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Analysis of Basin Drought for URMIA Lake in Iran with Standardized Precipitation Index Method (SPI)

İran URMIA Gölü Havzası'nda Standart Yağış İndeksi Metodu ile Kuraklık Analizi

Aslı Ülke Keskin*, Alyar Boustani Hezarani

Ondokuz Mayıs University, Civil Engineering Department, Atakum, Samsun, Turkey

Abstract

Drought is a natural and reversible feature of climate change and occurs almost in all climatic regimes, and its effects are not restricted simply to arid and semi-arid areas. Drought can also occur in areas with high precipitation in each season of year and cause considerable damages to agricultural and industrial sectors and to cities. Located at subtropical region and having semi-arid climate, Lake Urmia basin experiences drought frequently. Since some cultivations in this region are made in the form of rainfed farming, sudden decreased rain will leave many damages.

In the present study, drought of Lake Urmia basin was investigated according to the total monthly precipitation data obtained from synoptic stations in the area, using Standardized Precipitation Index (SPI) in four time scales (3, 6, 12, and 24 months). The results show that short-term scales response quickly to rainfall changes, while drought is continued more in long-term scales. That's why drought frequencies in long-term series (scales) minimize. In addition, by comparing the time scales, it is found that a region may be in wet conditions in a time scale, while be in dry conditions in another time scale simultaneously.

Keywords: Climate change, Drought, Iran, Standardized precipitation index, Urmia lake basin

Öz

Kuraklık, iklim değişikliğinin doğal ve tersine çevrilebilir bir sonucudur ve tüm iklim rejimlerinde görülebilir, kuraklığın etkileri sadece kurak ve yarı kurak bölgelerle sınırlı değildir. Yılın her sezonunda yüksek yağış alan bölgelerde de oluşabilen kuraklık, tarım, sanayi sektörlerine ve şehirlere önemli zararlara neden olmaktadır. Astropikal bir bölgede yer alan ve yarı kurak bir iklime sahip olan Urmia Gölü Havzası, sıklıkla kuraklıkla karşı karşıya kalmaktadır. Bu bölgelerde yağmurla beslenen sulu tarım yapıldığından yağışlardaki ani düşüşler pek çok zarara yol açar.

Bu çalışmada Urmia Gölü Havzası'nda sinoptik istasyonlardan elde edilen aylık yağış verileri kullanılarak 4 farklı zaman aralığında (3, 6, 12 ve 24 ay) standart yağış indeksi ile kuraklık analizi gerçekleştirilmiştir. Kısa zaman aralıklarında SPI sonuçlarının yağış değişikliklerine daha hızlı cevap verdiği, uzun zaman aralıklarında ise kuraklığın devam ettiği sonuçlardan anlaşılmaktadır. Bu yüzdendir ki uzun zaman ölçeklerinde kuraklık frekans değerleri küçüktür. İlaveten zaman ölçekleri bazında karşılaştırdığında bir bölge aynı anda hem yağışlı hem de kurak olabilir.

Anahtar Kelimeler: İklim değişikliği, Kuraklık, Iran, Standart yağış indeksi, Urmia gölü havzası

1. Introduction

Drought, which causes many damages every year, is one of the climatic phenomena. This phenomenon, in fact, constitutes the main recurring feature of different climates, and its effects are not restricted to simply arid and semi-arid areas. Drought occurs in both arid areas and wet areas and causes water supply deficit (Dracup et al. 1980). But drought characteristics such as drought frequency, severity, and duration vary from place to place. Although droughts cause many economic losses, environmental and social damages, they have been paid less attention than other meteorological phenomena, because defining, determining, and monitoring them are rather difficult (Mishra and Singh 2011).

In order to evaluate and monitor drought, climatologists have provided several indices each of which have been

*Corresponding author: asli.ulke@omu.edu.tr

Aslı Ülke Keskin orcid.org/0000-0002-9676-8377
Alyar Boustani Hezarani orcid.org/0000-0001-8763-6607

designed according to using meteorological variables and different computational methods (Richard and Heim 2002).

McKee et al developed the Standardized Precipitation Index (SPI) in order to define and monitor drought and determine rainfall deficit for time scales 3, 6, 12, 24, and 48 months (Mckee et al. 1993). In order to monitor drought and soil moisture reserve conditions, the National Drought Mitigation Center in the United States uses the Standardized Precipitation Index (SPI) (NDMC 1995). In Portugal, in order to mitigate drought, a regional distribution model has been used and the maps of drought zoning, and the curves of drought severity, area, and frequency have been drawn (Henriques and Santos 1998). Benjamin and Saaunders, studied the relationship between frequency and duration of droughts in Europe in different time scales and they concluded that in short-term time scale drought frequency is more than in long-term time scale and vice versa for drought duration (Benjamin and Saaunders 2002). Zou and Zhang used the daily precipitation and mean temperature series from 1951 to 2006, and concluded that the area affected from drought in northwestern China significantly decreased after the middle of 1980s (Zou and Zhang 2008).

Scientists have developed four classifications to describe drought because it is such a complex phenomenon: meteorological drought, agricultural drought, hydrological drought, and socio-economic drought (Wilhite and Glantz 1985). According to the analysis of the curves of drought severity, duration, and frequency, Dalezios et al. drew drought intensity contourmaps for Greece and concluded that the northern areas of Greece had more severe drought than its southern areas (Dalezios et al 2000). Wu et al stated that a drought index would be useful when it could provide a quantitative, simple, and clear evaluation from the main characteristics of drought including duration, severity, frequency, and drought affected area (Wu et al. 2001).

The SPI has been widely used to study drought in different regions, among other drought indices in USA (Hayes et al. 1999), Italy (Bonaccorso et al. 2003), Korea (Min et al. 2003), Greece (Tsakiris and Vangelis 2004), Spain (Lana et al. 2001), Iran (Noruzi 2007), Africa (Yacoub and Tayfur 2017) and Turkey (Sırdas and Sen 2003, Sonmez et al. 2005, Keskin et al. 2009, Bacanli et al. 2009, Doğan et al. 2012). The SPI has also been included in drought monitoring systems and management plans (Wu et al. 2005). In general, different studies have indicated the usefulness of the SPI to quantify different drought types and climate change studies (Hayes et al. 1999).

On the other hand, The Lake Urmia has also been widely studied by some researchers. Hassanzadeh et al. (2012), worked on a study which's purpose was to determine the main factors which reduce the water level of Urmia lake. A simulation model, based on system dynamics method, is developed for the Urmia Lake basin to estimate the lake's level by the authors. In the conclusion it was found that the main factor for 65% of the effect, constructing four dams was responsible for 25% of the problem, and less precipitation on lake has 10% effect on decreasing the lake's level in the recent years. Delju et al. (2013), analyzed the annual dry bulb temperature, maximum and minimum temperature, precipitation, and number of rainy and snowy days by statatistical methods for the period 1964-2005. Eventually they indicate that mean precipitation has decreased by 9.2 % and the average maximum temperature has increased by 0.8°C over these four decades. Nikbakht et al. (2013), had studied the streamflow drought severity which was identified by the percent of normal index (PNI) in the Lake Urmia located in northwest Iran. The streamflow records from 14 hydrometric stations for the period October 1975–September 2009 were used in the study. The temporal trends of the streamflow drought severity were detected by the parametric Student's t test and the nonparametric Mann–Kendall and Sen's tests. The authors indicated that the streamflow drought severity based on the PNI increased during the last 34 years.

2. Study Area

A region with the area of 51876 sq.km in the form of a closed basin in northwestern Iran with geographical coordinates as 44 degrees 13 minutes to 47 degrees 54 minutes east longitude, and 38 degrees 30 minutes to 40 degrees 35 minutes north latitude, is drained towards a surface water supply in shallow subsidence, known as "Lake Urmia Basin". The height of Lake Urmia basin varies from 1276 m in the lake bank to 3850 m in the proximity of Sabalan summit form the sea level. However, much of it ranging from 1280 m to 2000 m is in the form of a wide plain surrounding the lake. According to these characteristics, the region surveyed has, in a climatic sense, the features of semi high plains in the middle latitudes with cold climate in winter and relatively mild climate in summer. This lake constitutes of the few salt-supersaturated lakes in the world, whose water is not drinkable and cannot be used for agricultural and industrial applications. Figure 1 shows the location of Lake Urmia basin, and Table 1 shows the characteristics and coordinates of the stations surveyed in this study. And also Figure 2 shows the last position of Lake Urmia.

Table 1. Characteristics and coordinates of the stations surveyed.

No.	Station Name	Altitude (m)	Latitude	Longitude	Average Precipitation per annum (mm)
1	Urmia	1312	37° 32`	45° 5`	303/6
2	Tabriz	1349	38° 8`	46° 15`	342/6
3	Takab	1765	36° 23`	47° 07`	309/6
4	Mahabad	1500	36° 46`	45° 43`	514/2

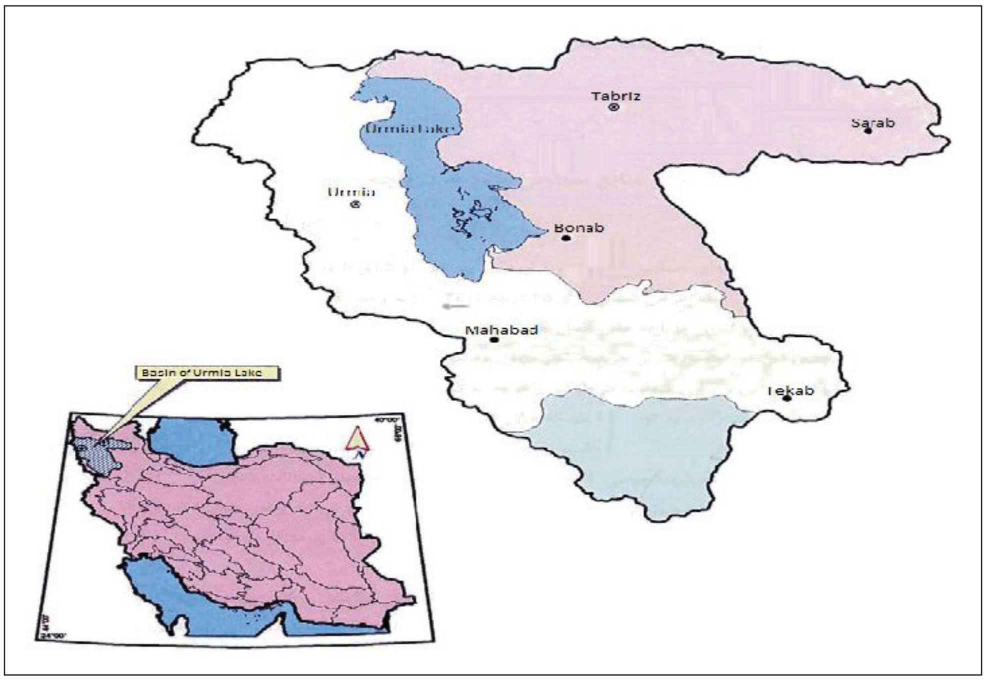

Figure 1. Location of Lake Urmia Basin.

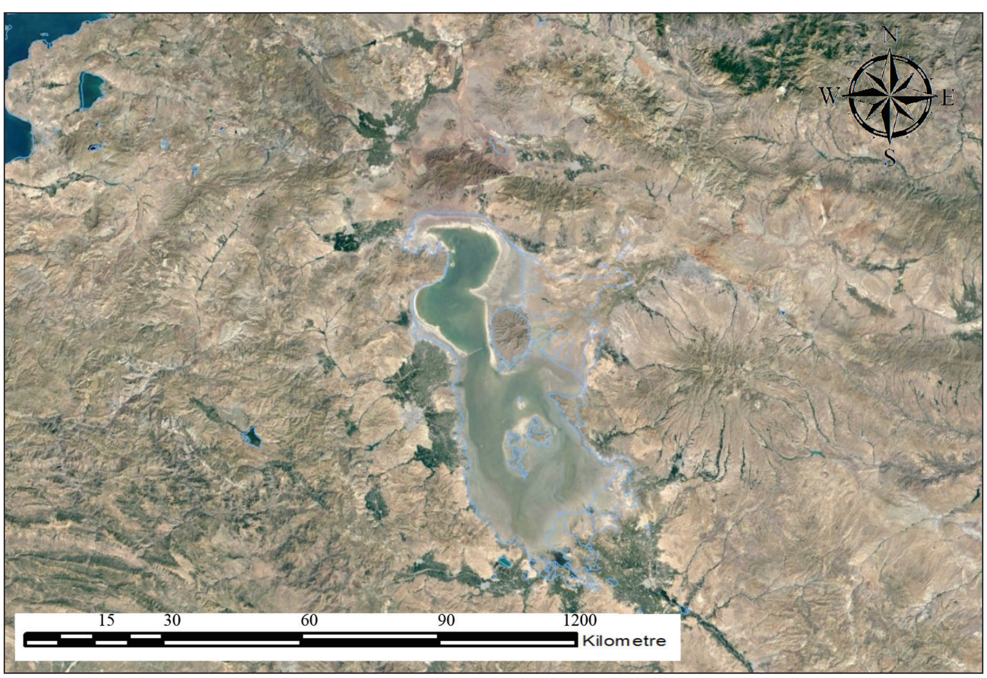

Figure 2. The last position of Lake Urmia.

3. Materials and Methods

In the present study, the total montly precipitation data in synoptic stations located at the study area was used for two stations of Urmia and Tabriz during the statistical period 1968-2011 and for the stations of Mahabad and Takab during the statistical period 1991-2011. To make statistical correction of the monthly precipitation data, randomization tests or data homogeneity test was conducted.

3.1. Homogeneity Tests

The methods used to determine the trend of a series, according to whether or not connected to a distribution of the series; parametric and non-parametric methods are grouped under two headings (Helsel and Hirsch 1992). In parametric methods, the actual value of the data in the series is important and this value is used in calculations. However, not the actual data value in nonparametric methods, low to high or high to low number of the resulting sequence is used with the correct ranking. Parametric statistical methods use the data to be independent from each other and must be random. Climate data is not always consistent with the normal distribution. It is of great importance that data belong to the same cluster in time series. The fact that the data belongs to the same cluster is important for a more secure analysis. For the series to be homogeneous, the data came from the same community and the data must be completely independent of each other.

Homogeneity of rainfall data used in climate change studies constitute a major problem. Changing the location of measuring stations, exposure to environmental factors, equipment and setting errors affect the homogeneity of climate data. Therefore, homogeneity analysis of precipitation data in climate change studies is important in terms of using statistical methods, trend analysis studies and tests to be performed.

3.1.1 The Standard Normal Homogeneity Test

Alexandersson developed by this method has been used successfully in testing many climatic and hydrological size (Alexandersson 1986). This method is flexible and simple to use. Alexandersson's studied data a "c" as a reference point divides and Equation 3.1, T (c) calculates the value.

$$T(c) = c.\bar{z}_1 + (n-c).c.\bar{z}_2^2 \quad c = 1.....n \tag{3.1}$$

$$\bar{z}_1 = \sum_{i=1}^{c} (y_i - \bar{y})/\sigma)/c \text{ ve } \bar{z}_2 = \sum_{i=1+c}^{n} (y_i - \bar{y})/\sigma)/(n-c) \tag{3.2}$$

The change occurred at the point of a "h", c = h point T (c) reaches the maximum value. T_0 is the test statistic as in Equation 3.

$$T_0 = \max_{1 \le c \le n} T(c) \tag{3.3}$$

Exceeds the value of the test statistic in Table 2, T_0 null hypothesis is rejected.

3.1.2 Pettitt Test

This test is a non-parametric rank test. The ranks $r_1, \ldots,$ r_n of the $Y_1, \ldots, Y_n$ are used to calculate the statistics. The significance level is given by Pettitt (1979). Critical values for X_E are given in Table 2 (Pettitt 1979).

$$X_k = 2\sum_{i=1}^{k} r_i - k(n+1) \qquad k = 1, 2, \ldots, n \tag{3.4}$$

The X_k in Equation 3.4, is depicted in the graphs representing the results of this test. If a break occurs in year E, then the statistic is maximal or minimal near the year k = E.

$$X_E = \max_{1 \le k \le n} |X_k| \tag{3.5}$$

The results obtained as a result of the homogeneity test, is less than the critical value in Table 2, it is referred to as a homogenous data set.

3.2. SPI

Standardized Precipitation Index (SPI) was introduced by McKee et al. (1993). In order to study precipitation deficit in several time scales, McKee defined this index. Indeed, the idea of SPI was based on this fact that the effect of drought on different natural components differs. The period of effect of precipitation deficit on underground waters with surface water supply differs and or soil moisture and snow coverage are affected by a different period of drought. Standardized Precipitation Index (SPI) is a powerful tool for analyzing precipitation data. The purpose of SPI is to assign a single numeric value to the precipitation that can be compared across regions with markedly different climates. For example, a rainfall that is considered to be a drought in tropical regions may appear as heavy rainfall in desert regions.

SPI is obtained by comparing total cumulative precipitation for stations or a specific region during a special time interval

Table 2. 1% and 5% critical values for the statistic of SNHT and Pettitt tests.

	α=0.01		α=0.05	
Stations	SNHT	Pettitt	SNHT	Pettitt
Tabriz Urmia	16.77	10458	12.34	8465
Mahabad Takap	14.61	3230	10.83	2610

with the average precipitation for the same time interval in all statistical period (Mckee at al. 1995). SPI is designed to quantify precipitation deficit in different time scales. The main characteristic of the SPI is its flexibility in measuring drought in different time scales because droughts are very vast in terms of duration. Therefore, identifying and monitoring them with various time scales are important.

Time scale shows the effects of drought on water supply potential. Precipitation deficit in short-term time scales affects mostly soil moisture condition, while precipitation deficit in long-term time scales often affect underground water, streamflow, and water reserves and supplies. In this respect, Mckee et al. (1995) calculated the time scales of 1 to 72 months. Calculation of SPI for any certain region is based on long-term statistics of precipitation for a desired period of three months, six months, and twelve months and so on. These long-term statistics can be used, by using fitted gamma distribution of the function obtained, to find cumulative probability of precipitation for a station and a certain month and different time scales. SPI is a normalized value with the average 0 and standard deviation (SD) 1. Thus, the SPI is a standard deviation value of the precipitation of a period of normal distribution. Positive SPI values represent precipitation more than the average rainfall and negative SPI values represent precipitation less than the average rainfall. Since SPI is normal, dry and wet climates can be shown by a single method, and wet periods can be studied by means of SPI as well. This index shows that it is possible for an area to simultaneously experience wet conditions on one or more time scales, and dry conditions at other time scales. That is, an area may suffer from agricultural drought, and wet conditions may govern it in terms of hydrology (Mckee at al. 1995).

3.3. Results of Homogeneity Tests

The results obtained from the homogeneity tests are shown in Table 3. On the first hand, the homogeneity percentage is 1% and the non-homogeneity percentage is 5% for SNHT, Tabriz and Urmia stations. According to the Pettitt tests, the stations are found nonhomogeneous for both 1% and 5%. The stations Mahabad and Takab are homogeneous for both two tests. It is very clear that the trends are stronger at the non-homogeneous stations.

3.4. Calculating SPI

Probability distribution function for long-term data is calculated by fitting data by means of gamma function. Gamma distribution function is defined as:

Table 3. Homogeneity test results for all stations.

	Results	
Stations	**SNHT**	**Pettitt**
Tabriz	13.870	73512
Urmia	12.795	70287
Mahabad	3.5444	1804
Takap	6.0204	2095

$$G(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \qquad x > 0 \tag{3.6}$$

where, α>0 is shape parameter, β>0 scale parameter, x precipitation, and Γ(α) gamma function.

The parameters of gamma probability density function are estimated from the sample data with the aid of maximum likelihood method for each station and for any selective time scale and for any month of the year. Therefore:

$$\hat{\alpha} = \frac{1}{4A} 1 + \sqrt{1 + \frac{4A}{3}} \tag{3.7}$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \tag{3.8}$$

$$A = Ln(\bar{x}) - \frac{\sum Ln(x)}{n} \tag{3.9}$$

where, n represents number of precipitation observations and $\bar{x}$, for a certain month, is the average cumulative precipitation for a month during the statistical period.

Then the calculated parameters are used to find the cumulative probability of precipitation for specific month and time scale for a specific station in the Eq. (3.10).

$$G(x) = \int_0^x g(x)\,dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \tag{3.10}$$

Assuming $t = \frac{x}{\beta}$, the cumulative probability converts into incomplete gamma function.

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha} e^{-t} dt \tag{3.11}$$

When gamma function is not defined for $x = 0$, and precipitation distribution has zero, the cumulative probability is calculated as below:

$$H(x) = q + (1-q)\,G(x) \tag{3.12}$$

where, q is the precipitation probability 0. If m is number of zeros in time series of precipitation, q can be estimated as $\frac{m}{n}$. Then H(x) becomes into the normal variable (Z) with the following approximation:

$$Z = SPI = -t - \frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \quad 0 < H(x) \leq 0.5$$
$$Z = SPI = +t - \frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \quad 0.5 < H(x) \leq 1 \qquad (3.13)$$

$$t = \sqrt{Ln \frac{1}{(H(x))^2}} \qquad 0 < H(x) \leq 0.5$$
$$t = \sqrt{Ln \frac{1}{(1-(H(x))^2}} \qquad 0.5 < H(x) \leq 1.0 \qquad (3.14)$$

The values C_0, C_1, C_2 and d_1, d_2, d_3 are the following constant coefficients.

$d_1 = 1.432788 \quad C_0 = 2.515517$
$d_2 = 0.189269 \quad C_1 = 0.802853$
$d_3 = 0.001308 \quad C_2 = 0.010308$

In this way, Eqs. (3.6) to (3.14) show the SPI of the normalized Z grade (Mckee at al. 1995).

3.5. Drought Severity According to SPI

SPI value for each dry month indicates drought severity. The SPI values are classified as Table 4.

3.6. Drought Duration According to SPI

Drought duration and period for the current drought are from the beginning of drought and for the past drought from the beginning to the end of drought.

3.7. Drought Degree According to SPI

Drought degree and importance (DM) is defined as below:

$$DM = -\sum_{i=1}^{x} SPI_{ji} \qquad (3.15)$$

where, i begins with the first month of drought beginning and continues until this period ends in the x month j indicates time scale of the relevant dry period.

Table 4. Classification of drought according to SPI.

Drought Severity	SPI Value
Mild Drought	0 to -0.99
Moderate Drought	-1 to -1.49
Sever Drought	-1.5 to -1.99
Very Sever Drought	-2 and less

DM has month unit and equals to drought numerically (in each dry month, SPI is assumed to be equal to -1).

3.8. Beginning and Ending Drought According to SPI

For a n-month time scale, a drought is calculated as follows: the period in which the SPI is continuously negative, reaches -1 and less, and ends when the SPI becomes positive.

The reason for the fact that the SPI values 0 to -0.99 (mild drought) are not calculated at the beginning of drought, can be the moisture existed from the past wet period. But at the end of drought, these SPI values indicate mild drought because the moisture reserve finishes and these values show moisture deficit after drought period.

4. Discussion

The results from the studies on four stations are shown separately in Tables 5 to 8 as well as the graphs for drought in the stations in four time scales (three, six, twelve, and twenty four months) in Figs. 3 to 6.

5. Conclusion

In this study, drought process in Urmia Lake basin was studied by using Standardized Precipitation Index (SPI) and the following general results were obtained:

1. Short-term (three-month) SPI responses to the monthly precipitation changes quickly. Therefore, short-term SPIs show properly the monthly precipitation reductions.
2. Drought appears first in short-term time series and, if continued, it appears in long-term SPIs as well.
3. The maximum drought severity is seen in three-month SPIs, that is due to the main effect of monthly precipitation on total three-month precipitation. So, three-month SPIs response quickly to decreased precipitation.
4. Drought frequencies in long-term series decrease and minimize. Therefore, drought duration is more in long-term series.
5. It is possible for a region to simultaneously experience wet conditions on one or more time scales, and dry conditions at other time scales.

Table 5. Droughts occurred in Urmia during 1968-2011 (43-year period).

Time Scale	Drought Frequencies	Max Duration (in month)	Max Drought Duration		Max Drought Severity	Average Drought Severity	Drought Degree
			Beginning	End			
3-months	32	36-months	1997/12	2000/11	-2.84	-0.83	-29.88
6-months	15	51-months	1998/01	2002/03	-2.76	-1.03	-52.82
12-months	11	46-months	1998/07	2002/04	-2.07	-1.4	-64.71
24-months	4	103-months	1998/12	2006/06	-2.39	-1.04	-106.93

Table 6. Droughts occurred in Tabriz during 1968-2011 (43-year period).

Time Scale	Drought Frequencies	Max Duration (in month)	Max Drought Duration		Max Drought Severity	Average Drought Severity	Drought Degree
			Beginning	End			
3-months	33	17-months	1990/02	1991/6	-2.0	-1.11	-19
6-months	18	19-months	2001/11	2005/05	-1.38	-0.82	-15.54
12-months	7	76-months	1995/12	2002/03	-1.69	-0.89	-67.74
24-months	4	79-months	1996/11	2003/05	-1.61	-0.95	-75.53

Table 7. Droughts occurred in Mahabad during 1991-2011 (20-year period).

Time Scale	Drought Frequencies	Max Duration (in month)	Max Drought Duration		Max Drought Severity	Average Drought Severity	Drought Degree
			Beginning	End			
3-months	17	10-months	1998/11	1999/08	-2.14	-0.92	-9.18
6-months	8	38-months	1998/11	2001/12	-2.38	-1.22	-46.65
12-months	4	38-months	1999/03	2002/04	-2.33	-1.41	-53.76
24-months	2	41-months	1999/11	2003/03	-2.19	-1.37	-56.53

Table 8. Droughts occurred in Takab during 1991-2011 (20-year period).

Time Scale	Drought Frequencies	Max Duration (in month)	Max Drought Duration		Max Drought Severity	Average Drought Severity	Drought Degree
			Beginning	End			
3-months	20	10-months	1998/11	1999/08	-2.8	-1.42	-14.24
6-months	6	21-months	1998/11	2000/07	-2.7	-1.38	-29
12-months	4	46-months	1999/04	2003/01	-2.49	-1.2	-55.37
24-months	2	43-months	1999/11	2003/05	-1.81	-1.28	-55

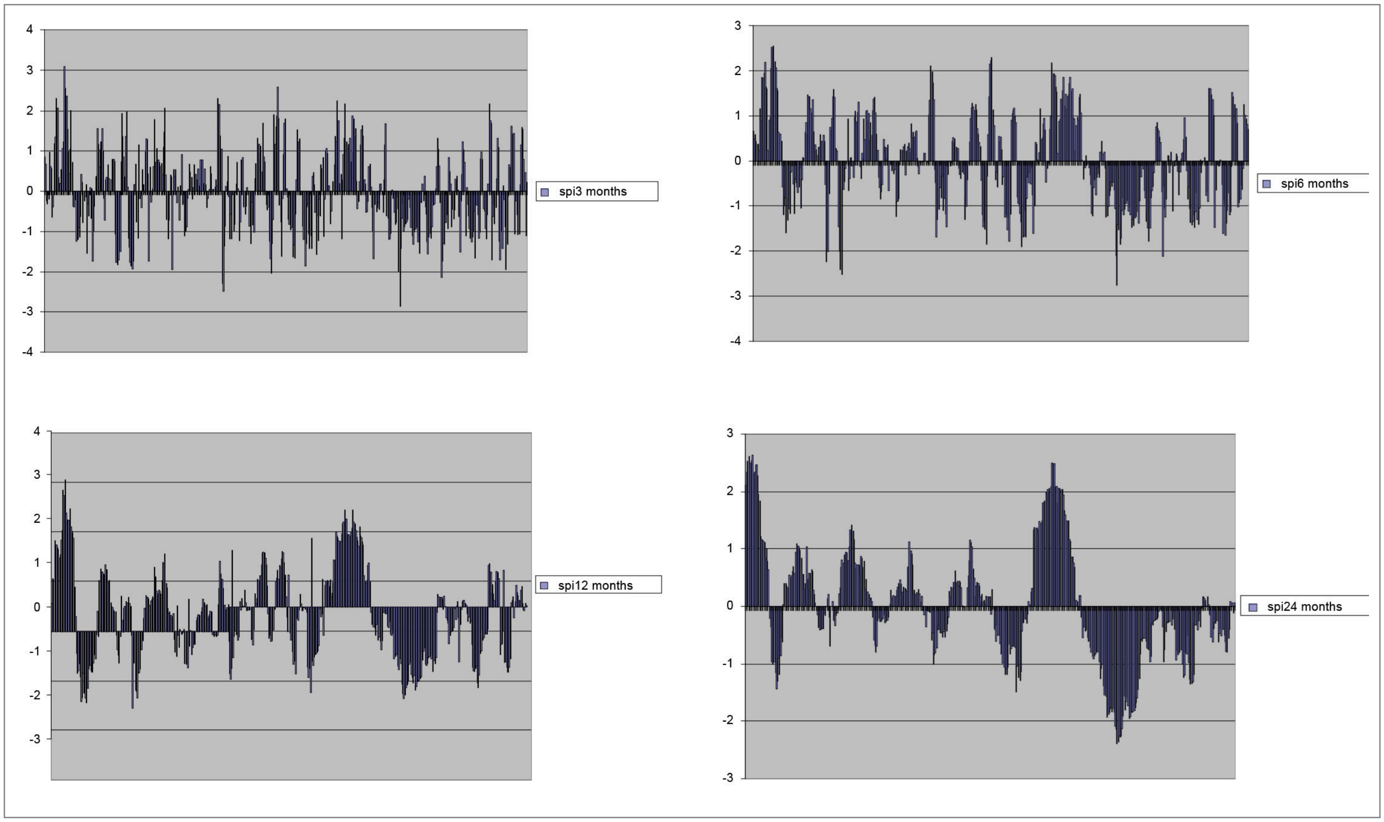

Figure 3. All Droughts of Urmia in four time scales during 1968-2011.

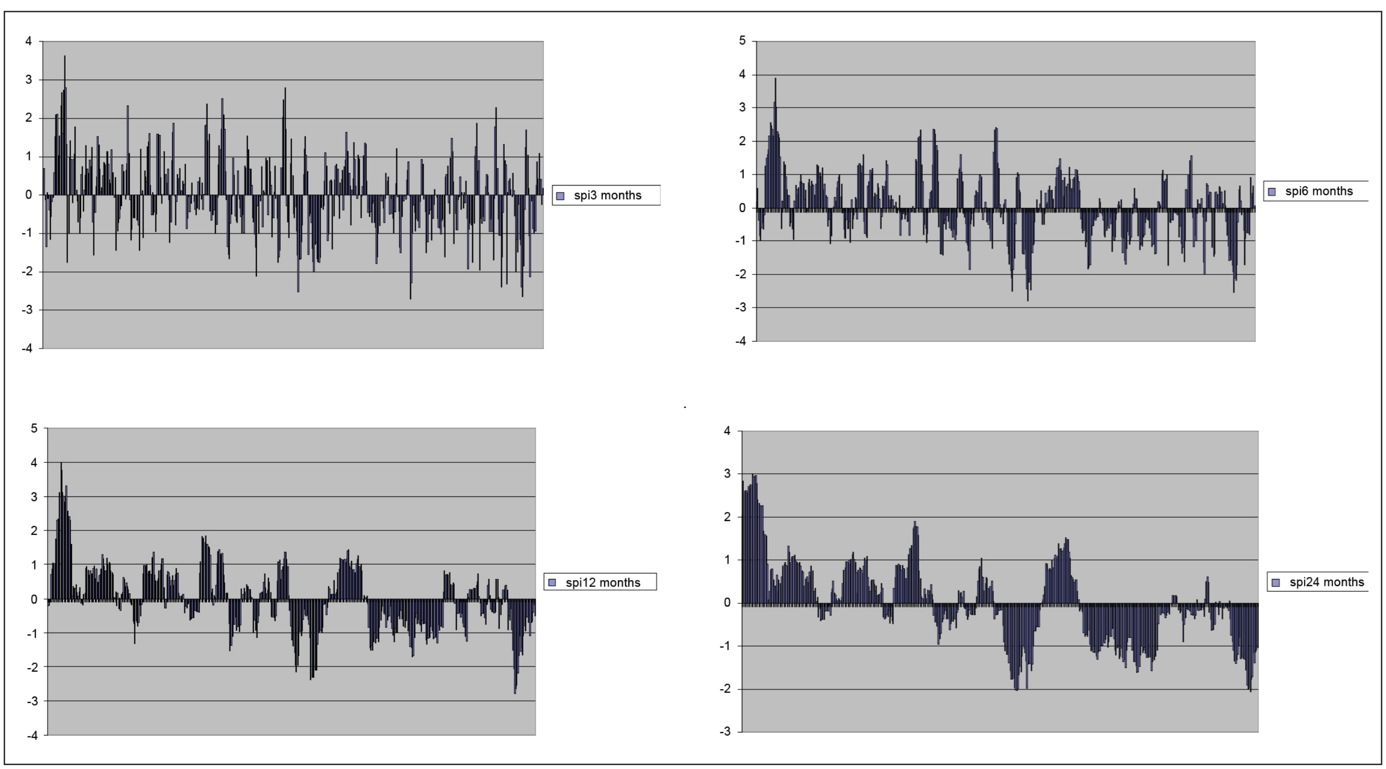

Figure 4. All Droughts of Tabriz in four time scales during 1968-2011.

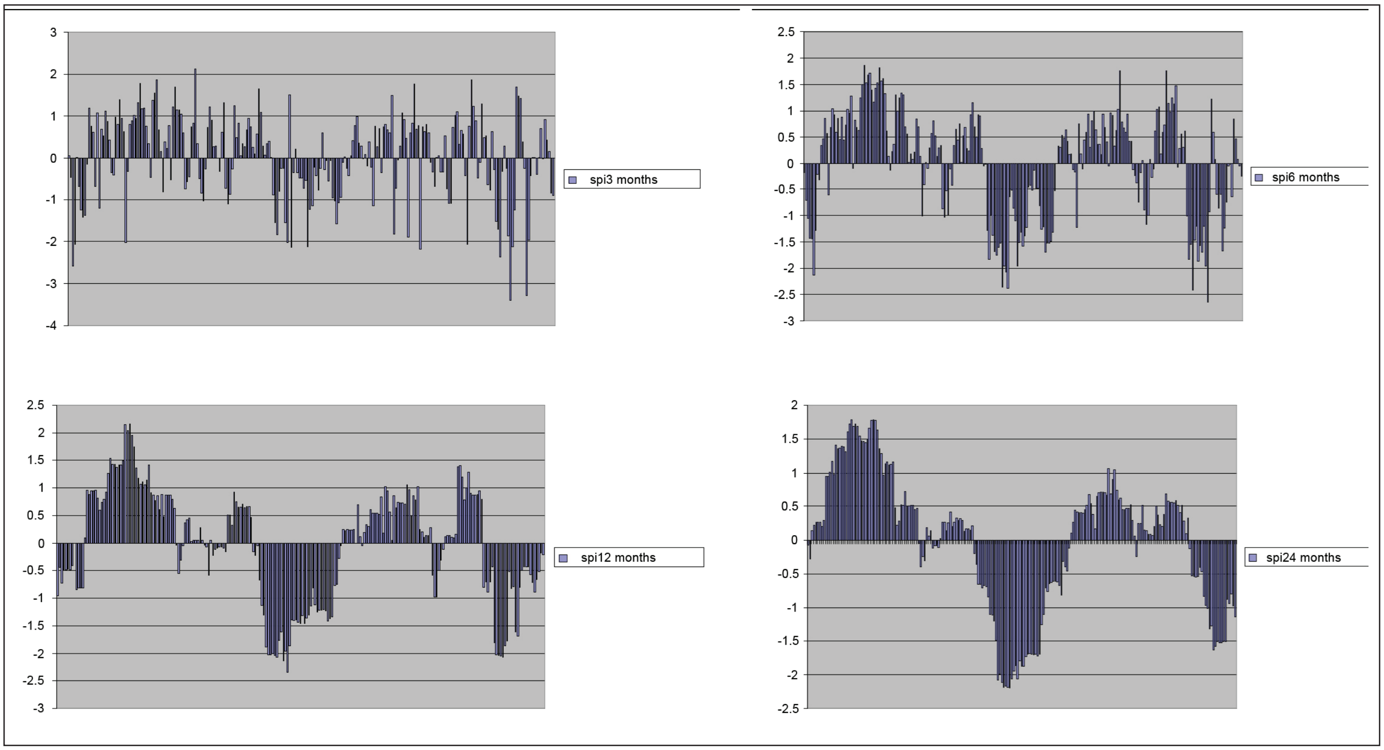

Figure 5. All Droughts of Mahabad in four time scales during 1991-2011.

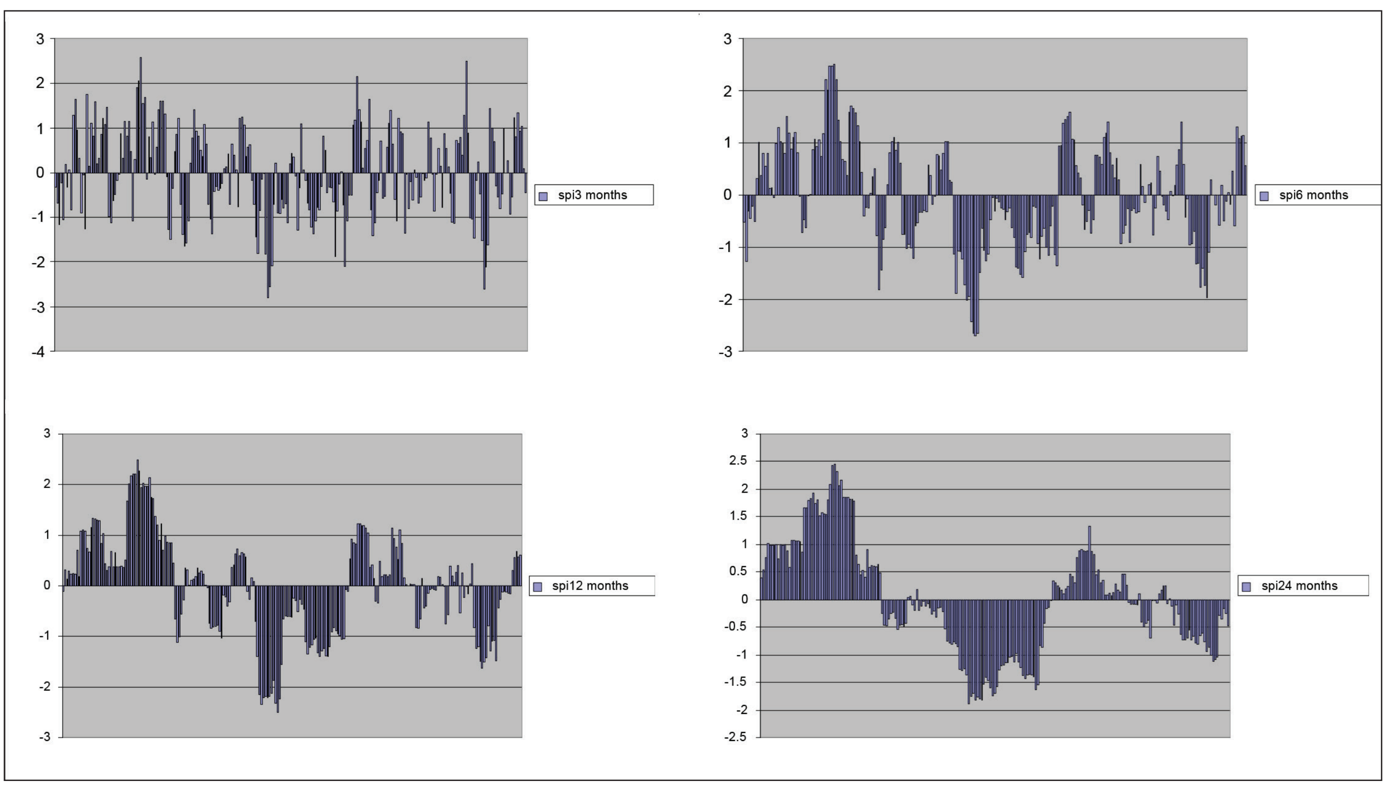

Figure 6. All Droughts of in Takab in four time scales during 1991-2011.

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