Nat Hazards
DOI 10.1007/s11069-015-1964-7

ORIGINAL PAPER

Spatial characteristics and temporal trends of meteorological and hydrological droughts in northwestern Iran

Majid Kazemzadeh[1] · **Arash Malekian**[1]

Received: 30 June 2014 / Accepted: 15 September 2015

Abstract In recent years, droughts have become more intense and frequent in arid and semi-arid regions like Iran on the one hand, and water demand has been rising on the other hand and, as a result, their impacts are being aggravated. Therefore, the meteorological and hydrological droughts are receiving much more attention. This paper focused on the meteorological and hydrological drought characteristics for the overlapping periods of 3, 6, 9, and 12 months in northwestern Iran over the period of 1981–1982 to 2010–2011. The results showed that the majority of drought events over the reference periods were in the last 15 years from 1995–1996 to 2010–2011. Furthermore, the driest year based on the meteorological drought index was 2007–2008, while it was detected to be 2010–2011 based on the hydrological drought index. The Spearman's rho and Kendall's tau tests were used for the temporal trends analysis of the meteorological and hydrological droughts. The decreasing time series trends were more evident for the streamflow droughts index than for the standardized precipitation index series. In general, the results of the meteorological and hydrological drought trends showed that the study area suffered from the hydrological drought more than meteorological droughts. Moreover, the results revealed that the study area has become drier during the last three decades. Finally, the Spearman correlation analysis was applied to explore the relationships between meteorological and hydrological droughts which indicated a strong correlation between May–Jul-SPI series and the Jun–Aug-SDI series with a value of 0.65.

Keywords Drought · Spatial distribution · Meteorological drought · Correlation · Temporal analysis

✉ Arash Malekian
malekian@ut.ac.ir

1 University of Tehran, Tehran, Iran

Published online: 22 September 2015

1 Introduction

Drought events and their related impacts on socioeconomic and natural environments are expected to increase in severity due to changing climate (Bates et al. 2008; Dai 2011; Romm 2011; Van Huijgevoort et al. 2013). Drought may cause a significant hazard to the environment and agriculture production, particularly in water-scarce regions (Zhang et al. 2012) like Iran. Increasing the water demands for an ever-growing population as well as for industrial and economic development, including irrigation and agricultural water scarcity due to frequent dry periods and drought conditions in Iran, makes a rational water management difficult (Raziei et al. 2008; Nikbakht et al. 2012). There is not a universal definition of drought, but it can be defined from different disciplinary perspectives, namely meteorological drought, agricultural drought, hydrological drought, and socioeconomic drought (Yang 2010). The three physical forms of drought, namely meteorology, hydrology, and agriculture, focus on the water shortage in the hydrological cycle (Wilhite and Glantz 1985; Bazrafshan et al. 2014). Among the different types of droughts, the meteorological drought occurs earlier than the other droughts.

Hydrological drought is defined as a significant decrease in the water availability in all its forms appearing in the land phase of the hydrological cycle (Nalbantis 2008). Hydrological drought may be affected by meteorological drought and the relationship between them is important for management approaches. For example, droughts impact both surface and groundwater resources and can lead to reduced water supply, increased water demand, deteriorated water quality, crop failure, reduced rangeland productivity, diminished power generation, disturbed riparian habitats, and suspended recreation activities and can also affect a host of economic and social activities (Riebsame et al. 1991; Mishra and Singh 2010).

Monitoring historical droughts can provide better information for future drought event forecasting. There are different approaches for the analysis of drought events that include the use of drought indices. Several drought indices have been developed to characterize meteorological and hydrological drought events over the years (Dracup et al. 1980; Tate and Gustard 2000; Smakhtin 2001; Heim 2002; Tallaksen and Van Lanen 2004; Chulsang et al. 2008; Liu et al. 2012; Tabari et al. 2013). The various indices devised for characterizing hydrological and meteorological droughts are, in general, data demanding and computationally intensive. In contrast, there are very simple and effective indices such as the Standardized Precipitation Index (SPI) and the Streamflow Drought Index (SDI) which have been developed by McKee et al. (1993) and Nalbantis and Tsakiris (2009), respectively. Among droughts indices, the SPI has found widespread applications, because it allows a reliable and relatively easy comparison between different climates (McKee et al. 1995; Heim 2000; Wilhite et al. 2000; Rossi and Cancelliere 2002; Morid et al. 2006; Paulo and Pereira 2007; Khan et al. 2008; Khalili et al. 2011; Tabari et al. 2012).

Drought indices have been widely used in different continents. Hisdal and Tallaksen (2003) analyzed the regional meteorological and hydrological drought characteristics in Denmark and showed that streamflow droughts were less homogeneous over the region, less frequent, and last for longer time periods than precipitation droughts. Nalbantis and Tsakiris (2009) used the SPI for the analysis of the meteorological droughts in Greece and the SDI was presented as a newly developed index. Khalili et al. (2011) utilized the SPI and Reconnaissance Drought Index (RDI) in different climate zones of Iran. Their results showed that the RDI by utilizing the potential evapotranspiration (ET0) can be very sensitive to climatic variability. Tigkas et al. (2012) applied the RDI and SDI in Greece;

they derived regression equations between RDI and SDI, forecasting the level of hydrological drought for the entire year in real time. Nikbakht et al. (2012) applied the Percent of Normal Index (PNI) for the streamflow drought severity analysis in northwest Iran. They found that the worst streamflow droughts at almost all the stations occurred in 1999–2000 and 2000–2001. The results also indicated that the streamflow drought severity based on the PNI has increased during the last 34 years. Hydrological droughts in northwestern Iran based on the SDI Index were assessed by Tabari et al. (2013). They suggested that almost all stations suffered from extreme droughts during 1975–2009. Additionally, they found that the extreme droughts occurred more frequently in the last 12 years from 1997–1998 to 2008–2009.

The main objective of this research is a comparative analysis of the *SPI* and *SDI* based on the data from selected rain gauge and hydrometric stations in northwestern Iran. The SPI and SDI were used for the overlapping periods of 3, 6, 9, and 12 months within each hydrological year over the period of 1981–1982 to 2010–2011. The current research adopts a nonparametric approach for detecting the meteorological and hydrological drought trends and their relationships over the last decades.

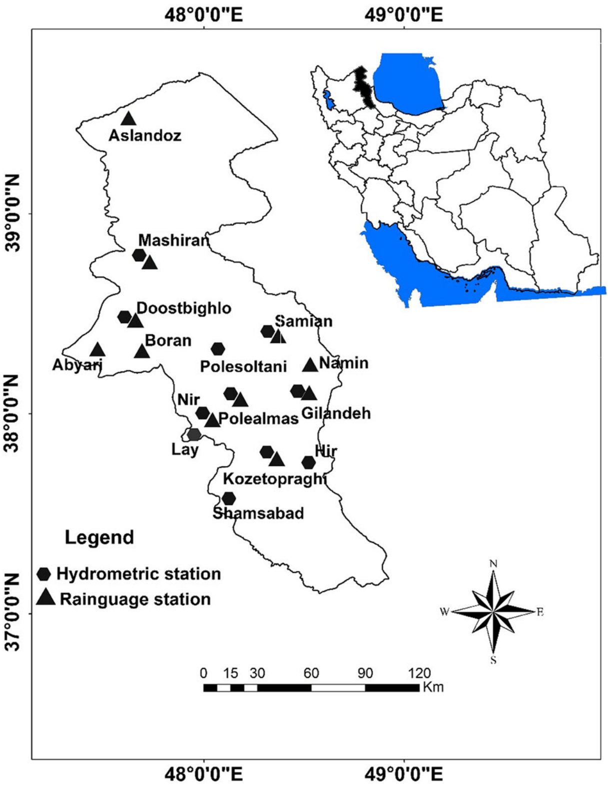

Fig. 1 Spatial distribution of the gauging stations in the study area

2 Study area and data

The study area, Ardebil province, with an area of 19,751 km^2, is located in the northwest of Iran. In this area, many people are engaged in agriculture and many agricultural products are exported to different parts of the country. It is a susceptible area in terms of variation of climatic factors such as precipitation.

Totally, 22 gauging stations in the region with valid and adequate data, including 11 rain gauges and 11 hydrometric stations, were selected (Fig. 1). The monthly observed precipitation and streamflow data were collected for the period of 1981–1982 to 2010–2011. Before using data for drought analysis, some statistical tests, including the homogeneity test via double mass curve method, the outlier detection test, and the normality test were applied. Details of the meteorological and hydrometric stations are presented in Table 1.

3 Methods

3.1 Standardized Precipitation Index (SPI)

The SPI is a simple way for defining and monitoring drought events which was developed by McKee et al. (1993) and has become a popular measure of drought across the globe (Do-Woo et al. 2009; Duggins et al. 2010). Positive SPI values indicate greater than mean precipitation (or rainfall surplus), negative values represent less than mean precipitation (or deficit rainfall) (Patel et al. 2007), and the magnitude of SPI values represent the intensity of drought and wet events.

The SPI is calculated in the following sequence. A monthly precipitation data set is prepared for a period of *m* months, ideally a continuous period of at least 30 years. A set of averaging periods is selected to determine a set of timescales of period *j* months where *j* is 3, 6, 12 months. Then, the SPI is calculated according to the procedure described by McKee et al. (1993). Table 1 summarizes the classification of the SPI values and the corresponding drought category.

3.2 Streamflow Drought Index (SDI)

Nalbantis and Tsakiris (2009) developed SDI following the methodology of the SPI for characterizing hydrological droughts. It is assumed that a time series of monthly streamflow volumes $Q_{i,j}$ is available, where *i* denotes the hydrological year and *j* the month within

Table 1 Wet and drought period classification according to the SPI (McKee et al. 1993)

Index value	Class
$SPI \geq 2.0$	Extremely wet
$1.5 \leq SPI < 2.0$	Very wet
$1 \leq SPI < 1.5$	Moderately wet
$-1 \leq SPI < 1$	Near normal
$-1.5 \leq SPI < -1$	Moderate drought
$-2 \leq SPI < -1.5$	Severe drought
$SPI \leq -2$	Extreme drought

that hydrological year ($j = 1$ for October and $j = 12$ for September). Based on this series, the cumulative streamflow volume is computed as follows:

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,k} \quad i = 1, 2, 3, \ldots \quad j = 1, 2, \ldots, 12 \quad k = 1, 2, 3, 4 \tag{1}$$

where $V_{i,k}$ is the cumulative streamflow volume for the i-th hydrological year and the k-th reference period, $k = 1$ for October–December, $k = 2$ for October–March, $k = 3$ for October–June, and $k = 4$ for October–September.

Based on the cumulative streamflow volumes $V_{i,k}$, the Streamflow Drought Index (SDI) is defined for each reference period k of the i-th hydrological year as follows:

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V_k}}{s_k} \quad i = 1, 2, \ldots \quad k = 1, 2, 3, 4 \tag{2}$$

where $\overline{V_K}$ and s_k are, respectively, the mean and the standard deviation of the cumulative streamflow volumes of the reference period k. (Nalbantis and Tsakiris 2009; Tigkas et al. 2012). While positive SDI values indicate wet conditions, negative values reflect a hydrological drought. States of the hydrological drought are defined based on the SDI which are identical to those used in the meteorological drought indices, including the SPI and RDI. Therefore, five states of hydrological drought are defined which are denoted by an integer number ranging from 0 (non-drought) to 4 (extreme drought). The different states are defined through the criteria stated in Table 2.

4 Results and discussion

4.1 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 0.25 while for October–December (3 month), they are greater than 0.15 which means that the normal distribution provides an adequate fit to the precipitation and streamflow series. The lowest p values are obtained for the Kozetopraghi and Doostbighlo stations of the streamflow series, which is mainly due to the fact that many of the series had zero values. Meanwhile, other distributions, such as the exponential,

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

State	Description	Criterion	Probability (%)
0	Non-drought	$SDI \geq 0$	50.0
1	Mild drought	$-1 \leq SDI < 0$	34.1
2	Moderate drought	$-1.5 \leq SDI < -1$	9.2
3	Severe drought	$-2 \leq SDI < -1.5$	4.4
4	Extreme drought	$SDI < -2$	2.3

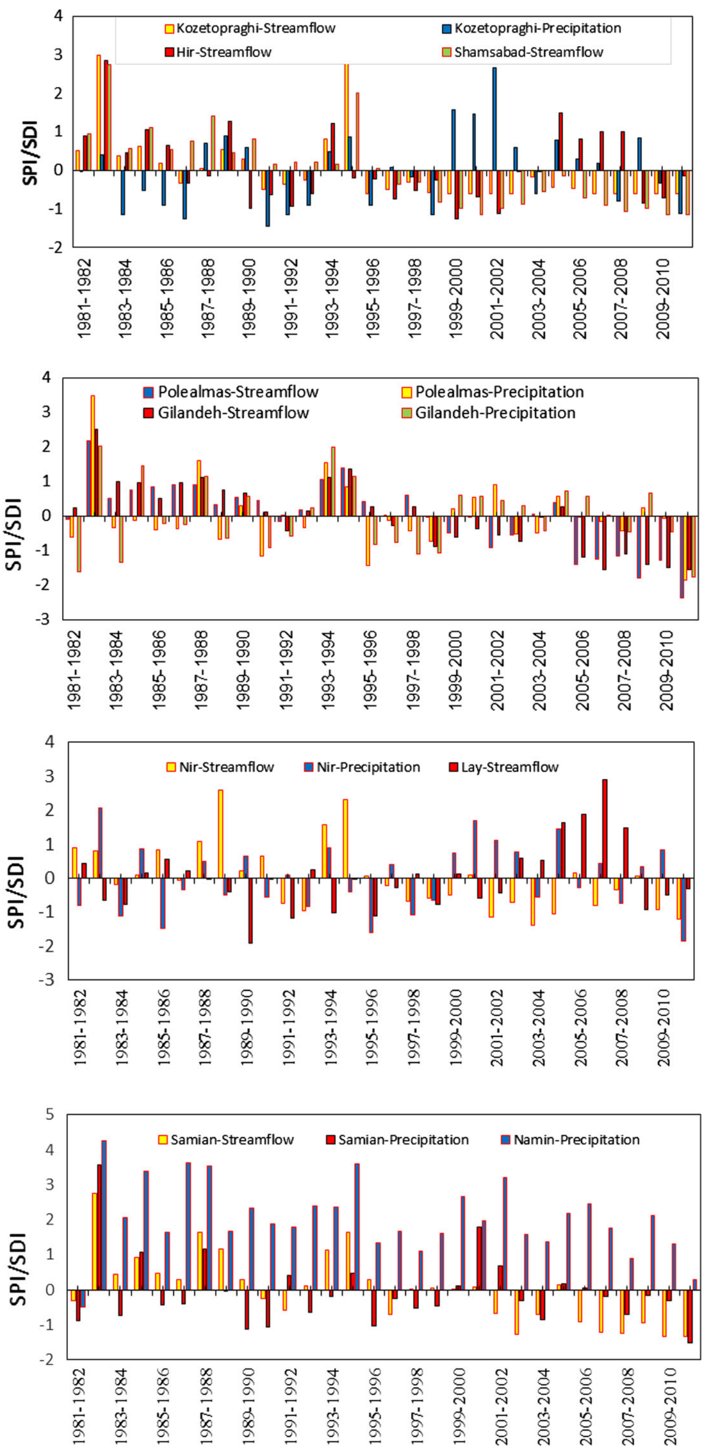

Fig. 2 SPI and SDI series of the reference period October–December

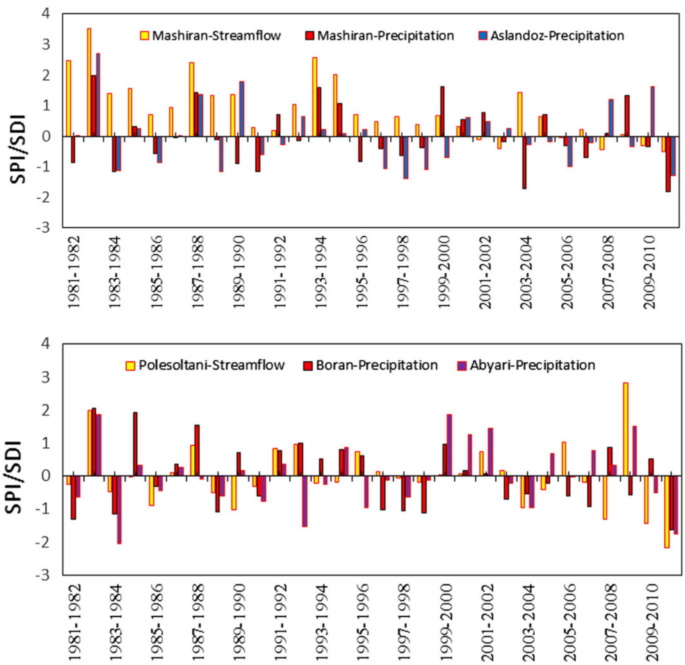

Fig. 2 continued

uniform, and gamma, were fitted to the data and the outputs indicated that these distributions could not provide a comprehensive fit for all of the precipitation and streamflow time series.

4.2 SPI and SDI series

The SPI and SDI series of the reference periods, based on the 30-year time series data, are represented for the October–December and October–March cumulative periods in Figs. 2 and 3, respectively. We used the hydrometric and rain gauge stations close together for the consideration of the meteorological and hydrological drought events. As shown, the majority of drought events for the reference periods of October–December and October–March were found in the last 15 years from 1995–1996 to 2010–2011. Moreover, almost all of the rain gauge and hydrometric stations experienced at least one extreme drought event over the reference periods of October–December and October–March. Over the considered periods, the most severe meteorological drought was identified at the Abyari station located along with the Gharasoo River and at the Mashiran station on the Darehrood River in 1983–1984 and 2003–2004, respectively. Compared with the meteorological drought, the most severe hydrological droughts were detected in the Polealmas and Polesoltani stations over 2010–2011 with the SDI values of −2.36 and −2.61, respectively. Furthermore, the long-term meteorological droughts were found at the Samian and Namin stations, while the long-term hydrological drought was only detected at the Samian station.

The SPI and SDI series for the reference periods of October–June and October–September are depicted in Figs. 4 and 5, respectively. In these time series, extreme metrological droughts were identified at the Doostbighlo and Namin stations with the same

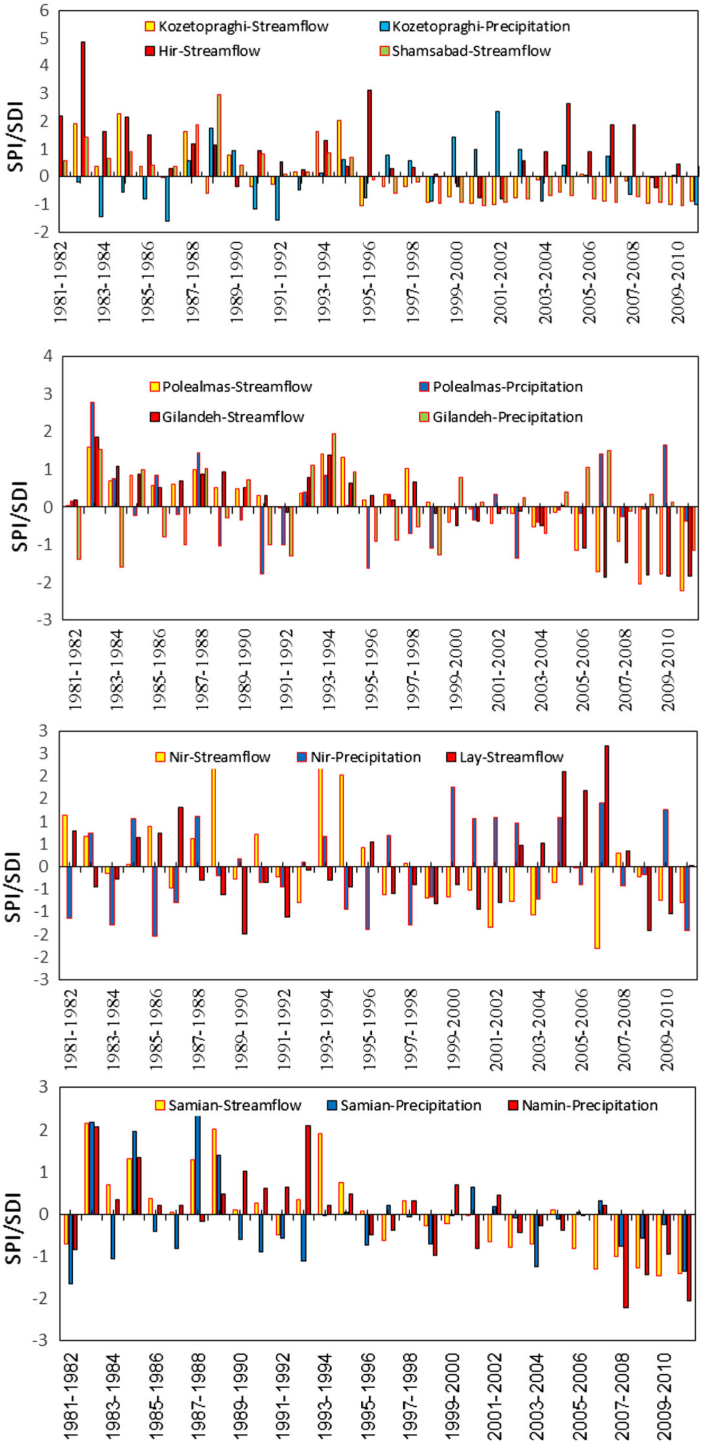

Fig. 3 SPI and SDI series for reference period October–March

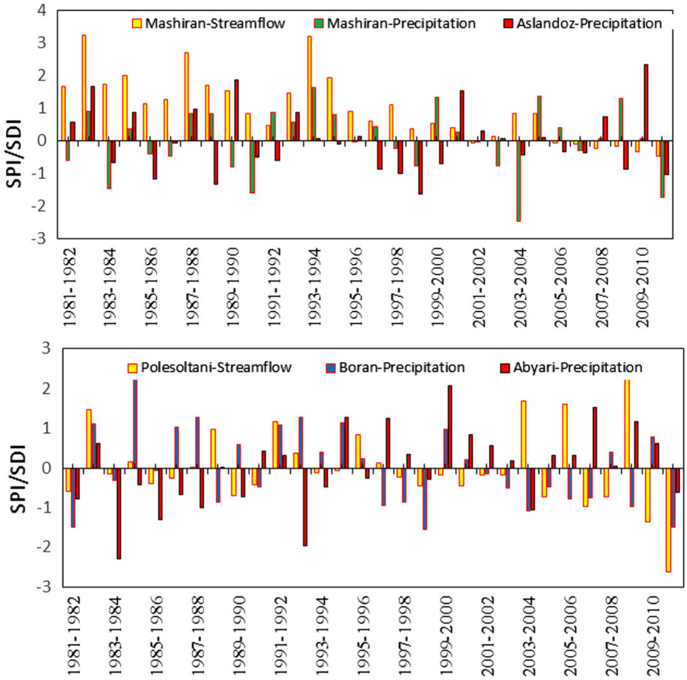

Fig. 3 continued

SPI value of −2.22 during 2007–2008. In addition, extreme hydrological droughts were indicated at the Polealmas station located on the Baleokhloo-chai River with a SDI value of −2.14 in 2010–2011. However, all of the meteorological and hydrological stations in the region experienced at least one extreme drought event in the reference periods of October–June and October–September. In general, the driest year based on the meteorological drought index was 2007–2008, while the driest year based on the hydrological drought index was 2010–2011. In other words, approximately all of the hydrometric stations had severe drought events in 2010–2011.

Babayi and Alijani (2013) pointed out that the north, east, and west of Iran were in mild and moderate drought conditions, which is mostly in agreement with this investigation. As the results indicated, the Polealmas station located on the Baleokhloo-chai River was posed to extreme drought in the last years; therefore, it is important that water resource planners carefully consider the last drought events. Baleokhloo-chai River is located at the center of the study area and drains to the Yamchi dam reservoir to supply drinking water. More importantly, almost all of the major agricultural lands are located there.

The results of area-averaged SPI and SDI series for the different reference periods are shown in Fig. 6. In the precipitation series, area-averaged SPI series showed moderate drought states for the years of 1986–1987, 1988–1989, 2003–2004, 2007–2008, and 2010–2011. In other words, five moderate drought events were found in the period of 1981–1982 to 2010–2011. In contrast, the area-averaged SDI series indicate moderate drought state only in 2009–2010 and 2010–2011. Hence, the results of area-averaged SPI and SDI reveal that the Ardebil province has been under moderate drought condition for the last three decades. As shown, for the reference periods of October–September (year),

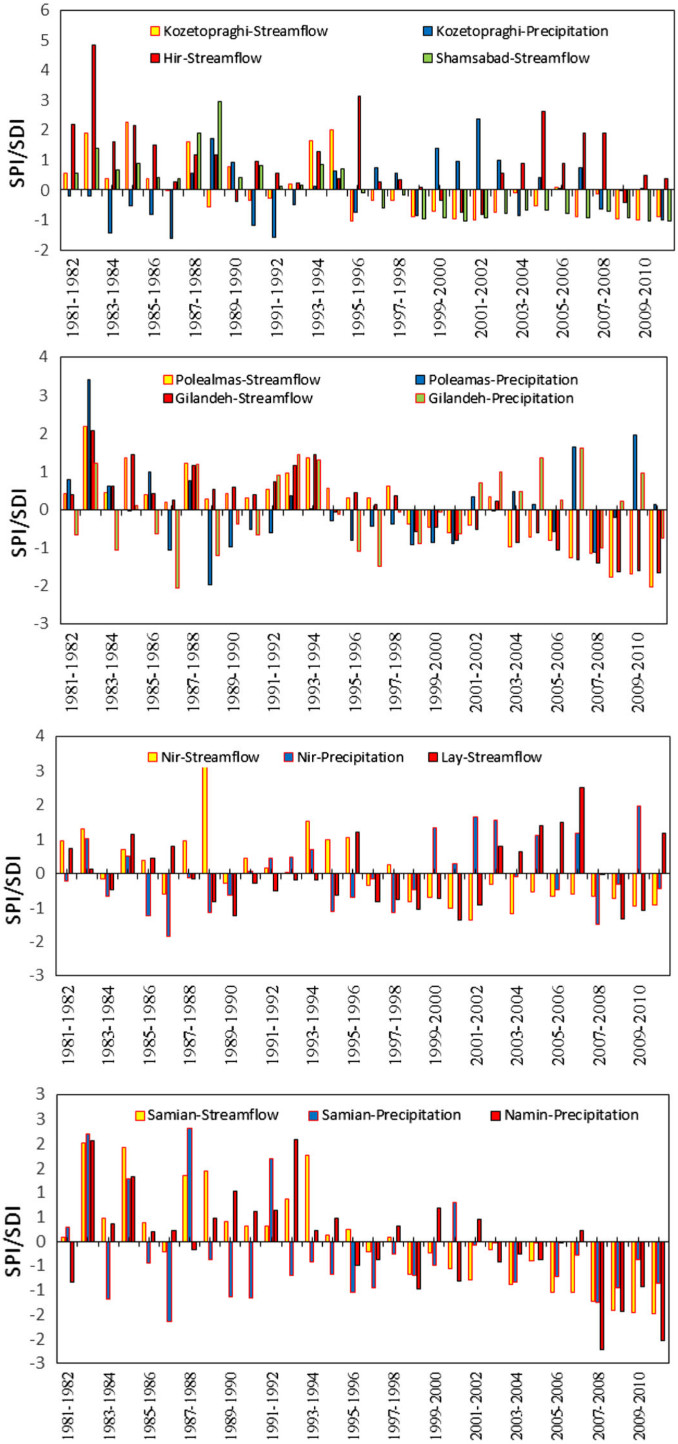

Fig. 4 SPI and SDI series of the reference period October–June

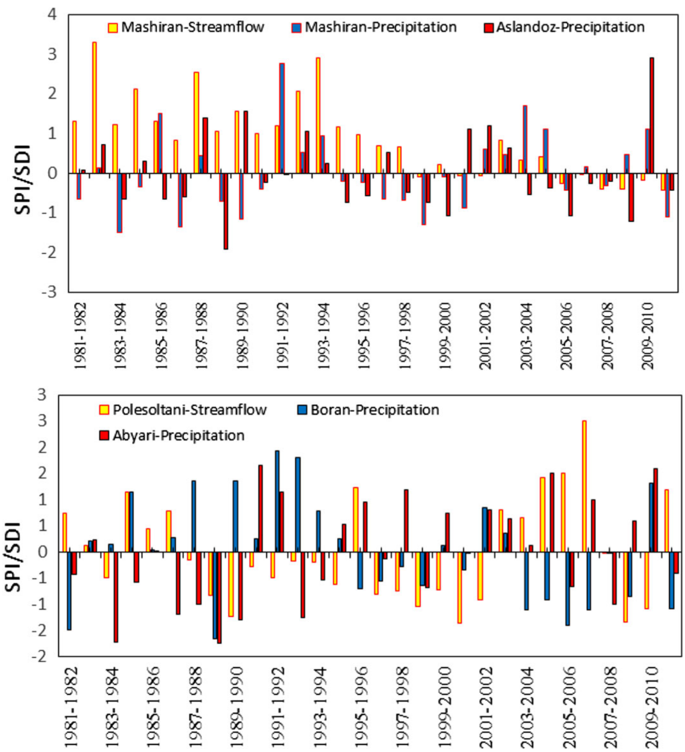

Fig. 4 continued

both streamflow and precipitation were deficient from expected or normal conditions during the period of 1987–1988 to 2002–2003. Nikbakht et al. (2012) characterized most severe streamflow droughts in 1999–2000 and 2000–2001. Prolonged droughts over 1998–2001 period had an effect on over half of the Iran's population (Raziei et al. 2008). The 1999 drought was the most destroying one to the agriculture and water resources of Iran, causing massive movement of people from rural to urban areas (Yazdani and Haghsheno 2008).

4.3 Trend and correlation tests

In this section, the trends of the meteorological drought are analyzed and their relationships with the hydrological drought trends are explored. Two nonparametric tests, the Spearman's rho and Kendall's tau, were applied for the meteorological and hydrological drought indices over the period of 1981–1982 to 2010–2011.

The outputs of the Spearman's rho and Kendall's tau tests for the different reference periods of SPI and SDI series are presented in Tables 3 and 4, respectively. The results of nonparametric tests, Spearman's rho and Kendall's tau, for the temporal trends of the meteorological droughts indicate decreasing trends of the SPI series for 59 and 54 % of the stations, respectively. Statistically significant trends are only found in 11.3 % of the SPI series at the 0.01 significance level by the Spearman test. In this regard, the Namin station had the highest decreasing trend at the 0.01 significance level.

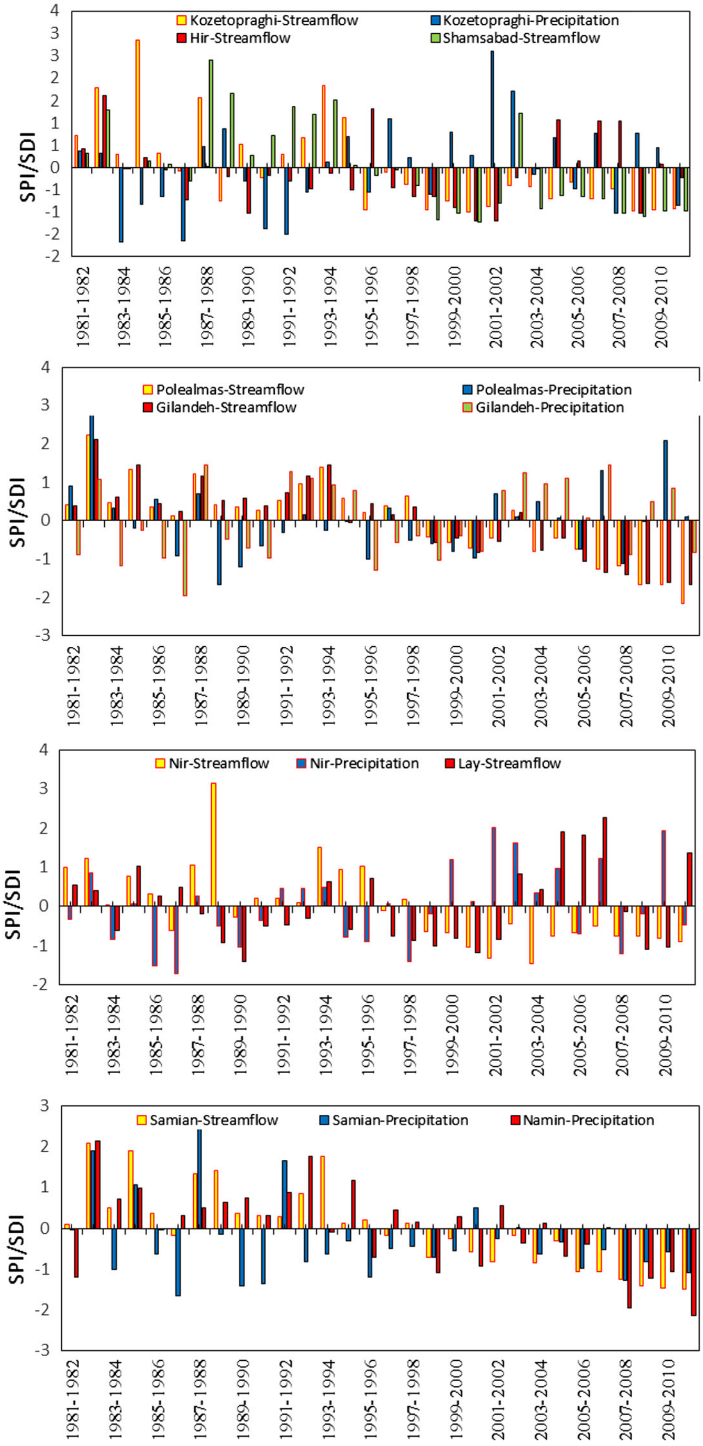

Fig. 5 SPI and SDI series of the reference period October–September (year)

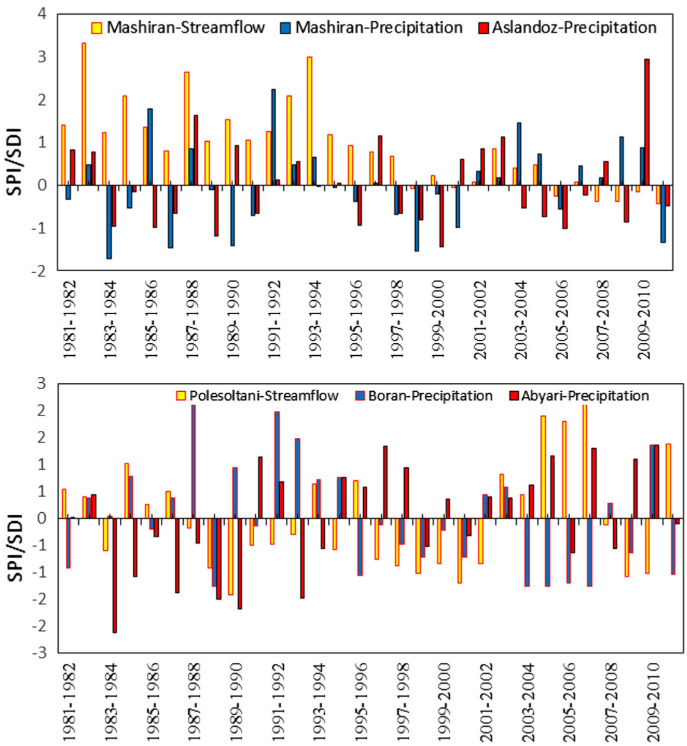

Fig. 5 continued

The results of Spearman's rho and Kendall's tau tests for the SDI series identify decreasing trends in 98 and 95 % of the stations over the last three decades, respectively. Meanwhile, negative trends are observed in the SDI series of 68 % of the stations, except for Lay, Polesoltani, and Hir, at the 0.01 significance level. Comparing the results of the trends for the SPI and SDI series, it can be concluded that the negative trend of the hydrological droughts is stronger than that of the meteorological droughts. As shown in Tables 3 and 4, the p values of the Spearman's rho and Kendall's tau tests for the SPI and SDI (in 12-month series) suggest a negative trend at the 0.01 significance level for the Polealmas rain gauge station. Moreover, the tests showed a negative trend in the 12-month SDI series at the 0.01 significance level for all of the hydrometric stations except for Lay, Polesoltani, and Hir. The negative trends in most of the SPI and SDI series suggest that the study area has become drier over the last three decades. However, the decreasing trends are much more evident for the streamflow droughts index than for the precipitation drought index series. This means that the study area has suffered from the hydrological drought more than from the meteorological drought.

4.4 Seasonal correlation analysis between SPI and SDI

The Spearman correlation test was further applied to explore the relationships between meteorological droughts and hydrological droughts based on the SPI and SDI series, respectively. In doing so, different combinations of periods including no-lag, 1 month-lag,

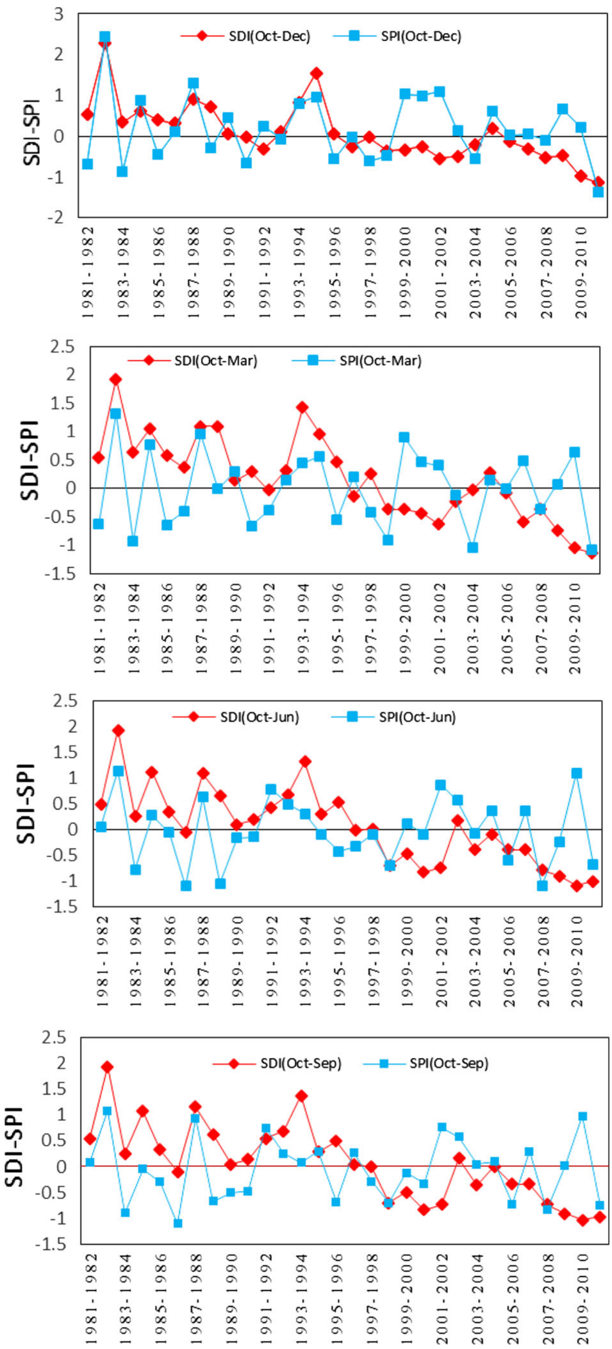

Fig. 6 Area-averaged SPI and SDI series for different reference periods

Table 3 *P* values of Spearman's rho and Kendall's tau tests for the different reference periods of SPI series

Stations	Spearman's rho				Kendall's tau			
	Oct–Dec	Oct–Mar	Oct–Jun	Oct–Sep	Oct–Dec	Oct–Mar	Oct–Jun	Oct–Sep
Aslandoz	(−) 0.623	(−) 0.590	(−) 0.678	(−) 0.971	(−) 0.656	(+) 0.555	(−) 0.708	(−) 0.929
Nir	(+) 0.643	(+) 0.230	(+) 0.185	(+) 0.105	(+) 0.630	(+) 0.205	(+) 0.148	(+) 0.097
Polealmas	(−) 0.794	(−) 0.443	(−) 0.725	(−) 0.866	(−) 0.735	(−) 0.464	(+) 0.803	(−) **0.002**
Gilandeh	(+) 0.869	(+) 0.505	(+) 0.247	(−) 0.215	(+) 0.748	(+) 0.464	(+) 0.212	(−) 0.261
Kozetopraghi	(+) 0.299	(+) 0.256	(+) 0.283	(+) 0.131	(+) 0.372	(+) 0.326	(+) 0.253	(+) 0.129
Namin	(−) **0.005**	(−) **0.001**	(−) **0.001**	(−) 0.021	(−) **0.001**	(−) 0.051	(−) **0.001**	(−) 0.050
Samian	(−) 0.822	(−) 0.781	(−) 0.388	(−) 0.243	(−) 0.817	(−) 0.721	(−) 0.422	(−) 0.232
Doostbighlo	(−) 0.388	(−) 0.243	(+) 0.775	(−) 0.864	(−) 0.422	(−) 0.232	(+) 0.817	(−) 0.901
Mashiran	(+) 0.864	(+) 0.825	(−) 0.825	(−) 0.825	(+) 0.708	(+) 0.992	(−) 0.225	(−) 0.369
Boran	(−) 0.708	(−) 0.825	(−) 0.825	(−) 0.708	(−) 0.300	(−) 0.047	(−) 0.104	(−) 0.080
Abyari	(+) **0.001**	(+) 0.040	**(+) 0.002**	(+) 0.708	(+) 0.055	(+) 0.040	(+) 0.032	(+) 0.052

The bold values indicate significant trend at 0.01 intervals

Table 4 *P* values of Spearman's rho and Kendall's tau tests for the different reference periods of SDI series

Stations	Spearman's rho				Kendall's tau			
	Oct–Dec	Oct–Mar	Oct–Jun	Oct–Sep	Oct–Dec	Oct–Mar	Oct–Jun	Oct–Sep
Nir	(–) **0.001**	(–) **0.002**	(–) **0.000**	(–) **0.001**	(–) **0.001**	(–) **0.002**	(–) **0.000**	(–) **0.000**
Polealmas	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**
Gilandeh	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**
Mashiran	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**
Samian	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**
Doostbighlo	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**
Kozetopraghi	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**
Lay	(–) 0.305	(–) 0.831	(–) 0.967	(+) 0.873	(+) 0.251	(–) 0.721	(–) 0.701	(+) 0.901
Polesoltani	(–) 0.539	(–) 0.194	(–) 0.420	(–) 0.219	(–) 0.581	(–) 0.159	(–) 0.401	(–) 0.218
Hir	(–) 0.315	(–) 0.890	(–) 0.089	(–) 0.605	(–) 0.301	(–) 0.091	(–) 0.091	(–) 0.601
Shamsabad	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**	(–) **0.000**

The bold values indicate significant trend at 0.01 intervals

Table 5 Relationships between meteorological and hydrological droughts (Cc: correlation coefficient)

1 month-lag			2 month-lag			3 month-lag			No-lag		
SPI	SDI	Cc	SPI	SDI	Cc	SPI	SDI	Cc	SPI	SDI	Cc
Oct–Dec	Jul–Sep	0.28	Oct–Dec	Dec–Feb	0.19	Oct–Dec	Jan–Mar	0.22	Oct–Dec	Oct–Dec	0.32
Jul–Sep	Dec–Feb	0.18	Dec–Feb	Feb–Apr	0.28	Jan–Mar	Apr–Jun	0.11	Jan–Mar	Jan–Feb	0.02
Dec–Feb	Jan–Mar	0.32	Feb–Apr	Apr–Jun	0.00	Apr–Jun	Jul–Sep	**0.49**	Apr–Jun	Apr–Jun	0.29
Jan–Mar	Feb–Apr	0.12	Apr–Jun	Jun–Aug	**0.62**	Jul–Sep	Oct–Dec	−0.35	Jul–Sep	Jul–Sep	0.34
Feb–Apr	Mar–May	−0.03	Jun–Aug	Aug–Oct	0.21						
Mar–May	Apr–Jun	−0.02	Aug–Oct	Oct–Dec	0.16						
Apr–Jun	May–Jul	**0.50**									
May–Jul	Jun–Aug	**0.65**									
Jun–Aug	Jul–Sep	**0.64**									
Jul–Sep	Aug–Oct	0.23									

The bold values indicate significant trend at 0.05 intervals

2 month-lag, and 3 month-lag between the meteorological and hydrological droughts were considered. The results are listed in Table 5 and show that the majority of the significantly correlated series between the SPI and SDI occur for the 1 month-lag case. Moreover, the correlation analysis indicates strong relationships between May–Jul-SPI series and the Jun–Aug-SDI series with a correlation coefficient of 0.65. Thus, the highest correlations between the meteorological and hydrological droughts are identified for the spring and summer seasons.

5 Conclusions

In this study, the meteorological and hydrological droughts based on the SPI and SDI in northwestern Iran over the period of 1981–1982 to 2010–2011 were quantified. The K–S test was applied to all time series to test which distribution fitted the time series best. The exponential, gamma, uniform, and normal distributions were tested, and ultimately, the latter was used to calculate the SPI and SDI. The results showed that the majority of drought events for all of the reference periods occurred in the last 15 years from 1995–1996 to 2010–2011. Furthermore, the results of area-averaged SPI and SDI series exhibited that the study region has been in moderate and severe drought states over the study period. Generally, the driest year based on the meteorological drought index was 2007–2008, while the driest year based on the hydrological drought index was identified to be 2010–2011.

The nonparametric tests of Spearman's rho and Kendall's tau were used for the temporal trends analyses of the meteorological and hydrological droughts. The results showed decreasing trends of the SPI series for 59 and 54 % of the stations, and of the SDI series for 98 and 95 % of the stations, respectively. Additionally, comparing the results of the trends for the SPI and SDI series suggested that the negative trend of the hydrological droughts is stronger than that of the meteorological droughts. In general, for most of the SPI and SDI series, negative trends were found; hence, the study area has become drier over the last three decades. Finally, the Spearman correlation test, which was used to check the relationship between meteorological and hydrological droughts, revealed strong correlations between May–Jul-SPI series and the Jun–Aug-SDI series with a correlation coefficient of 0.65. This research showed that the study region has suffered from the meteorological and hydrological droughts over the study period, so that appropriate management strategies should be implemented to mitigate their effects on the water resources in the region.

Acknowledgments The authors would like to appreciate the anonymous reviewers for their helpful suggestions and comments.

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