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Variations in temporal occurrence of discharge in Urmia Lake Basin

Behzad Hessari[1]*, Kamran Zeinalzadeh[2]

[1]Assistant Professor of Water Engineering Department, Urmia University and Urmia Lake Research Institute, Urmia University, Urmia, Iran, Email: b_hessari@yahoo.com

[2]Associate Professor of Water Engineering Department, Urmia University and Urmia Lake Research Institute, Urmia University, Urmia, Iran, Email:kzeinalz@yahoo.com

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Corresponding author:
b.hessari@urmia.ac.ir
b_hessari@yahoo.com

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Abstract

Urmia Lake has experienced a critical environmental condition in recent years. This paper discusses changes in various hydrological measures in the Urmia Lake Basin (ULB) and its tributaries. The Mann-Kendall test with Trend-Free Pre-Whitening (TFPW) approach was used to estimate the trend in annual time series (1978-2011) of average and peak values of discharge recorded in 65 and 55 stations of ULB, respectively. Accordingly, the Cumulative Sum (CUSUM) control chart test was used for change detection analysis and T-statistic to compare the discharge in two periods (before and after 1995 as the year in which the Urmia Lake water level started to decline). The results revealed that 55 stations (~86%) had a descending trend in recorded average values of discharge data. In 38 stations (~59%), this diminishing trend was significant at 95% confidence level. The trend of peak data recorded in 42 out of 55 stations was declining. This falling trend was significant at 95% confidence level in seven stations. The average value of T-statistic for all stations (2.8) represented a significant difference between discharge values in two periods at most of the studied stations. The CUSUM results indicated that in more than 50% of the stations, which recorded discharge series of 11 rivers, the existing jump was significant at 95% of confidence level. The trend of 0-1 m^3/s interval was ascending, but the trend of other discharge ranges (more than 1 m^3/s) was descending. The results of this study also revealed that the amount of peak and discharge volume entering the lake in 1998-2011 decreased in comparison with 1978-1997.

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Introduction

In recent years, detection of the trend of meteorological and hydrological time series has received considerable attention. The trend in time series can be detected by two commonly used tests including parametric and non-parametric tests. The non-parametric trend tests are less powerful than parametric ones, as in the former methods, the type of data distribution is not important (Hamed and Rao 1998; Khanmohammadi et al., 2017a). However, because of this relaxed condition, the non-parametric tests are more appropriate. Two common non-parametric tests are Spearman's Rho and Mann-Kendall, which have been applied by many researchers for trend detection (e.g., Xu et al., 2006; Li et al., 2008; Fatichi et al., 2009; Shadmani et al., 2012; Merabti et al., 2018). The power of the Spearman's Rho and Mann-Kendall tests is similar for trend detection (Yue et al., 2002a).

The parameters considered in trend analysis such as temperature (Saboohi et al., 2012; Kousari et al., 2013; Malekian and Kazemzadeh 2016; Shrestha et al., 2017), precipitation (New et al., 2001; Krishnakumar et al., 2009; Pandey and Khare, 2018), reference evapotranspiration (Bandyopadhyay et al., 2009; Khanmohammadi et al., 2017b; Shi et al., 2017), relative humidity (Singh et al., 2008; Kousari et al., 2011; Eymen and Köylü 2018) and wind speed (Laapas and Venäläinen 2017; Kohler et al., 2018) have been investigated by some researchers in the past two decades. Some of the mentioned studies such as Khanmohammadi et al., (2017b) have used Iran as their case while other are related to ULB (for example Malekian and Kazemzadeh, 2016).

Similar to other parameters, discharge trend has been extensively analyzed in several parts of the world and in different times (Birsan et al., 2005; Lins and Slack 2005; Dixon et al., 2006; Do et al., 2017). Kumar et al., (2009) investigated the stream flow trends for 31 stations using four variations of the Mann-Kendall method. The stations were located in Indiana and they had over 50 years of recorded data. The results of the mentioned study revealed that the type of flow statistics, length of used data, and autocorrelation structure can affect the trend results. Sabzevari et al., (2015), using five statistical tests alongside precipitation trend, analyzed the trend of river discharge on annual and monthly scales during 56 years. They used the data on 13 hydrometric stations located in the southwest of Iran. The results of trend discharge indicated a significant increase for annual series as well as for October through April series. Minaei and Irannezhad (2018) investigated variations of temperature, precipitation, and river discharge. They used data for 17 stations located in northeast of Iran. They applied the Mann-Kendall and Sen's slope methods via trend-free pre-whitening method (TFPW) approach for trend analysis. If there is autocorrelation in the time series, the TFPW is applied to eliminate the correlation. The obtained results revealed a significant growing trend in temperature and precipitation, plus a downward trend in river discharge during 1953–2013.

Given the importance of ULB, several studies were conducted in this basin (Abbaspour and Nazaridoust 2007; Abbaspour et al., 2012; Salehi Bavil et al., 2017; Ahmadaali et al., 2018). Some of the studies about discharge trend are related to ULB. Niazi et al., (2014) explored the trends in Aji-Chay River discharge and used Mann-Kendall test for the river's water quality at Vanyar station. Based on the obtained results, in wet and dry seasons, with the downward trend of discharge in this river, all water quality parameters had upward trend. The results also indicated that the decreasing trend in discharge was more rapid in wet seasons in comparison with dry seasons. Fathian et al., (2014) applied four versions of the Mann-Kendall test, and then evaluated the trends in hydrologic plus climatic data in ULB. They applied the data for 35, 35, and 25 of rain, stream, and temperature gauge stations, respectively. The results of this study revealed that for stream flow, unlike temperature, the downward trends were more pronounced than the upward ones. Fathian et al., (2015) employed three statistical tests in the trend of streamflow, precipitation, and temperature on annual and seasonal scales. They used data recorded (>30 years) in 95 stations (35, 35, and 25 rain, stream, and temperature gauge stations, respectively) of ULB. According to the obtained results, streamflow had a general falling trend which was pronounced in the stations located in downstream of the basin. The trend of temperature was positive in most stations and there was an area-specific trend for precipitation.

So far, several researchers have investigated discharge and its trend in Iran, but literature review shows that there is no comprehensive study on changes in streamflow of the ULB's rivers, and especially discharge's frequency. As the first attempt in the ULB, the main goal of the present study was to investigate the trend of average and peak discharge values as well as to evaluate the changes of discharge frequency for 65 gauging stations located in 14 basins and one floodway in ULB.

Materials and methods

Urmia lake basin and used data

The ULB with an area of about 52,000 km2 is located in the northwest of Iran (longitudes 44° 14' to 47° 53' E and latitudes 35° 40' to 38° 20' N). A large area of ULB is located in the East and West Azerbaijan provinces. More than seven million people live in these two provinces and perform agricultural, industrial, and service activities. Artemia harvesting, salt extraction, as well as tourism and recreational activities are sources of income in the coastal region (Delju et al., 2013). The dominant climate of the basin is semi-arid and it annually receives a precipitation of about 300-mm (Feizizadeh and Blaschke 2013). This basin has 14 main sub-basins surrounding the lake. The areas of these sub-basins are within 431-11,759 km2 (Fathian et al., 2015).

The Urmia lake, with the highest depth of about 11.32 m and an average depth of 5.08 m, in 1995 experienced a record water level of 1278.39 m.a.s.l with an area of about 5500 km 2 and volume of 33 BCM. From 1995, its level has been declining by about 40 cm annually. Urmia Lake being 40-55 km wide and 140 km long is the largest lake in Iran and is a hyper saline lake in the world with an average TDS=267 gr/lit and Ec=503 during 1966-2002, with 640 ds/m record in 2015. This lake is fed by 20 permanent and seasonal rivers. Further, few springs and submarine streams feed the lake. Zarrineh-Roud, Simineh-Roud, and Aji-Chay are the most important rivers (Fathian et al., 2015). The length of these rivers varies from 20 to 260 km. The data of the rivers are recorded by several hydrometer stations (more than 165 cases). In this study, all of the hydrometer stations were investigated. Some of the stations had long term recorded data. Thus, these stations were selected for the research. The geographical location of 65 selected stations can be seen in Figure 1. Also, Figure 1 displays the basin of each studied river separately. Note that 55 stations with long-term recorded peak data can be seen in this figure. The selected stations have recorded the data of all permanent rivers of the ULB. These rivers include Zula-Chay, Nazlu-Chay, Rouzeh-Chay, Shahr-Chay, Barandoz-Chay, Gadar-Chay, Mahabad-Chay, Zarrine-Roud, Simine-Roud, Soufi-Chay, Javan-Chay, Galeh-Chay, Azar-Shahr, and Aji-Chay. In addition, in this research, one floodway named Tasouj was investigated. Table 1 presents more details on the studied basins and their hydrometer stations. Note that, in addition to discharge data, precipitation data recorded in the ULB were applied. Figure 1 also displays the stations located in the outlet of each studied basin.

Methodology

The average and peak values of discharge and precipitation data on a monthly scale were collected from Iran Water Resources Research Organization (IWRRO) for the studied stations. The tests were conducted using “Trend” package and SPSS software. The most common period of 1978-2011 was chosen for statistical and frequency trend analysis of discharge in the studied stations. In this research, the frequency of monthly discharge was classified in different ranges including 0-1 m3/s, 1-5 m3/s, 5-30 m3/s, 30-100 m3/s as well as more than 100 m3/s. Then, the trends of discharge and discharge frequency were analyzed using the non-parametric method Mann-Kendall as proposed by Mann (1945) and developed by Kendall (1975). The computation steps of Mann-Kendall method are presented by Eqs. (1) to (4):

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(x_j - x_i) \quad (1)$$

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

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

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

where, xj and xi represent the consecutive data values of time series, respectively. N is the number of data, sgn (xj–xi) denotes the sign function, Var(S) is the S variance by normal distribution, m shows the number of tied values, ti reflects the number of ties for the ith value, and Z is the statistic of Mann-Kendall test (Yue et al., 2002a). Z>0 and Z<0 represent that the time series have an ascending trend or descending trend, respectively. When this value is greater than 1.96, it means that the trend is significant at 95% confidence level (Peng et al., 2017). Z=0 indicates no trend for data. Further, in order to apply Mann-Kendall method, significant autocorrelation which may exist in the studied time series must be removed. To detect significant autocorrelation in time series, autocorrelation test was applied. For this purpose, lag-1 autocorrelation coefficient (r1), expected value E(r1), and its variance Var(r1) in random data time series were determined as:

$$r_1 = \frac{\left[\sum_{i=1}^{n-1}(x_i - \bar{x})(x_{i+1} - \bar{x})\right]}{\left[\sum_{i=1}^{n}(x_i - \bar{x})^2\right]} \quad (5)$$

$$E(r_1) = -1/n \quad (6)$$

$$Var(r_1) = (n^3 - 3n^2 + 4)/\left[n^2(n^2-1)\right] \quad (7)$$

The statistic of autocorrelation test (Z) is calculated as:

$$Z = \left|r_1 - E(r_1)\right| / Var(r_1)^{0.5} \quad (8)$$

The descriptions for the statistic of Mann-Kendall test are contained in autocorrelation analysis statistic.

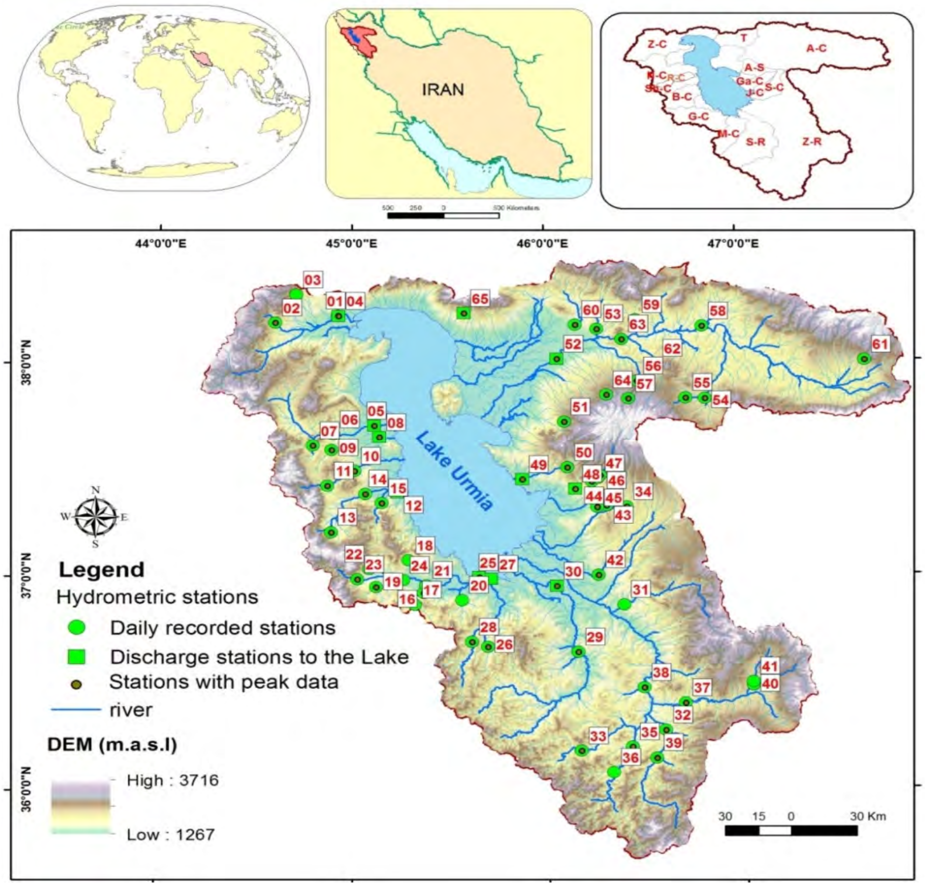


Figure 1. Location of studied hydrometer stations in the ULB

Trend-Free Pre-Whitening (TFPW) approach

As mentioned, to apply the Mann-Kendall method, the autocorrelation in data series should be considered and removed (Shadmani et al., 2012). There are several methods to eliminate the autocorrelation. One of the proposed methods is TFPW approach, as proposed by Yue et al., (2002b). This method has been applied in several studies such as Zhang et al., (2008), Shadmani et al., (2012), and Khanmohammadi et al., (2017c). In this study, the TFPW approach was used to remove the impact of significant autocorrelation at 95% confidence level.

Table 1. General information at selected 65 hydrometer stations

Map code	River (Sign)	Station	OS	RD	RP	Map code	River (Sign)	Station	OS	RD	RP
01	Zula-Chay (Z-C)	Chahrigh-Olia		*	*	34	Zarrineh-Roud (Z-R)	Moganjigh		*	*
02		Nazar-Abad		*	*	35		Pol-Anyan		*	*
03		Orban		*		36		Pol-Gheshlagh		*	
04		Yalghoz-Aghaj	*	*	*	37		Safa-Khane		*	*
05	Nazlu-Chay (N-C)	Abajalo-Sofla	*	*	*	38		Sari-Ghamish		*	*
06		Tapik		*	*	39		Sante		*	*
07		Karim-Abad		*	*	40		Shakhe-chap-Alasghol		*	
08	Rouzeh-Chay (R-C)	Pol-Ozbak	*	*	*	41		Shakhe-Rast-Alasghol		*	
09		Kalhor		*	*	42		Shirin-Kand		*	*
10	Shahr-Chay (Sh-C)	Band		*	*	43	Soufi-Chay (S-C)	Chekan		*	*
11		Mir-Abad		*	*	44		Esfestanj		*	*
12	Barandoz-Chay (B-C)	Baba-Roud	*	*	*	45		Gheshlagh-Amir		*	*
13		Bi-Bakran		*	*	46		Kahlic-Darasi		*	*
14		Dizaj		*	*	47		Taze-Kand		*	*
15		Ghasemlo		*	*	48	Javan-Chay (J-C)	Khorma-Zard	*	*	*
16	Gadar-Chay (G-C)	Balghchi		*	*	49	Galeh-Chay (Ga-C)	Shishvan	*	*	*
17		Bayazid-Abad		*		50		Yengaje		*	*
18		Eslam-Abad		*		51	Azar-Shahr (A-S)	Ghermizegol		*	*
19		Chapar-Abad		*	*	52	Aji-Chay (A-C)	Akhola	*	*	*
20		Mohammad-Shah		*		53		Anakhaton		*	*
21		Naghadeh		*	*	54		Bostan-Abad		*	*
22		Oshnavieh		*	*	55		Diznab		*	*
23		Pey-Ghale		*	*	56		Hervi		*	*
24		Pie-Jic		*		57		Lighvan		*	*
25		Pol-Bahramloo	*	*	*	58		Merkid		*	*
26	Mahabad-Chay (M-C)	Bitas		*	*	59		Nahand		*	*
27		Gerd-Yaghob	*	*		60		Pol-Sanikh		*	*
28		Koter		*	*	61		Sahzab		*	*
29	Simineh-Roud (S-R)	Dashband		*	*	62		Saeed-Abad		*	*
30		Miandoab	*	*	*	63		Venyar		*	*
31	Zarrineh-Roud (Z-R)	Chobloche		*		64		Zinjenab		*	*
32		Dare-Panbedan		*	*	65	Tasouj (T)	Darian	*	*	*
33		Ghabghablo		*	*						

Note: OS stands for the stations located in outlet, while RD and RP mean stations with recorded discharge and recorded peak, respectively.

CUSUM approach

To investigate and analyze the probable jump in data, non-parametric test (distribution free CUSUM) (Grayson et al., 1996; Chiew and Siriwardena 2005) was applied. This method has been applied in a few studies such as Salehi Bavil et al., (2017).

Results and Discussion

Temporal discharge variations in the ULB

Based on discharge changes in studied stations, Eslam-Abad and Sari-Ghamish stations have the lowest and highest recorded average value of discharge, respectively (Figure 2). This figure depicts a decreasing trend for the two studied stations. In other words, Figure 2 shows that the discharge has been negative in stations with the lowest and highest discharge.

To quantify the trend in data time series, the Mann-Kendall test was chosen. To apply the Mann-Kendall test, it is necessary to eliminate the autocorrelation that exists in data. Figure 3 illustrates the lag-1 autocorrelation coefficient in all studied stations. For stations where lag-1 autocorrelation coefficient lies within the defined range, the use of Mann-Kendall test for trend analysis is sufficient and the TFPW approach is not needed. However, for stations with a significant lag-1 autocorrelation coefficient, the use of TFPW approach is required. According to Figure 4, the discharge of 20 stations (~31%) has a significant lag-1 autocorrelation coefficient in the studied series. Thus, the trend analysis in these stations should be calculated through the Mann-Kendall and the TFPW approach.

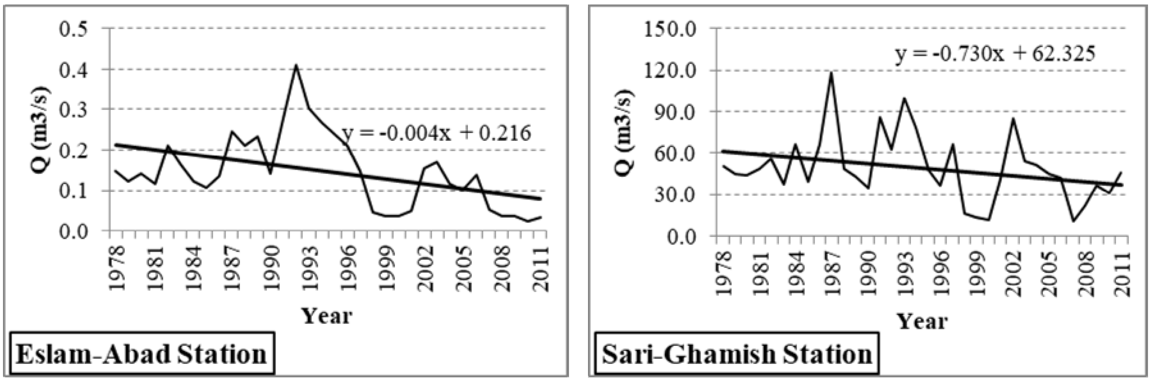


Figure 2. Variations of annual discharge in the two studied stations.

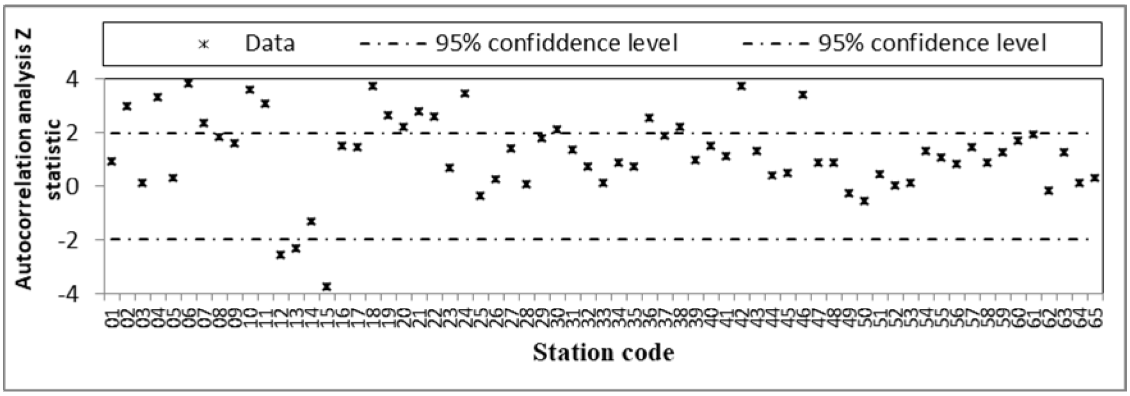


Figure 3. Autocorrelation analysis results for discharge data in all studied stations (the point shows the data and dotted line represents the 95% confidence level)

Figure 4 presents the spatial distribution of discharge trend calculated based on the Mann-Kendall test in the ULB. This figure shows that in stations located in the south, south-west, and southeast of the Urmia Lake, the trend of discharge is negative in most of the stations and this downward trend is significant at 95% and 99% confidence levels. This figure also demonstrates a critical condition in Zarrine-Roud and Simine-Roud basins, which are the most important rivers that feed the lake.

The falling trend in these basins means that the incoming discharge to the lake has decreased. This affects the Urmia Lake level reducing the water level, surface, and volume of the lake.

To illustrate the results of Figure 4, the percentage of stations with a downward or upward trend are presented in Figure 5. As seen in Figure 5, 55 stations (~86%) had a descending trend while the trend of discharge was increasing in nine stations (~14%). The discharge data in Ghasemlo station had no trend (Z=0). The falling trend of 38 stations (~59%) was significant at 95% confidence level, but the growing trend in some stations was not significant. Also, according to Figure 5, among 55 stations with a diminishing trend, the decreasing trend in 69% of the stations was significant at 95% confidence level. The main point in this figure is that the trend of an average discharge in most of the studied stations of ULB was decreasing.

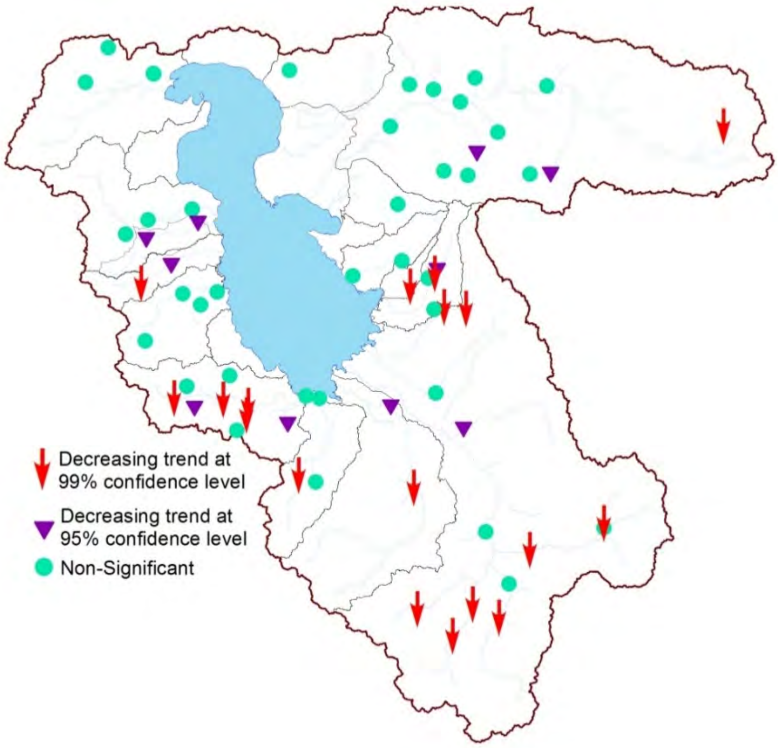


Figure 4. Spatial distribution of discharge trend in the ULB

The results of the CUSUM test for jump analysis on the mean discharge for the stations of the studied basins are outlined in Figure 6. It shows except in three rivers named Barandoz-Chay, Azarshahr, and Tasoj, a jump has occurred in the discharge of some stations along the rivers. In 12 mentioned rivers (except Aji-Chay), the recorded discharge series in more than 50% of the stations had a significant jump at 95% confidence level.

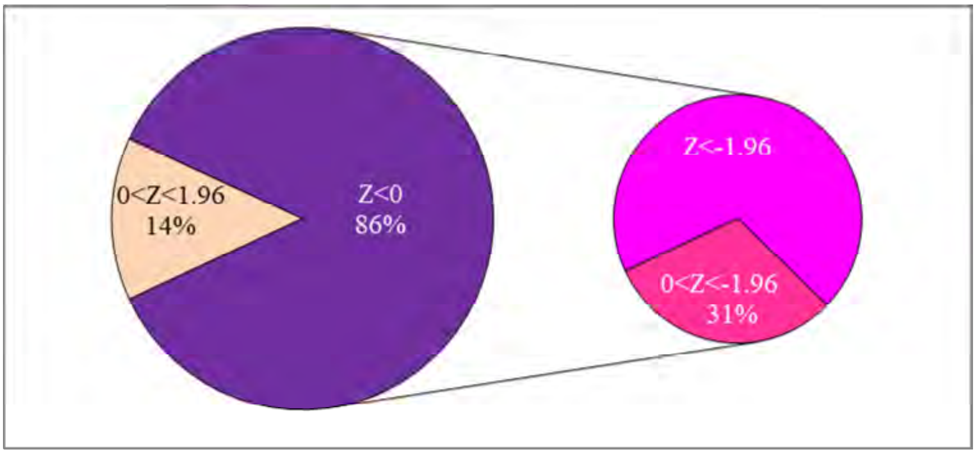


Figure 5. Percentage of the studied stations with rising or falling trend in discharge

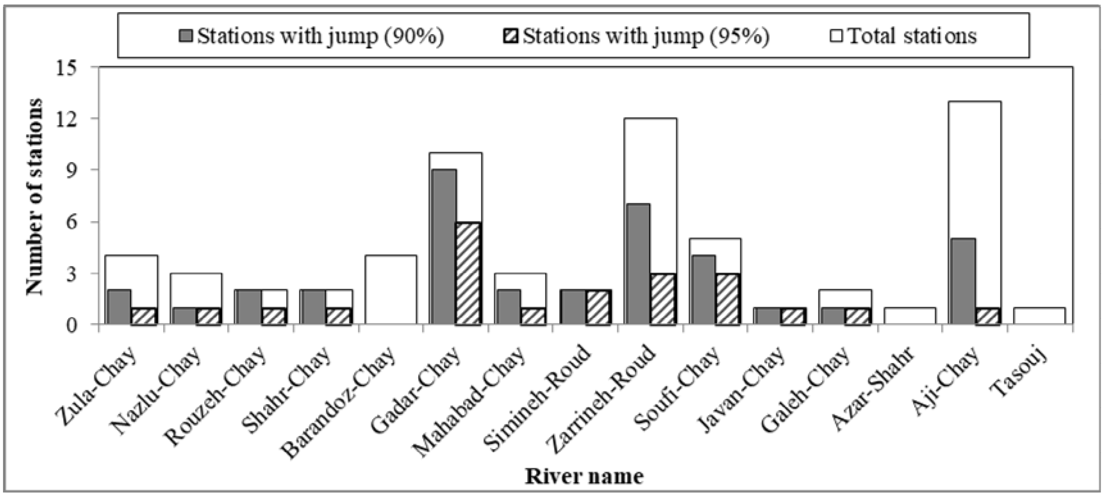


Figure 6. Jump analysis by the CUSUM test for all stations

Also, to analyze the annual changes of discharge in the ULB by unit time series, the dimensionless discharge data with 95% confidence level bound were applied as the range of discharge across numerous stations was different. To calculate dimensionless discharge data, discharge of each station (Q) was divided by the average value of discharge calculated in the same station (Q_{mean}). After determining dimensionless time series for each station, the average values of all the studied stations were calculated. Figure 7 indicates variations of annual dimensionless discharge in ULB. In this figure, a downward trend of discharge for the studied basin can be seen. This figure shows the condition of discharge in all years in ULB, simply depicting the declining trend of discharge in this basin.

The falling trend for Aji-Chay has been reported by Niazi et al., (2014). Similarly, the results of Fathian et al., (2014 and 2015) showed that streamflow in the ULB had a descending trend, especially at downstream stations.

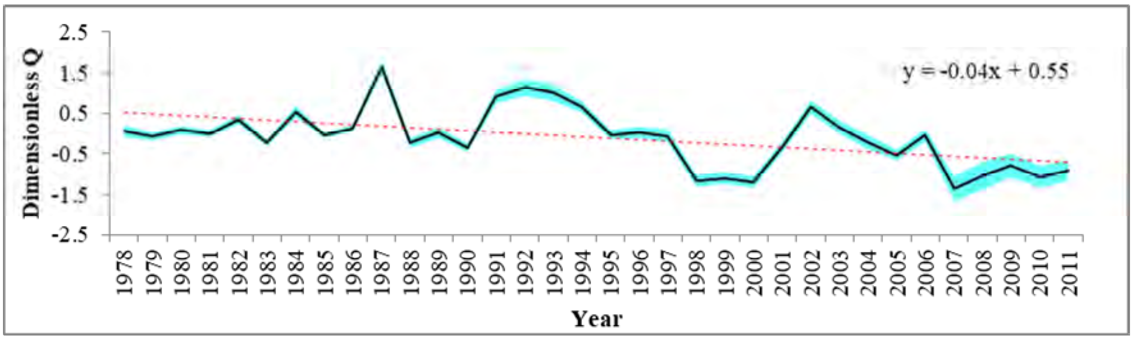


Figure 7. Time series of dimensionless discharge in the ULB with ±95% confidence bound

Discharge frequency change in the ULB

In addition to discharge of the ULB, the changes of discharge frequency were investigated for the 34-year period (1978-2011). For data classification, all data recorded at 65 stations during 1978-2011 were used. The data were sorted where the values 50th, 75th, 90th, 95th, and 99th percentage of data were calculated as 1, 5, 10, 30, and 100 m^3/s. Thus, the discharge frequency change was evaluated within ranges including 0-1 m^3/s, 1-5 m^3/s, 5-30 m^3/s, 30-100 m^3/s, and more than 100 m^3/s. The results of autocorrelation analysis for discharge frequency in studied the stations are displayed in Figure 8. Based on Figure 8, 38 (58%), 30 (46%), 18 (28%), and nine (14%) stations had a significant lag-1 autocorrelation coefficient in their discharge frequency data within ranges 0-1, 1-5, 5-30, and 30-100, respectively. Thus, the use of the TFPW approach is justified.

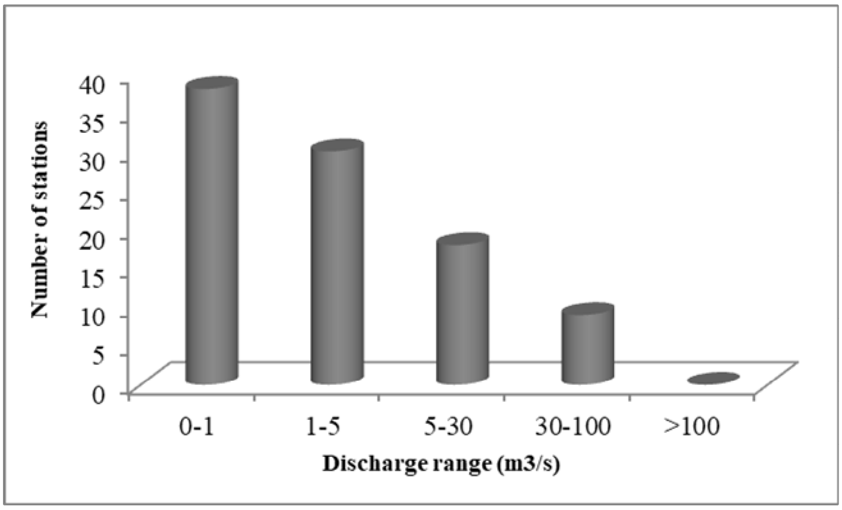


Figure 8. Number of stations with a significant autocorrelation in discharge frequency data (95% confidence level)

The trend of discharge frequency in the studied stations of the ULB is reported in Table 2. Note that "discharge ranges" in some stations are missing. As seen in Table 2, the trend of discharge frequency in 0-1 m^3/s range was increasing at 94% of stations and at some stations this increasing trend was significant at 95% confidence level. However, this trend was negative for larger ranges (more than 1 m^3/s) in more than 50% of stations.

To summarize the result of Table 2, the number of stations with a downward or upward trend in different discharge ranges at each basin is presented in Figure 9. As seen, the number of stations with a significant growing trend at 95% confidence level for the discharge range 0-1 m^3/s was 19, and one station had a rising trend in discharge with 1-5 m^3/s range. However, 14, 8, and 6 stations had a significant falling trend for 1-5, 5-30, and

30-100 m^3/s ranges, respectively. The stations located in Zarrine-Roud sub-basin in the south and the stations located in Aji-Chay in east-north had the largest number of stations for the discharge range more than "0-1m^3/s".

Table 2. The Mann-Kendall results calculated for discharge frequency in different discharge ranges (1978-2011) in studied rivers

Code	River (Sign)	0-1	1-5	5-30	30-100	>100	Code	River (Sign)	0-1	1-5	5-30	30-100	>100
01	Zula-Chay (Z-C)	↑	↑	↓	-	-	34	Zarrineh-Roud (Z-R)	↑*	↓*	↑	-	-
02		↑	↓	0	-	-	35		↑	↑	↓*	0	↑
03		↑*	-	-	-	-	36		↑	↑	↓	0	↑
04		↑	↓	↓	-	-	37		↑	↑	↓*	0	0
05	Nazlu-Chay (N-C)	↑	↓	↓	0	-	38		0	↑*	↑	↓*	0
06		↑	↑	↓	↓	0	39		↑*	↓	0	0	-
07		↑	0	↑	0	-	40		↑	↓*	↓	-	-
08	Rouzeh-Chay (R-C)	↑	↓	-	-	-	41		↑*	↓*	↓	↑	-
09		↑	↓	0		-	42		↑*	↓*	↓*	-	-
10	Shahr-Chay (Sh-C)	↑	↑	↓	0	-	43	Soufi-Chay (S-C)	0	↑	-	-	-
11		↑*	↓	0	0	-	44		↑	0	-	-	-
12	Barandoz-Chay (B-C)	↑	↑	↓*	0	-	45		↑*	↓*	↓	-	-
13		↑	↑	0	↑	-	46		↑*	↓	0	-	-
14		↑*	↑	↓*	0	-	47		↑*	↓*	0	0	-
15		↑	↓	0	↑	-	48	Javan-Chay (J-C)	↑	↓	↑	-	-
16	Gadar-Chay (G-C)	↑	↓	0	-	-	49	Galeh-Chay (Ga-C)	↑*	↓*	↓	0	-
17		↑	↓	-	-	-	50		↑	↓	0	-	-
18		↑	0	-	-	-	51	Azar-Shahr (A-S)	0	0	↑	-	-
19		↑	↓	-	-	-	52	Aji-Chay (A-C)	↑	↑	↓*	↓	0
20		↑*	↓*	0	-	-	53		↑	↓	0	-	-
21		↑*	0	↓	↓*	-	54		↑*	↓*	↓*	-	-
22		↑	↑	0	-	-	55		↑*	↓*	0	-	-
23		↑	↓	0	↓	-	56		↑	↓	0	-	-
24		↑*	↓*		-	-	57		↑	↓	↑	-	-
25		↑	0	↓	↓*	-	58		↑	↑	↓*	0	-
26	Mahabad-Chay (M-C)	↑	↓*	0	-	-	59		↑	0	↑	-	-
27		↑	↓*	↓	0	-	60		↑	↓	0	-	-
28		↑	↑	↑	↑	↑	61		↑	↓	↑	-	-
29	Simineh-Roud (S-R)	↑*	↑	0	↓*	0	62		↑	0	-	-	-
30		↑*	↑	↑	↓*	↓	63		↑	↑*	↓	↓*	0
31	Zarrineh-Roud (Z-R)	↑	↓	↓	↑	-	64		0	↑	-	-	-
32		↑*	↑	0	↓	0	65	Tasouj (T)	↑	↓	-	-	-
33		↑	↑	↓	0	-							

Note: ↑ and ↓ represent the positive and negative trends, respectively and * means significant level at 95%.

In addition to discharge, the peak data series play an important role in the Urmia Lake's level. Also, the peak data as a category of discharge can confirm the change in discharge frequency trend in the ULB. For this reason, along with discharge, the trend of peak data in this basin was separately analyzed. Based on the obtained results, the peak data recorded in 11 out of 57 studied stations had a significant lag-1 autocorrelation coefficient in their series. Thus, the TFPW approach was used for the data. The Mann-Kendall results are presented in Figure 10. The results indicate that most of the studied stations (42 cases) had a falling trend. This declining trend was significant at 95% confidence level in seven stations.

name	Zula-Chay			Nazlu-Chay		Rouzeh Chay		Shahr-chay			Barandoz-Chay				Gadar-Chay				Mahabad-Chay		
Q(m3/sec)	0<Z<1.96	Z>1.96	0>Z>-1.96	0<Z<1.96	0>Z>-1.96	0<Z<1.96	0>Z>-1.96	0<Z<1.96	Z>1.96	0>Z>-1.96	0<Z<1.96	Z>1.96	0>Z>-1.96	Z<-1.96	0<Z<1.96	Z>1.96	0>Z>-1.96	Z<-1.96	0<Z<1.96	0>Z>-1.96	Z<-1.96
0-1	3	1		3		2		1	1		3	1			7	3			3		
1-5	1		2	1	1		2	1		1	3		1		1		6	2	1		2
5-30			2	1	2					1				2			2		1	1	
30-100					1						2						3	2	1		
>100																			1		

name	Simineh-Roud				Zarrineh-Roud				Soufi-Chay				Javan-Chay		Galeh-Chay				Azar-Shahr	Aji-Chay				Tasouj	
Q(m3/sec)	0<Z<1.96	Z>1.96	0>Z>-1.96	Z<-1.96	0<Z<1.96	Z>1.96	0>Z>-1.96	Z<-1.96	0<Z<1.96	Z>1.96	0>Z>-1.96	Z<-1.96	0<Z<1.96	0>Z>-1.96	0<Z<1.96	Z>1.96	0>Z>-1.96	Z<-1.96	0<Z<1.96	0<Z<1.96	Z>1.96	0>Z>-1.96	Z<-1.96	0<Z<1.96	0>Z>-1.96
0-1		2			6	5			1	3			1		1	1				1	2			1	
1-5	2				5	1	2	4	1		1	2		1			1	1		3	1	5	2		1
5-30	1				2		5	3			1		1				1		1	3		1	3		
30-100				2	2		1	1														1	1		
>100			1		2																				

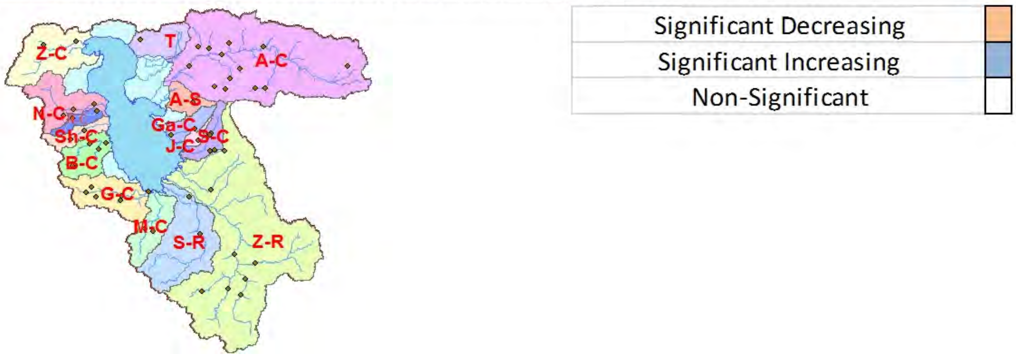


Figure 9. Number of stations with a decreasing or increasing trend in different discharge ranges at each sub-basin

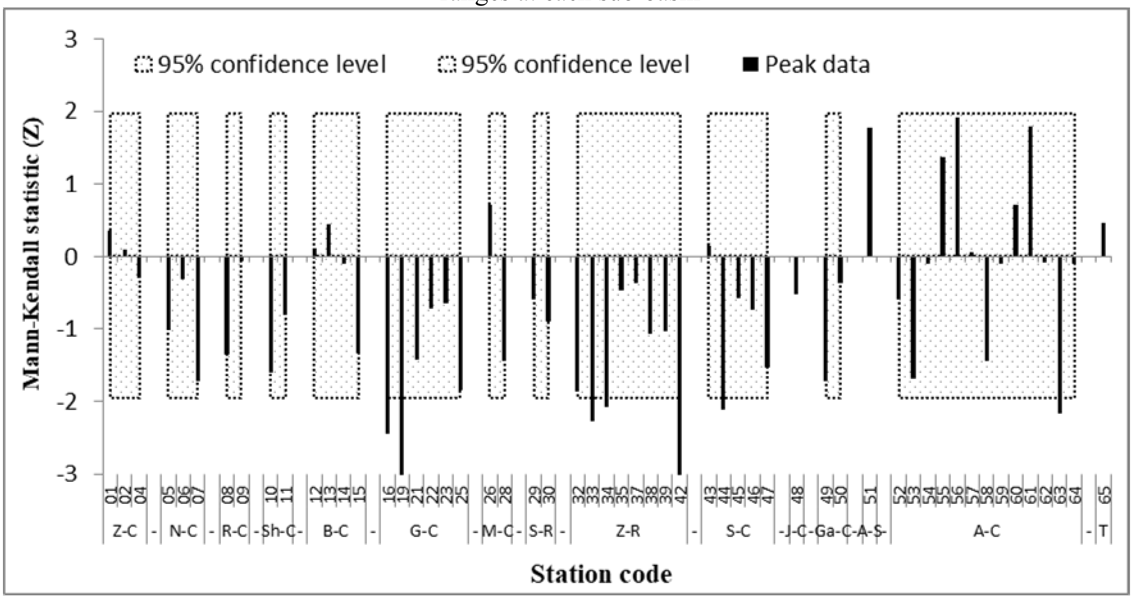


Figure 10. Trend analysis of peak discharge series in the ULB

The spatial distribution of peak discharge series trend in the ULB is shown in Figure 11. According to this figure, there is no significant trend in most of the stations. Six stations with a significant falling trend (at 95% and 99% confidence levels) are located in the southeast and southwest of Urmia Lake.

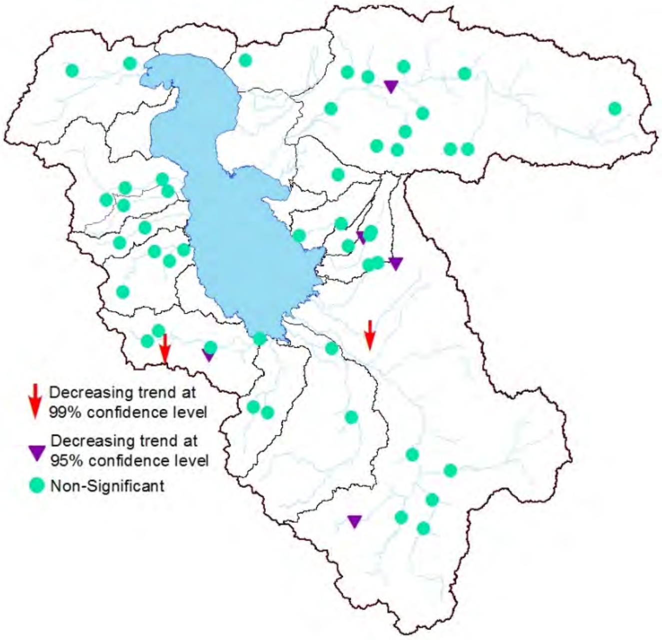
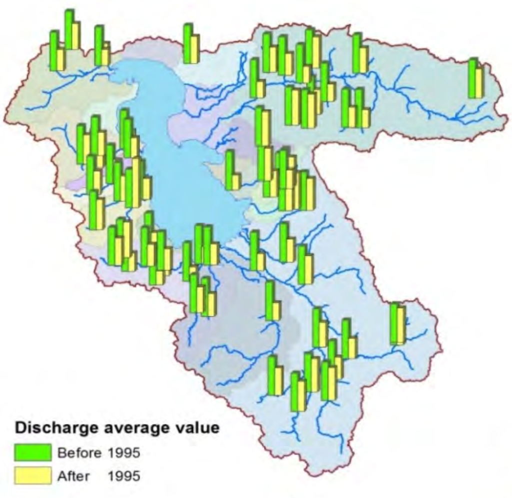


Figure 11. Spatial distribution of peak data trend in the ULB

Changes of discharge entering Urmia Lake

According to the sensitivity analysis presented by Abbaspour et al., (2012), the lake is highly sensitive to discharge of rivers. Based on water level in Urmia Lake, the lake has started to decline from 1995. Thus, considering 1995 as a base year, the change of discharge recorded in the studied stations was analyzed in years before and after 1995 (two periods). To compare the discharge value in the mentioned two periods (years before and after 1995), T-statistic was used depicted in Figure 12. The dotted line in this figure shows the critical value of T-statistic. Based on T-statistic in Figure 12, in 47 stations (72.3%), the average value of discharge in the years before and after 1995 had a significant difference at 95% confidence level. The average value of T-statistic for all stations (2.8) represents the significant difference between discharge in the two periods for most of the studied stations.



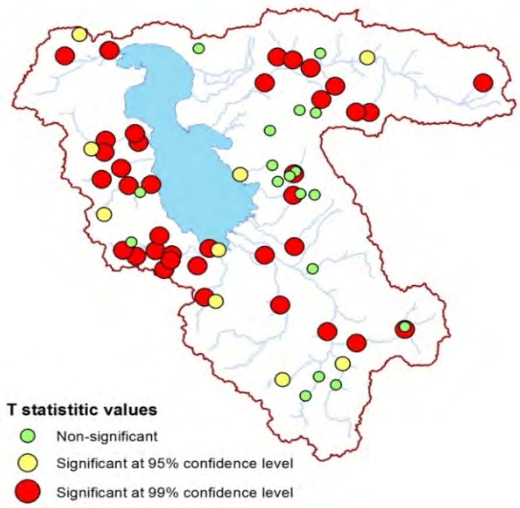


Figure 12. T-statistic values for comparison of average discharge values in two periods (before and after 1995)

In order to analyze the changes of discharge to Urmia Lake, the recorded data in the stations located near the rivers entering Urmia Lake were separately studied. The Box-plot diagram of average (Q) and peak (Qp) values of discharge in the mentioned stations for seven separated periods is presented in Figure 13. As seen in Figure 13, after four and five-year intervals (1978-1997), the discharge and peak values of water entering the lake has dropped. The 1998-2002 interval had the lowest discharge and peak range entering the lake while lake condition has been critical. Based on the results, the discharge and peak in the last three studied intervals (1998-2011) were lower than those of the first four studied intervals (1978-1997). In other words, the amount of peak and discharge entering the lake in 1998-2011 decreased in comparison with 1978-1997.

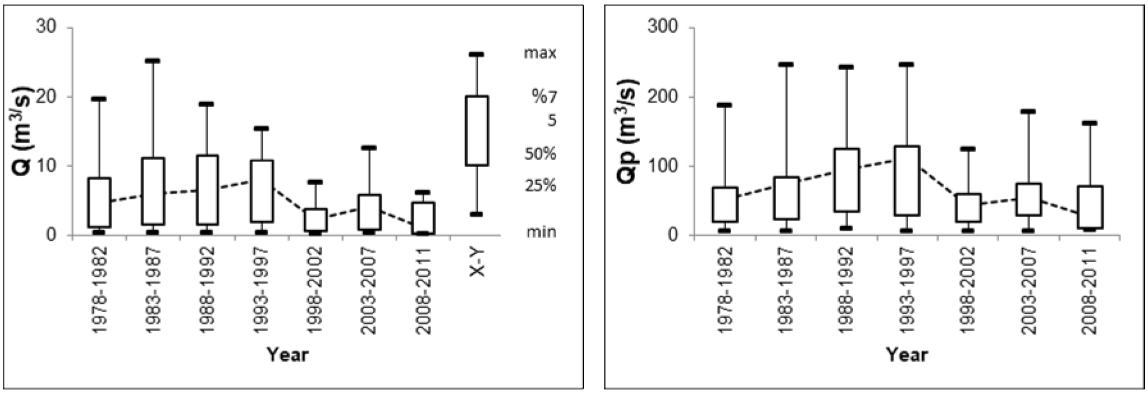


Figure 13. Changes of discharge in outlet stations discharged to Urmia Lake

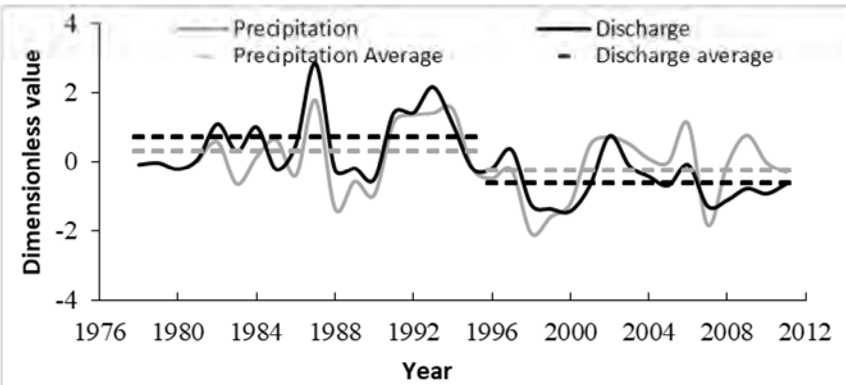


Figure 14. Dimensionless value of basin's precipitation and discharge entering Urmia Lake

To find the effect of precipitation on discharge entering Urmia Lake, dimensionless time series of average basin's precipitation and discharge recorded in outlet stations were reported in Figure 14. $Y=(x-\bar{x})/\sigma$ was used to calculate the dimensionless values of data (x) with average $\bar{x}$ and standard deviation of σ. In Figure 14, the average value of precipitation and discharge before and after 1995 is recognized by dotted lines. The falling value of precipitation and discharge can be seen in this figure for the years after 1995 and in comparison with the previous years. The average precipitation and discharge were 350 mm and 4.8 BCM before 1995 which changed to 307mm and 2.08 BCM, respectively after 1995. It is noted that only in 1987, 9.26BCM of water entered the lake from rivers being almost equal to 1/3 of the total volume of the lake. These values indicate that reduction in discharge was greater than the decline of precipitation. It means that the falling trend of discharge entering Urmia Lake can be described by precipitation, but precipitation reduction is not a sufficient factor. Human activities can be the second effective factor. Expanding cultivated areas and increasing use of surface water by several dams have reduced the discharge entering Urmia Lake.

The paper goes through several statistical analyses, and finds that there is a decrease in both river discharges and the lake water level. The water level of Urmia as a shallow lake is influenced by its entering water changes and water balance issues. One of the important factors in level change of this lake is surface discharge from rivers as the results of research by Abbaspour and Nazaridoust (2007) revealed that 3086 MCM of water should be annually fed to Urmia Lake until this lake has a sustainable ecosystem. The methods used to investigate the basin-wide changes of discharge are standard in the hydrological literature. Thus, in this study, the trend of average and peak values of discharge and the discharge frequency were investigated. The results indicated the declining trend of average and peak values of discharge and downward path of discharge frequency in most of the studied stations. Also, it was interesting that the reduction of the entering discharge occurred simultaneously with the beginning of water level decline in Urmia Lake. The fall of discharge in ULB is higher because of: a) the changes in the frequency of precipitation (Salehi Bavil et al., 2017), b) existence of nine reservoirs and 32 medium dams (ULRI database), c) human activities such as conversion of natural areas to rainfed land and conversion of rainfed areas to irrigated agriculture, d) development of service and industry sector for agricultural activities, e) publicizing wet agriculture technologies and policies in a dry and semi-dry area like Iran and emphasizing on production increase per hectares instead of water productivity improvement, f) unsustainable irrigation development, j) substitution and cultivation of high demand crops such as sugar beet and horticulture development and k) development of agricultural water pools to reserve water in upstream areas and etc. Some of the above-mentioned issues were unavoidable because of population growth and economic growth policies, exacerbated by improper land use policies.

Conclusion

Analysis of surface water in the ULB river gauges showed that 55 stations (~86%) had downward trend in recorded average discharge values. In 38 stations (~59%), this falling trend was significant at 95% confidence level. The trend for 0-1 m^3/s interval was upward, while the trend for other discharge ranges (more than 1 m^3/s) was downward. The results of this study also indicated that the amount of peak and discharge volume entering the lake in 1998-2011 decreased in comparison with 1978-1997.

This declining trend in surface water can change the type of water supply for agricultural activities by farmers. With reduction of surface water, the farmers use other water sources such as groundwater and gray waters. With farmers excavating wells and extracting groundwater to irrigate cultivated crops, groundwater reserves will be reduced and aquifers will be drained. Through agricultural strategic management and proper operation of ULB's dams, the amount of discharge entering the lake will be increased and peak discharge will reach the lake which may help restore Urmia Lake. Urmia Lake environmental crisis is a multi-dimensional and complex issue, and as such further research is required covering other aspects of sustainable solutions to water crisis in Urmia Lake.

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