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ORIGINAL ARTICLE

An investigation of drought magnitude trend during 1975–2005 in arid and semi-arid regions of Iran

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Abstract In addition to drought intensity, drought magnitude (DM) is an important parameter in drought analysis. Therefore, in this study, the drought intensity and DM trends are investigated based on the standardized precipitation index (3, 6, 9, 12, 18 and 24 monthly SPI time series) from 1975 until 2005 in 25 synoptic weather stations located in arid and semi-arid regions of Iran. Although the DM is commonly computed for negative SPI values, for analysis the wet years besides drought conditions, this study has also involved positive SPI values and therefore, each time series was divided into four drought intensity conditions as follows: drought (D; SPI values less than −1), normal near drought (ND; SPI values more than −1 and less than 0), normal near wet (NW, SPI values more than 0 and less than +1), and wet (W; SPI values more than 1). The non-parametric rank-based Mann–Kendall test was used to detect trends of SPI values (drought intensity and DM) for 3, 6, 9, 12, 18 and 24 monthly time scales. Based on the results, a considerable percentage (50 %) of the stations at the level of 0.05 showed a significant trend with regards to drought intensity when compared with the DM trend (5.8 %). Generally, it can be said that the arid and semi-arid areas of Iran had a negative SPI trend and it means the more drought severities. Also, the more frequent significant positive DM trend in comparison to negative ones is a sign of increasing DM during the three past decades.

Keywords Arid and semi-arid · Drought magnitude · Iran · Mann–Kendall statistics · SPI

Introduction

Droughts are recognized as an environmental disaster and have attracted the attention of environmentalists, ecologists, hydrologists, meteorologists, geologists, and agricultural scientists (Mishra and Singh 2010). Drought is usually defined as a significant temporary reduction in water availability below the expected amount for a specified period and for a particular climatic zone (Bonaccorso et al. 2003). Although droughts occur in virtually all climatic zones, including high and low rainfall areas (Mishra and Singh 2010), they are a more important natural hazard in arid and semi-arid countries such as Iran, which has serious problems for providing sufficient water resources. Severe and prolonged droughts in Iran are one of the main origins of the extensive cost and losses imposed to many parts of the country which seriously threats food security. For example, according to Raziei et al. (2009), 10 out of the 28 provinces of Iran were affected by one of the worst and prolonged droughts in 1998–2001 period, leaving an estimated 37 million (over half of the country's population) vulnerable to food and water shortage.

Moreover, climate change is one of the most important concerns and challenges for scientists, managers, and

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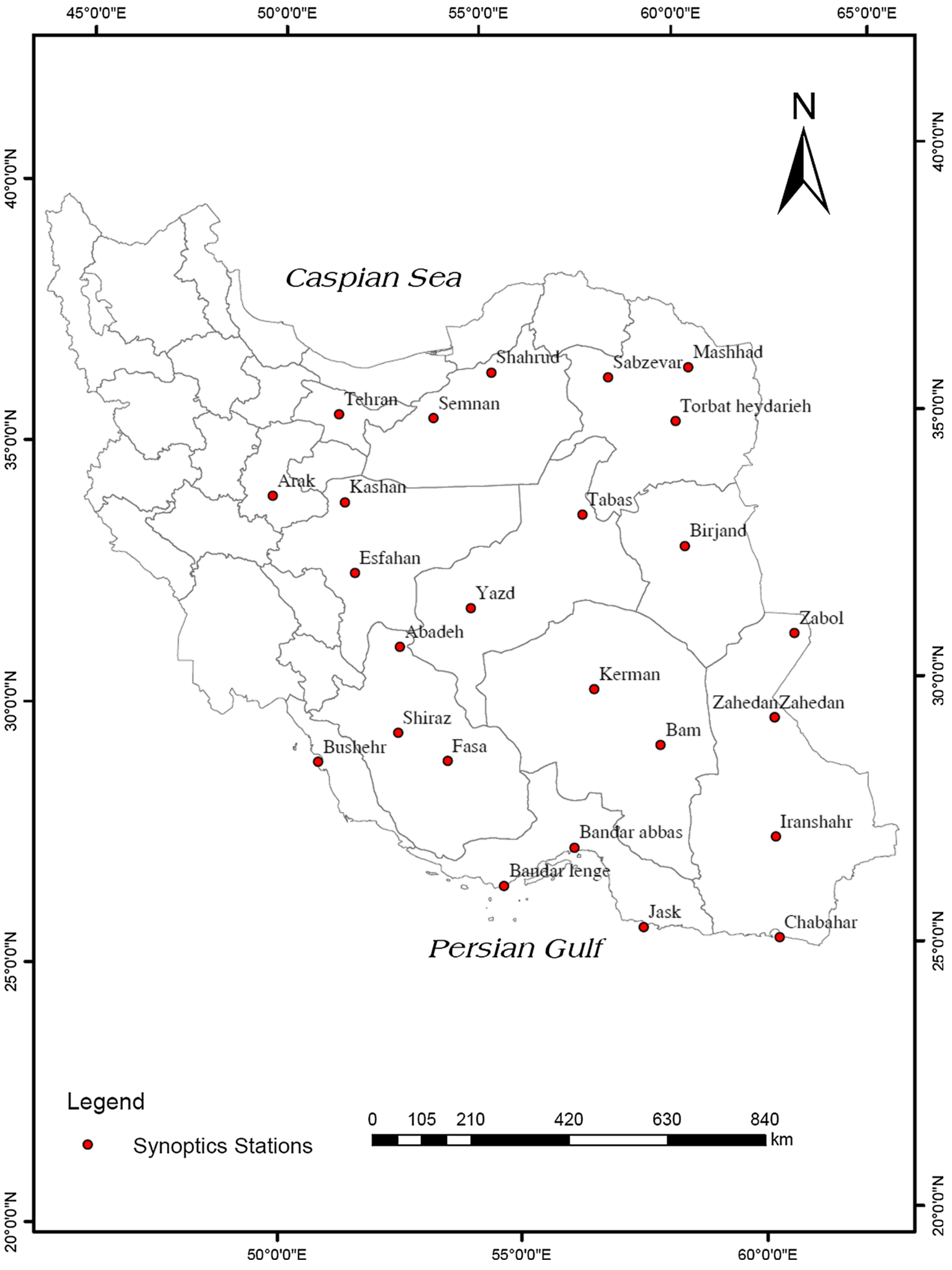
decision makers throughout the world. Global warming has the potential to impact various aspects of human society such as agriculture, construction, transportation, water resource management, power generation, and phenology (Jiang et al. 2007). During recent years, the impacts of climate changes in combination with the effect of droughts have caused serious problems in different areas of the world (Dastorani and Afkhami 2011). Researchers in Iran have analyzed the long-term trends of climate variables. Kousari et al. (2010) surveyed the monthly and yearly change trends in the minimum, maximum and mean temperatures, relative humidity and the precipitation of 26 synoptic stations in Iran over a 55-year period. The results showed the same temperature changes for the centrally located stations that were observed in the eastern and northern stations, while precipitation time series did not show considerable trends particularly in the Zagros regions. Modarres and Sarhadi (2009) surveyed the spatial and temporal trend analysis of the annual and 24 h maximum rainfall of a set of 145 precipitation gauging stations in Iran. The study showed that the annual rainfall decreased for 67 % of the stations, while the 24-h maximum rainfall increased for 50 % of the stations. Tabari and Hosseinzadeh Talaee (2011) surveyed the annual and seasonal precipitation trends of 41 stations in Iran for the period 1966–2005. Their data were analyzed using the Mann–Kendall test (MK), the Sen's slope estimator, and linear regression. The results indicated a decreasing trend in annual precipitation for approximately 60 % of the stations. The magnitude of the significant negative trends in annual precipitation varied from (−)1.99 mm/year at Zanjan station to (−)4.26 mm/year at Sanandaj station. The spatial distribution of the annual precipitation trends showed that the significant negative trends occurred mostly in the northwest of Iran. Therefore, in addition to trend analysis of long-term meteorological variables under conditions of global warming and climate changes, the investigation of drought is very considerable. Bari Abarghouei et al. (2011) have surveyed the changes and trend of drought under the current global climate changes using the non-parametric MK statistical test for 42 synoptic stations located in different areas within Iran. The obtained results have indicated a significant negative trend for drought in many parts of Iran, particularly the Southeast, West and Southwest regions. Of course, the effect of serial correlation in trend detection has not been considered in the mentioned study. Kousari et al. (2014) analyzed the drought trends in arid and semi-arid regions of Iran based on the application of reconnaissance drought index (RDI) for assessment drought severities and also the implementation of non-parametric MK statistics and Sen's slope estimator for trend detection. Results indicated the frequent decreasing trends in RDI time series particularly for long-term time series (12, 18 and 24 monthly time series) than short-term ones. Tabari et al. (2012) analyzed the temporal trends and spatial characteristics of drought and rainfall in arid and semi-arid regions of Iran. 12 monthly SPI time series was used as drought index. The trend analyses of the time series were also performed using the Kendall and Spearman tests. On the basis of the results of the trend tests, a downward rainfall trend was seen in the spring, summer, autumn, and winter series at 90, 60, 60 and 50 % of the stations, respectively. Based on the results of 12 monthly SPI time series, the study area has become drier during the last 4 decades, although no significant trends were found in the SPI-12 series of the stations.

Although drought intensity trend has been considered by many researchers, however, other important characters of drought such as drought magnitude (DM) have not been considered in Iran. DM is one of the main properties of drought. Various statistical parameters for DM are beneficial for drought characterization (Mishra and Singh 2010). Therefore, in this study, drought intensity and DM trend have been surveyed in 25 synoptic stations located in the arid and semi-arid regions of Iran in the past 3 decades. The standardized precipitation index (SPI) in 3, 6, 9, 12, 18, and 24 monthly SPI time series was used for this purpose. SPI used long-time precipitation time series as the input. It is a simple but famous and effective drought index which can easily be applied in different parts of the world. Also, SPI can be computed on various time scales, so as to allow monitoring most of the drought types (i.e., meteorological, agricultural, and hydrological) (Raziei et al. 2009). This study has investigated DM and drought intensity trends by implementation of non-paramedical MK test on various types of SPI time series. Also, trend-free pre-whitening (TFPW) to more effectively reduce the effect of serial correlation on the MK test has been considered in the current research. The results can be considered by the wide range of researchers who is interested in drought management under condition of climate changes.

Study area

Iran, with about 1,648,195 km^2 area, is located in the Southwestern area of the Asia. Iran consists of various geographical and topographical features; hence, it has different climates. There are two mountain ranges, Alborz located in the northern part and Zagros in the western part of Iran. The highest point of Iran is located in Alborz mountain range with an elevation of 5,628 m above mean sea level. The Alborz and Zagros mountain ranges prohibit the entrance of Mediterranean moisture-bearing systems into the central and eastern parts of the country, respectively. The Zagros mountain range is an obstacle to the entrance of the major portion of rain-producing air masses

Fig. 1 The spatial distribution of 42 selected synoptic stations in Iran



from the west and northwest of Iran. These air masses produce high amounts of rainfall (Sadeghi et al. 2002). The main source of water is precipitation which normally amounts to 251 mm or 413 billion m^3 annually. This precipitation depth is less than one-third of the worldwide average precipitation (831 mm) and about one-third of the average precipitation in Asia (732 mm) (Malekinezhad 2009). According to Raziei et al. (2009), precipitation in Iran has a high spatial and time variability and there are regions in the south of Caspian Sea, which receive up to 2,000 mm of annual precipitation, whereas portions of central and eastern part of the country get less than 50 mm. More than 50 % of the rain falls during the winter and less than 18 % occurs during the summer. While 1 % of the world's population lives in Iran, the country's share of renewable freshwater is only 0.36 % (Malekinezhad 2009). Also, approximately 90 % of the country is arid or semi-arid. Figure 1 shows Iran's location, boundaries and distribution of the 25 synoptic stations used in this study. These stations have a good distribution with suitable period of weather data (31 years). Table 1 shows geographical and climatic characteristics of the 25 surveyed stations.

Table 1 General characteristics of surveyed 25 stations

Station name	*X* coordinate	*Y* coordinate	Elevation (m)	Average of annual precipitation (mm)	Zone (Kousari and Ahani 2011)
Abadeh	52.67	31.18	2,030	143.3	Arid
Arak	49.77	34.1	1,708	322.6	Semi-arid
Bam	58.35	29.1	1,066.9	59.3	Hyper-arid
Bandar abbas	56.37	27.22	98	152.9	Arid
Bandar lenge	54.83	26.53	22.7	205.6	Arid
Birjand	59.2	32.87	1,491	172.4	Arid
Bushehr	50.83	28.98	196	277.2	Arid
Chabahar	60.62	25.28	8	117.5	Arid
Esfahan	51.67	32.62	1,550.4	126.5	Arid
Fasa	53.68	28.97	1,288.3	316.5	Semi-arid
Iranshahr	60.7	27.2	591.1	112.4	Arid
Jask	57.77	25.63	5.2	139	Arid
Kashan	51.45	33.98	982.3	137	Arid
Kerman	56.97	30.25	1,753	142.1	Arid
Mashhad	59.63	36.27	999.2	271	Semi-arid
Sabzevar	57.72	36.2	977.6	205.1	Arid
Semnan	53.55	35.58	1,130.8	145.6	Arid
Shahrud	54.95	36.42	1,345.3	162.6	Arid
Shiraz	52.6	29.53	1,484	348	Semi-arid
Tabas	56.92	33.6	711	88.3	Arid
Tehran	51.32	35.68	1,190.8	245.5	Arid
Torbat heydarieh	59.22	35.27	1,450.8	288.1	Semi-arid
Yazd	54.28	31.9	1,237.2	64.4	Arid
Zabol	61.48	31.03	489.2	62.6	Hyper-arid
Zahedan	60.88	29.47	1,370	75.3	Arid

Materials and methods

Standardized precipitation index

McKee et al. (1993) have defined SPI as the value of standard deviations that the observed cumulative rainfalls at a given time scale would deviate from the long-term average. As a single numeric value, the SPI can be compared across regions with markedly different climates.

The SPI is widely accepted and used throughout the world in both research-based and operational management studies since it is normalized to a location and time scale (Wu et al. 2007). A drought event occurs at the time when the value of SPI is continuously negative. The event ends when the SPI becomes positive. Table 2 shows a drought categorization based on SPI.

Table 2 Drought categorization based on SPI

SPI values	Class
>2	Extremely wet
1.5–1.99	Very wet
1.0–1.49	Moderately wet
−0.99 to 0.99	Near normal
−1 to −1.49	Moderately dry
−1.5 to −1.99	Severely dry
<−2	Extremely dry

The SPI is calculated by fitting a probability density function to the frequency distribution of precipitation, summed over the time scale of interest. This is performed separately for each month (or any other temporal basis of the raw precipitation time series) and for each location in space. Then, each probability density function is transformed to a standardized normal distribution (Mishra and Desai 2005). The gamma distribution is defined by its probability density function as stated below:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{a-1} e^{-x/\beta} \quad \text{for}: \ x > 0 \tag{1}$$

where $\alpha > 0$ and $\beta > 0$ are shape and scale factors, respectively, and $x > 0$ is the amount of precipitation. The $\Gamma(\alpha)$ is the gamma function, which is explained as:

$$\Gamma(\alpha) = \int_{0}^{\infty} y^{\alpha-1} e^{-y}\, dy. \tag{2}$$

Fitting the distribution to the data requires that α and β be estimated. For this, Edwards and McKee (1997) have suggested a method using the approximation of Thom (1958) for maximum likelihood. The equation is stated below:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (3)$$

$$\beta = \frac{\bar{x}}{\alpha} \quad (4)$$

where

$$A = \ln(\bar{x}) - \frac{1}{n}\sum_{i=1}^{n} \ln(x_i). \quad (5)$$

The above derivation is used for the ‘n’ observations.

The derived parameters are then used to obtain the cumulative probability of an observed precipitation event for the given month or any other time scale:

$$G(x) = \int_0^x g(x)\,dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \quad (6)$$

Then, substituting t for $\frac{x}{\beta}$ forms Eq. 7 to an incomplete gamma function as follows:

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-t}\,dt. \quad (7)$$

Since the gamma function is undefined for x equal to zero and a precipitation distribution may contain zeros, particularly in arid and semi-arid regions, the cumulative probability becomes:

$$H(x) = q + (1 - q)\,G(X) \quad (8)$$

where q is the probability of precipitation equal to zero. The cumulative probability, $H(x)$, is then transformed to the standard normal random variable (Z) with the zero average and the variance of one, which is the value of SPI. According to the studies of Edwards and McKee (1997) and Hughes and Saunders (2002), an approximate conversion has been performed during the present study, as provided by Abramowitz and Stegun (1965), as an alternative:

$$Z = spi = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t_1^2 + d_3 t^3}\right) \quad \text{for} \quad 0 \langle H(X) \langle 0.5 \quad (9)$$

and

$$Z = \text{SPI} = \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t_1^2 + d_3 t^3}\right) \quad \text{for} \quad (0.5 \langle H(x) \langle 1.0) \quad (10)$$

where

$$t = \sqrt{\ln\left(\frac{1}{H(X)^2}\right)} \quad \text{for} \quad 0 \langle H(X) \langle 0.5 \quad (11)$$

and

$$t = \sqrt{\ln\left(\frac{1}{(1 - H(X))^2}\right)} \quad \text{for} \quad 0.5 \langle H(X) \langle 1.0 \quad (12)$$

and $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, and $d_3 = 0.001308$ (Mishra and Desai 2005).

Drought magnitude computation

Drought magnitude is defined as McKee et al. (1993):

$$\text{DM} = -\left(\sum_{j=1}^{x} \text{SPI}_{ij}\right) \quad (13)$$

where j begins with the first month of a drought period and continues to increase until the end of the drought (x) for any of the i time scales. The DM has units of months and would be x numerically equivalent to drought duration if each month of the drought has SPI = −1.0. In fact, many droughts will have a DM very similar to the duration in months since most of the SPI values are between 0 and −2.0 (McKee et al. 1993). In other studies such as those in McKee et al. (1993) and López-Moreno et al. (2009), DM is defined as accumulated deficit below a certain threshold, which is the sum of negative SPI anomalies belonging to the same drought event. Although the DM is considered for negative SPI values particularly those ones less than −1, to have more in-depth view and analysis on the DM, in this study DM has been computed based on four main classes of drought intensities and the positive values of SPI have been also involved in DM analysis. In fact, more positive SPI values illustrate the weaker occurrence of drought or wetter conditions. Therefore, we divided each time series into four drought intensity conditions: drought (D; SPI values less than −1), normal near drought (ND; SPI values more than −1 and less than 0), normal near wet (NW, SPI values more than 0 and less than 1), and wet (W; SPI values more than 1). This process is shown in Table 3 as a schematic example. In this table, there are two D events with 3 and 2 months and 1.52 and 1.28 DM. It is clear that because of the negative sign in DM equation (Eq. 13), the DM for SPI values more than zeros has negative sign. In the long-time series of SPI values (in different time scale) and in relation to each drought intensity (D, ND, NW and W), this process was repeated and the DM of each event was determined.

Table 3 An example for determining the DM of four drought intensities (D, ND, NW and W)

SPI values	−2	−1.53	−1.03	−0.6	0.1	0.4	0.8	1.2	1.67	0.9	0.08	−0.36	−0.87	−1.2	−1.36
Class	D	D	D	ND	NW	NW	NW	W	W	NW	NW	ND	ND	D	D
D conditions	(−2 + (−1.53) + (−1.03))/ 3 = 1.52			–										1.28	
ND conditions	–			0.6	–						0.615			–	
NW conditions	–				−0.433				−0.49		–				
W conditions	–					−1.435			–						

Trend detection by the Mann–Kendall test

To trend detection in precipitation time series as well as drought intensity and DM, the non-parametric MK test (Sneyers 1990) was considered. According to Zhai and Feng (2008), this test has the following advantages: (1) the data do not need to conform to a particular distribution, thus extreme values are acceptable (Hirsch et al. 1993), (2) missing values are allowed (Yu et al. 1993), (3) relative magnitudes (ranking) are used instead of the numerical values, which allows 'trace' or 'below detection limit' data to be included as they are assigned a value less than the smallest measured value, and (4) in a time series analysis, it is not necessary to specify whether the trend is linear or not (Sneyers 1990; Yu et al. 1993; Silva 2005).

Before using MK test, removing significant lag-1 serial correlation effect from the time series by pre-whitening is necessary. However, Yue et al. (2002) believed that removal of a positive serial correlation component from time series by pre-whitening resulted in a reduction in the magnitude of the current trend; and the removal of a trend component from a time series as a first step prior to pre-whitening eliminates the effect of the trend on the serial correlation and does not seriously affect the estimate of the true AR (1). Therefore, they suggested the TFPW to more effectively reduce the effect of serial correlation on the MK test.

In this study and according to Yue et al. (2002) and also Sonali and Kumar (2013), following steps were pursued:

1. The slope of a trend in sample data is computed based on Sen's slope (Sen 1968) method.
2. If the Sen's value differs from zero, it is assumed that slope is linear and the sample data are detrended. The lag-1 correlation coefficient from the detrended series with defined significance level α is computed.
3. If lag-1 correlation coefficient is significant with the considered significance level, then the MK test will be implemented to the detrended pre-whitened series recombined with the estimated slope of trend using Sen's slope, else the MK test is applied to the original sample series (Yue et al. (2002); Sonali and Kumar (2013)).

Based on the above statements, the MK test was performed to the time series of precipitation, SPI time series, and DM values in different time scales. MK test is a well-known test and its details can be found in Sonali and Kumar (2013) and Dinpashoh et al. (2011).

Results

Table 4 shows the precipitation trend and SPI intensity trend results based on the application of MK test (Z parameter) for different time series. In this table, the asterisk symbol (*) illustrates upward trends (Z parameter more than 1.96) and downward trends (Z parameter less than −1.96), $\alpha < 0.05$. Both downward and upward trends can be seen in this table.

In Table 4, stations such as Abadeh, Esfahan, Kashan, Shiraz, Tehran, Tabas, and Zabol do not have a significant trend in all surveyed SPI time series. Stations such as Arak, Bam, Bushehr, Fasa, Kerman, Mashhad, Sabzevar, Semnan, Zahedan, and Torbat heydarieh do not have a significant trend in the short-term time series (3 and 6 months). In the long-term SPI time series (18 and 24 months) based on Table 4, 16 stations indicated negative significant trends and just one station (Bushehr) showed a positive significant trend. In regards to the 9- and 12-month SPI time series, only 13 negative significant trends were found. In the 6-month time series, there were nine negative significant trends. In the 3-month time series, there were four negative significant trends. As 1, 1, 1, 0, 0, and 0 of the stations showed positive trends for 24, 18, 12, 9, 6, and 3 monthly SPI time series, respectively.

Based on Table 4, the trend for precipitation is negative in all stations. However, only three stations Chabahar, Iranshahr, and Jask showed a negative significant trend.

Figures 2, 3 and 4 indicate different time series (3, 6, 9, 12, 18 and 24 monthly SPI and precipitation) for the three selected meteorological stations of Yazd, Shiraz and Zabol.

According to these figures, the first order fitted line shows the linear trend for each time series. Based on Figs. 2 and 3, there was a negative trend in the Yazd and Zabol stations at all time series; with increasing time series,

Table 4 *Z* factor derived by the application of MK test on precipitation and SPI time series for all synoptic stations

Station name	SPI 3	SPI 6	SPI 9	SPI 12	SPI 18	SPI 24	Precipitation
Abadeh	−1.26	−1.24	−1.02	−1.31	−1.11	−1.35	−1.62
Arak	−1.11	−1.81	−2.81*	−4.49*	−4.17*	−5.65*	−1.15
Bam	0.00	−1.36	−2.59*	−3.47*	−3.90*	−4.53*	−0.75
Bandar abbas	−1.54	−3.04*	−4.22*	−5.53*	−6.08*	−6.58*	−1.63
Bandar lenge	0.00	−3.36*	−4.57*	−5.13*	−5.35*	−5.41*	−1.71
Birjand	−1.53	−2.30*	−3.42*	−4.60*	−5.26*	−7.16*	−1.52
Bushehr	0.00	0.80	1.91	3.14*	3.39*	4.06*	−0.41
Chabahar	−3.21*	−4.32*	−5.05*	−6.21*	−7.00*	−7.31*	−4.39*
Esfahan	−0.68	−0.45	0.20	0.39	0.13	1.57	−0.74
Fasa	−1.43	−0.93	−0.93	−1.43	−1.57	−2.06*	−1.67
Iranshahr	−3.61*	−4.47*	−4.66*	−4.79*	−4.89*	−4.44*	−3.12*
Jask	−3.49*	−5.27*	−6.91*	−8.00*	−7.77*	−7.27*	−4.61*
Kashan	−0.39	−0.20	0.12	0.17	0.52	0.36	−0.42
Kerman	−0.99	−1.27	−1.63	−2.99*	−2.97*	−3.97*	−0.87
Mashhad	−0.97	−1.86	−3.42*	−4.68*	−5.75*	−7.71*	−0.62
Sabzevar	−1.69	−2.15*	−3.49*	−4.65*	−4.69*	−6.72*	−1.42
Semnan	−0.49	−0.67	−0.93	−0.97	−1.27	−2.15*	−0.68
Shahrud	−2.03*	−2.67*	−3.66*	−4.77*	−5.00*	−6.71*	−1.41
Shiraz	0.00	−0.27	0.65	1.10	1.43	1.89	−0.91
Tabas	−1.21	−0.89	−0.56	−0.56	−0.76	0.00	−1.91
Tehran	−0.19	−0.37	−0.11	0.56	−0.70	−1.17	−0.27
Torbat heydarieh	−0.58	−1.05	−1.81	−3.02*	−2.69*	−3.09*	−0.48
Yazd	−1.55	−3.06*	−4.33*	−5.83*	−7.13*	−10.83*	−1.67
Zabol	0.00	−0.92	−0.70	0.00	−0.39	−1.13	−1.20
Zahedan	−1.15	−1.92	−2.27*	−2.79*	−2.63*	−2.28*	−1.63

Z values more than 1.96 represent upward significant trend, less than −1.96 shows the decreasing trend at $\alpha < 0.05$

* indicates upward trends (*Z* parameter more than 1.96) and downward trends (*Z* parameter less than −1.96)

there was an increase in the steepness of the fitted curves. Figure 4 shows that the Shiraz station has a negative trend in the short-time series (3 and 6 months). However, over the long-time series, to some extent, there were positive trends. With an increase in the SPI time series, the positive steepness of the fitted curves increased.

In addition, Fig. 5 indicates the spatial distribution of *Z* parameter of the MK test for the surveyed stations. In this figure, solid up-pointing triangles indicate positive (increasing) significant trend at the 95 % confidence level. Solid down-pointing triangles represent (negative) decreasing significant trend at the 95 % confidence level. Open triangles are non-significant trends. The results exhibited the existence of increasing, decreasing and non-significant trends. It was considerable that the numbers of decreasing trends were more than those of the increasing trends. This figure illustrates that non-significant trends were distributed in the central parts of Iran. Near the boundary of the country, there were significant trends, particularly the negative significant ones. Figure 5 shows that in the long-term time series, more significant trends can be found compared to the short-term ones particularly negative significant trends. The southern and southeastern areas of Iran had negative significant trends in all of the time series. The northern and southwestern areas showed fewer significant trends in comparison to those in the south and southeast parts.

Tables 5 and 6 show the DM trend results in various classes based on the application of MK test (*Z* parameter) for the 3, 6, 9 and 12, 18 and 24 monthly SPI time series, respectively.

Tables 5 and 6 show the existence of increasing, decreasing and non-significant trends. SPI DM trends with D intensity classes have seven significant positive values against three negative significant values in all of the time series. In regard to the DM trends with ND intensity classes in the various time series, 11 positive significant trends and 1 negative value can be found. In the DM trends with NW intensity classes, four positive significant trends and three negative values can be seen. Finally, in the DM trends with W intensity classes, one positive significant trend and five negative data are observed. The numbers of non-significant trends were more considerable than the significant increasing or decreasing trends as seen in Figs. 6, 7 and 8. These figures show that in the long-term time series (18 and 24 months), fewer significant trends can be found in comparison to those in the short-term time series (3 and 6 months).

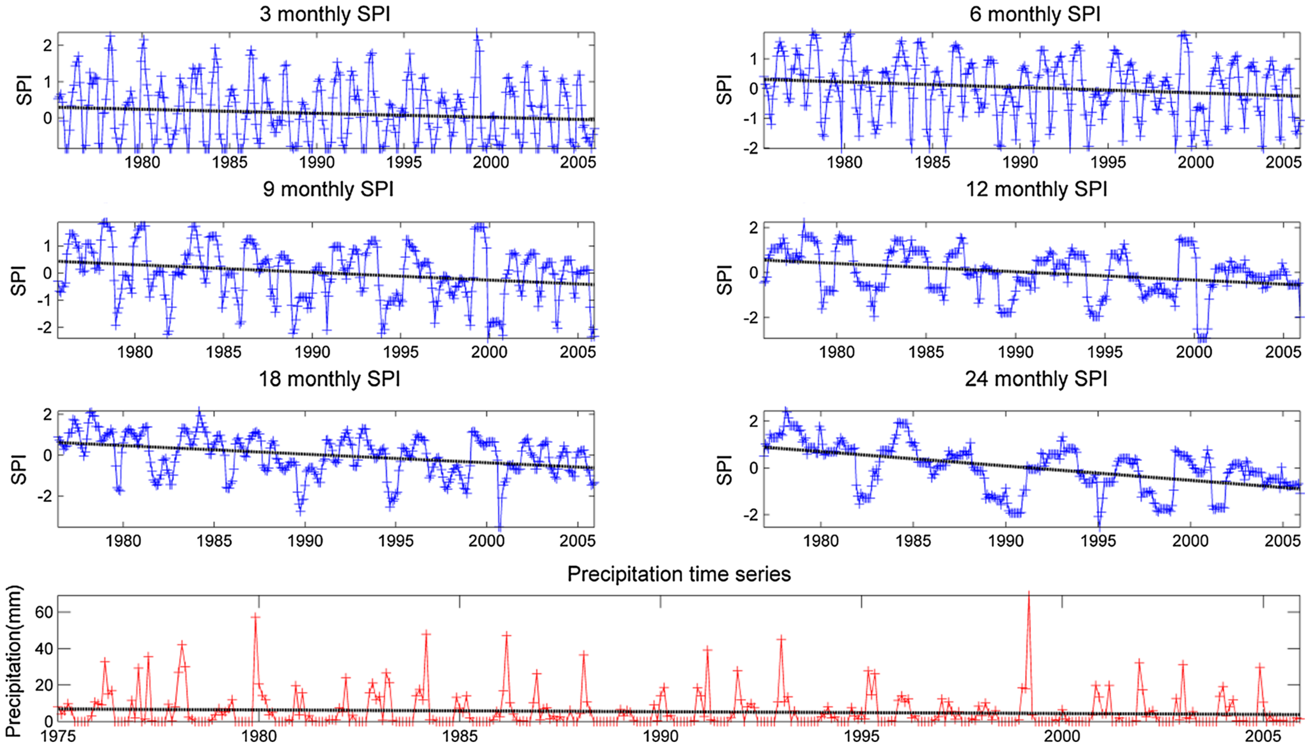


Fig. 2 Different time series (3, 6, 9, 12, 18, and 24 monthly SPI and precipitation) for the synoptic meteorological station of Yazd

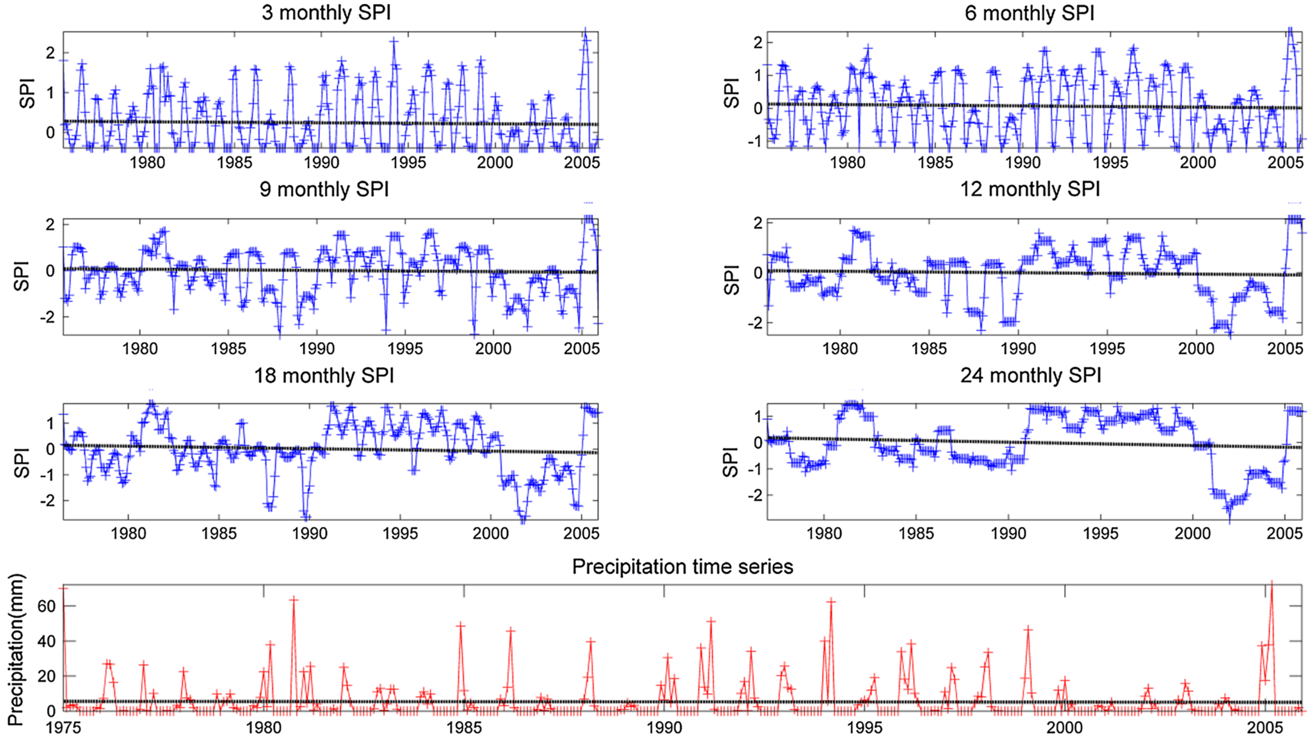


Fig. 3 Different time series (3, 6, 9, 12, 18, and 24 monthly SPI and precipitation) for the synoptic meteorological station of Zabol

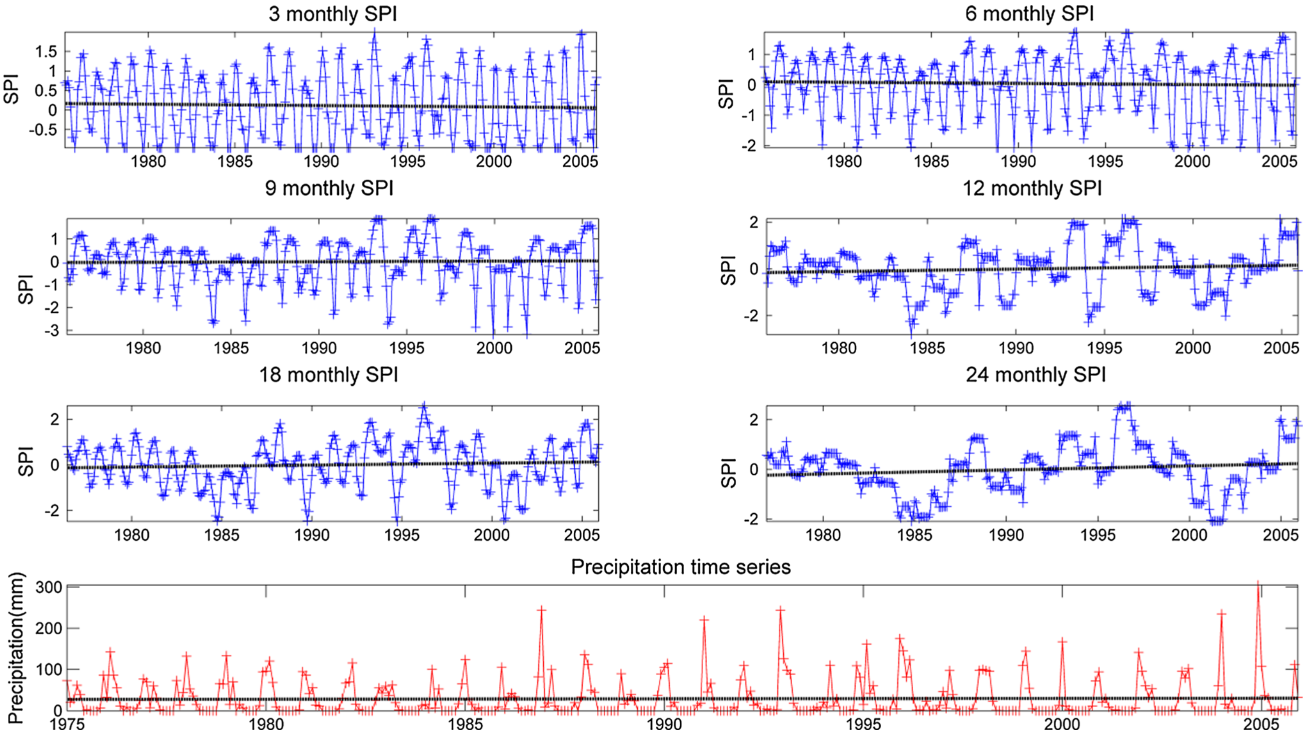


Fig. 4 Different time series (3, 6, 9, 12, 18, and 24 monthly SPI and precipitation) for the synoptic meteorological station of Shiraz

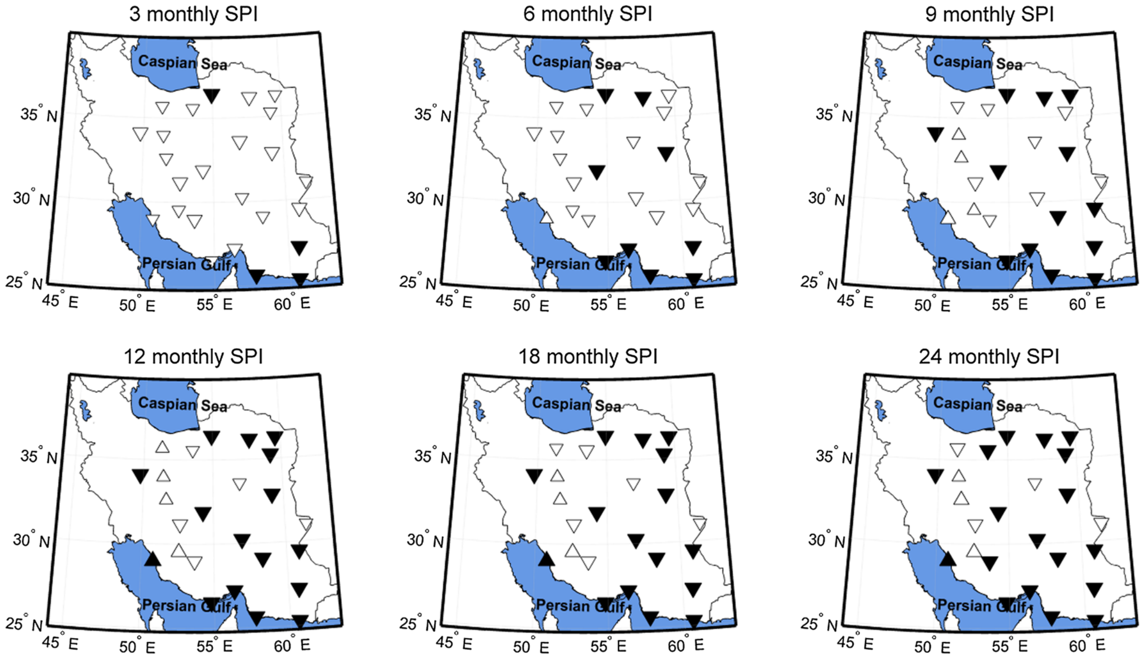


Fig. 5 Spatial distribution of increasing, decreasing, and non-significant SPI intensity trends in time scales

Discussion and conclusion

This study reviewed precipitation, drought intensity and DM trends in the arid and semi-arid regions of Iran from 1975 until 2005. Although the precipitation time series did not reveal considerable significant trends, the SPI time series which mainly were representative of drought intensity showed substantial negative trends in comparison to positive ones. Based on the results, a considerable percentage (50 %) of the stations located in the arid and semi-arid regions in the

Table 5 SPI DM trend results based on the application of MK test (*Z* parameter) for 3, 6 and 9 monthly SPI time series

Station name	3 monthly SPI				6 monthly SPI				9 monthly SPI			
	D	ND	WN	W	D	ND	WN	W	D	ND	WN	W
Abadeh	−2.15*	−0.32	1.09	−0.94	−0.32	−0.06	0.76	−0.44	−0.85	−0.04	0.37	0.48
Arak	−0.54	1.28	1.01	0.72	0.71	0.98	−0.47	0.98	0.85	0.98	−1.75	0.66
Bam	0.00	−0.70	−0.57	0.03	−0.28	−0.21	2.06*	−0.99	0.52	2.63	−1.60	0.21
Bandar abbas	0.00	3.25*	−2.76*	−1.01	0.94	−1.33	−0.90	0.67	1.21	1.72	−0.73	0.30
Bandar lenge	0.00	1.36	0.90	−0.51	1.21	1.02	1.11	0.00	0.91	0.36	−0.84	−0.52
Birjand	0.00	1.53	−0.52	−0.02	1.93	1.07	0.08	−0.70	1.75	1.32	0.96	−0.92
Bushehr	0.00	1.28	−0.01	−0.13	2.40*	0.00	1.32	−0.67	−0.37	−0.49	0.08	−0.73
Chabahar	0.00	2.67*	0.11	−1.03	1.31	−1.39	−0.10	−1.71	1.16	0.04	1.42	−1.20
Esfahan	0.69	0.91	1.42	0.79	−0.60	−0.25	−0.19	0.49	0.00	−1.12	−0.58	−0.66
Fasa	0.00	0.12	−0.23	0.00	1.25	0.44	0.17	−1.71	0.45	−0.37	1.67	−0.37
Iranshahr	0.00	0.96	2.32*	−1.47	1.20	2.29*	−0.12	−1.20	1.53	0.83	1.35	0.55
Jask	0.00	2.79*	0.00	−1.28	1.33	−0.50	0.00	−0.18	0.45	1.16	0.40	−0.30
Kashan	0.00	1.41	−0.35	1.02	−0.38	−0.58	0.06	0.79	−0.36	−0.65	0.80	1.28
Kerman	−2.60*	0.57	0.23	−0.18	1.94	−0.01	−0.47	0.35	1.59	0.17	−0.68	−0.90
Mashhad	−1.31	1.77	0.16	1.91	−0.91	−0.70	−1.99*	−0.14	0.56	0.70	−1.16	−0.31
Sabzevar	−0.50	0.37	−0.52	−0.96	0.26	0.00	−1.44	−0.45	0.57	2.59	1.40	0.06
Semnan	0.37	0.35	0.21	−0.79	0.67	0.60	−0.02	−1.52	−0.57	1.27	0.95	1.19
Shahrud	−1.44	2.23*	−0.50	−0.29	1.12	−1.84	1.30	−1.13	−0.90	0.16	0.01	−0.16
Shiraz	0.00	1.03	1.70	−0.28	1.72	1.13	0.54	−0.59	0.37	−0.63	−0.21	−1.61
Tabas	0.00	3.49*	1.70	−1.37	2.50*	−0.81	0.35	0.20	−0.05	−0.26	0.51	0.94
Tehran	−0.79	1.25	2.36*	−0.75	−0.57	0.09	0.94	−0.88	1.30	0.78	0.66	0.55
Torbat heydarieh	−0.16	−0.03	−1.94	0.69	0.49	−0.38	−0.42	0.86	0.68	0.21	−0.97	−0.07
Yazd	0.00	1.44	1.20	0.72	0.66	1.54	−1.81	1.75	0.19	−1.26	−0.82	0.36
Zabol	0.00	1.85	0.82	−1.72	2.11*	−0.35	0.00	−1.76	0.13	0.32	0.02	−2.61*
Zahedan	0.00	1.70	0.19	−0.88	1.53	1.13	−1.84	−0.48	0.14	−0.70	1.82	−0.87

* indicates upward trends (*Z* parameter more than 1.96) and downward trends (*Z* parameter less than −1.96)

level of 0.05 showed a significant trend mainly negative one with regards to drought intensity. It was more considerable than DM trend (5.8 %). The negative trend of SPI time series means more frequency of negative SPI values and consequently more drought conditions.

It is important to note that in the analysis of the results for the DM trend, the negative sign in the DM equation should be taken in account. In other words, unlike the SPI time series that the negative trends are more hazardous, the positive trends in DM are disturbing. For instance, because of negative sign in DM equation, the positive trend of DM in D or ND drought intensity classes means more negative SPI values and therefore more DM. Also, for the W and NW ones, the positive trend means lower positive SPI values and it refers again to the negative sign of DM equation.

It should be mentioned that although, the DM significant trends are not so considerable compared to the SPI time series, the more frequent positive significant trends of DM than negative ones are in agreement with the frequent negative significant trend of drought intensity. Of course, it should be considered that the SPI or drought intensity trend involves different components such as drought frequency, magnitude and duration. Therefore, different combination of components can affect the SPI time series trends and in this study, besides drought intensity trend, the trends in DM were also investigated.

A total of 16, 32, 52, 60, 60, and 68 % of stations showed decreasing trends for 3, 6, 9, 12, 18, and 24 monthly SPI time series, respectively. As it can be seen, the long-term time series showed more significant trends compared to the short-term ones. The same results have been reported by Abarghouei et al. (2011). Fewer trends in short-term SPI time series than long-term ones can be attributed in two main causes. The first cause is the more similarity of short term of SPI values to precipitation time series. As it can be seen in the Table 4, the *Z* values of short-term time series particularly 3 monthly one are very similar to precipitation *Z* values. Since the SPI uses the summed values of the precipitation, with increasing in the

Table 6 SPI DM trend results based on the application of MK test (*Z* parameter) for 12, 18 and 24 monthly SPI time series

Station name	12 monthly SPI				18 monthly SPI				24 monthly SPI			
	D	ND	WN	W	D	ND	WN	W	D	ND	WN	W
Abadeh	−1.39	−0.21	0.90	0.78	−0.06	−0.35	−1.42	0.18	1.36	−0.66	−1.20	−0.12
Arak	0.00	0.69	1.05	1.64	1.28	0.59	0.93	0.00	1.43	0.15	−0.91	0.72
Bam	0.21	0.42	0.73	−0.89	0.52	0.85	−0.26	0.43	0.73	−0.44	−0.77	−1.50
Bandar abbas	0.36	0.94	0.27	0.37	0.18	0.96	−0.17	−0.72	0.00	1.25	−0.59	0.52
Bandar lenge	−0.30	−0.28	−0.56	−0.60	0.90	−0.32	0.41	−0.75	1.04	0.62	0.36	0.34
Birjand	0.12	2.65*	−1.02	0.31	1.71	0.56	−0.59	0.14	−1.02	0.59	0.94	−0.87
Bushehr	0.10	0.00	1.07	1.22	−0.34	0.00	1.48	0.00	−0.62	−0.41	−0.34	0.34
Chabahar	1.61	0.32	0.42	−1.13	0.00	1.97*	0.41	−0.38	0.00	0.21	0.22	−1.71
Esfahan	−1.97*	0.06	−0.27	−0.31	−0.79	0.14	0.95	−1.76	0.38	0.07	−1.13	0.89
Fasa	1.09	0.94	0.88	−1.97*	−0.31	−0.54	−0.13	−0.89	0.00	1.65	−0.31	−2.25*
Iranshahr	0.00	0.88	−0.35	−0.12	0.00	2.48*	−0.12	0.21	0.00	1.09	0.11	1.50
Jask	1.36	−1.29	2.13*	0.00	2.10*	1.27	1.06	−0.52	1.70	1.61	0.00	0.00
Kashan	−0.31	−0.89	−0.14	−0.18	−0.33	−2.27*	−0.21	1.53	1.15	0.82	−1.21	−0.37
Kerman	0.75	−1.12	0.73	0.10	0.93	0.86	1.56	−0.82	−0.30	1.14	−0.27	−0.62
Mashhad	0.72	−0.95	0.85	0.43	0.88	1.87	−0.60	0.33	1.04	−0.45	0.82	−0.90
Sabzevar	0.41	0.82	0.42	0.22	1.58	−0.09	−1.99	1.13	2.10*	−1.80	1.31	−0.54
Semnan	0.07	1.11	−0.39	−0.62	2.35*	1.07	−0.15	0.12	0.89	−0.92	0.00	1.87
Shahrud	−1.65	1.82	1.10	0.31	−0.92	0.00	1.36	−0.31	1.25	1.13	1.28	−1.70
Shiraz	−0.54	0.10	1.14	−0.31	−0.40	−0.82	0.54	−2.19*	−0.12	−0.42	0.44	0.00
Tabas	0.30	−1.12	−0.35	−0.72	0.78	0.00	0.48	0.18	0.60	−0.40	0.36	0.16
Tehran	1.36	0.26	−0.97	0.21	1.65	0.31	0.75	−2.43*	2.25	−0.27	0.90	−0.31
Torbat heydarieh	0.62	0.00	−0.70	−1.67	1.75	0.91	0.59	−0.79	1.04	−1.20	0.48	0.00
Yazd	−0.16	0.07	−0.08	0.31	−0.22	0.73	−0.24	2.54*	−0.62	0.12	1.14	0.12
Zabol	0.30	−1.04	−0.96	−1.36	1.56	−0.13	−0.26	−0.21	0.00	0.00	−1.94	0.62
Zahedan	0.38	0.77	−0.45	0.00	1.15	0.63	−0.49	−1.50	0.00	−0.67	0.59	−1.04

* indicates upward trends (*Z* parameter more than 1.96) and downward trends (*Z* parameter less than −1.96)

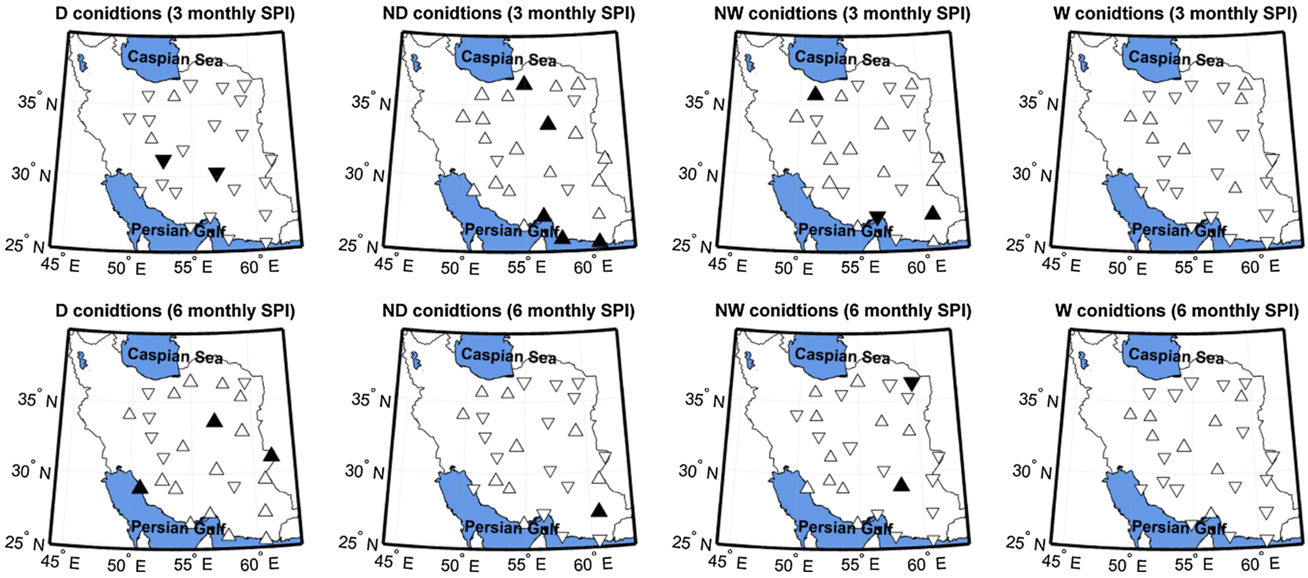

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Fig. 6 Spatial distribution of increasing, decreasing, and non-significant SPI DM trends for 3 and 6 monthly SPI time series

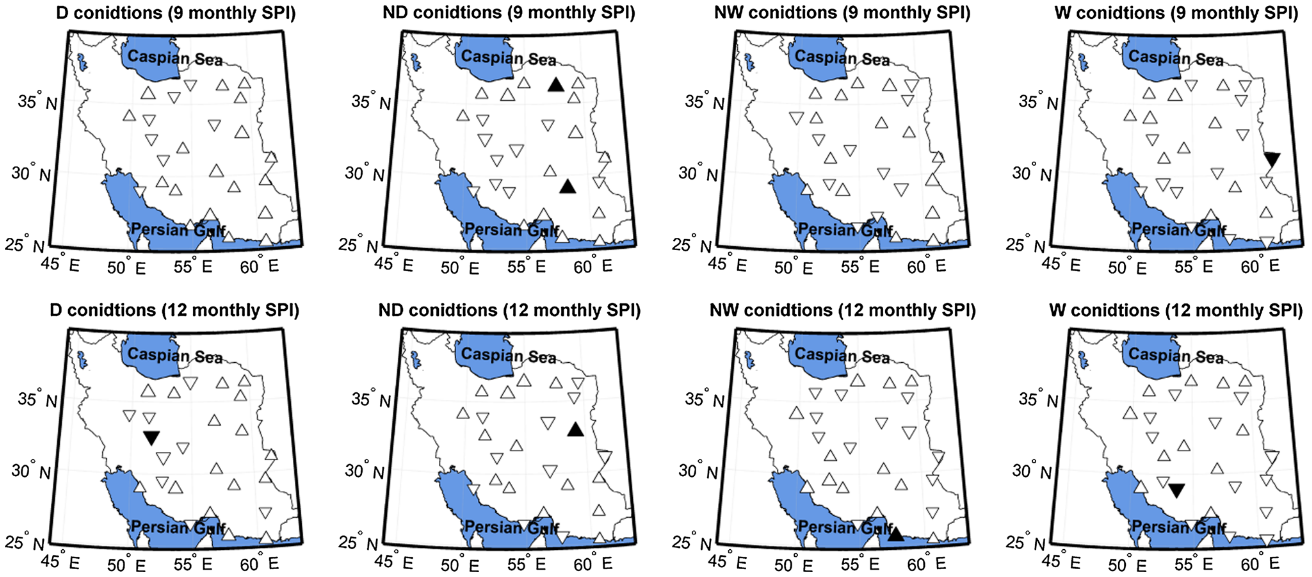

Fig. 7 Spatial distribution of increasing, decreasing, and non-significant SPI DM trends for 9 and 12 monthly SPI time series

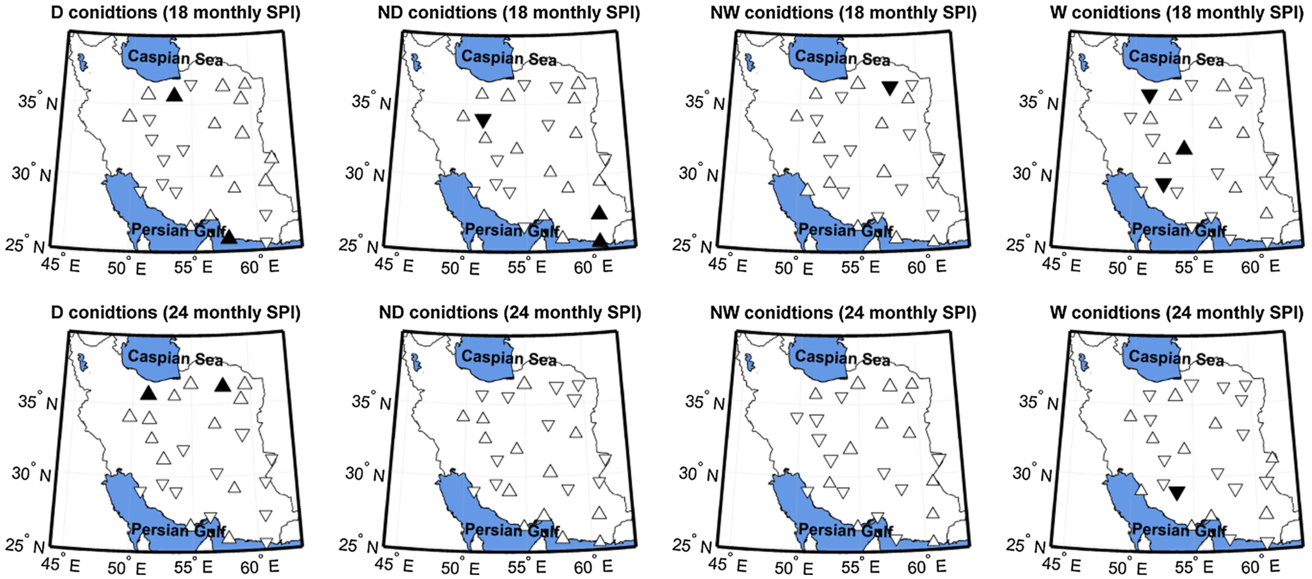

Fig. 8 Spatial distribution of increasing, decreasing, and non-significant SPI DM trends for 18 and 24 monthly SPI time series

term of the SPI, the similarity of SPI with precipitation time series decreases. As the results showed, the time series of precipitation did not indicate considerable trend. Therefore, the lower number of trends in short-term SPI time series is observed. The second reason refers to some limitations of SPI calculation in arid and semi-arid regions which includes its inability to define drought in extremely low-precipitation areas at shorter time scales, where a zero or a small amount of drought occurs for the entire time period using the 1-month and occasionally 3-month SPI test. This was the result of precipitation median for these areas, for the periods on record, being zero. When the time scales increased and more months were considered, this problem was solved (Kangas and Brown 2007). Of course, using other probability distribution functions with more fit to initial precipitation data can reduce this issue. Also, some different conditions of drought trend based on 12 monthly SPI time series are reported by Tabari et al. (2012) that these time series did not show significant trend in arid and semi-arid regions of Iran hence they explained that the study area has become drier during the last 4 decades. Of course, the time period in their study and current ones is different and therefore this difference can be attributed to this factor.

Anyway, the results of this study showed the increasing trend of drought intensity and in the second order in DM. Undoubtedly, this occurrence is an enormous threat for water resource management in the arid and semi-arid regions of Iran. The most parts of Iran have had increasing drought intensity trends in various time series. The arid and semi-arid regions of Iran cover more than 90 % of the country climatically and these areas have faced to serious problems in regard to have sufficient water resources. Demand for the world's increasingly scarce water supply is rising rapidly which challenges its availability for food production and puts global food security at risk. As the demand for water by all users grows, the groundwater is being depleted (Rosegrant et al. 2002). Therefore, the more integrated water resource management programs with efficient strategies are needed to overcome or reduce the effect of such enormous obstacle. Also, there is a need to analyse more aspects and properties of drought in Iran to find the most effective drought statistical parameters on the reported trends. Different components of drought occurrence such as drought duration, frequency and its spatial extent should be investigated in more comprehensive researches.

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