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Investigation of spatiotemporal variation of drought in Iran during the last five decades

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Abstract

The present study was conducted to assess the changes in Iran's drought severity for the duration of 1964 to 2014. For this purpose, the spatial distribution of drought was annually and seasonally evaluated using climate data from 26 synoptic stations over Iranian territory based on standardized precipitation index (SPI). In this regard, the climate classification in the study area was performed applying Dermartone method. Moreover, the annual and seasonal values of SPI were calculated for the whole Iranian territory and each climate region. The SPI index for monotonic trend was calculated in each climate region utilizing Mann-Kendall and Theil Sen estimators. Our results implied that the minimum and maximum values of SPI (-3.86 and 2.89, respectively) appeared during spring in dry and Mediterranean climate regions. In addition, the maximum and minimum values of annual continuous SPI appeared in 1999-2004 and 1974-1982, respectively. The maximum and minimum values of seasonal continuous SPI also appeared for a duration of 9 years during summers respectively in the period of 1977 to 1985 and springs in the period of 2006 to 2014. The application of Mann-Kendall and Theil Sen estimator analyses revealed that 9 out of 26 stations had a significant decreasing SPI trend. Moreover, the annual and seasonal time series in moderately dry regions indicated a meaningfully decreasing trend in winter and annual SPI. Additionally, winter, spring, autumn and annual values of SPI had a meaningful decreasing trend in the Mediterranean climate region. In dry and very wet climate regions, no obvious trend was detected for the annual or seasonal SPI index.

Keyword: SPI indices; Drought duration; Spatial pattern; Trend analysis

1. Introduction

Drought, defined as the lack of precipitation, is considered as one of the most costly and least understood natural disasters (Kao and Govindaraju, 2008). It has resulted in negative impacts on water resources, agriculture, vegetation, wildlife, environmental factors, and human health all around the world (Afzali *et al*., 2016; Asefjah *et al*., 2014; Masoudi and Hakimi, 2014). Generally, drought originates from a shortage of precipitation, high evapotranspiration, and overexploitation of water resources, or a combination of all these factors (Byun and Wilhite, 1996). Climate changes have negatively affected Iran's water resources (Abbaspour *et al*., 2009; Afzali *et al*., 2016; Asefjah *et al*., 2014; Delju *et al*., 2013; Morid *et al*., 2009). Drought and climate changes have decreased the long term annual water budget from 130000 million cubic meters (MCM) down to 89000 (MCM). Furthermore, the country runoff has decreased by 40% in the recent decade (IPRC, 2017). The impacts associated with climate changes have also decreased the annual precipitation by 10% and altered the precipitation pattern (Tabari and Talaee, 2011a; Zarghami *et al*., 2011). During 1997 to 2001, a severe 40-year return period drought affected half of Iran's territory, with a loss in the agricultural section estimated to be over 10 billion US dollars. Most of the important rivers and lakes went completely dry during this drought period (Foltz, 2002) and a Gross Domestic Product (GDP) reduced by 4% (Salami *et al*., 2009). On top of that, a more recent severe

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drought period (2007–2009) devastated the country on a larger scale compared to the previously mentioned one. A 19-billion-US dollars damage in the agricultural section has been reported from 2006 to 2008. A 20% decline in the rainfall in 2008 has been reported over the medium of 30 past years. Therefore, studying the spatiotemporal variation of drought could provide the water resources managers the possibility to introduce the necessary plans in order to mitigate the widespread effects of this phenomenon. In this regard, the application of drought indices appropriately makes the transforming information of climatic irregularity easier and allows the researcher to quantitatively survey the climatic anomalies in terms of their severity, duration, frequency, and spatial extent (Wilhite, 2000). This information is highly useful for the application of water resource development schemes (Tsakiris *et al*., 2007). Different drought monitoring indices, such as Palmer Drought Severity Index (PDSI), the China-Z Index (CZI), the Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), Present of Normal Index (DNI), and Effective Drought Index (EDI) has been employed in drought analysis (Alley, 1994; Helim, 2002; Yacoub and Tayfur, 2017). In this study, we applied the SPI index owing to the quality of the available data and the confidence to the capability of this index of detecting the drought identification in Iran (Bazrafshan and Khalili, 2013; Morid *et al*., 2006). In recent years, we have observed a rapidly growing trend concerning the number of studies on drought in Iran. For example, Zarei et al. (2015) utilized RDI to analyse the spatial pattern of drought in southern Iran. Herein, the findings showed that annual drought, precentage of areas with normal condition, and severe and extreme dry condition had a significant increasing trend. In winter drought, the percentage of areas with a severe and extreme dry condition had a significantly increasing trend. In spring and summer droughts, the precentage of moderately dry areas had an increasing trend. Moreover, the precentage of severely dry areas illustrated a significantly increasing trend in autumn drought. No significant trends was observed in other classes of drought in different time scales (Zarei, 2016). Literature reviews showed that despite the important role of climate in drought indices, no investigation has been carried out concerning station climate effect on drought severity across the Iranian territory. This reveals the importance of this research as it aimed to investigate the drought pattern in different climate regions of Iran. In the current research, we estimated the temporal pattern of SPI index in Iran employing Mann- Kendall and Theil Sen estimators.

2. Study Area

The study area covered the entire territory of Iran, lied approximately between 25 °N and 40 °N in latitude and between 44 °E and 64 °E in longitude. Iran is mostly located within arid and semiarid climate which is characterized by low rainfall and high potential of evapotranspiration (Amiri and Eslamian, 2010). This country is of various climates from north to south. The northern part of the country is humid with wet climate while the southern, eastern, and central parts of Iran are dry and under severe water stress, and are highly relied on dwindling groundwater resources (Abbaspour, 2009). The mean annual precipitation all over Iran is less than one-third of the mean global precipitation. Additionally, only 8% of Iran receives annual precipitation of over 500 mm.

3. Materials and Methods

Monthly precipitation and average temperature time series from 26 synoptic stations was obtained from the Islamic Republic of Iran Meteorological Organization (IRIMO, 2017). There are more than 200 synoptic stations in Iran, among which only 26 stations used in this study had a continuous record of data time series. A record length of 50 years (1965–2014) was considered from the selected stations. Figure (1) represents the geographical location of the stations and Table (1) shows the station statistical and geographical character.

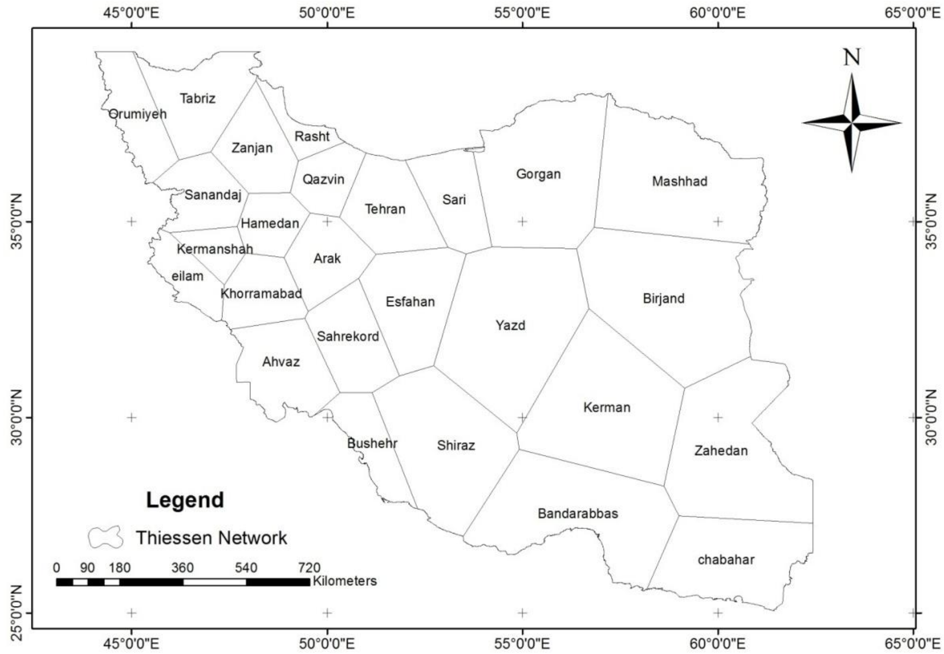

Fig. 1. Location of selected synoptic station and its thiessen network used in this study

Table 1. Geographical descriptions of the synoptic stations used in the study and statistical parameters of monthly precipitation

Station name	Longitude (E)	Latitude (N)	thiessen area($\mathbf{Km^2}$)	Elevation (m)	Mean (mm)	SD (mm)	CV (%)	Sk	Ku
Khuramanad	48.35	33.49	33725.90	1147.00	496.07	123.39	24.87	0.10	-0.29
Sari	53.06	36.55	37113.20	23.00	899.49	168.16	18.70	0.09	0.28
Birjand	59.21	32.86	133873.00	1491.00	162.00	51.04	31.50	0.25	0.02
Gorgan	54.44	36.83	106580.00	0.00	571.88	121.10	21.18	-0.07	-0.15
Zanjan	48.49	36.68	38249.20	1663.00	306.21	71.21	23.25	-0.09	0.22
Hamadan	48.51	34.79	24248.30	1741.00	316.26	84.06	26.58	0.01	0.13
Kerman	57.07	30.29	124824.00	1753.00	135.64	46.42	34.22	0.52	0.76
Arak	49.70	34.09	36896.20	1708.00	325.55	94.49	29.03	0.34	0.16
Oromiye	45.06	37.54	36484.60	1328.00	332.28	96.93	29.17	0.84	0.35
Zahedan	60.85	29.49	117371.00	1370.00	22.83	16.09	70.46	4.13	18.00
Tabriz	46.30	38.06	50716.80	1361.00	277.93	73.90	26.59	0.63	0.03
Yazd	54.35	31.87	131210.00	1237.00	58.82	25.02	42.53	0.42	-0.33
Rasht	49.60	37.26	14206.40	-8.60	1336.66	256.72	19.21	0.53	0.03
Fars	52.53	29.61	105018.00	1484.00	319.02	108.86	34.12	0.09	0.17
kermansahh	47.08	34.33	16495.10	1318.00	442.40	121.75	27.52	0.70	0.27
Khuzestan	48.68	31.31	53227.60	22.50	224.10	84.09	37.52	0.35	0.56
Esfahan	51.65	32.66	61194.60	1550.00	128.69	47.88	37.20	0.31	-0.12
Mashhad	59.58	36.30	114165.00	999.00	250.93	73.12	29.14	0.41	-0.44
Tehran	51.36	35.72	46664.70	1190.00	234.10	70.96	30.31	0.10	-0.59
Eilam	46.41	33.63	24304.70	1550.00	151.45	104.18	68.79	2.62	7.63
Shahrekurd	50.85	32.33	44984.70	2048.00	35.25	82.70	234.61	3.39	10.34
Qazvin	50.00	36.28	24621.50	1279.00	317.31	86.31	27.20	0.29	-0.32
Sanandag	46.99	35.31	34393.50	1373.00	440.34	123.71	28.09	0.46	0.61
Bandarabbas	56.28	27.18	116133.00	9.80	173.23	113.15	65.32	1.09	0.84
Bushehr	50.83	28.94	32119.90	9.00	246.38	110.09	44.68	1.28	3.48
Chabahar	60.62	25.28	80373.50	8.00	310.30	32.34	10.42	-4.97	28.03

In the present research, we used Dermartone climate classification, SPI nd Sen's slope estimator methods (Akritas *et al*., 1995). A brief description of the methods is presented below:

SPI

SPI, introduced by McKee et al. (1993), is an index that represents the occurrence probability of a measured precipitation amount compared with the precipitation climatology at a certain location during a historical reference period. To calculate the SPI, the gamma probability density function (PDF) should be initially fitted to the long term time series of precipitation (McKee et al., 1993). The gamma distribution is determined as in Eq. (1):

$$\text{If } x \geq 0; \text{ Then } g(x, \alpha, \beta) = \frac{1}{\beta^{\alpha} \times \Gamma(\alpha)} x^{\alpha-1} \times e^{-x/\beta} \quad (1)$$
$$\text{If } x < 0; \text{ Then } g(x) = 0$$

where both parameters of α and β satisfy $\alpha > 0$ and $\beta > 0$. Γ is gamma function defined for $\alpha > 0$ as in Eq. (2):

$$\Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1} e^{-x} dx \quad (2)$$

To fit the gamma function to the recorded data, both α and β should be estimated as in Eqs. (3) and (4) (Karavitis *et al*., 2011):

$$\alpha = 0.25\text{A}\left(1 + \sqrt{\frac{4\text{A}}{3}}\right) \quad (3)$$

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

A is calculated for n measurement as in Eq. (5):

$$\text{A} = \ln\left(\overline{x}\right) - \frac{\sum \ln(x)}{n} \quad (5)$$

Integrating the PDF considering the three parameters of x, α, and β results in Eq. (6) for the cumulative probability (Zarch, 2015):

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

where $t = -x/\beta$.

Since the gamma distribution is undefined for $x = 0$, the cumulative probability is written as in Eq. (7):

$$H(x) = q + (1-q)G(x) \quad \text{where} \quad q = \text{P}(x = 0) \quad (7)$$

The SPI value is equal to variable Z obtained by transformation of $H(x)$ to the standardized normal distribution function as given in Eqs. (8) and (9):

$$Z = \text{SPI} = -\left(t - \frac{2.515517 + 0.802853t + 0.010328t^2}{1 + 1.432788t + 0.189269t^2 + 0.001308t^3}\right) \quad (8)$$
$$\text{where} \quad t = \sqrt{\ln\left(\frac{1}{H(x)^2}\right)} \quad \text{and} \quad 0 < H(x) < 0.5$$

$$Z = \text{SPI} = -\left(t - \frac{2.515517 + 0.802853t + 0.010328t^2}{1 + 1.432788t + 0.189269t^2 + 0.001308t^3}\right) \quad (9)$$
$$\text{where} \quad t = \sqrt{\ln\left(\frac{1}{\left(1 - H(x)\right)^2}\right)} \quad \text{and} \quad 0.5 < H(x) < 1.0$$

Positive and negative SPI values respectively determine the precipitations greater and less than the median value.

The calculation of seasonal SPI index is based on the total precipitation in each season of the year.

Trend detection

In this study, the Mann-Kendall (MK) test was employed for the detection of trends in datasets. In this regard, the null and alternative hypotheses were a set of m independent variables and a sample that followed a monotonic trend. This test is calculated as Eq. (10).

$$S = \sum_{k=1}^{m-1} \sum_{j=k+1}^{m} \text{sgn}\left(x_j - x_k\right) \quad \text{where} \quad \text{sgn}(x) = \begin{cases} 1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0 \end{cases} \quad (10)$$

in which m is the number of data points. The mean and variance of S are zero and unit, respectively. For $m > 10$, S statistic is transformed to the standard normal variable Z with Eq. (11) (Tabari and Talaee, 2011):

$$Z = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases} \quad (11)$$

where σ is standard deviation of S.
In Eq. (11), positive and negative values show the increasing and decreasing trends in the used dataset, respectively.

Slope of trend calculation

The SSE, introduced by Sen (1968), is widely utilized to determine the slope of a trend in a historical dataset since it is not highly affected by missing data and outliers (Partal Caps, 2017). This method starts by estimating the slope of K pairs of data with Eq. (12):

$$Q_i = \frac{x_j - x_k}{j - k} \quad i = 1, \ldots, K \quad (12)$$

In Eq. (12), Q = slope between the data points is measured at time j (x_j) and k (x_k), and $j > k$. Subsequently, Sen's slope is computed a the median value of Q_i as presented in Eqs. (13) and (14) for odd and even pairs of data, respectively:

$$Q_{med} = Q_{[(K+1)/2]} \quad (13)$$

$$Q_{med} = 0.5\left(Q_{[K/2]} + Q_{[(K+2)/2]}\right)Q_{[(K+1)/2]} \quad (14)$$

Theafter, Q_{med} should be tested with a two-sided test at the 100(1 – α)% confidence interval and the true slope can be calculated with the non-parametric test (Partal and Kahya, 2006). In this work, the upper and lower confidence limits for Sen's slope were calculated considering the confidence interval of 0.01. More details about the SSE method are given by Partal *et al*. (2012) (Partal, 2012).

In the output of this method, Q and B respectively represent linear slope and width from origin, also lower and upper limit of the 95% confidence interval represent via Q_{95} and B_{95}.

Dermartone climate classification

The Dermartone climate classification method is defined by the ratio of precipitation to temperature.

$$I = \frac{P}{T+10} \quad (15)$$

In the above-mentioned equation, I represents Dermartone climate index, and P and T are annual Precipitation (mm) and Temperature (°C), respectively. $I < 10$ represents dry climate, $10 < I < 20$ represents moderately dry climate, $20 < I < 24$ and $24 < I < 28$ represent Mediterranean climate and very wet climate, respectively. $28 < I$ shows extremely wet climate regions.

4. Results and Discussion

Ahead of drought indices investigation, there is a brief description of precipitation and temperature data. Precipitation magnitude and variation indicated strong spatial and temporal character. The maximum precipitation occurred in the north station (along the Caspian Sea with a decreasing trend from west to east), and the minimum precipitation occurs in the central part of Iran. The maximum annual precipitation is observed in Rasht station in 1972 (1967.6mm) whereas the minimum precipitation records occur in Yazd station in 2010 (9.3 mm). Moreover, the maximum precipitation variation is found beside the Caspian Sea in the north and Persian Gulf in the south. The average annual precipitations in the 18 stations are higher than that in the study area. Figure (2) represents the annual precipitation range across the selected synoptic station in Iran.

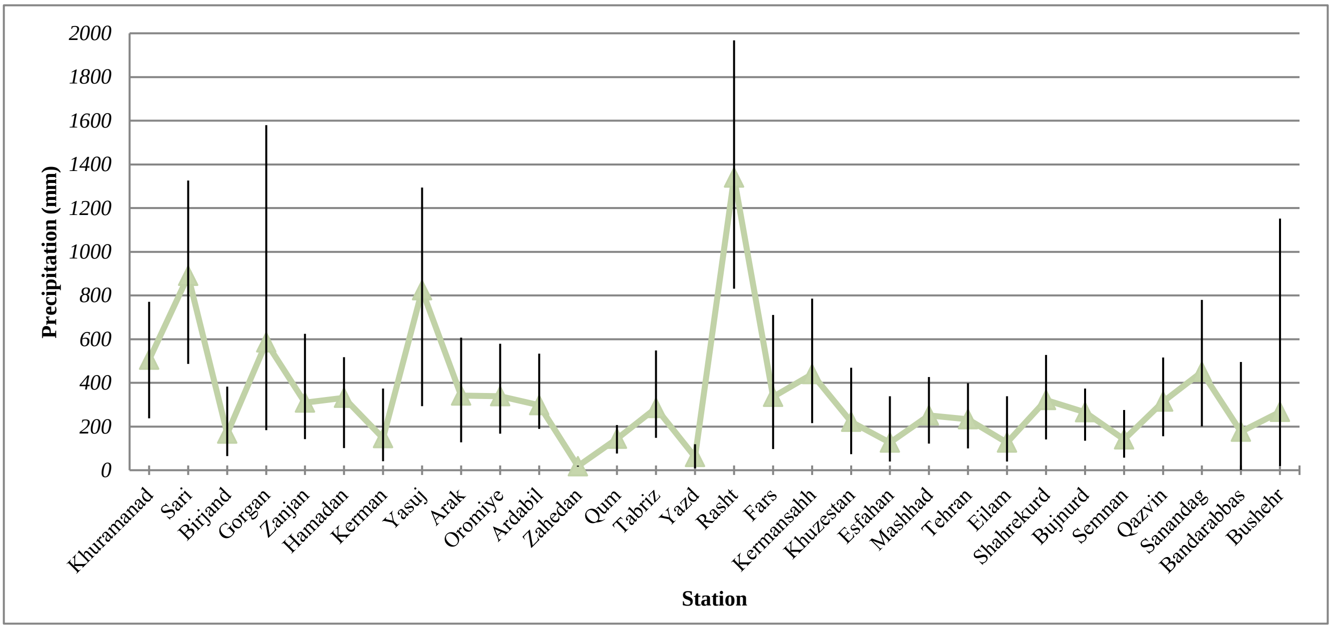

Fig. 2. Annual precipitation across the selected station in Iran

The average annual precipitation in this country over the five past decades was 254.37 mm with a maximum of 346.2(in 1982) and a minimum of 157.8 (in 2010). 29.9 % of the annual precipitation falls in autumn, 18.5% in spring, 6.4% in summer, and 45.2% in winter.

The seasonal precipitation falls in the range of 23.67-118.94 mm in autumn, 14.42-86.9 mm in spring, 4.49-30.23 mm in summer, and 63.57-180.39 mm in winter. The average annual precipitations mostly occur from October to March. The major winter precipitation falls in the west, east and central stations and summer precipitation mostly occurs in the northern station. On the margin of the Caspian Sea in the north of the country, there is significant summer rainfall and on the shores of the Persian Gulf and Oman Sea, we could observe a decline in the winter rainfall from the west to the east. Furthermore, the dominant spring rainfall is concentrated in the west and north of the country

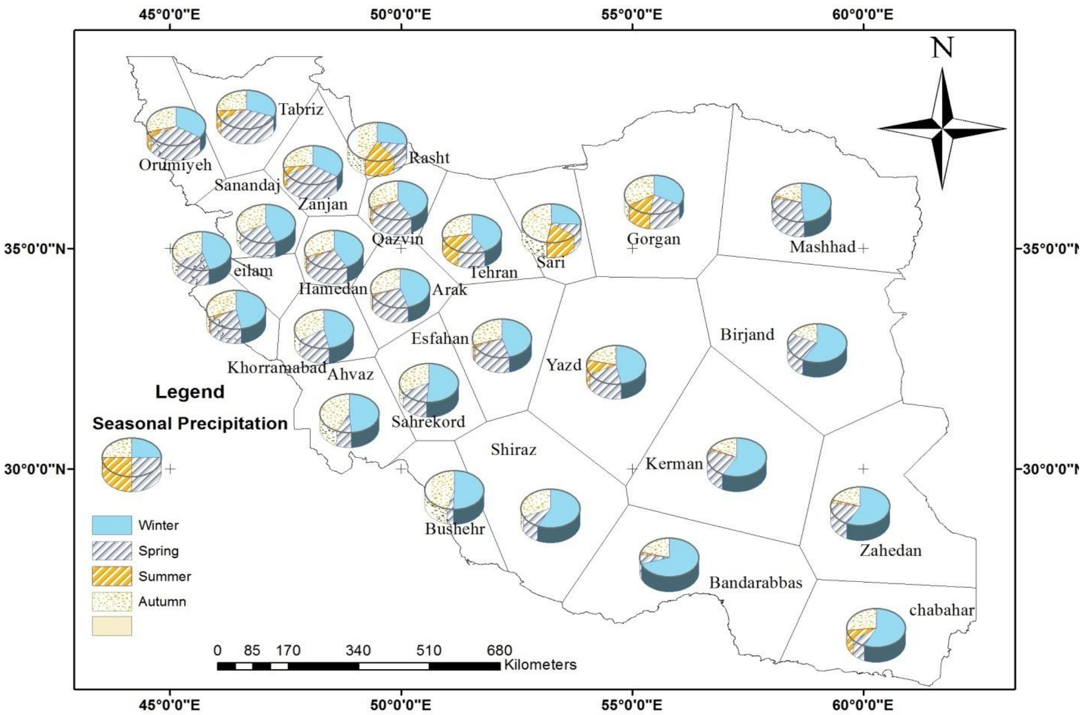

Fig. 3. Distribution of precipitation in each season of the year across Iran

The maximum temperature zone is across the Persian Gulf border in south, and there is the minimum temperature mainly in the west and northwest of the country. The minimum annual average temperature record in 1992 was 16.5℃ and the maximum temperature reached 19.1℃ in 2010. Figure (4) depicts the average annual temperature and precipitation across Iran.

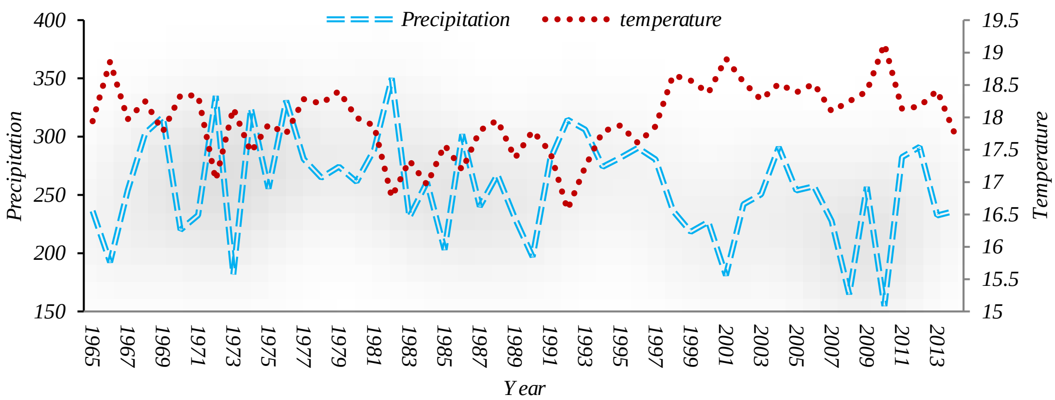

Fig. 4. Annual embrothermic diagram based on the selected 26 synoptic stations across Iran

Yearly drought SPI shows that 2001, 2008 and 2010 were the driest and 1976, 1972 and 1982 were the wettest year in Iran. The seasonal SPI severity also indicates that drought amplitude is on the increase in all seasons. In winter, the driest years were 2001, 2008 and 2013 and the wettest years were 1996, 1972 and 1982. Moreover, continuous dry winters in the recent years might reduce the snow supply in mountains and lead to hydrological drought in the future. According to the available official data, the snow supply in Iran in 2014 reduced down to 36% of its annual average supply (www.ndwmc.irimo.ir, 2017).

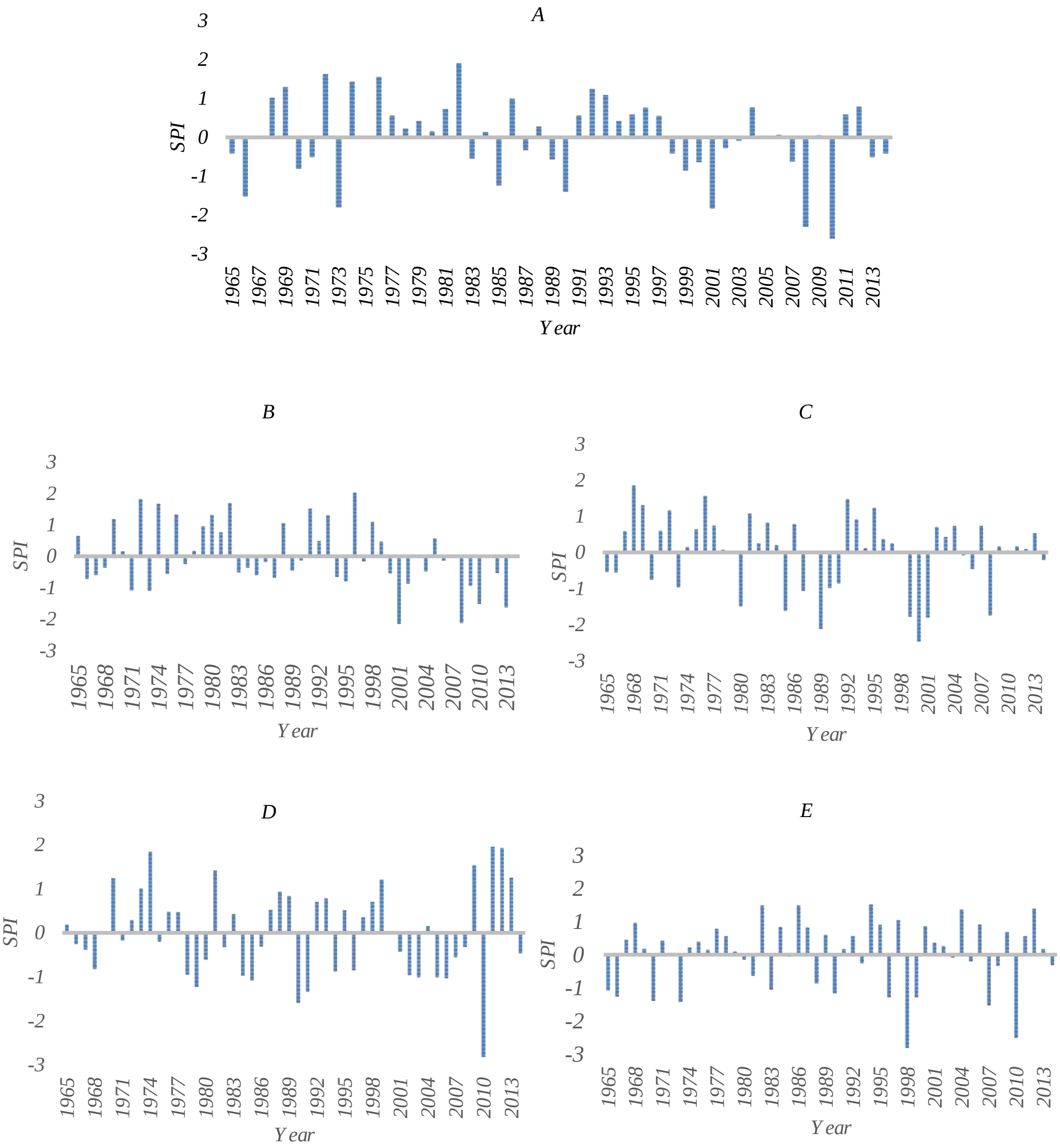

Fig. 5. Seasonal and annual SPI index over Iran territory A: yearly SPI, B: Seasonal SPI (Winter), C: seasonal SPI (Spring), D: seasonal SPI (Summer), E: seasonal SPI (Autumn)

Spatial pattern of drought indices shows that in 1982 (extremely wet year), 2.97% of Iran was extremely wet, 12.7% moderately wet, 33.7% very wet, and 50.3% was in near normal conditions. In the most severely dry year (2010), 10.23% of Iran was in severely dry, 30.29% in near normal, 37.4% in extremely dry, and 22.02% in moderately dry condition.

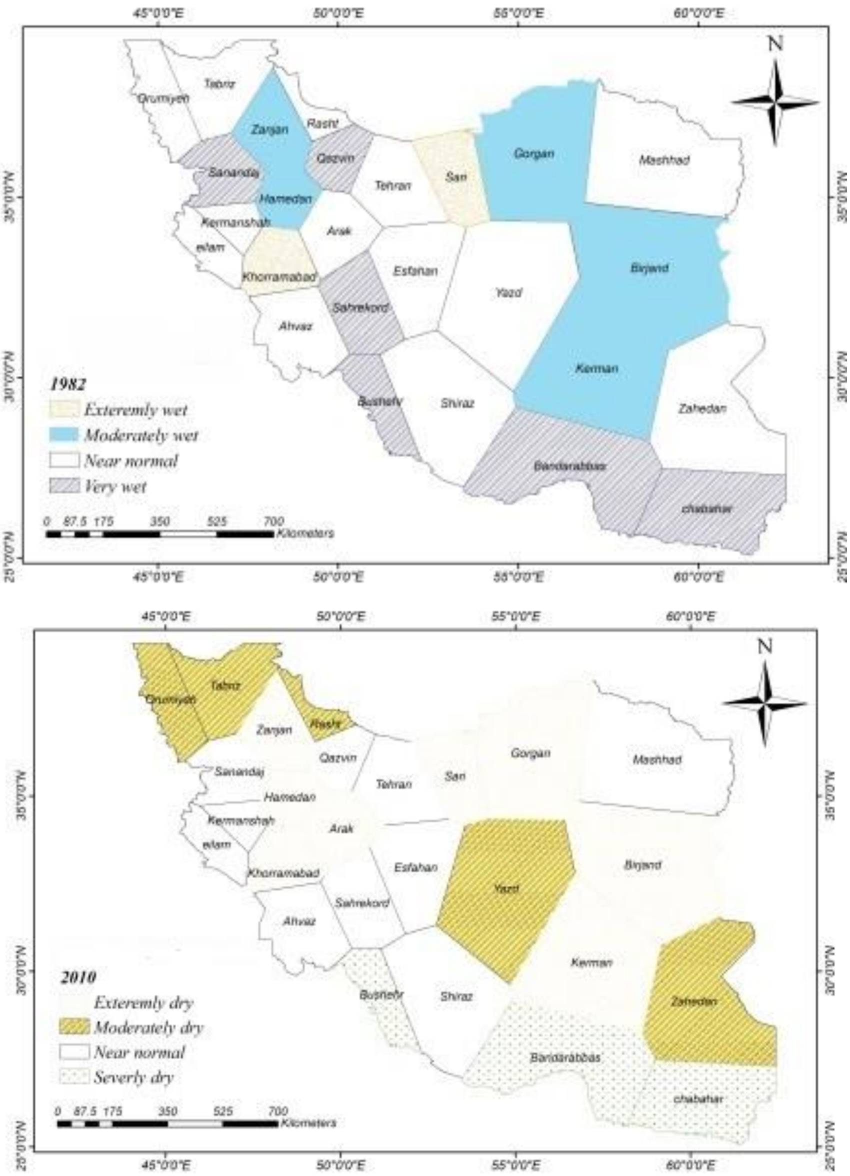

Fig. 6. Spatial patter of drought across Iran in drier and wet years

The application of Mann-Kendall and Theil sen estimators on SPI in yearly and seasonal time series showed that the significance level in all the investigations was greater than 0.1 and no obvious trend was detected in seasonal or yearly SPI across Iran. However, the application of this trend analysis on the selected 26 synoptic stations shows that 9 stations (30.6% of total Iran) had a significantly decreasing SPI trend and the potential to be drier. According to this station, Gorgan Province has a greater SPI decreasing and Khuzestan Province has the least SPI decreasing trend.

Table 2. Value of statistics Z of the Mann–Kendall test and value of statistics Q of the Sen Slope for the station with valid trend (1965-2014)

station	Test Z	Q	$Qmin_{95}$	$Qmax_{95}$	B	$Bmin_{95}$	$Bmax_{95}$
Khuramanad	-2.685	-0.028	-0.043	-0.011	1.373	1.946	0.622
Birjand	-1.807	-0.020	-0.038	0.002	1.055	1.862	-0.026
Gorgan	-3.254	-0.036	-0.055	-0.015	1.670	2.432	0.750
Arak	-2.133	-0.022	-0.041	-0.003	1.117	1.802	0.117
Oromiye	-1.899	-0.019	-0.038	0.001	0.776	1.723	-0.130
Tabriz	-3.204	-0.033	-0.051	-0.014	1.437	2.163	0.472
Kermansahh	-2.936	-0.030	-0.049	-0.012	1.343	2.455	0.358
Khuzestan	-1.857	-0.017	-0.035	0.001	0.911	1.706	0.068
Sanandag	-3.915	-0.034	-0.051	-0.018	1.538	2.429	0.731

In order to analyses the effects of different climate regions on drought patterns, we carried out climate classification based on Dermatome climate classification method. The area coverage of different types of climate in Iran is 56.2% dry, 6.5% Mediterranean, 34.16% moderately dry and 3.1% very wet. Figure (7) represents the geographic distribution of different climate types in Iran.

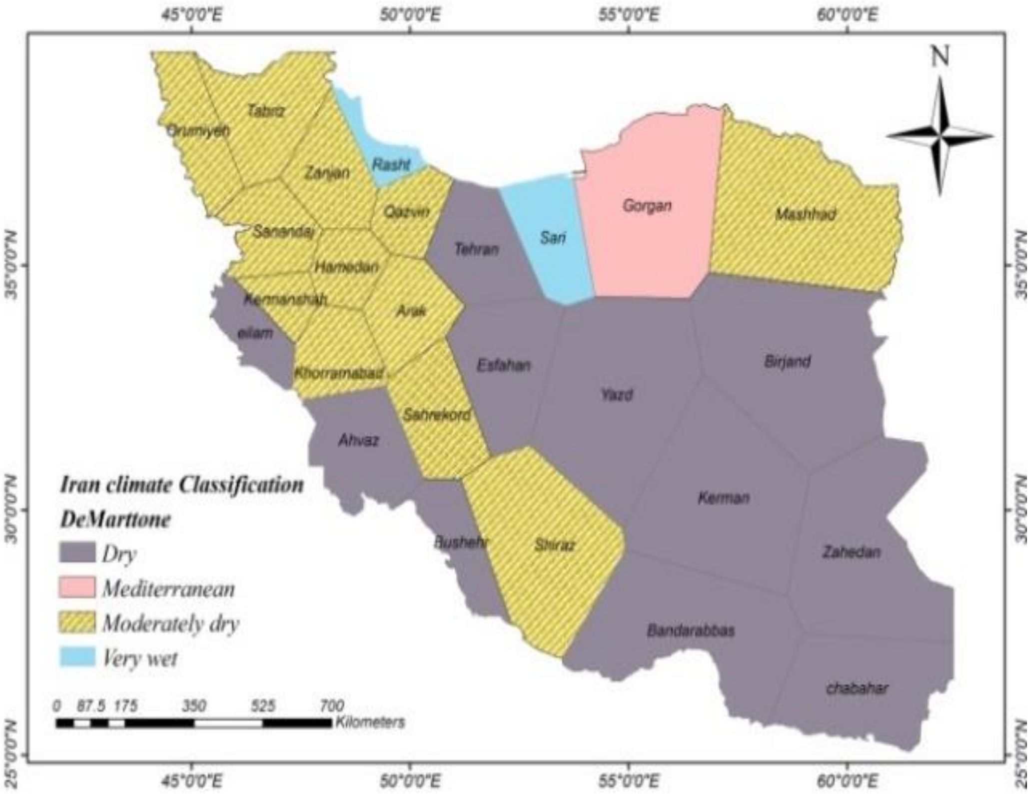

Fig. 7. Iran climate classification based on Dermatome climate classification method

Moderately dry regions experienced the yearly extreme dry condition in 1973 with the SPI of -2.73 and very wet condition in 1982 with the SPI of 1.94. In the seasonal cross section, regarding winter, 2001 and 2008 were extremely dry while 1972 and 1974 were very wet seasons. The springs of 2000, 2008, and 1989 were extremely dry and 1969, 1976, and 1968 were wetter. Concerning summer, 1978 was extremely dry whereas 1974 and 2009 were extremely wet. Regarding autumn, 2010, 1998, and 1973 were extremely dry and 1982, 1986, and 1994 were very wet.

The application of Mann-Kendall and Theil sen estimators on SPI in yearly and seasonal time series in moderately dry regions demonstrated that winter and yearly SPI has a meaningfully decreasing trend.

Table 3. Value of statistics Z of the Mann–Kendall test and value of statistics Q of the Sen Slope for moderately dry regions SPI (1965-2014)

Time series	Test Z	Significance level	Q	$Qmin_{95}$	$Qmax_{95}$	B	$Bmin_{95}$	$Bmax_{95}$
Winter	-1.92	0.1	-0.809	-1.649	0.006	170.65	220.47	134.34
Yearly	-2.19	0.05	-1.248	-2.525	-0.136	362.56	435.11	313.76

In dry region climate, yearly analysis on drought pattern indices (SPI) showed that 1973 and 2010 were extremely dry years in the dry climate of Iran, and 1982 was an extremely wet year in this region. In addition, the seasonal SPI analysis indicated that the winter in 2001, 2010, 2013, and 1973 were the most severely dry and in 1996, it was the wettest winter. The spring in 2000 and 1999 were extremely dry and in 1968, it was very wet. Concerning summer, 2010 was found to be extremely dry and 2012, 2014, 2011, and 2013 were extremely wet. The autumn in 1995 was extremely wet and in 1973, it was extremely dry.

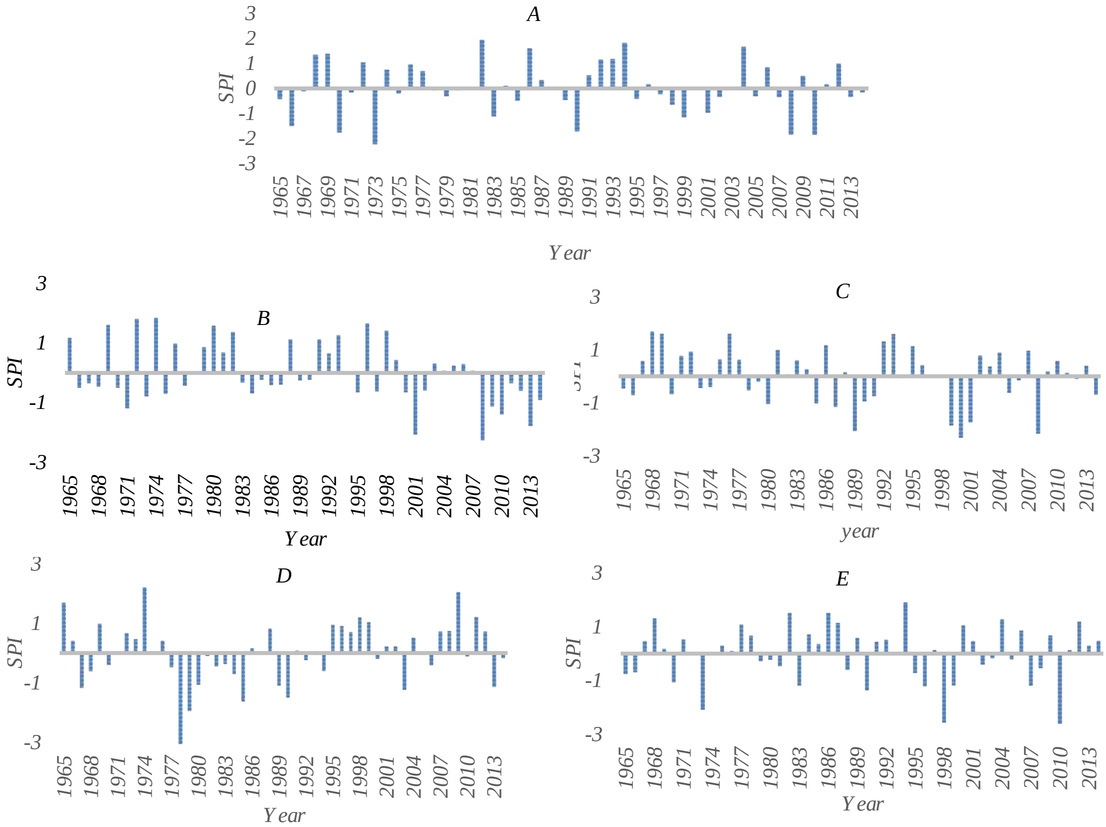

Fig. 8. Seasonal and annual SPI index in moderately dry climate region of Iran, territory A: yearly SPI, B: Seasonal SPI (Winter), C: seasonal SPI (Spring), D: seasonal SPI (Summer), E: seasonal SPI (Autumn)

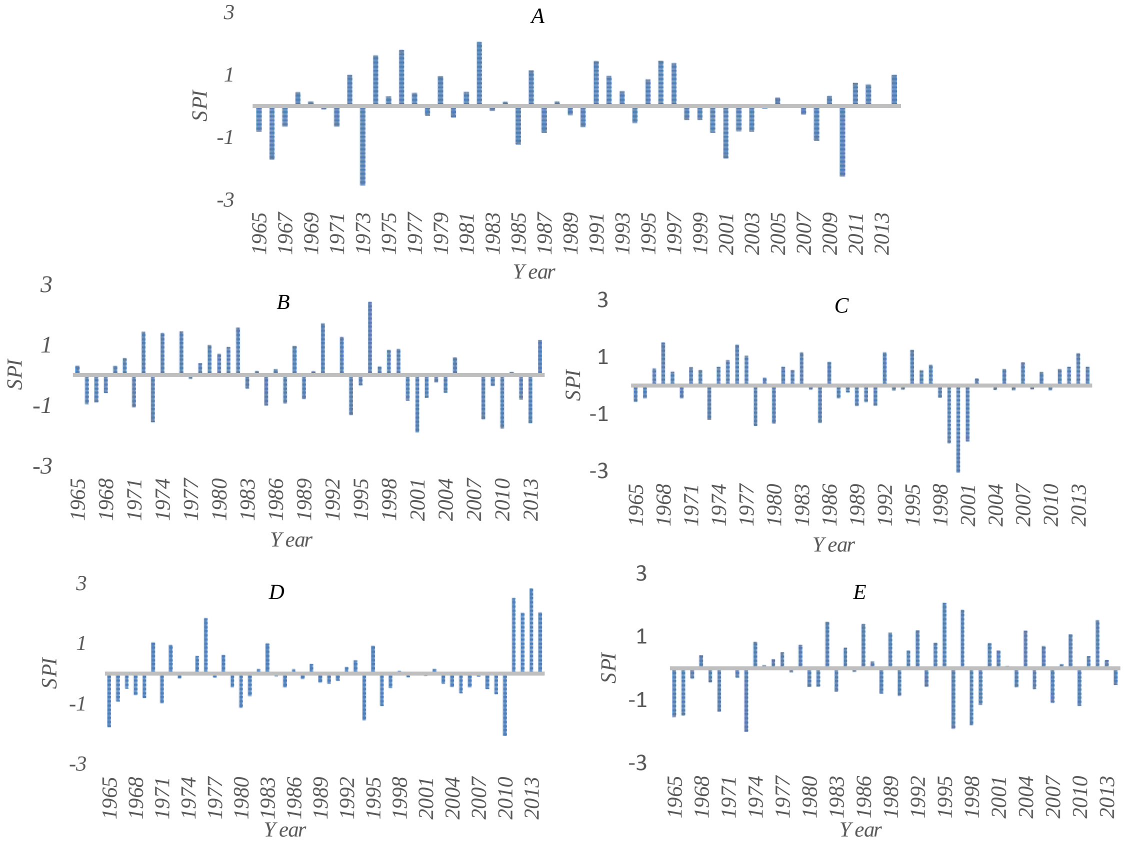

Fig. 9. Seasonal and annual SPI index in dry region of Iran, territory A: yearly SPI, B: Seasonal SPI (Winter), C: seasonal SPI (Spring), D: seasonal SPI (Summer), E: seasonal SPI (Autumn)

The application of Mann-Kendall and Theil sen estimator on SPI in yearly and seasonal time series in dry regions depicted that no trends existed with a significance level of less than 0.1 and no obvious trends were detected in this climate region. In Mediterranean climate region, the yearly SPI showed that 2008 and 2014 were dry while 1969 was extremely wet. The seasonal SPI also implied that 2008 was extremely dry whereas 1969 and 1980 were very wet in winter. 1989 and 2008 were extremely dry while 1972 and 1978 were very wet in spring. Regarding summer, 2010, 2006, and 1971 were extremely dry while 1981, 1970, 1999, 1974, 2009, and 1973 were very wet. 1998 was extremely dry whereas 1867 and 1969 were extremely wet in autumn.

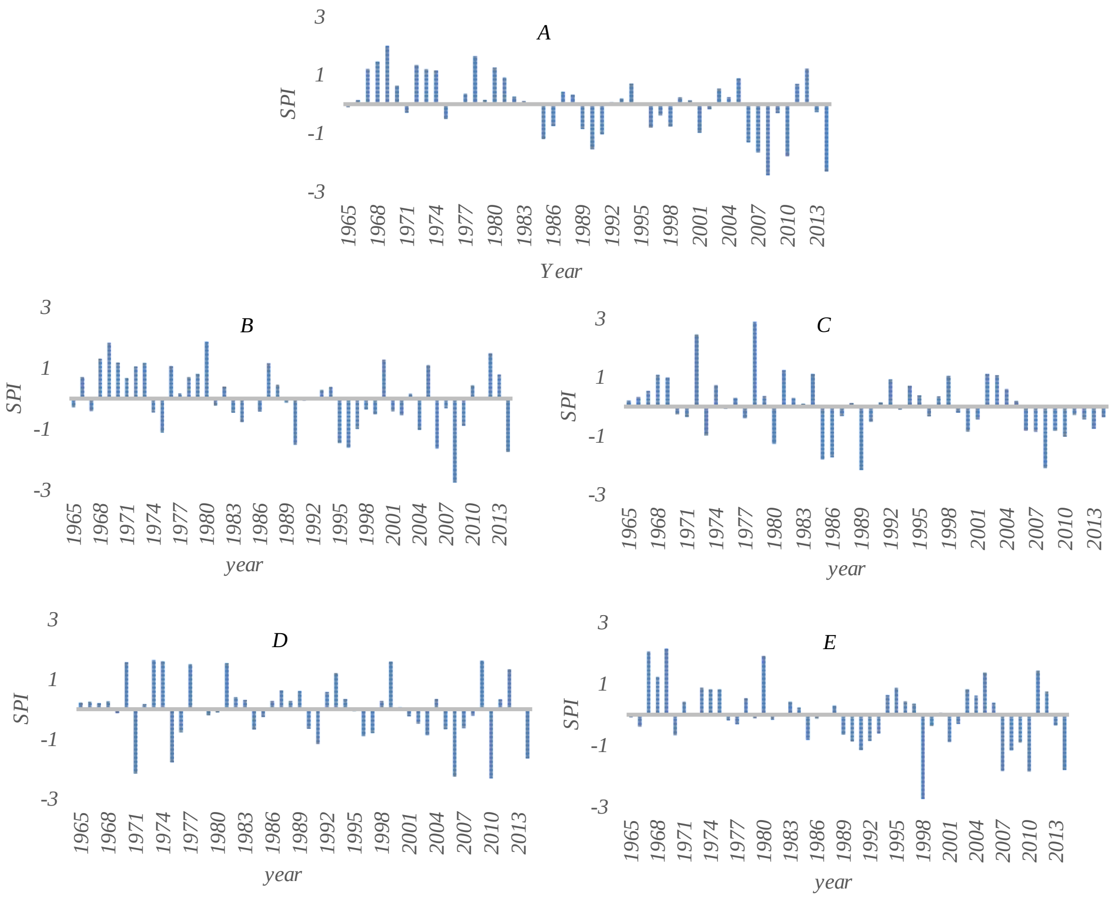

Fig. 10. Seasonal and annual SPI index in Mediterranean climate region of Iran, A: yearly SPI, B: Seasonal SPI (winter), C: seasonal SPI (spring), D: seasonal SPI (summer), E: seasonal SPI (autumn)

The application of Mann-Kendall and Theil sen estimators on SPI in yearly and seasonal time series in Mediterranean climate region revealed that winter, spring, autumn and yearly SPI had a meaningfully decreasing trend.

Table 4. Value of statistics Z of the Mann–Kendall test and value of statistics Q of the Sen Slope for seasonal and annual SPI in Mediterranean climate region (1965-2014)

Time series	Test Z	Significance level	Q	$Qmin_{95}$	$Qmax_{95}$	B	$Bmin_{95}$	$Bmax_{95}$
Winter	-2.59	0.010	-0.029	-0.049	-0.007	1.30	2.24	0.27
Spring	-2.30	0.050	-0.020	-0.040	-0.003	0.89	1.78	0.10
Autumn	-2.16	0.050	-0.022	-0.045	-0.002	0.93	1.99	0.04
Yearly	-3.25	0.010	-0.036	-0.055	-0.015	1.67	2.43	0.75

In very wet climate regions, the yearly SPI showed that 2010 and 2014 were extremely dry while 1992 and 2011 were very wet. The seasonal SPI in this climate region also indicated that in winter, 1981, 1995, 1987, and 2001 were severely dry and 1992 and 1982 were extremely wet. Concerning spring, 1989 and 1985 were extremely dry while 2004 was extremely wet. 1997, 1989, and 1981 were very wet whereas 1971 and 2014 were extremely dry in summer. In autumn, 2010 and 1998 were extremely dry while 2002 was extremely wet.

The application of Mann-Kendall and Theil sen estimator on SPI in yearly and seasonal time series in very wet climate region also showed that there were no trends with a significance level of less than 0.1 and no obvious trends in this climate region.

The minimum and maximum SPI (-3.86, 2.89) were observed to appear in spring (3months) in dry and Mediterranean climate region. Maximum continuous negative SPI (12 month) appeared in 1999-2004 for a duration of 6 years in dry regions and the maximum continuous positive SPI (12 month) appeared in 1974-1982 for a duration of 8 years. The maximum continuous negative SPI (3 month) was found in summer (moderately dry region) in 1977-1985 and spring (Mediterranean) in 2006 - 2014 for a period of 9 years.

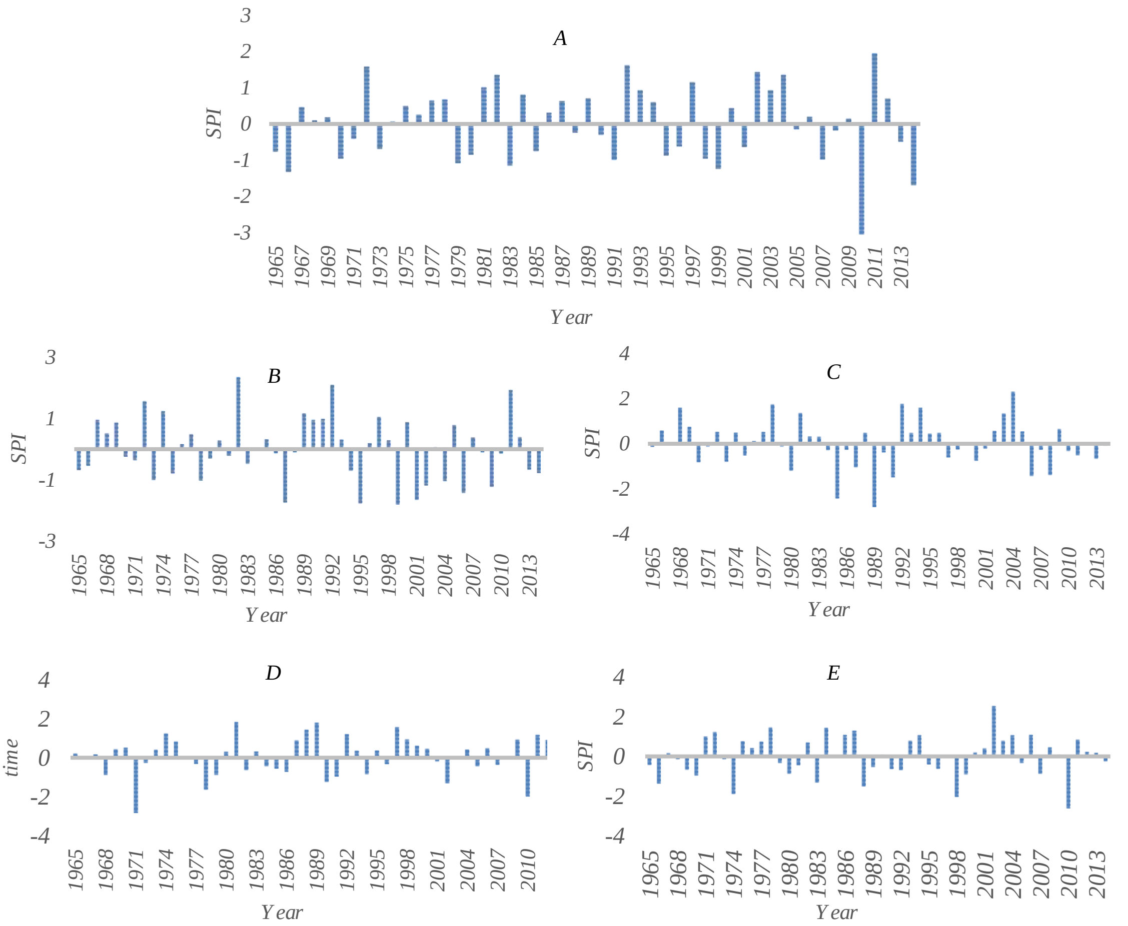

Fig. 11. Seasonal and annual SPI index in very wet climate region of Iran, A: yearly SPI, B: Seasonal SPI (Winter), C: seasonal SPI (Spring), D: seasonal SPI (Summer), E: seasonal SPI (Autumn)

5. Conclusion

In the current research, we analyses the severity and extent of droughts in Iran for duration of 1965 - 2014 using SPI indices based on the selected 26 synoptic stations which have the longest records of metrological data available in Iran. The climate of each station was defined employing Dermatome climate classification. Based on Dermatome climate classification method, the area coverage of different types of climate in Iran is as follows: 56.2% dry, 6.5% Mediterranean, 34.16% moderately dry, 3.1% very wet. SPI indices output shows that the SPI values in Iran ranged from 3.86 to +2.89. The maximum continuous negative SPI (12 month) was observed in 1999-2004 for a duration of 6 years in the dry region and the maximum continuous positive SPI (12 month) appeared in 1974-1982 for a duration of 8 years. The maximum continuous negative SPI (3 month) appeared in summer (moderately dry region) of 1977-1985 and spring (Mediterranean) of 2006 - 2014 for a duration of 9 years. Afterwards, utilizing Mann-Kendall and Theil –Sen estimators, trend analysis on drought severity indices (SPI) was investigated in the yearly and seasonal cross sections. The results associated with this stage implied that based on yearly and seasonal time series in moderately dry regions, winter and yearly SPI have a meaningful decreasing trend. In dry and very wet climate regions, no obvious trends were detected for neither yearly nor seasonal SPI indices. In the Mediterranean climate region, winter, spring, autumn, and yearly SPI depicted a meaningfully decreasing trend. Furthermore, Theil Sen estimator and Mann-Kendall trend analysis indicated that 9 stations (30.6% of the total Iranian territory) have a significantly decreasing SPI trend.

Table 5. Drought SPI indices limit and drought duration

region	time series	MNS	Duration	MPS	Duration	minimum SPI	Maximum SPI
Whole Iran	yearly	6	1998-2003	8	1974-1982	-2.6	1.9
	Winter	5	1983-1987	5	1978-1982	-2.16	2.02
	Spring	5	1987-1991	5	1993-1997	-2.47	1.85
	Summer	3	2006-2008	3	1972-1974	-2.58	1.87
	Autumn	2	1965-1966	6	1974-1979	-2.82	1.51
dry	Yearly	7	1999-2004	4	1974-1977	-2.55	2.04
	Winter	5	2000-2004	5	1978-1982	-1.9	2.41
	Spring	5	1987-1991	4	1974-1977	-3.86	1.5
	Summer	5	1965-1969	4	2011-2014	-2.08	2.82
	Autumn	5	1969-1973	4	1974-1977	-2.01	2.07
moderately dry	Yearly	3	1997-1999	4	1991-1994	-2.24	1.94
	Winter	7	2008-2014	5	2003-2007	-2.26	1.84
	Spring	3	1999-2001	3	2009-2011	-2.31	1.68
	Summer	9	1977-1985	6	1971-1976	-3.18	2.21
	Autumn	3	1979-1981	4	1984-1987	-2.26	1.9
very wet	Yearly	2	2013-2014	5	1974-1978	-3.23	1.94
	Winter	3	2008-2010	5	1989-1993	-1.81	2.34
	Spring	5	2010-2014	5	1992-1996	-2.81	2.3
	Summer	2	2007-2008	4	1973-1976	-2.84	1.81
	Autumn	2	1995-1996	4	1975-1978	-2.61	2.53
Mediterranean	Yearly	5	2006-2010	7	1976-1983	-2.44	2
	Winter	4	1989-1992	5	1969-1973	-2.75	1.85
	Spring	9	2006-2014	5	1965-1969	-2.16	2.89
	Summer	3	2006-2008	4	1986-1989	-2.31	1.64
	Autumn	4	1990-1993	4	1994-1997	-2.75	2.14

MNS=maximum negative SPI duration, MPS=maximum positive SPI duration, Yearly=12 month

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