using Pettitt test

Preparing the daily river flow rate data
↓
Extracting the MIDLP for all of the days using Equation 3
↓
Subtracting daily river flow data from the MIDLP to calculate ND
↓
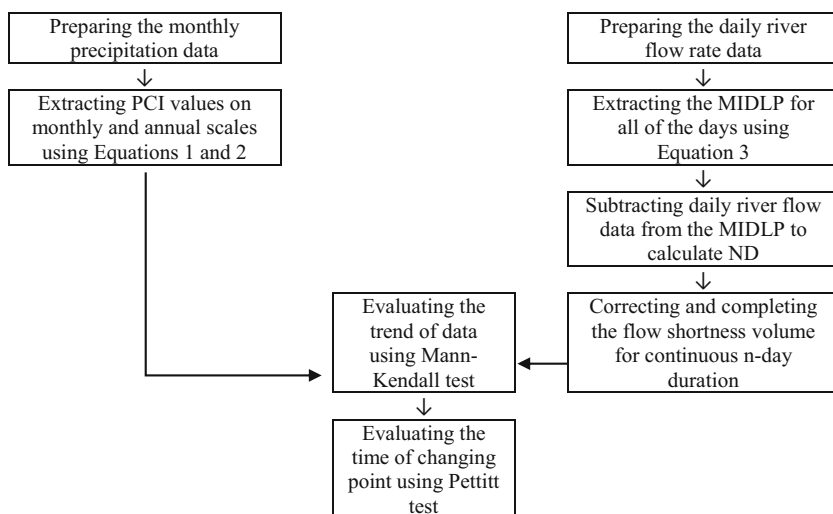Correcting and completing the flow shortness volume for continuous n-day duration

Table 2.   Values of average PCI index for the rain gauge stations of LUB

No.	X_UTM	Y_UTM	Spring	Summer	Autumn	Winter	Annual
R1	628,539	4,127,290	11.9	20.0	12.1	9.9	15.3
R2	655,535	4,185,095	11.7	17.1	12.7	9.8	15.0
R3	628,773	4,206,830	11.1	16.8	12.4	10.2	15.0
R4	701,672	4,219,409	11.5	17.8	11.1	10.8	15.9
R5	699,604	4,184,196	11.4	19.7	11.8	9.3	15.3
R6	721,474	4,190,308	11.6	16.6	13.2	10.2	16.9
R7	600,422	4,130,604	12.8	23.2	13.0	10.6	17.4
R8	603,238	4,141,735	12.7	21.5	13.2	10.3	17.1
R9	687,099	4,217,210	11.9	16.8	11.9	10.7	16.9
R10	602,130	4,230,498	11.2	18.8	12.2	11.1	15.6
R11	569,903	4,244,952	10.9	18.7	11.6	10.2	15.4
R12	639,111	4,201,450	12.0	17.3	14.0	10.3	17.0
R13	669,248	4,231,622	11.4	17.5	12.5	10.1	14.9
R14	598,064	4,204,554	11.8	20.1	12.6	10.7	17.1
R15	561,305	4,226,388	12.3	20.3	12.4	10.4	17.4
R16	682,714	4,217,111	11.2	15.1	12.4	10.5	15.5
R17	532,053	4,241,014	12.1	17.7	13.3	11.1	17.6
R18	611,438	4,189,928	10.7	19.2	13.0	10.3	16.0
R19	557,052	4,043,148	13.6	22.1	13.0	9.6	17.1
R20	683,041	4,039,877	12.9	21.7	14.3	9.5	16.1
R21	520,490	4,139,581	13.4	21.5	13.8	10.8	17.4
R22	663,820	4,081,365	12.3	22.0	11.5	9.3	15.6
R23	658,254	4,039,018	12.6	23.7	13.8	10.2	18.1
R24	464,363	4,214,549	10.4	14.9	12.3	10.5	14.2
R25	624,549	4,082,095	14.2	25.0	12.4	10.6	18.5
R26	604,229	4,056,986	13.5	23.3	13.5	10.2	18.1
R27	563,788	4,094,597	13.3	22.1	13.6	10.8	19.7
R28	586,755	4,031,106	14.8	23.8	14.5	10.3	18.6
R29	647,580	4,049,351	13.6	23.0	14.0	9.7	17.0
R30	705,960	4,043,501	13.3	23.0	12.9	9.5	16.9
R31	517,436	4,175,992	12.5	21.2	13.8	11.6	18.5
R32	534,795	4,090,995	13.0	21.2	12.7	10.6	17.0
R33	502,663	4,094,287	13.6	21.0	12.0	9.6	15.9
R34	563,126	4,069,480	12.8	21.5	13.0	10.5	17.8
R35	633,518	4,038,435	13.0	21.2	12.7	10.6	17.0
R36	468,231	4,175,171	11.5	17.3	12.0	10.7	16.0
R37	489,613	4,218,563	12.2	21.1	15.1	12.8	19.1
R38	490,988	4,170,717	13.0	20.2	14.8	11.4	18.3
R39	475,445	4,244,172	11.4	18.1	12.3	13.3	17.5
R40	599,592	4,092,413	13.1	21.0	13.1	10.2	17.4
R41	689,112	4,062,234	12.2	21.8	14.9	9.4	16.9
R42	496,768	4,119,904	13.7	20.7	13.3	10.6	16.8
Average			12.4	20.2	13.0	10.4	16.8

LUB, the results obtained through the zoning at the annual scale are presented in Fig. 3. In order to draw zoning maps of PCI values and Z statistic of MMK test, Kriging and inverse distance weighted (IDW) methods were compared. The results revealed that Kriging method with a higher correlation coefficient between measured and simulated data had better results than IDW method, which is in accordance with Khalili et al. (2014) and Asong et al. (2015) results.
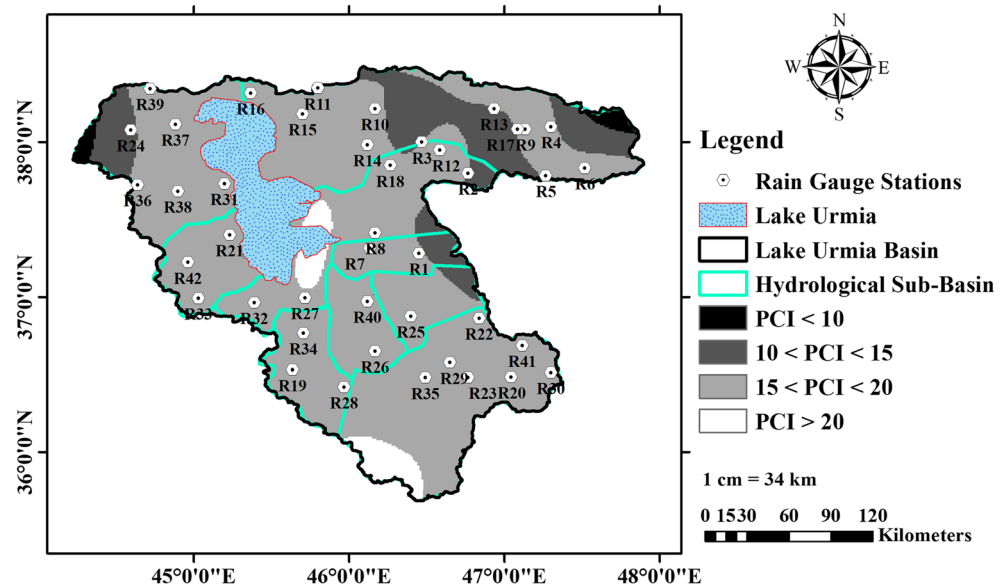
As can be observed in Fig. 3, at the annual scale, the precipitation distribution is irregular at most of the stations in LUB. This means that the precipitation distribution is irregular across the months of the year. Note that the southeast of the Lake Urmia has a highly regular precipitation concentration at the annual scale. The highly irregular concentration of precipitation distribution in the southeast of Lake Urmia suggests increased extreme precipitations in these areas. It can be also concluded that the precipitation in these areas occurred only in a few events over the years. Some areas in the northwest and northeast of the Lake Urmia tend to have a more regular concentration. The results of this study are in accordance with the research of Khalili et al. (2016) in evaluating the precipitation concentration trend of rain gauge stations of Iran. Indeed, the results indicated a critical situation in terms of precipitation distribution and precipitation pattern in the southeast of the lake. The results of examination of time of change point and Z statistic of MMK of annual PCI values are presented in Table 3. Also, the results of zoning the Z statistic of MMK test are reported in Fig. 4.

According to the results, the changes in the trend of PCI values indicated that at the annual scale, the APCI (annual PCI) values in the southern and northwestern areas of the Lake Urmia along with the eastern and southern regions of the study area have a significant trend. The most significant descending trend in the APCI values of station R12 with Z statistic of MMK test was − 2.26, while the most significant increasing trend relates to station R40 with Z statistic of MMK test as 3.28. The mean value of Z statistic of MMK test at the annual scale was increasing, and most of the studied stations over LUB had an ascending trend for APCI values. This suggests intensified irregularities of the concentration and distribution of annual precipitation in the study area over the studied period. The rise in the irregularities in the annual

precipitation is the result of precipitation shortage in recent years (Khalili et al. 2016). The irregular pattern of annual precipitation and an increase in extreme precipitation are also the consequences of decrease in precipitation. Using the Pettitt test, the time of change point of meteorological drought values (PCI) was detected.

The results indicated that during the studied period and among whole stations, only 6 stations showed their change point between 1995 and 2000. It suggests an increase in the irregularity of the annual precipitation regime in LUB over the two last decades. The results also indicated that the growing trend in the precipitation irregularities has not occurred in a specific year and it has happened during the studied period gradually and continuously in LUB.

3.2 The results of investigating DVSI in LUB

After evaluating the meteorological drought index, PCI, and its trend of changes in LUB, the changes of flow shortness volume over the studied basin were investigated using the river flow rate of the hydrometric stations in the basin. Based on the definition presented in this research, all of the mean daily river flow rates within Lake Urmia were utilized after investigating the validation of data in the studied time period. Then, the flow shortness volume values of the studied rivers were extracted for an up to 60-day duration. Selection of a 60-day duration in this study had several reasons: (a) In this study, the maximum continuous durability for flow shortness volume durations was 60 days; (b) in studied rivers, the flow rate was lower than the mean daily long term for the maximum consecutive 60 days; and (c) in some rivers, the flow rate was lower than the mean daily long term for more than 60 days, but due to the same durability choice, the 60-day duration was selected.

Table 3. *Z* statistic of MMK test of annual PCI and time of changing point using the Pettitt test for LUB (1984–2013)

No.	*Z* Statistic	Time of change point	
	Annual scale	PCI data	Rainfall data
R1	1.14		
R2	− 0.06		
R3	0.58		1997
R4	− 1.82	1998	
R5	0.13		1998
R6	− 1.35		1998
R7	− 0.58		
R8	1.98	1996	1995
R9	− 2.01		
R10	1.29		
R11	0.41		
R12	− 2.46		1996
R13	− 1.29		
R14	0.02		
R15	1.48		1991
R16	0.96		
R17	0.73	1999	1996
R18	0.00		
R19	1.71		
R20	0.09		
R21	1.33		1996
R22	− 0.28		
R23	− 0.47		
R24	− 0.28		
R25	1.74		1994
R26	0.47		
R27	2.27	2000	
R28	1.41		
R29	0.88		
R30	− 0.51		
R31	1.82		
R32	1.11		
R33	0.86		
R34	1.94	2000	
R35	1.11		
R36	− 0.54		
R37	− 0.69		
R38	− 0.24		
R39	0.99		
R40	3.28	1995	1995
R41	0.67		
R42	− 0.14		

Among these, the 1-, 10-, 30-, and 60-day durations of stations H47 and H45 were chosen randomly to be plotted in Figs. 5 and 6. Further, to examine long-term changes of flow

shortness volume of the studied stations, the trend of changes was calculated (see Table 4). As can be observed in Figs. 5 and 6, the patterns of flow shortness volume changes in 1-, 10-, 30-, and 60-day durations are the same and show similar changes. Regarding this fact and the high correlation between different durations of flow shortness volume at each studied hydrometric station, it is possible to calculate the trend of one of the durations and attribute it to the others. Using the MMK test, the trend of changes of the 30-day duration of flow shortness volume of the studied rivers was inspected as presented in Table 4.

Further, the results of evaluating the flow shortness volume values indicated that in most of the studied rivers from 2005 onwards, increased flow shortness volume can be seen (see Table 4). This suggests reduced river flow rate compared to the mean long-term value. Indeed, each of these durations represents the flow shortness volume compared to the mean data. Further, the decreasing trend reflects an improved hydrological condition of the river in terms of flow rate. For example, at station Kalhur (H45), a diminishing trend in the flow shortness volume values in 1989, 1993, 1994, and 1997 to 2013 approved the increase in the river flow rate throughout the last decade (Fig. 6).

Flow shortness volume durations of 1 to 60 days indicated that within 1 to 60 consecutive days, the river flow rate was less than its mean long term. As observed in Figs. 5 and 6, the changes of flow shortness volume in different durations over the studied time period are the same. These figures are a proper tool to compare the flow shortness volume with the long-term annual average of river flow rate. By fitting statistical distribution functions to the flow shortness volume values, the return period of flow shortness volume can be calculated in different return periods. By employing intensity, duration, and frequency curves of flow shortness volume, it can be estimated at different return periods.

The trend changes of flow shortness volume values over the study area revealed that the trend of 11 of 12 stations was growing. Meanwhile, the trend changes of DVSI values were significantly diminishing at station H45, which represent a significant decline in the flow shortness volume and therefore a growth in the river flow rate. This station has the lowest average river flow rate during the studied time period. Considering the spatial variation of precipitation over the study area, the rise in the average annual river flow rate in this station may be attributed to increasing extreme precipitations. Stations H52 and H47 had a non-significant ascending trend in flow shortness volume. On the other hand, the other stations (H43, H44, H46, H48, H49, H50, H51, H53, and H54) experienced a significant growing trend in flow shortness volume, reflecting river flow rate decline in the studied time period. The major ascending trend was observed at station H44, which has a *Z* statistic of MMK test equal to 3.98. The

Fig. 4. Spatial variation of annual trend of PCI
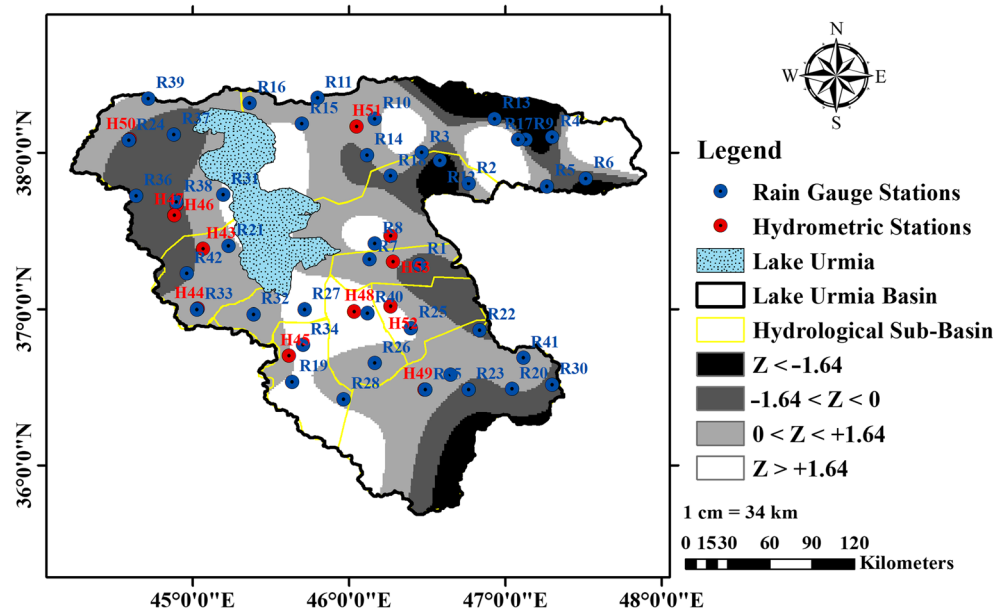
annual precipitation in sub-basin H44 was also falling during the studied time period. Further, it seems that the air masses entering Iran are experiencing a shortage of input precipitation in the study area (Khalili et al. 2016). Evaluation of the flow shortness volume in the studied scale suggested that almost all of stations had experienced a continuous flow shortness volume. The highest flow shortness volume belonged to station H49 located in the southeast of LUB. Further, the lowest flow shortness volume value belonged to station H52 located in the east of LUB (Table 4). Considering the hydrological sub-basins depicted in Fig. 7, the rain gauge stations R22, R41, R30, R20, R29, and R35 affect H49, and caused a growing flow shortness volume trend at this station. Rain gauge station R25 has affected this hydrometric station and has a non-significant increasing trend of flow shortness volume.

3.3 Trend analysis of flow shortness volume and PCI values using hydrological sub-basin

Since hydrometric station H45 with rain gauge stations R19, R28, and R34 is located in an individual sub-basin, thus, the same behaviors are expected to be obtained. The results of exploring the trend of the flow shortness volume values and APCI values along with considering the hydrological sub-basins both revealed a significant diminishing trend in the flow shortness volume values. Accordingly, reduced flow shortness volume values in the mentioned hydrometric station proved that the condition of the river improved in the studied time period. As the APCI values increased significantly, then the precipitation irregularity of basin H45 was intensified. In other words, irregularities in the precipitation concentration and distribution pattern in this basin suggest heightened river
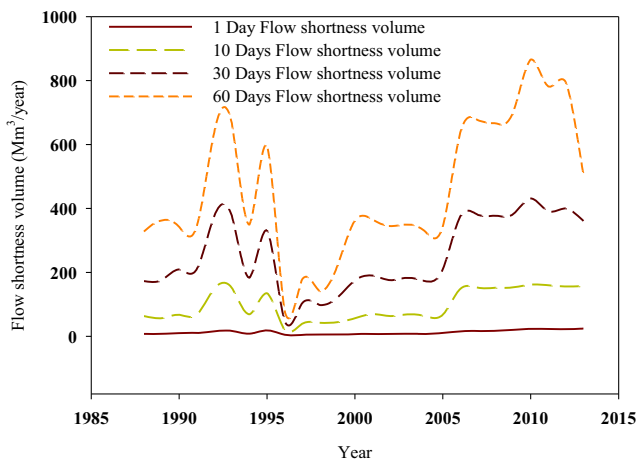

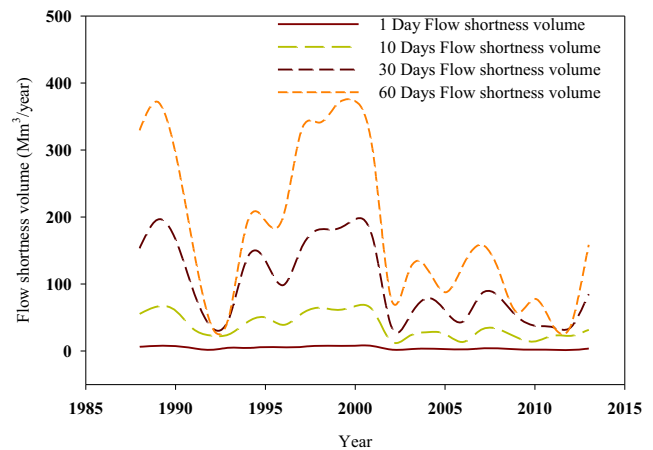**Fig. 5.** Flow shortness volume of Mahabadchai River in different durations in H47

Fig. 6. Flow shortness volume of Rozehchai River in different durations in H45

Table 4.   Maximum and minimum of volume flow shortage values and Z statistic of MMK test for DVSI values in LUB during 1984–2013

Station number	Station name	Max volume flow shortage (mm^3/year/60 days)	Min volume flow shortage (mm^3/year/60 days)	Annual Z statistic
H43	Dizaj	943.4	61.3	2.10
H44	Pey Ghala	1673.6	82.9	3.98
H45	Kalhur	372.6	35.3	-3.03
H46	Tapik	1624.0	75.2	3.63
H47	Kutar	781.8	177.1	0.41
H48	Tazakand Simineh	432.1	48.9	2.13
H49	Sari Ghamesh	5114.7	169.6	3.85
H50	Chehreq	475.2	41.2	3.53
H51	Akhola	1655.0	93.3	3.19
H52	Shirinkand	351.7	25.7	0.54
H53	Geshlaq Amir	402.0	52.1	1.80
H54	Tazekand Sofi	409.5	38.3	2.25
Sum		14,234.6	900.9	

flow rate. Consequently, with elevation of the extreme values, river flow rates also increased at this station. Regarding the average annual river flow rate of 1.14 m^3/s, it is obvious that the extreme events have been able to increase the average annual river flow rate at this station, which was followed by reduced flow shortness volume. The irregularities in the precipitation distribution indicate that the majority of precipitation is falling with a high intensity which may cause floods which is not temporally distributed evenly. This can elevate the peak flow of the river and has a positive impact on the mean long term. In sub-basin H43, there is a significant increasing trend in flow shortness volume (hydrological
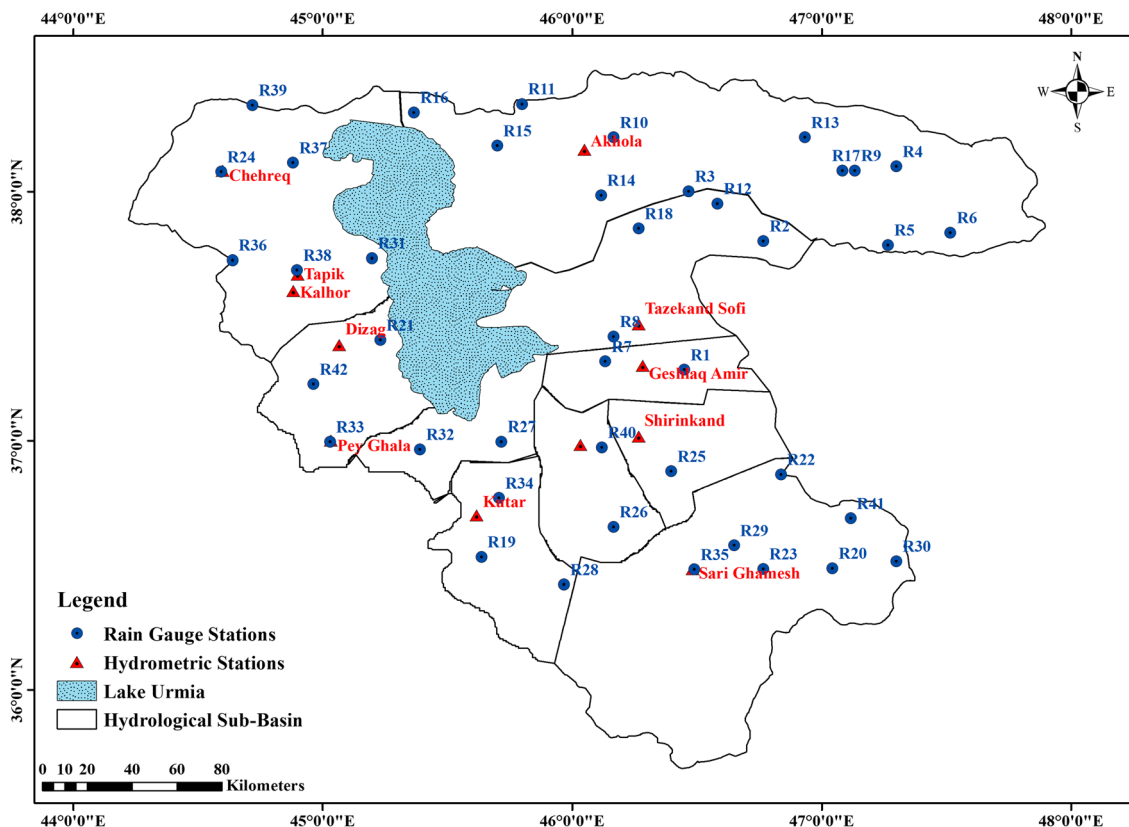

Fig. 7.   Location of rain gauge stations placed in the identified hydrological sub-basin

drought). In general, the values of APCI have an increasing trend in the basin. The growth of irregularities of the annual precipitation in this sub-basin increased the flow shortness volume. This, in turn, lowered the river flow rate at station H43. Sub-basin H44 had the greatest increase in the flow shortness volume. Accordingly, the results indicated that the rise in the irregularities of annual precipitation in this basin (increasing trend of the APCI values) intensified the flow shortness volume in the studied period. Similar to sub-basin H44, the same behavior was also observed in H26 and H46. The trend of APCI values in these sub-basins had minor fluctuations. Sub-basin H49 had also a significant growing trend in the flow shortness volume. The dominant trend of APCI values of the rain gauge stations was ascending in this sub-basin.

The area delineated through station H52 revealed a rising trend in flow shortness volume and APCI values. The similar area delineated by hydrometric station H53 had two rain gauge stations, with one (R2) of them affecting the river flow rate directly; this rain gauge also showed an ascending trend in APCI values. Sub-basin H54 had four rain gauge stations, with the trend of most of the APCI values being of declining type. The decrease in the values of APCI caused reduced irregularity of precipitation distribution, thereby generating an ascending trend of the flow shortness volume.

The Pettitt test was employed to investigate the time of change point of flow shortness volume values and the meteorological drought (PCI values). The results of evaluating the time of change point of the flow shortness volume values are presented in Table 5.

Having examined the time of change point of the flow shortness volume values in the studied period, it was found that all stations had a time of change point. In general, all the studied hydrometric stations experienced a time of change

Table 5. The results of time of changing point of volume flow shortage values using the Pettitt test for LUB (1984–2013)

Station number	Changing point (year)
H43	2000
H44	2000
H45	2003
H46	2001
H47	1996
H48	1996
H49	1998
H50	1997
H51	1999
H52	1998
H53	1994
H54	1996

point in flow shortness volume values within the period between 1993 and 2003.

By inspecting the time of change point of meteorological drought (PCI) and the values of hydrological drought and considering the hydrological sub-basin, it was concluded that hydrometric station H54 experienced the time of change point of flow shortness volume in 1996 (see Table 5). Although the gauge stations R12, R8, and R18 were located within hydrological sub-basin H54, it experienced a time of change point of meteorological drought data in 1999. The results also showed that the first time of change point in the sub-basin H54 occurred in 1995 at the rain gauge station R8, which was close to and in the southeast of Lake Urmia. This station also is located in the southwest of hydrometric station H54. Afterwards, in 1996, a time of change point happened in the flow shortness volume. Then, in 1998 and 1999, times of change points occurred in PCI values at stations R12 and R18. The trend of flow shortness volume at hydrometric station H54 and the trend of PCI values in its sub-basin rain gauge stations were both ascending. The results indicated that in the sub-basin of hydrometric station H54, the changes of flow shortness volume began from Lake Urmia (rain gauge station R8) in 1995, and affected the hydrometric station H54 in 1996 which was far away from the lake. Later, in 1998 and 1999, two others influenced rain gauge stations R12 and R18, which were located at the farthest point of Lake Urmia. Overall, the flow shortness volume changes (an increasing trend) at hydrometric station H54 started in 1995 from the vicinity of Lake Urmia and moved toward the East of basin in 1999. The time of change point of the hydrological drought data (flow shortness volume values) of hydrometric station H45 experienced a failure in the trend of time series data in 2003.

However, the PCI values started to increase in 2000. According to the results, the increasing time of change point of flow shortness volume values was influenced by the enhanced values of PCI in 2000. This represents the beginning of drought or the start of changing patterns of precipitation in basin H45 whose impact can be seen in the amount of river flow rate and flow shortness volume in 2003. Rain gauge station R40, within the sub-basin H48, experienced a time of change point in the trend of PCI data in 1995, where this time of change point in the precipitation pattern caused changes in flow shortness volume in 1996. At rain gauge station R40, time of change point in the trend of PCI values occurred in 1995. In this regard, the results revealed that the change of the precipitation pattern in these two sub-basins in the southeast of the lake started in 1995 and reached the south of Lake Urmia in 2000. Overall, based on the results, the first sign of altered precipitation patterns in the LUB occurred at rain gauge stations located near Lake Urmia. These changes in the precipitation pattern also affected the river flow rate. At station H52, a time of change point occurred in the flow shortness volume values in 1998, corresponding to the change

point observed in precipitation values of R25 in 1994. Similar evidence was seen at rain gauge stations located in basin H51, which had a time of change point in precipitation and PCI values during the study period in 1996 and 1999. The time of change point of the flow shortness volume values also occurred in the same years.

4 Conclusion

Although drought is a creeping phenomenon in which the beginning and end time cannot be predicted, some features can be determined partly with the tests in time series to resolve time of change point for precipitation trend and drought values.

One of the advantages of studying drought indices such as PCI is the possibility of observing precipitation distribution across the months of a season or a year and determining its distribution, as well as employing the output results when facing drought or heavy rainfalls. The results of evaluating the precipitation concentration of Lake Urmia indicated that precipitation distribution is irregular over the basin. According to the results, with comparing the last 10 years of the studied period with first 10 years, the precipitation concentration index increased by 0.38 and 4.1% at the selected stations in the west and east of Lake Urmia, respectively. Also distributions of precipitation in LUB based on PCI values were proved high irregularity in summer with PCI amount of 20.1 and most regularity in winter with PCI amount of 10.4.

On the other hand, the finding revealed that in all sub-basins, the changing point occurred in the flow shortness volume values after the time of change point of precipitation time series. In other words, the flow shortness volume was evident with 1- to 4-year delays after the time of change point of precipitation across all of the studied sub-basins. The outcome of evaluating the studied flow shortness volume values with different durations indicated that apart from station H45, all of the studied stations had the minimum volumetric flow shortage in the early years of the time period until 1995, after which the volumetric flow shortage increased in an ascending order. These findings revealed reduced river flow rate since 1995 in 92% stations. Station H45, unlike the other hydrometric stations, indicated a different behavior which since 2002 onwards experienced a downward trend in flow shortness volume values. In general, the eastern stations of Lake Urmia had less flow shortness volume within the studied period. These stations had the minimum influence on the water level of Lake Urmia compared to the other stations due to a lower river flow rate. Nevertheless, the low value of flow shortness volume at these stations does not imply that the condition of these basins is better. An increase in the flow shortness volume in future periods would create concerns about the condition of Lake Urmia and its basin. The reason is that the intensified flow

shortness volume originates from the reduced river flow rate and can lead to diminished input flow into Lake Urmia. The results of investigating the time of change point of PCI and flow shortness volume values showed that the changes in the trend of PCI data started earlier than the changes in the flow shortness volume values.

However, the flow shortness volume at all of the stations (except station H45) increased more considerably over the last 10 years of the studied time period. The time of change point of the flow shortness volume values also confirms this change. In perennial rivers, the rise of PCI value will be followed by increased flow shortness volume. Indeed, for analyzing these two indices (PCI and DVSI), natural river conditions should be considered.

As the main outcome of this research, it should be noted that supposing a high flow shortness volume (with duration 60 days), it is expected to face with a 900 million cubic meter decrease in inflow and even it may be increased to 14 billion cubic meter in worst conditions.

Compliance with ethical standards

Conflict of interest   The authors declare that they have no conflict of interest.

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