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ORIGINAL PAPER

Application of factor analysis in defining drought prone areas in Lake Urmia Basin

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Abstract Data reduction methods such as principal components analysis and factor analysis can be used to define drought prone areas of a basin. In this study, factor analysis method applied for the purpose of projecting the information space on the few dominant axes. The main aim of this study is regionalization of Lake Urmia Basin from the view of drought using factor analysis. For this purpose, monthly precipitation data of 30 weather stations in the period 1972–2009 were used. For each of the selected stations, 3- and 12-month Standardized Precipitation Index (SPI) values were calculated. Factor analysis conducted on SPI values to delineate the study area with respect to drought characteristics. Homogeneity of obtained regions tested using the *S* statistics proposed by Wiltshire. Results of factor analysis of 3- and 12-month SPI values showed that 5 (6) factors having eigenvalues >1 accounted for 68.08 (78.88) % of total variance. The Lake Urmia Basin was delineated into the five distinct homogeneous regions using the 3-month SPI time series. This was six in the case of the 12-month SPI time series. It can be concluded that there are different distinct regions in Lake Urmia Basin according to drought characteristics. The map of regions defined using the 3- and 6-month SPI time series presented in this paper for Lake Urmia Basin.

Keywords Eigenvalue · SPI index · Factor analysis · Drought · Principal component · Lake Urmia

1 Introduction

Droughts are recognized as an environmental disaster and have attracted the attention of environmentalists, ecologists, hydrologists and agricultural scientist. Droughts occur in

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virtually all climatic zones, such as humid as well as arid areas and are mostly related to the reduction in the amount of precipitation received over an extended period of times such as a season or a year. Many factors, such as air temperature, high wind speed, low relative humidity, timing and decrease in rain, including distribution of rainy days during crop growing seasons, intensity and duration of rain, onset and termination, play a significant role in the occurrence of droughts. In contrast to aridity, which is a permanent feature of climate and is restricted to rainfall areas, a drought is a temporary aberration from normal condition. Droughts may affect inversely both surface and groundwater resources and can lead to reduction in water supply, deteriorate water quality, crop failure, disturb riparian habitats and suspend all water-related activities, and affect inversely economic and social activities (Mishra and Singh 2011).

Drought can be classified as meteorological, agricultural and hydrological, based on the different components of the hydrological cycle affected by a drought event. Meteorological drought is an extended period with precipitation below normal levels and usually appears before other types of drought. Meteorological drought is the consequence of deficiency in precipitation. This type of drought selected to analyze in the present work. It can be defined using several indices such as the Standardized Precipitation Index (SPI) proposed by McKee et al. (1993). Agricultural droughts can be defined according the type of crop and use the soil moisture content in different phonological period of crops. Hydrological droughts analyze the water shortage in groundwater and or discharge of rivers.

Water resource management is critical, especially to rapidly expanding urban and rural communities that suffer from drought. Mismanagement may lead to overuse or misuse, which in turn may lead to water disputes among competing water-related activities. For example, about 40 % of the world population lives in 250 major river basins that are shared by multiple countries (Wu et al. 2001). It may be create crises among countries if there is no scientific management of water in such regions.

Many investigators used data reduction methods such as principal component analysis (PCA) and factor analysis (FA) for regionalization studies across the world. Bordi et al. (2003) applied rain gage observations to analysis the time–space variability of dry and wet periods during the last 50 years in nine Chinese watersheds. The SPI used to assess the wet and dry spells. In order to regionalize the area, they conducted PCA on SPI values. Results showed that there are three main distinct areas including the region near the Yellow River, region nearby the Yangtze River and Huaihe or Zhujiang Basin. Furthermore, they showed that the northern basins from the seventies experienced dry conditions, more frequently, which attributed to the presence of a negative trend in the SPI time series.

Vicente-Serranos et al. (2004) studied drought patterns in Valencia Region in the period 1951–2000 using 95 monthly precipitation series and SPI. The general evolution of drought was obtained by PCA. The areas identified by the most significant components did not show any overlap pattern. They also found differences in frequency, duration and intensity of drought among distinct area. Drought increased significantly in the mid of northern area, whereas in the rest of the region, the spatial patterns were more complex. The results showed that great caution should be exercised when applying global output results at the sub-regional level when such extreme events are managed.

Several studies conducted on drought analysis in different regions of Iran. For instant, Dinpashoh (2002) studied meteorological drought characteristics in Iran using the information of 77 weather stations in the period 1956–1998. He used FA and clustering methods for regionalization of drought characteristics all over the country. He showed that in Iran, there are 5 homogeneous rainfall areas and just one heterogeneous area. Safdari et al. (2002) have studied regionalization of drought frequency of Karoon using the SPI in GIS.

For this purpose, they have used 29 stations which were located in the Karoon basin. They used the 28-year time period (1972–1999) and used SPI in three times scales (i.e. 3-, 6- and 12-month time scales). Results showed that drought frequency in southeast and north of the Karoon basin is more than other parts, so these areas are called as parts with vulnerable to droughts which should pay special attention to water resources management in drought condition. Razei et al. (2007) studied drought periods in Sistan-Balochistan province with using SPI in two time scale of 3-, 6-month time scales in the period 1965–2000. He analyzed the intensity and duration of drought periods for both time scales. Results showed that by increasing the drought duration, the number of drought spells will be reduced and the most drought events happen in duration of 1–3 months. Conducting clustering analyses on SPI values in 3- and 6-month time scales revealed that the north and south parts of the mentioned province were homogeneous for drought characteristics. They found that duration of droughts in south of the study area were less than other parts of the province. They also showed that dry spells replaced with normal spells in shorter times. In north area, duration of drought periods is more than other parts which caused that droughts have more unpleasant effects. Eivazi et al. (2009) conducted a study on forecasting drought characteristics using the artificial neural network and using the multilayers perceptron (MLP) and radial basis function (RBF). For this aim, they used rainfall data of Noode station having 41-year data located in Gorgan-Rood basin. He calculated the 1-, 3-, 6- and 9-month SPI as well as the long time period of 12, 24 and 48 months in that humid area of Iran. Results showed that MLP predicted SPI and drought values with high accuracy comparing to RBF. Comparing the results with ARIMA (Auto Regressive Integrated Moving Average) method in time series analysis showed that ANN had high accuracy.

Mohammadian et al. (2010) used monthly rainfall data stations in Northern Khorasan province in the period 1986–2005 for comparing drought characteristics using the PNI, DI and SPI indices. They calculated intensity and duration of drought for each station in annual time scale for the purpose of comparing the above indices. For investigation of drought extent, they prepared regionalization maps with IDW method. Findings of regionalization drought intensity showed that across Northern Khorasan, the most extent and severe droughts happened from 1990 to 2001. Also the longest duration observed in the period 1994–1997 using the SPI values.

In recent years, level of water surface of Urmia Lake has descended to the lowest level in the last century. It seems a detailed drought-related study is needed to prevent water crisis in Lake Urmia Basin. Based on our best knowledge regionalization of drought characteristics did not study in Lake Urmia Basin. Therefore, the main aim of this study is to delineation of the Lake Urmia Basin using the drought characteristics using the 3- and 12-month SPI time series.

Given the above consideration, different stages of the paper are as follows. After the Introduction section, the Materials and Methods explained in the Sect. 2. In the next section, Results and Discussion included as Sect. 3. Conclusion of the paper presented in Sect. 4.

2 Materials and methods

2.1 Study area and data

Urmia Lake is the largest everlasting interior lake, which is located in the northwest of Iran plateau between two provinces, namely West-Azararbayjan and East Azarbayjan. Lake

Urmia Basin lies approximately between 35°40′–39°29′N latitude and 44°13′–47°53′E longitude. The difference between the highest and lowest parts of the basin is about 2,576 m. The average of rainfall on the basin is about 398 mm. This basin had the second rank in receiving large annual rainfall among all main watersheds in Iran. In this study, the 30 stations having sufficient information selected. Precipitation data were gathered in the period of 38 years (1972–2009) from East Azarbayejan and West Azarbayejan Meteorological Offices. The monthly rainfall data were used to calculate the SPI in 3- and 12-month time scales. Data of the two stations, namely Khoy and Piranshahr, located out of the basin margins were used due to their valuable information. Few missing data estimated by using simple linear regression method. For this purpose, contemporary data of the station with missing data and the nearby station having complete data were considered. Correlation coefficient between them computed and tested for significance relationship ($p < 0.05$). This was repeated for at least four surrounding stations. Then, the site with the highest correlation coefficient selected as the bench mark station and missing data at the station of interest estimated.

2.2 Methodology

Computation of the SPI values involves fitting a gamma distribution function to a given observed precipitation data. The alpha (scale parameter) and beta (shape parameter) of the gamma distribution estimated for each station and each time scale (3 and 12 months). In the present study, parameters of the mentioned distribution estimated using the maximum likelihood method (MLM). Details of the SPI method can be found in Ghorbani-Aghdam (2012).

The estimated values of SPI series of each station considered in historical order. This was done either for 3- or 12-month SPIs. Then, FA conducted on 3-month SPI series of stations. Using variance–covariance matrix, the eigenvalues and eigenvectors were calculated. Scree plot was used for selecting logical number of factors.In order to conduct FA principal components analysis (PCA) conducted for SPI series first. This method represents main components as the linear combination of original SPI series. Details of PCA and FA can be found in Rencher (1995). Assume S is the variance–covariance matrix, and the eigenvalue corresponding to a given eigenvector can be obtained from the following equation:

$$|S - \lambda I| = 0 \quad (1)$$

In which $\mathbf{I}$ is the Identity unit matrix with the dimension $p \times p$ and lambda is the eigenvector corresponding to a given eigenvalue. In this study, the elements of S obtained from the following equation:

$$S = \frac{X^T X}{(n-1)} \quad (2)$$

In which X is the matrix of computed SPI values (here) and X^{T} is the transpose of the X matrix. Each column of X attributed for each site and each raw to every year. In order to reduce the dimensionality of data, several criteria exist for selecting the number of dominant factors (Rencher 1995). In the present study, only those factors having the eigenvalue of great than unity selected for further analysis. After determining the main factors, the axes of factors rotated using the varimax normalized method. The aim of axis rotation is changing the place of them so that they pass from the cloud of points after rotation (Rencher 1995). Based on the loadings obtained after rotation, stations grouped into distinct classes. This grouping obtained after drawing isopleths for a given selected factor. N maps, which N is the number of selected factors, prepared for the study area. On every map, area having absolute value of factor loadings >0.5 isolated as a distinct area. Therefore, N distinct areas with different characteristics distinguished on the study area.

Every obtained area from SPI_3 to SPI_{12} time series tested against homogeneity (Wiltshire 1986). For this aim, SPI values of stations located on a distinct group considered. Then, coefficient variability (CV) of each SPI series of a station computed from follow equation:

$$\mathrm{CV} = \frac{S}{\overline{\overline{X}}} \tag{3}$$

In which $\overline{X}$ $\bar{x}$ and S are mean of the SPI values and the standard deviation for a certain station, respectively. The V_j value for the jth site computed from the following equation:

$$V_j = \frac{\left(n_j - 1\right) \sum_{i=1}^{n_j} \left[C^i_{v_{n-1}} - \frac{\left(\sum_{l=1}^{n_j} C^l_{v_{n-1}} \right)}{n_j} \right]^2}{n_j} \tag{4}$$

Where $C^i_{v_{n-1}}$ is the CV calculated following the removing the ith value from data series and n_{j} is the number of data for the jth station.

After computing the V_j for every site in a given group of stations in Lake Urmia Basin, the value of V, weighted mean, obtained for a group using the following equation:

$$V = \frac{1}{N} \sum_{j=1}^{N} n_j V_j \tag{5}$$

Where N is the number of stations in a group of sites. Once the value of V calculated for a region, the U_{j} computed from the following equation:

$$U_j = \frac{V}{n_j} \tag{6}$$

The statistic C_{vo} calculated for a given region having N sites as follows:

$$C_{\mathrm{vo}} = \frac{\sum_{j=1}^{N} \frac{C_{\mathrm{vj}}}{U_j}}{\sum_{j=1}^{N} \frac{1}{U_j}} \tag{7}$$

Finally, the C_{vo} used to find the S statistic for a given region as:

$$S = \sum_{j=1}^{N} \frac{\left(C_{\mathrm{vj}} - C_{\mathrm{vo}}\right)^2}{U_J} \tag{8}$$

Then, the computed S was compared with the chi-square value obtained from chi-square value table using the n–1 degree of freedom and 0.05 for significance level. If S obtained from (8) was less than the chi-square value, then the null hypothesis (the region is homogeneous) is accepted. Otherwise, the null hypothesis is rejected and the alternative (the region is heterogeneous) is accepted. Homogeneity of every region, obtained by 3- and 12-month SPI valued, tested in a same manner, separately.

3 Results and discussion

Tables 1, 2 represent the results of FA of SPI_3 and SPI_{12} series in Lake Urmia Basin, respectively. Results from SPI_3 show that the first 5 factor accounts for more than 68 % of data variance. First factor accounts for about 46 % of variance. The first 5 factors based on having eigenvalue >1 selected as important factors. Other factors account for less variance of data. This is due to the fact that they had low eigenvalues (<1). Therefore, all other factors deleted from further analysis. Fig. 1 shows the Scree plot obtained from of FA of the SPI_3 series.

Before axis rotation, the first factor indicated that the sites, namely Miandoab, Naghade, Urmia and Oshnavie, which are located in south and southwest of Urmia Lake from one side and AghcheKohol and Bashizojan stations in the interior of the basin from other side can be grouped in a class. Also, the first factor grouped the sites in a class in which their names are Khormazard, KhosheMehr and Malekan which are located in southeast of Urmia Lake. Zarnagh, Maraghe, Sarab and Tabriz stations are grouped by the first factor. Before the rotation of factor axes, the second, third, fourth and fifth factors did not group sites in a class. This is true even if we use the 0.7 as a criterion for factor loadings instead of 0.5. So, it can be concluded that we should rotate axis to have better distinction of areas. In this research, rotation has been done by varimax normalized method, which is an orthogonal rotation scheme.

Results showed that after rotation, the variance and eigenvalues of five selected factors changed. For instance, the eigenvalue of the first and second factors before rotation was 13.7 and 2.2, but it changed to 3.9 and 6.5 following rotation. However, the total variance accounted by the selected five factors remained unchanged. Results showed that after rotation, the first factor accounts for two sites, namely Mehraban and Ghazalche. The second factor delineates sites, namely Miandoab, Khormazard, Khoshemehr, Malekan and Maraghe stations which are located in eastern part of middle section of the basin of in a region. The third factor defined a region having stations, namely Mirabad in west and Saghez in south of the basin. The forth factor defined a region having four sites, namely Basmanj, Charmkharan, Shabestar and Zinjenab. There is no possible to define any region using the fifth factor by the 0.7 iso-loading curves. So, we decided to use the 0.5 isopleth curve.

Table 1 Results of factor analysis of 3-month SPI series in Lake Urmia Basin (1972–2009)

Factor number	Before rotation		After rotation	
	Eigenvalue	Percent of cumulative variance	Eigenvalue	Percent of cumulative variance
1	13.768	45.895	3.928	13.09
2	2.191	53.199	6.512	34.801
3	1.854	59.381	1.897	41.12
4	1.527	64.473	5.093	58.102
5	1.084	68.087	2.995	68.087

Table 2 Results of factor analysis of 12-month SPI time series in Lake Urmia Basin (1972–2009)

Factor number	Before rotation		After rotation	
	Eigenvalue	Percent of cumulative variance	Eigenvalue	Percent of cumulative variance
1	12.802	42.676	7.642	25.475
2	3.702	55.018	3.472	37.049
3	3.170	65.588	5.295	54.700
4	1.424	70.337	1.965	61.241
5	1.332	74.780	2.344	69.057
6	1.230	78.882	2.947	78.882

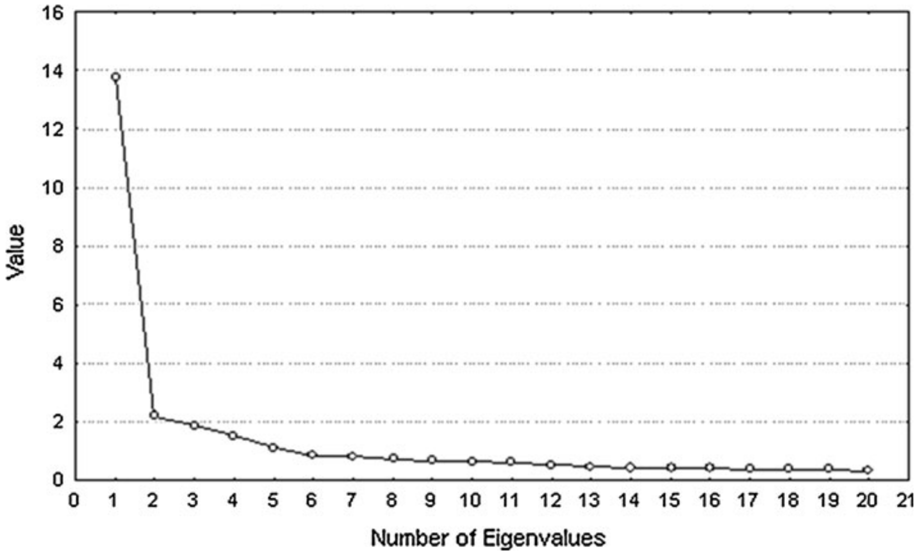

Fig. 1 Scree plot from factor analysis of 3-month SPI time series in Lake Urmia Basin

Table 2 shows the results of factor analysis of 12-month SPI time series. The first six factor accounts for more than 78 % of variances. The eigenvalue of each of the mentioned six factors was >1. However, all other factors showed eigenvalue <1. Therefore, the first six factors selected as dominant factors. So, other unimportant factors (7th, 8th and so on) have negligible information was removed from this study. The first factor lonely accounts for about 43 % of variances. Figure 2 shows the scree plot obtained from FA of SPI_{12} series. For better interpretation of factors, we rotated the axes orthogonally using the varimax method.

After axis rotation based on 0.7 iso-loading curve, each of the first six factors defined part of the basin in a region. Regions contained the same drought characteristics considering the 12-month SPI time series. According to the first factor, a region with seven stations defined. Each of the second, third and fourth factor defined regions with 2, 5 and 2 stations in the Lake Urmia Basin. The fifth factor did not distinguish any region. And finally, the sixth factor based on 0.7 iso-loading curves defined a region having 2 stations.

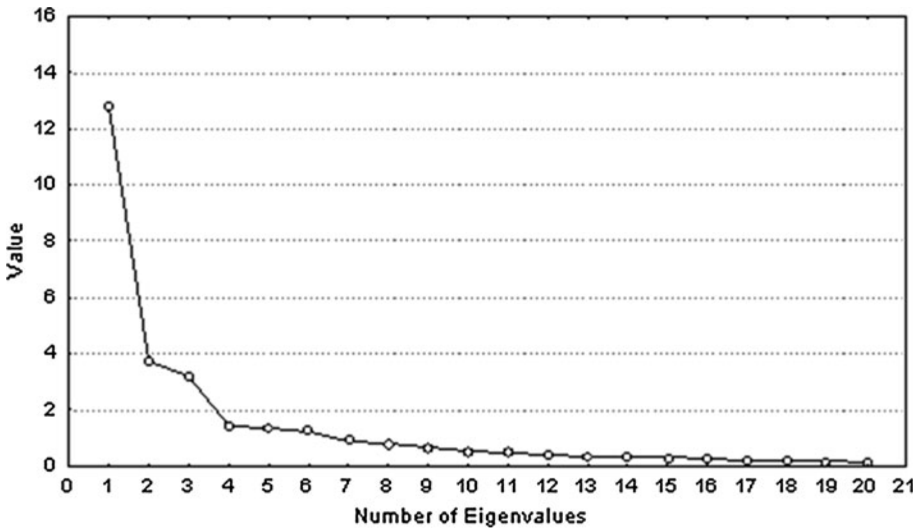

Fig. 2 Scree *plot* from factor analysis of 12-month SPI time series in Lake Urmia Basin

In the other scenario, we used the 0.5 iso-loading curves for better regionalization purposes. After factors rotation by varimax normalize, the results showed that the first factor accounts a region with sites, namely Oshnavie, Naghade, Miandoab, Malekan, Khooshe-Mehr, Khormazard and Maraghe. The second factor accounts a region with two sites, namely Shabestar and Charmkharan. The third factor accounts a region with two sites, namely Mehraban, Ghazalche, which are located in North West part of the basin as well as three other sites, namely Mahabad, Saeed-Abad and Sarab. The forth factor defined a region with two sites which are Saghez and Mirabad. The fifth factor did not define any region. The sixth factor accounts a region with two sites, namely Saray and Basmanj.

Table 3 Results of homogeneity test of regions defined by three-month SPI time series

Number of region	Number of sites	*S* statistic	*df*	Chi-square	Result
1	5	5.62	4	9.49	Homogeneous
2	10	2.24	9	16.92	Homogeneous
3	2	0.78	1	3.84	Homogeneous
4	7	1.92	6	14.07	Homogeneous
5	3	0.37	2	5.99	Homogeneous

Table 4 Results of homogeneity test of regions defined by 12-month SPI time series

Number of region	Number of sites	*S* statistic	*df*	Chi-square	Result
1	12	0.03	11	19.68	Homogeneous
2	3	6.02	2	5.99	Homogeneous
3	8	0.00	7	14.07	Homogeneous
4	2	0.83	1	3.84	Homogeneous
5	3	0.23	2	5.99	Homogeneous
6	4	0.01	3	7.81	Homogeneous

Fig. 3 The regions defined using the 3-month SPI time series in Lake Urmia Basin

Tables 3, 4 show the results of homogeneity test for regions defined by FA of 3- and 12-month SPI time series using the method proposed by Wiltshire. The results of homogeneity test indicated that all of the obtained regions were homogeneous. It should be mentioned about SPI_{12} that the region defined by the second factor had S statistic slightly great than that of the chi-square value. Therefore, we assumed this region as homogeneous too.

Figures 3, 4 show the regions defined using the 3-month SPI time series and 12-month SPI time series in Lake Urmia Basin.

4 Conclusion

In this study, Lake Urmia Basin delineated to different regions based on 3- and 12-month SPI time series. For this purpose, FA was used. Factor analysis conducted separately for SPI series in 3- and 12-month timescales.

Results showed that in 3-month timescale, 5 factors had eigenvalue more than unity. So, the study area divided into some sub-regions according to drought characteristics. For having better possibility for dividing area factor axes have rotated by varimax normalized which is an orthogonal rotation method. We attributed sites to sub-regions using loadings

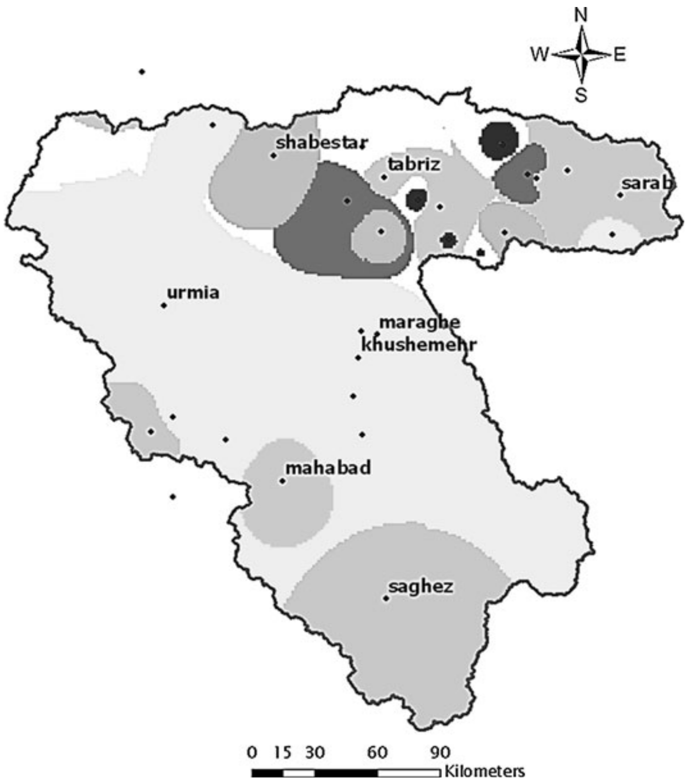

Fig. 4 The regions defined using the 12-month SPI time series in Lake Urmia Basin

of selected factors. Our results indicated that the stations, namely Mehraban, Mahabad, Ghezelche and saeedabadand sarab, constitute distinct region using the first factor. Stations, namely Miandoab, Khormazard, Tasooj, Piranshahr, Naghade, Urmia, Oshnavie, Khooshemehr, Malekan and Maraghe, included to the second region according the second factor. Similarly sites, namely Mirabad and Saghez, constitute the third area according to the third factor. Based on the forth factor stations, namely Basmanj, Charmkharan, Shabestar, Pardil, Esfahlan, Aghche and Zinjab, included in the fourth area and finally three sites, namely Tabriz, Zarnagh and Heris, included in the fifth area.

Results from SPI_{12} months showed that based on the first factor stations, namely Oshnavie, Naghade, Miandoab, Piranshahr, Urmia, Tasooj, Malekan, Khooshe-Mehr, Khormazard, Heris and Maraghe included in the first subarea. According to the second factor, stations, namely Shabestar, Charmkharan, and Zinjenab, included to the second area. Based on the third factor stations, namely Mehraban, Ghezelche, Saeedabad, Sarab, Khooy and Tabriz, included to the third area. According to the fourth factor, two sites, namely Saghez and Mirabad, include to the fourth area. According to the fifth factor, two other stations, namely Zarnagh and Esfahlan, constitute the fifth area. Finally, according to the sixth factor, four sites, namely Saray, Basmanj, Bashizoojan and Aghche, included the sixth area. Homogeneity of each area tested according to the coefficient of variation of SPI time series separately. Results indicated that every area was homogeneous at 5 % significance level. It is worthy to mention that based on 12-month SPI time scales, there is just one area which we approximately homogeneous. In this study, rainfall data were used in order to regionalization of Lake Urmia Basin. According to Tabari and Talaee (2011), annual precipitation decreased considerably in Lake Urmia Basin. They reported that trend line slope in Tabriz was −3.4 mm/year. This was −3.6 for Urmia. Other stations showed similar decreasing rate for annual precipitation. Sigaroodi and Ebrahimi (2010) showed that due to land use change in Lake Urmia Basin, the mean annual discharge of rivers has not changed significantly, but maximum daily discharge increased and minimum daily discharge reduced. Furthermore, several dams constructed over Lake Urmia Basin recently. Although they had many advantages, however, they had significant negative effect in reducing water table in aquifers and Urmia Lake water elevation. Other environmental effects may arise in next years. Raziei et al. (2011) showed that precipitation occurrence over Western Iran is particularly occurred when a trough extends over the eastern Mediterranean to Iraq. Decrease in precipitation and stream flow in the study area create sever droughts in recent decades. Scientific management of available water needed for drought preparedness.

It is highly recommended to conduct similar study to investigate the characteristics of hydrological droughts of Lake Urmia Basin using runoff and/or groundwater level information.

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