



Hydrological drought analyzing and monitoring by using Streamflow Drought Index (SDI) (case study: Lorestan, Iran)

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Abstract

In the presented study, the hydrological drought continuity and severity in Lorestan province, Iran, was investigated by employing the Streamflow Drought Index (SDI). The SDI method is a technique for prediction of the drought onset and its duration. This method uses the cumulative flow rate of the river as well as the spatial extent of drought for assessing and monitoring the hydrological droughts. Four different periods of 3, 6, 9, and 12 months were investigated in this study of the selected location. The required data were gathered from ten hydrometric stations for a 32-year period between 1984 and 2016. To normalize the hydrometric stations' discharge data, a normal probability distribution was used at a confidence level of 10% by exerting the Kolmogorov-Smirnov test (K-S). Furthermore, by applying the IDW method in the Arc GIS software, the drought zoning from 2005 to 2016 was mapped for the mentioned periods. The results of SDI showed that all the hydrometric stations in the considered location have experienced at least one severe drought. Most parts of the region, we affected by the drought for 11 years during 2005 to 2016. These results are consonant with the discharge values in the same period. Finally, based on the zoning results, it was found that in most parts of this region, the rivers stream flow was in the mild to moderate levels.

Keywords Hydrological drought · Streamflow Drought Index · Probability distribution · Drought zoning · Lorestan province

Introduction

The water crisis and drought are among the main problems that the human beings are facing in the recent years (Lindsay et al. 2017). The droughts quantity and consequently their social, economic, and environmental impacts have increased, and this trend is expected to be the result of the climate changes (Bates et al. 2008; Van Huijgevoort et al. 2014). Considering the happening time and the causes, the droughts are divided into several types, the most important of which are meteorological, hydrological, agricultural, and socioeconomic droughts. Among these various types, the hydrological droughts are vitally important due to the dependence of many human activities on the surface water resources (industrial,

urban water supply, and hydroelectric power generation) (Vasiliades et al. 2011).

This type of the droughts is characterized by different factors such as: lower river flows, lower rainfalls, lower levels of the lakes and reservoirs, reduced soil moisture, lower groundwater levels, changes in the runoff pattern, the rate of evaporation and transpiration, etc. By studying these parameters, the drought severity can be quantified (McCleskey et al. 2010). Due to the complexity of the governing rules on the hydrological cycle, a lot of statistical data on different variables for a longer period is needed to study the hydrological droughts. There are some indices such as the PHDI (Guttman 1991; Palmer 1965) and SWSI (Kwon and Kim 2010; Shafer and Dezman 1982) which practically cannot be used in many regions of the world because of their dependence on a massive amount of data. The need for an easier method made the researchers to look for a more understanding and feasible index requiring simpler data like the surface flow rate of the rivers. In this regard, (Nalbantis and Tsakiris 2009) developed a novel method for the assessment of the droughts. They studied the hydrological drought in the Angus region in Greece.

By the assumption that the main process has the nonstationary Markov chain structure, they introduced the SDI

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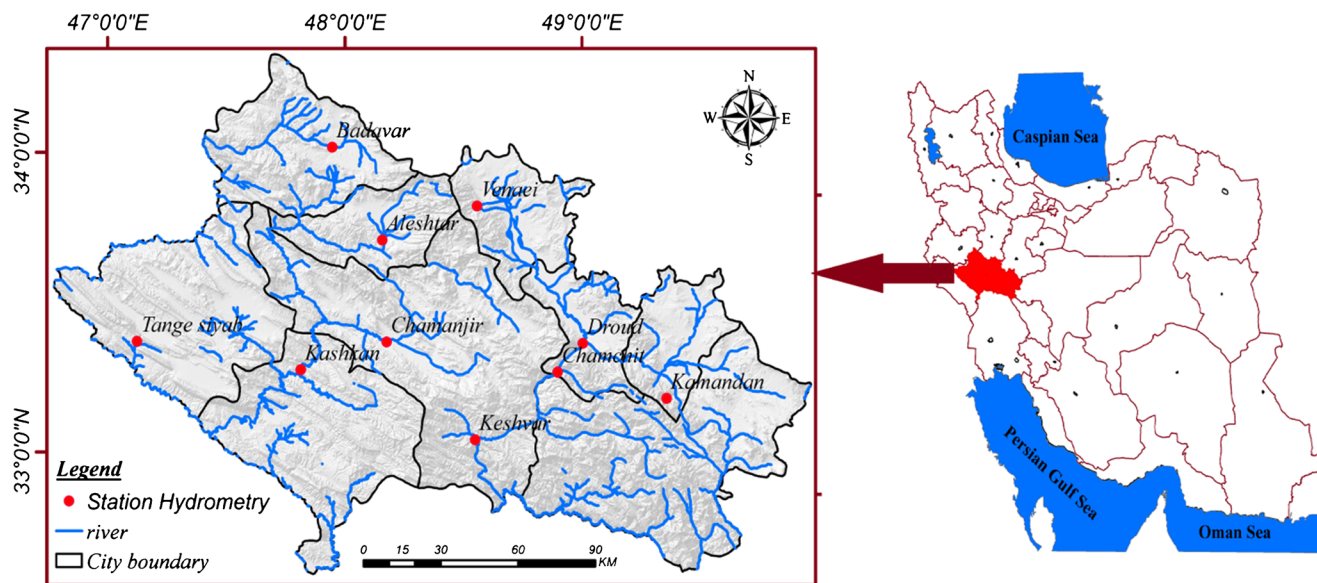


Fig. 1 Geographic location of the study area and spatial distribution of the hydrometric stations

Table 1 Details of the hydrometric stations used in the study

| River | Station | Code | Latitude (N) | Longitude (E) | Altitude (m) | Area (Km) |
|--------------|------------|--------|--------------|---------------|--------------|-----------|
| Keshvar | Sorkhab | 21–289 | 48.63 | 33.13 | 730 | 336 |
| Doab | Seyed Ali | 21–171 | 48.20 | 33.78 | 1540 | 773 |
| Kamandan | Kamandan | 21–273 | 49.42 | 33.30 | 2075 | 35 |
| Absabzeh | Cham Chit | 21–281 | 48.96 | 33.37 | 1290 | 345 |
| Tireh | Droud | 21–267 | 49.06 | 33.47 | 1430 | 3400 |
| Khorramabad | Cham Anjir | 21–175 | 48.24 | 33.44 | 1120 | 1590 |
| Kashkan | Afrineh | 21–177 | 47.89 | 33.33 | 810 | 6700 |
| Norabad | Badavar | 21–145 | 47.97 | 34.08 | 1790 | 615 |
| Dareh Dozdan | Tang Siyab | 21–163 | 47.20 | 33.39 | 850 | 568 |
| Sarab Sefid | Venaei | 21–257 | 48.59 | 33.91 | 1960 | 64 |

method for predicting the hydrological droughts. They employed the SDI and evaluated the hydrological drought in four timescales of 3, 6, 9, and 12 months. By a good agreement of the results with the actual data, they showed that this index is a reliable factor for assessment of the hydrological droughts. The SDI method defines the frequency and severity of the hydrological droughts mostly based on the drought impact on the river basin. One of the main advantages of SDI is its dependency on the streamflow. This method requires at least 30 years of statistical data and predicts the onset of the drought and its duration by using simple parameters such as the cumulative volume of the streamflow and the spatial extent of the drought (Tabari et al. 2013; Tigkas et al. 2012; Fischer et al. 2013). By employing SDI, the water balance indicators can be obtained for a hydrologic. The streamflow drought is defined as a certain decrease in the amount of available water in all of its forms. These forms include the streamflow itself, water level of the reservoirs

and lakes, and groundwater level in the land phase of the hydrological cycle. The streamflow of a river has two main and distinct behaviors; one is its response to the precipitations during the humid seasons and the other is the main stream

Table 2 Definition of states of hydrological drought based on SDI (Nalbantis and Tsakiris 2009)

| State | Description | Criterion | Probability (%) |
|-------|------------------|----------------------|-----------------|
| 0 | Non drought | $0 \leq SDI$ | 51.6 |
| 1 | Mild drought | $-1 \leq SDI < 0$ | 25 |
| 2 | Moderate drought | $-1/5 \leq SDI < -1$ | 12.5 |
| 3 | Severe drought | $-2 \leq SDI < -1/5$ | 10.9 |
| 4 | Extreme drought | $SDI < -2$ | 0 |

By importing the required data gathered from the local stations to the MATLAB software, the values of SDI were calculated for the whole statistical period between the years 1984 and 2016. Furthermore, the IDW interpolation method was used to map the drought severity in the ArcGIS software

conditions in the dry seasons. In all the cases, the streamflow plays an important role in determining the status of surface water resources. Hence, the hydrological droughts are associated with the decrease in the streamflow (Nalbantis and Tsakiris 2009).

The hydrology and the water resources of the western parts of Iran have drawn lots of attention in the recent years (Eslamian et al. 2011; Masih et al. 2009; Hessari et al. 2012;

Saadat et al. 2013; Farahani and Khalili 2013). In many of the conducted studies, the SDI method has been employed to evaluate the hydrological droughts. (Tabari et al. 2013) assessed the drought in the Urmia region located in the north-west of Iran. They utilized SDI and showed that almost all the hydrometric stations in that region suffer from a severe drought. (Eghtedari and Bazrafshan 2016) evaluated the hydrological drought in the Karkheh aquifer in the southwest of

Fig. 2 SDI series at the study stations for reference period (October–December)

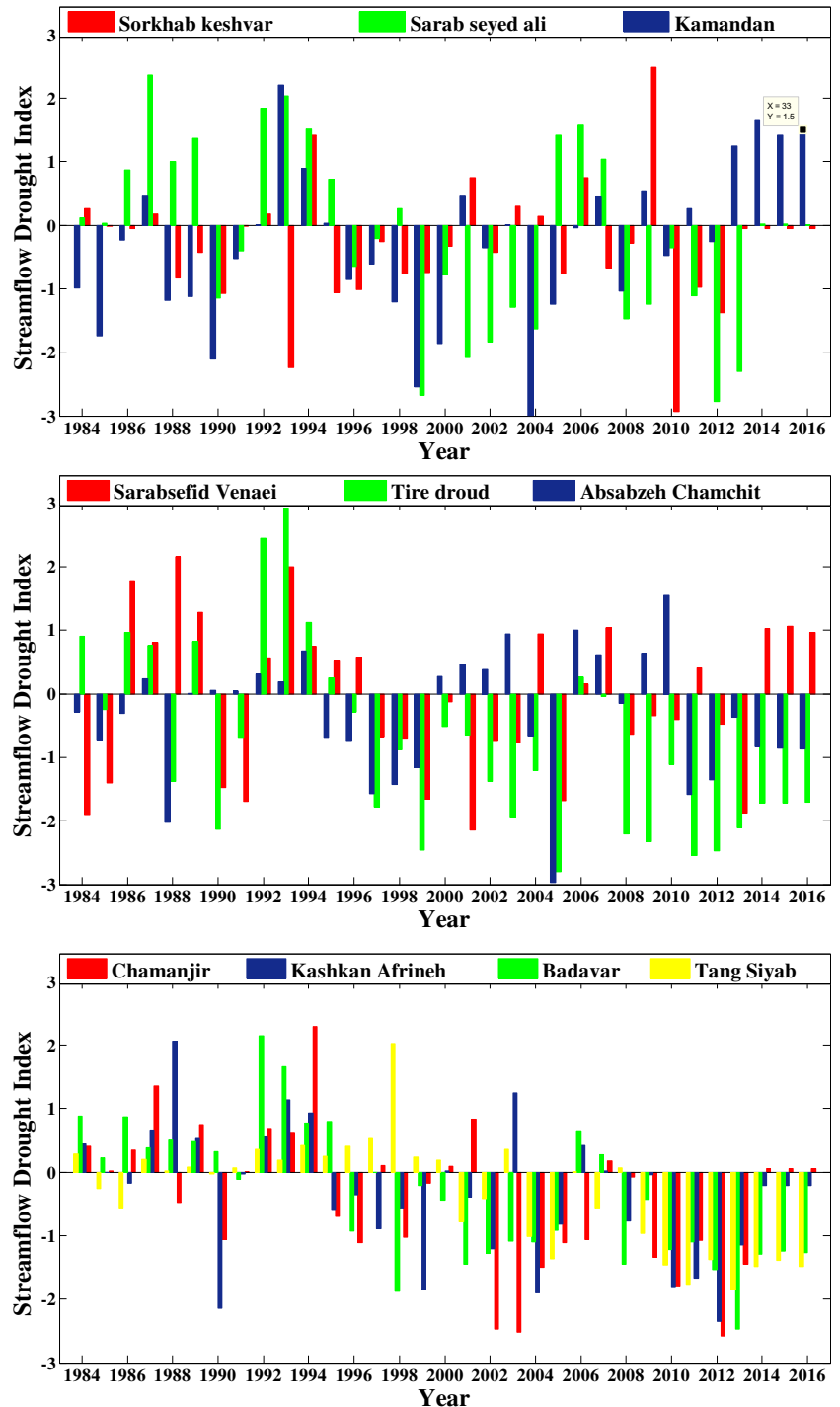


Table 3 Drought characteristics for the study area for the 3-month period

| Station | Continuity | Severity | Number of courses |
|--------------------|------------|----------|-------------------|
| Sorkhab Keshvar | 2010–2016 | 2010 | 5 |
| Seyed Ali Aleshtar | 2008–2013 | 2012 | 4 |
| Kamandan | 1996–2000 | 2004 | 4 |
| Cham Chit | 2011–2016 | 2005 | 4 |
| Sarab Sefid Venaee | 1997–2003 | 2001 | 5 |
| Tireh Droud | 2007–2016 | 2005 | 3 |
| Cham Anjir | 2008–2013 | 2012 | 4 |
| Kashkan Afrineh | 2008–2016 | 2012 | 5 |
| Badavar | 1996–2005 | 2013 | 2 |

Iran, using the SDI. They predicted the status if the drought using a nonstationary Markov chain. Bahramand (2014) evaluated the drought using the SDI in the Halilrood river in Iran. They reported that there is a strong correlation between the standard rainfall index and the hydrologic index (Kazemzadeh and Malekian (2016) examined the spatial and temporal characteristics of hydrological and meteorological droughts using the SPI-SDI indices, for the northwest of Iran. In another study, Saadat et al. (2013) investigated the spatial and temporal changes of the streamflow drought in the region of semiarid Karkheh watershed using the threshold method. Their results revealed that generally, the spatial patterns are a sign of a drought in the seasonal flow of the river in the studied area. Furthermore, Zamani et al. (2015) evaluated the drought using the SDI in the Karkheh basin. The results indicated that for the 3-month timescale, the region was homogenous, while for larger timescales the region was divided into two subregions. For all timescales and subregions, the Pearson Type III and Generalized Pareto distributions provided a better fit to the data than the generalized logistic, generalized extreme

Table 4 Drought characteristics for the study area for the 3-month period

| Station | Continuity | Severity | Number of courses |
|--------------------|------------|----------|-------------------|
| Sorkhab Keshvar | 2010–2016 | 2010 | 5 |
| Seyed Ali Aleshtar | 2008–2013 | 2012 | 4 |
| Kamandan | 1996–2000 | 2004 | 4 |
| Cham Chit | 2011–2016 | 2005 | 4 |
| Sarab Sefid Venaee | 1997–2003 | 2001 | 5 |
| Tireh Droud | 2007–2016 | 2005 | 3 |
| Cham Anjir | 2008–2013 | 2012 | 4 |
| Kashkan Afrineh | 2008–2016 | 2012 | 5 |
| Badavar | 1996–2005 | 2013 | 2 |

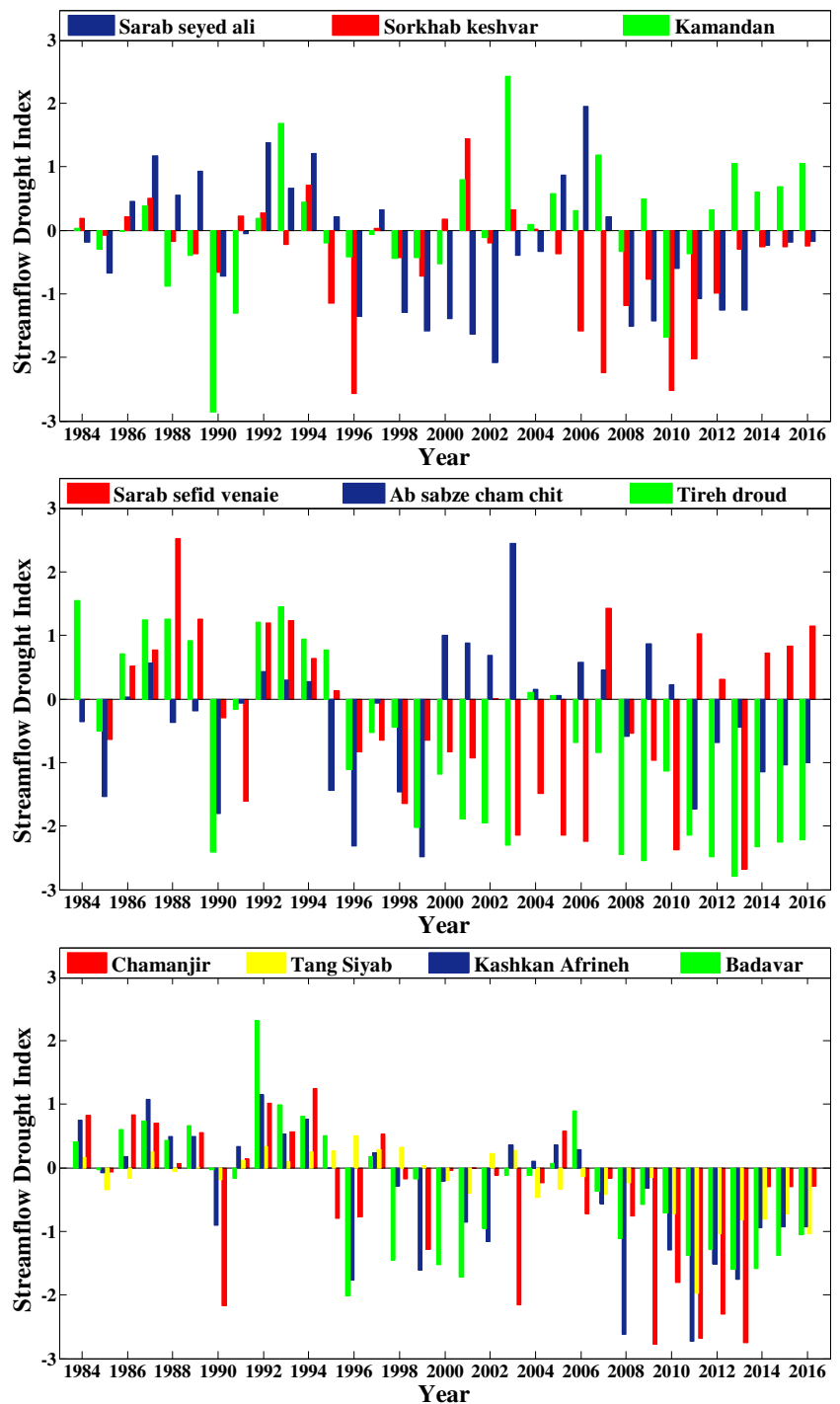
value, and log-normal distributions. The simulation results of the estimated regional quantiles showed that the accuracy of the quantile estimates decreased as return period increased. Furthermore, higher probability of severe droughts is expected at regional scale compared with site scale.

In 2016 (Pathak et al. 2016) analyzes multi-time step hydrological drought by Stream flow Drought Index (SDI) and Standardized Runoff Index (SRI). In Ghataprabha river basin, a subbasin of Krishna river is considered. Results of both indices indicate moderate drought between 1986 and 1988 and 2001 and 2005 continuously. While comparing both indices, there is a good correlation between 9-month SRI and SDI that is observed and it increases for 12-month SRI and SDI. This study may help to choose the appropriate drought indices among SRI and SDI for different lengths of drought studies. Also, Hong et al. (2015) conducted a drought assessment using the SDI index in Yangtze in China. By employing the bootstrap method, the impact of sample size on the sampling uncertainty of the SDI was analyzed. The longer record is used to derive the SDI, the narrower the shifting ranges of the parameters of the streamflow volume probability distribution functions and corresponding interval estimators of SDI are. The upper Yangtze River basin has experienced successive alternation of wet and dry years, and the spring seems to be the driest season within a year. The current difficulty in fighting against increasing droughts in upper Yangtze River basin is upgrading. Considering the possible misjudgment of drought degree results from the sampling uncertainty, attention should be paid to the preparation of drought relief strategies in order to reduce the potential losses. In 2015, Tabari et al. (2015) analyzed the streamflow drought with different Markov chain methods in the Karkheh basin. Their results showed that the frequency of the expected drought is higher for smaller timescales of 3 and 6 months. The present study aims to investigate the seasonal-temporal-spatial patterns of droughts in the river streams in the Lorestan province. Until now, this index has not been applied to the studied area for a single period. The main focus of this study is to determine the temporal and spatial patterns of the streamflow droughts based on the long-term analysis the droughts characteristics. The results of this research can be used for assessing regional and subregional available water resources and drought management planning.

The study area

In this paper, the Lorestan province has been considered as the case study. This region has an area of 28,160 km² with the geographical coordinates between 47°05' E and 49°57' E in the longitude and between 32°52' N and 34°21' N in the latitude, which is about 71.2% of that mountainous (about 20,000 km²) and the rest is 28.8 The percentage is 30 in the

Fig. 3 SDI series at the study stations for reference period (October–March)



plain of the index (about 8100 sq. Km), which includes the entire area of the Quaternary alluvial sediments and the present covenant. This zone has a general Mediterranean climate with three distinct weather zones: mountainous cold zone, temperate central zone, and southern warm zone. The average annual precipitation is 550 mm. The province is located north of Hamedan and Central provinces, south to Khuzestan and Chaharmahal and Bakhtiari, east to Isfahan province, and west to Kermanshah and Ilam provinces. The highest Oshtoran

Kooh height is about 4150 m in the east, and its lowest point is 500 m above sea level in the area of Pol Dokhtar. According to the classification of the study areas of the country, Lorestan province consists of 27 study areas (6 internal study areas and 21 joint study areas with adjacent provinces). Of these, 14 districts, including Bakhtiari, Halilan, Molubakh, etc., and adjoining neighboring provinces are governed by seven provinces of Ilam, Chaharmahal and Bakhtiari, Khuzestan, Isfahan, Hamedan, Central, and Kermanshah. The other

Table 5 Drought characteristics for the study area for the 6-month period

| Station | Continuity | Severity | Number of courses |
|--------------------|------------|----------|-------------------|
| Sorkhab Keshvar | 2005–2016 | 1996 | 4 |
| Seyed Ali Aleshtar | 2008–2016 | 2002 | 4 |
| Kamandan | 1995–2000 | 1990 | 3 |
| Cham Chit | 2011–2016 | 1999 | 4 |
| Sarab Sefid Venaei | 1996–2001 | 2013 | 5 |
| Tireh Droud | 2006–2016 | 2013 | 3 |
| Cham Anjir | 2006–2016 | 2009 | 3 |
| Kashkan Afrineh | 2007–2016 | 2011 | 3 |
| Badavar | 2007–2016 | 1996 | 3 |
| Tang Siyab | 2004–2016 | 2011 | 4 |

thirteen study areas are Ostanan, Borujerd Dorood, Azna-Aligudarz, Awaj, Sarab Jloodon (Basin of the Karun River in the province), Alshatr, Noorabad, Khorramabad, Kuhdasht, Shirvand, Rumshakan, Pol Dokhtar, Choghlvandi (Karkheh river basin in the province). It is mainly internal and their trustees are Lorestan province. This province is located in the middle zone of Zagros in the direction of the flow of two air masses. One of the hot and humid streams of Sudanese from the Red Sea and the Arabian Plateau from the southwest and the other moderate and humid Mediterranean flows enter to the Lorestan province from the west. Whenever these two air masses collide, the rainy fronts make up the very best of rainfall.

As a result, the discharge regime of most of the rivers of the province is also affected by snow melting and elevation as well as by rainfall. High rainfall with topographic topography and good weather has made it one of the most diverse ecosystems in our province, which is economically important. The same factors have helped to bring the province's river network with more than 130 permanent and seasonal rivers with a length of about 8877 km. The four main rivers are Seymareh, Kashkan, Caesar, and Bakhtiari, with a length of about 1454 km, and the rest include permanent branches in their important season are about 7423 km in the two basins of Karun (Dez) and Karkheh.

The provincial river network is one of the country's richest water networks, which drains the lake after the dams and karkha dams, with the deductible of more than 12 billion cubic meters of water from the adjacent provinces, of which this amount is close to 4 billion cubic meters of adjacent provinces and 8 billion cubic meters of production in the province (permanent rivers are about 7 and seasonal rivers of about 1 billion cubic meters). The volume of water output in the province is about 12% of the country's total current water. Also, the geological complex (about 12,000 km² of karst formations) and the 10 underground aquifers with a 1629 square-meter observation wells network contain over 5 billion cubic meters of groundwater resources, based on annual

inventory of water resources for the 2010. The number of fountains in the province of 6439 with the annual output of 600 million cubic meters and the qanat of 1341 fields with annual output of about 40 million cubic meters, and the wells of the province are 7324 looms with an annual discharge of about 600 million cubic meters and a total of about 1215 million cubic meters Release groundwater resources annually (Fig. 1).

Methodology

In this research, the data from ten hydrometric stations were gathered for the Lorestan province. Table 1 shows the local characteristics of the hydrometric stations. Moreover, the daily flow rates have been obtained from the local water organization. To eliminate the errors resulted by the incorrect data, they have been excluded from the calculations. The run tests were employed to check the modified data quality, and the test results showed the data are reliable. In the next step, the 30-year statistical period of 1984 to 2016 was chosen for all the stations. Then the SDI method was employed for four different periods of 3, 6, 9, and 12 months to assess and analyze the hydrological drought.

Streamflow Drought Index (SDI)

In this method, the cumulative flow rate of the river is calculated as follows (Nalbantis and Tsakiris 2009):

$$Q_{i,j} = \sum_{j=1}^{3k} q_{i,j} \quad i = 1, 2, 3, \dots, j = 1, 2, 3, \dots, 12 \quad k = 1, 2, 3, 4 \quad (1)$$

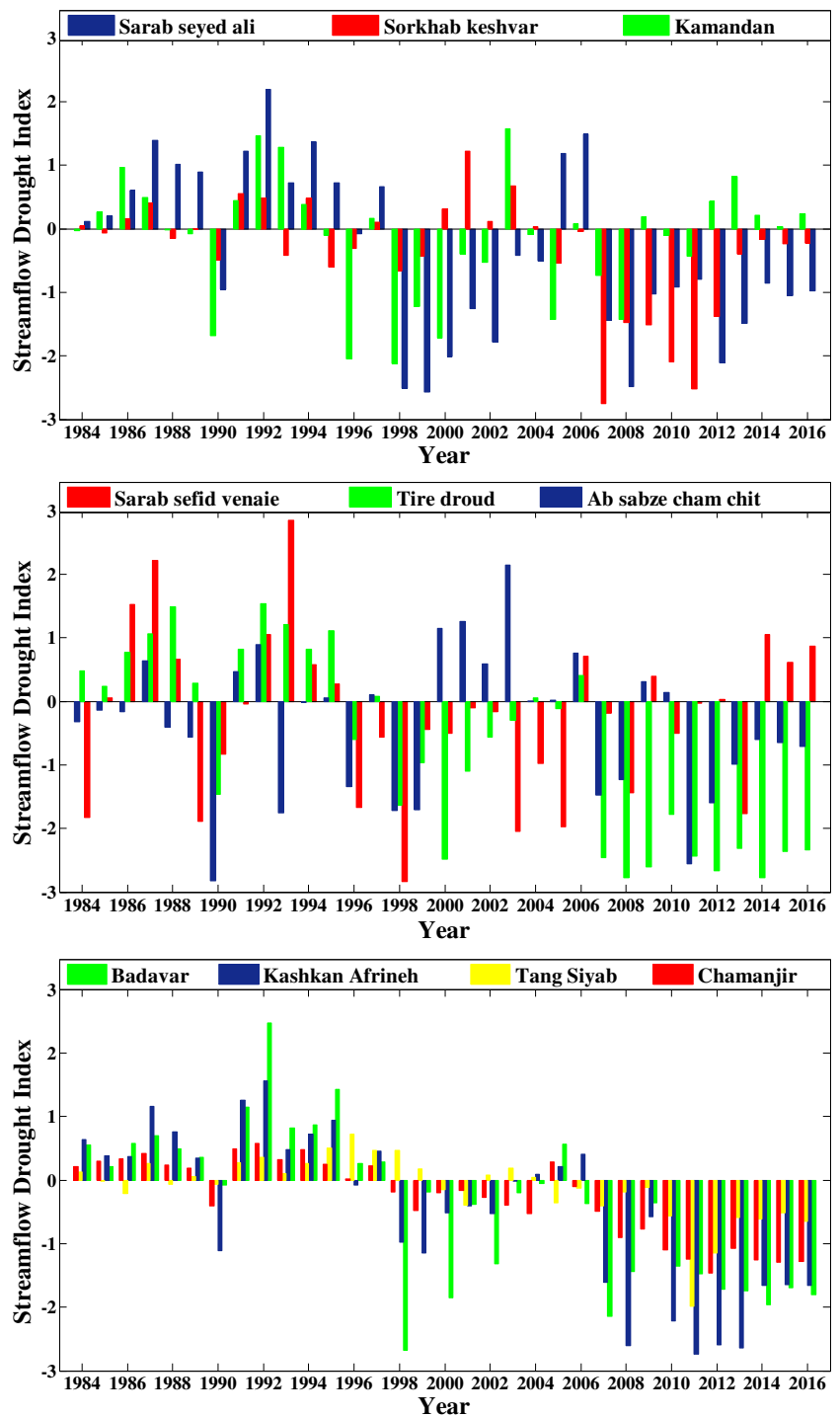
where $Q_{i,j}$ is the cumulative and $q_{i,j}$ is the total streamflow volumes for the i -th hydrological year and the k -th reference period. The subscript “ j ” refers to the month in the hydrological year ($j = 1$ for September and $j = 12$ for August). The values of k are: $k = 1$ for October–December, $k = 2$ for October–March, $k = 3$ for October–June, and $k = 4$ for October–September.

Furthermore, the SDI is defined based on the cumulative streamflow volume for each reference period of k in the i -th hydrological year as follows (Nalbantis and Tsakiris 2009):

$$SDI_{i,k} = \frac{Q_{i,k} - \overline{Q}_k}{S_k} \quad i = 1, 2, 3, \dots, k = 1, 2, 3, 4 \quad (2)$$

where \overline{Q}_k and S_k are the average and the standard deviation of the cumulative volume of the streamflow for the reference period of k and in a long period, respectively. With this definition, \overline{Q}_k is considered as the threshold level. The SDI is actually equivalent to the river standardized streamflow volume. In this method, instead of the volume, the mean river flow rate data are used.

Fig. 4 SDI series at the study stations for reference period (October–June)



Predicting the hydrological drought severity

To predict the probability of the different status of drought severities, the SDI was calculated using the long-term data of the streamflow from the stations in the Karkheh and Dez basins. The drought severity is determined by the values given Table 2.

Drought zoning

The IDW considers the neighborhoods of the selected points that the variable is depicted by reducing the distance effect of its sample location. In this research, IDW method was used for Lorestan province. The SDI index was used for zoning

drought in this province, which was calculated over a 12-month period. Then, a table with XLSX format containing station names, UTM coordinates (UTM-WGS 1984-ZONE 39 N) was plotted and data entered Arc Map software and drought zoning was performed by IDW method by SDI.

Results and discussion

Normality tests of data series

The Kolmogorov-Smirnov (K-S) test at the 0.05 significance level was used to check the goodness of fit of the precipitation and streamflow data by means of an adjusted normal distribution. The higher p values indicate the acceptance of the null hypothesis of K-S test which means that the observed data are coming from this distribution. The results showed that all of the series follow a normal distribution. Furthermore, they showed that for October–March (6 month), October–June (9 month), and October–September (12 month), the p -values are greater than 0.23, while for October–December (3 month), they are greater than 0.14 which means that the normal distribution provides an adequate fit to the precipitation and streamflow series. Within the normalization process, tree probability distributions of normal, exponential, and uniform were evaluated. It should be noted that the null hypothesis of K-S test is that the observed data is come from the proposed distribution and, hence, higher p -values are interpreted as tendency toward accepting the null hypothesis. Among the distributions, the normal probability was selected as the top distribution.

The lowest p values are obtained for the Cham Anjir, and Afrineh stations of the streamflow series, which is mainly due to the fact that many of the series had zero values. Furthermore, the October–March streamflow series at three stations Cham Chit station did not follow the normal distribution.

SDI series

In the next step, the values of the SDI have been calculated. Figure 2 shows the SDI for the 3-month period (October–December). Also, the continuity, severity, and the number of drought and wet periods are reported in Table 4. Moreover, the longest duration of the droughts for each hydrometric station between the years 1984 and 2016 are given in this table.

The Badavar and Tireh Droud hydrometric stations had the longest drought duration with 9 years of continuity between 1996 and 2005 and 2007 and 2016. Also, the shortest drought has occurred in Kamandan hydrometric station during 1996 to 2000. The statistical year 2012–2013 was the driest year in the studied period. Moreover, according to Table 4, between the years 1984 and 2016, the hydrometric stations of Sorkhab,

Sarab Sefid Vanaei, and Kashkan Afrineh had highest number of droughts in five different periods. On the other hand, the hydrometric stations of Badavar with two drought periods experienced the lowest number of droughts. The same parameters introduced in Table 3 are reported in Table 4 for the 6-month period. Also, Fig. 3 shows the values of SDI for this period. The most sever streamflow drought for Kamandan station occurred during year 2004 with a yearly (October–September) SDI value of -2.99 .

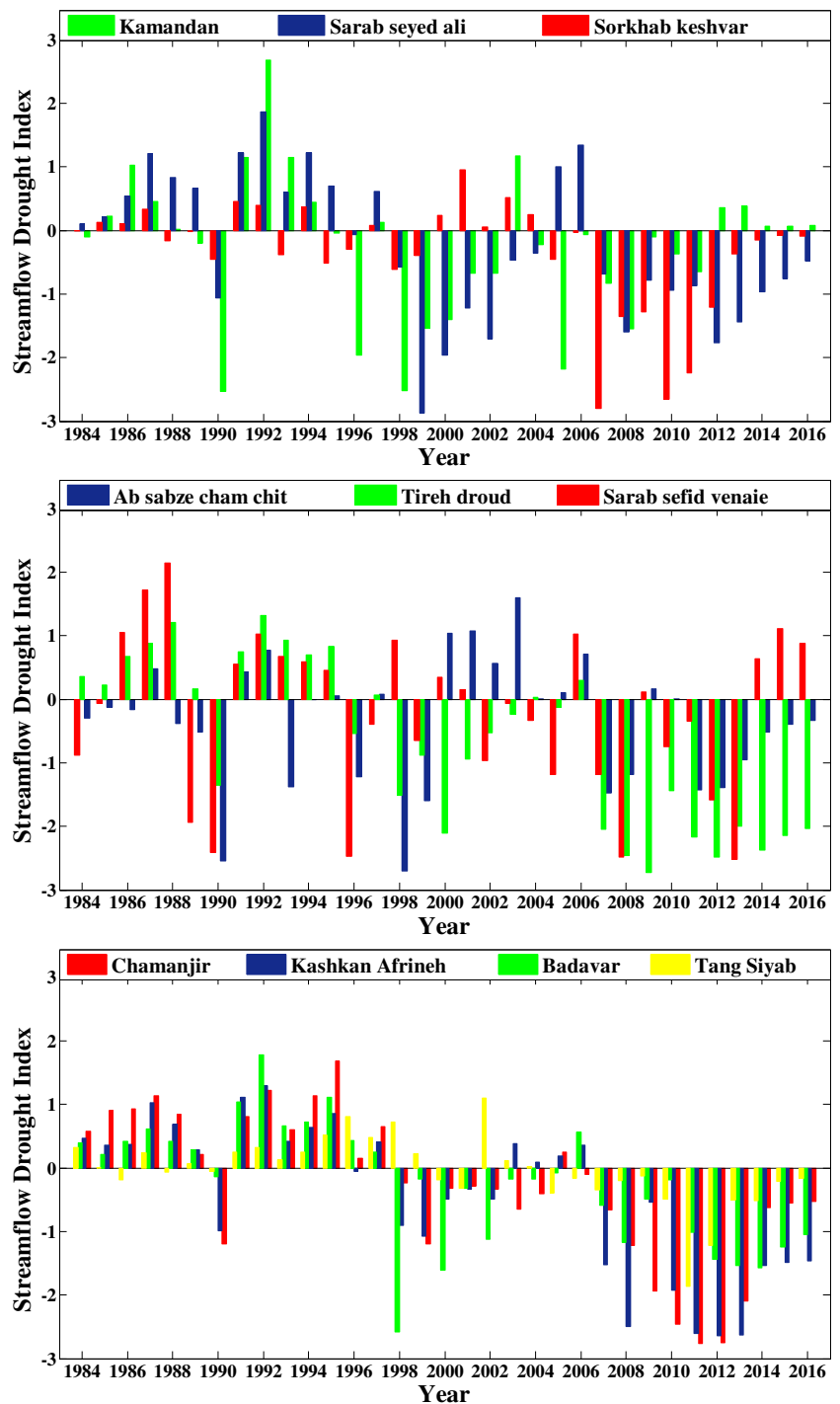
In the 6-month period case, the Tang Siyab station had the longest duration of the drought with 12 years of continuity between the years 2004 and 2016. The shortest duration belongs to the Cham Chit and the Sarab Sefid Vanaei and Kamandan hydrometric stations from 2011 to 2016 and 1996 to 2001 and 1995 to 2000, respectively. The years 2011 to 2013 are the driest years in the studied period. According to Table 5, the hydrometric stations of Sarab Sefid Vanaei with five periods of drought had the highest number of droughts. Also the hydrometric station of Badavar, Kashkan Afrineh, Tireh Droud, Cham Anjir, and Kamandan with tree drought occurrences had the lowest number of droughts during the statistical period of 1984 to 2016. Similar to the investigations on the periods of 3 and 6 months, the same results are reported in Fig. 4 and Table 5. The most sever streamflow drought for Cham Anjir station occurred during year 2009 with a yearly (October–March) SDI value of -2.75 .

By investigating the results for the 9-month period, the hydrometric stations of Tang Siyab and Sorkhab Keshvar had the longest drought duration with 9 years of continuity in the years 2005 to 2016. The shortest duration is obtained for the hydrometric station of Kamandan between the years 1998 and 2002. Also, the driest years are 2005 to 2016. According to Table 6, the hydrometric stations of Kamandan and Cham Chit with six times of drought occurrence had the highest number of droughts. In contrary, the Badavar, Sarab Seyd

Table 6 Drought characteristics for the study area for the 9-month period

| Station | Continuity | Severity | Number of courses |
|--------------------|------------|----------|-------------------|
| Sorkhab Keshvar | 2005–2016 | 2007 | 3 |
| Seyed Ali Aleshtar | 2007–2016 | 1999 | 2 |
| Kamandan | 1998–2002 | 1998 | 6 |
| Cham Chit | 2011–2016 | 1990 | 6 |
| Sarab Sefid Vanaei | 1996–2005 | 1998 | 4 |
| Tireh Droud | 2007–2016 | 2014 | 2 |
| Cham Anjir | 2006–2016 | 2012 | 2 |
| Kashkan Afrineh | 2007–2016 | 2011 | 2 |
| Badavar | 2006–2016 | 1998 | 2 |
| Tang Siyab | 2005–2016 | 2011 | 3 |

Fig. 5 SDI series at the study stations for reference period (October–September)



Ali Aleshtar, Cham Anjir, Kashkan Afrineh and Tireh Droud stations had the lowest number of droughts with two times of occurrence during 1984 to 2016 statistical period. The same results for the 12-month period are given in Fig. 5 and Table 6. The most sever streamflow drought for Tireh Droud station occurred during year 2014 with a yearly (October–June) SDI value of -2.93 .

The longest drought continuity for each hydro-metric station during the 1984–2016 statistical period is reported in

Table 7. The hydro-metric station of Tang Siyab and Sorkhab Keshvar had the longest drought duration of 9 years between 2005 and 2016. Also, the Cham Chit station had the shortest drought duration with 4 years of continuity in 2011 to 2016. Moreover, the statistical years of 2005 to 2016 were the driest years in the studied period. The hydro-metric stations of Sarab Sefid Venaie had the most number of droughts, and the Badavar, Sarab Seyd Ali Aleshtar, Cham Anjir, Kashkan Afrineh, and Tireh Droud stations had the least number during

Table 7 Drought characteristics for the study area for the 12-month period

| Station | Continuity | Severity | Number of courses |
|--------------------|------------|----------|-------------------|
| Sorkhab Keshvar | 2005–2016 | 2007 | 4 |
| Seyed Ali Aleshtar | 2007–2016 | 1999 | 2 |
| Kamandan | 2004–2011 | 1990 | 4 |
| Cham Chit | 2011–2016 | 1998 | 5 |
| Sarab Sefid Venaei | 2010–2013 | 2013 | 6 |
| Tireh Droud | 2007–2016 | 2009 | 2 |
| Cham Anjir | 2006–2016 | 2011 | 2 |
| Kashkan Afrineh | 2007–2016 | 2012 | 2 |
| Badavar | 2006–2016 | 1998 | 2 |
| Tang Siyab | 2005–2016 | 2011 | 2 |

1984 to 2016. The most sever streamflow drought for Cham Anjir station occurred during year 2012 with a yearly (October–September) SDI value of -2.91 .

Because most of the hydrometric stations have somehow experienced prolonged droughts during the studied period, the drought zonings were also investigated in this paper. Based on the periods of 3, 6, 9, and 12 months, the drought zoning of the considered region has been studied for the years 2005 to 2016, using IDW. Figures 6, 7, 8, and 9 show the zonings for the periods of 3, 6, 9, and 12 months respectively. Figure 6 indicates that the hydrometric station of Tireh Droud was affected by severe drought and the Kamandan hydrometric station was drought-free. Also, according to this figure, most of the studied area was affected by a mild drought. Figure 7 shows that for the 6-month period, generally the same results are expected. Only the zone affected by the moderate drought differs for

Fig. 6 SDI zoning for the studied area is based on the 3-month period

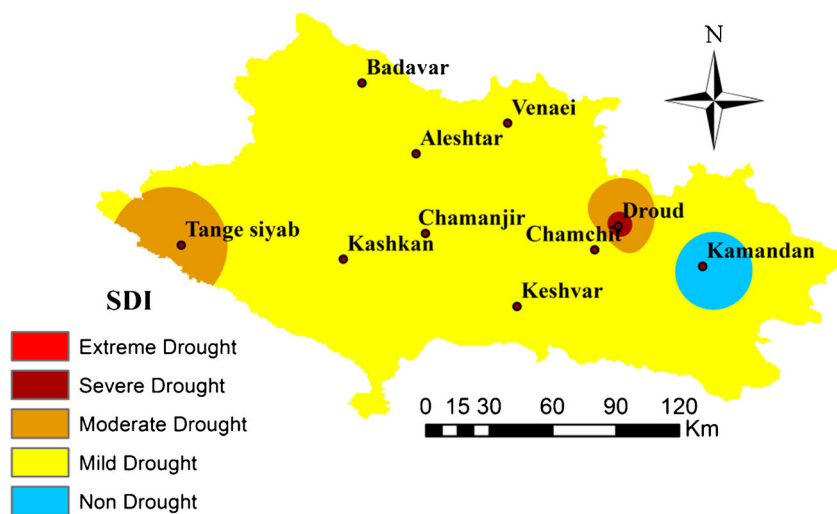


Fig. 7 SDI zoning for the studied area is based on the 6-month period

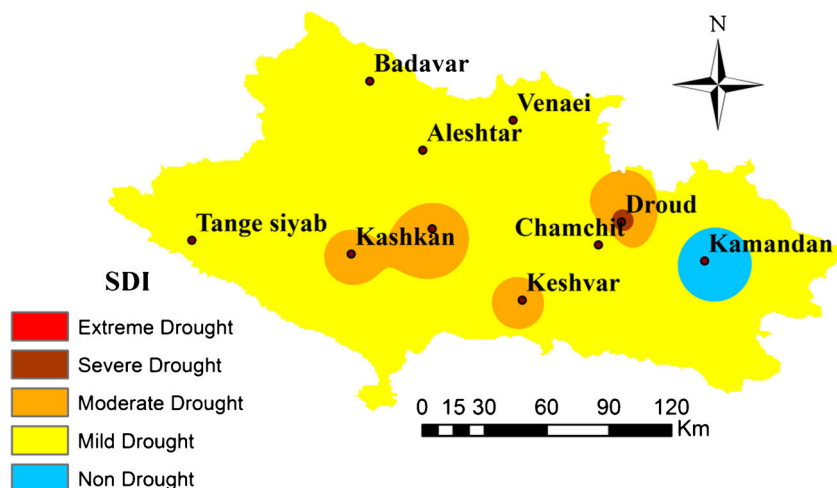


Fig. 8 SDI zoning for the studied area is based on the 9-month period

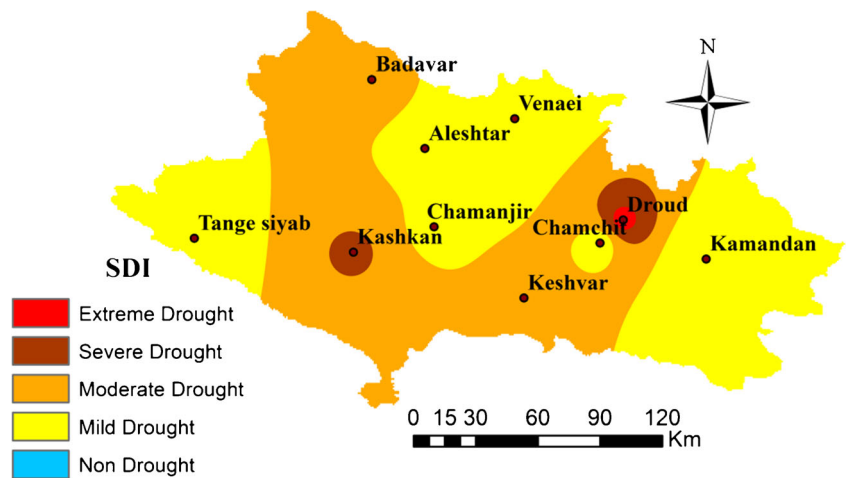
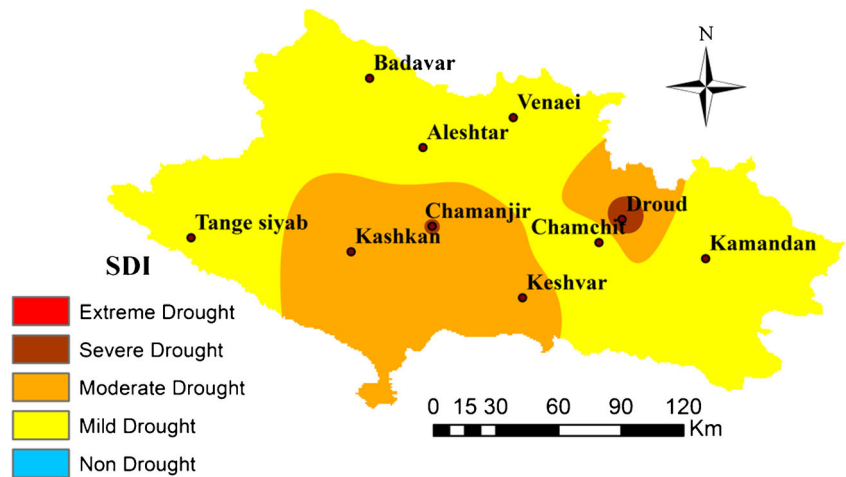


Fig. 9 SDI zoning for the studied area is based on the 12-month period



this case. Also for the 9-month period, as shown in Fig. 8, the Tireh Droud station was affected by a severe drought. Moreover, in this period, the Kashkan Afrineh station was also affected by severe drought. Most of the studied area for the 9-month period was affected by a moderate drought. Finally, Fig. 9 corresponding to the 12-month period shows that the three hydrometric stations of Tireh Droud and Cham Anjir were affected by severe drought and most of the study area was undergone a mild drought.

normalize the flow rate data of the hydrometric stations. The data were normalized by employing the Kolmogorov-Smirnov (K-S) test. The result of SDI showed that at all hydrometric stations in the Lorestan province had at least one severe drought. During 2005 to 2014, most parts of this region was affected by a hydrological drought for 9 years. These results are in a good consonance with the flow rate values during 2005 to 2016. Also it was revealed that during this period, most of the understudy area was affected by mild to moderate droughts.

Conclusion

In this research, the hydrological drought was assessed by SDI based on periods 3, 6, 9, and 12 months and for a period of 32 years between 1984 and 2016. Moreover, the normal probability distribution was used at the confidence level of 0.10 to

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