Investigating the Trends of Drought Severity Changes in Iran

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Abstract

Nowadays, competing for having access to water resources has become a worldwide problem. This problem would impose new challengeable dimensions to the most of the world regions especially Middle East countries in the near future. In recent years, mostly due to world climatic changes, precipitation anomalies have been increased in various areas of Iran. Additionally, extreme spatial and temporal drought fluctuations have imposed enormous expenses on this country`s economy, especially during recent decades. This study aimed at investigating the trends of drought severity changes in Iran through two seasonal and annual temporal scales. To this end, monthly precipitation data of 63 synoptic stations during 30 years of statistical period (1986-2016) were obtained from Iranian meteorological organization. Using monthly precipitation data, stations` seasonal and annual precipitation were assumed. To recognize the various drought degrees` frequency, Standard Precipitation Index (SPI) was utilized. Moreover, to detect the trends of drought severity changes, Sen`s Slope Estimator Non-Parametric Method was used. The results of the current study indicated that the trends of drought severity changes in Iran had excessively varied across one season to the other, and from one temporal scale to the other. In autumn, the trend of drought severity changes in Iran had increased except for south and southern-east parts of Caspian Sea and it decreased during winter and spring. In other words, the drought severity of Iran had increased in autumn and it had decreased in winter and spring. Regarding annual scale, the trends of drought severity changes signified a reducing process for the most of Iranian areas.

Keywords: Natural Disaster, Standardized Precipitation Index (SPI), Sen's Slope Estimator, Trend, Iran

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Introduction

Any unexpected natural event that undermines and destroys the economic, social, and physical capabilities of a community is defined as "Natural Disasters". Examples of such disasters include earthquakes, floods, droughts, sewage, volcanoes, storms, and natural pests (Farajzadeh, 2005). The drought phenomenon, which is said to be a shortage of precipitation in a long period of time, is one of the most important natural disasters due to its spatial distribution and short-term, long-term economic, social and environmental consequences (Mahmoudi et al., 2015).

The vast country of Iran with one-third of global precipitation is located in one of the arid and semi-arid regions of the world, and drought is one of the main attributes of its climate (Kardavni, 2012). The average precipitation of Iran is about 250 mm; about 61 mm of this precipitation becomes a runoff. Approximately 175 mm of precipitation is evacuated to the atmosphere through evapotranspiration, and only about 14 mm of precipitation penetrates into the earth, which is the main source of supplying a large portion of Iran's water as underground reserves (Rigi, 2014). In recent years, due to reasons often associated with global climate change, precipitation anomalies have increased in different parts of the country and severe spatial and temporal fluctuations in drought have caused significant damage to the economy of Iran, especially during recent decades. Reducing the yield of rangelands, reducing crop production, especially dryland, reducing agricultural and drinking water supplies, reducing surface water and underground resources, flooding pests and diseases of plants and animals, increasing migration and, ultimately, bad effects of environmental, economic and social are the negative effects of droughts which threatens Iran's sustainable development. Therefore, determining the characteristics of drought or wet years in a region is one of the basic needs of environmental and economic planners, especially water resource planners. In many water resource management programs, it is necessary to outline the future status of the precipitation and the wet and dry spells for the study area (Fatemi and Karami, 2011).

The droughts variability in triple time periods is indicated by the trend, oscillation, and fluctuation. Trends describe the long-term behavior of the time series, and fluctuation expresses unique and unrepeatable behaviors. But the distinctive aspect of the oscillation is its repetitive pattern. In this case, the climate system, after a long time, makes the configuration "similar" to the previous pattern with a slight different (Daneshmand and Mahmoudi, 2018).

Many studies have looked at trend changes in the severity of droughts in different parts of the world, which can be divided into two categories. The group that claims the frequency of droughts has increased since the late twentieth century (Meshcherskaya and Blazhevich, 1997; Dai and Trenberth, 1998; Min et al., 2003; Piccarreta et al., 2004; Khazanedari et al., 2009; Moafi Madani et al., 2012; Salehnia et al., 2013), and those who claim to have reduced the frequency of droughts in parts of the world (Pandey and Ramasastri, 2001). In Iran, various studies have also studied trends in the severity, duration, and frequency of droughts (Moradi et al., 2007; Montazeri and Ghayoor, 2010; Zareabyaneh et al., 2011; Maleknejad and Soleimani Motlaq, 2012; Keshavarz et al., 2013; Aziz Zade and Javan, 2013; Hasani et al., 2013). However, due to their wide variation in using various indicators of drought, many variations in using different time scales and the their limited study area to a basin, a province or, ultimately, a region of Iran, uniform results of the state of change in the severity of drought in Iran have not been achieved. Daneshmand and Mahmoudi (2016) with spectral analysis of time series obtained from effective drought index (EDI) for 41 stations studied have revealed the detection of periodic droughts in Iran. The results of the study showed that the prevailing periods in time series of the Iranian drought are very diverse and ranged from 2 years to 30 years. In another study, they also showed that the severity of the emergence of Iran's wet years is decreasing and the severity of its droughts is increasing. In addition, they explicitly demonstrated that the likelihood of the occurrence of droughts in Iran is increasing, that is, the period of returning droughts is getting shorter compared to the past (Daneshmand and Mahmoudi, 2018; Mahmoudi and Daneshmand, 2018).

Therefore, in this study, according to the available research background, it is planned to consider the trend of changes in Iran's drought severity in two annual and seasonal scales in a comprehensive study.

Materials and methods

Due to the fact that the occurrence of drought is a rare natural phenomenon, like other climate studies, long-term statistics are needed for analysis. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). therefore, in this study, monthly precipitation data of 63 meteorological stations were used during a 30 year period (1986-2016) that was received from Iran Meteorological Organization. Data from seasonal precipitation and annual precipitation were derived from monthly precipitation data. The distribution of the stations studied is shown in Figure 1.

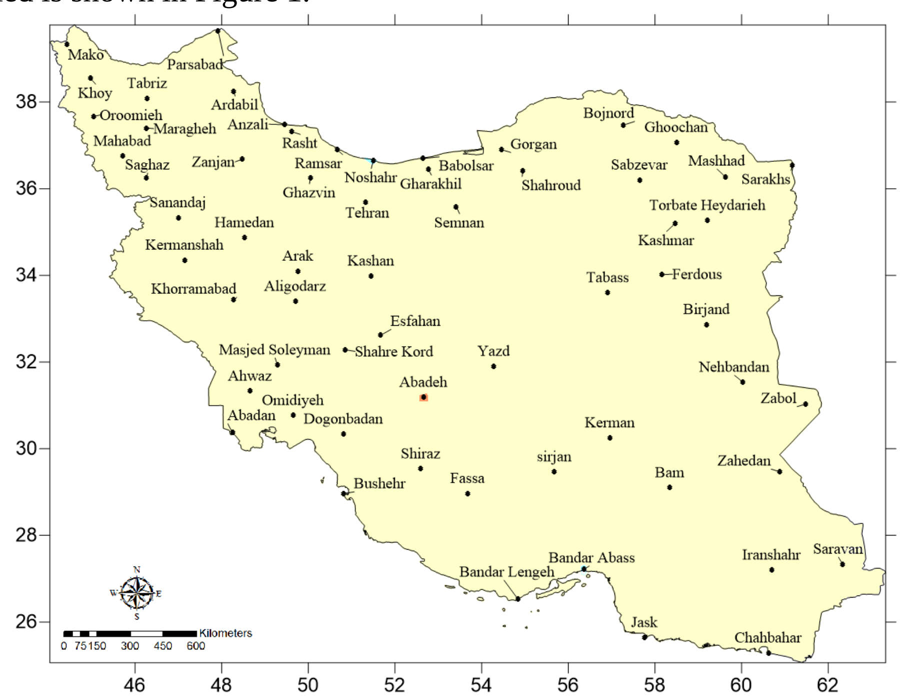

Figure 1: Spatial distribution of synoptic stations over Studied regions

After the formation of the database needed to identify the frequency of different classes of drought in Iran, the standardized precipitation index (SPI) was used in seasonal and annual time scales. This index was provided by McKee et al. (1993, 1995) and widely used globally. This index is based only on the precipitation parameter and is a suitable tool for identifying drought phenomena in different regions. The computational steps of this index are fully presented in the study of Negaresh et al. (2010). Further, after computing the standardized precipitation index (SPI) for all stations studied in two seasonal and annual time scales, the Sen's slope estimator was used to study the trend of drought severity changes.

This method was originally developed by Thiel in 1950 and was then extended by Sen in 1968. Like many other nonparametric methods including Mann-Kendall, this method is also based on analyzing the difference between observations of a time series. This method can be used when the trend in the time series appears to be linear. This implies that $f(t)$ in Equation 1:

$$f(t)=Qt+B \quad (1)$$

Where Q denotes the trend line slope and B is constant.

In order to calculate the trend line slope, Q, the slope between each pair of observational data should be firstly calculated using Equation 2:

$$Q_i=\frac{x_j-x_k}{j-k} \quad (2)$$

Where $j>k$. Here, in this equation, x_j and x_k denote observational data at times of j and k, respectively. Using this equation, a slope is obtained for each pair of observational data. A time series is calculated from the slopes when they are placed next to each other. This implies that if there is a N in the time series (n = 30), then we will have $N=n(n-1)/2$ which will estimate the slope Q_i.

Next, the median of studied time series should be calculated. To do this, N of Q_i should be arranged from small to large and then the median of the time series is determined using one of the following equations. If the number of time series observations is odd, equation 3 is used and equation 3 for even number:

$$Q=Q_{[(N+1)/2]} \quad (3)$$

$$Q=\frac{1}{2}\left[Q_{[N/2]}+Q_{[(N+2)/2]}\right] \quad (4)$$

As a result, the trend line slope Q_{med} is calculated. If the trend of line slope is positive, it represents an increasing trend and a negative slope a decreasing trend.

Then, the slope obtained is tested at a confidence interval of α= 0.05. The following is used to perform this test:

$$C_a=Z_{1-\alpha/2}\sqrt{VAR(S)} \quad (5)$$

Where Z refers to the standard normal distribution statistic in a two-way test which $Z = 1.96$ for confidence level of α= 0.05 and $VAR(S)$ also refers to the parameter variance. To calculate the parameter value S as well as $VAR(S)$, the following steps should be followed:

Calculating the difference between individual series sentences with each other and applying the sign function and extracting the parameter S

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sgn}(x_j - x_k) \tag{6}$$

Where n denotes the number of series observations (30 years), x_j and x_k also denote the data of j and k series, respectively.

The sign function is calculated as follows:

$$\mathrm{sgn}(x) = \begin{cases} +1 & if \quad (x_j - x_k) > 0 \\ 0 & if \quad (x_j - x_k) = 0 \\ -1 & if \quad (x_j - x_k) < 0 \end{cases} \tag{7}$$

Calculating the variance S by one of the following relationships. If the number of series data is greater than 10, Equation 8 can be used and if it is smaller than 10, the equation 9 is used.

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t(t-1)(2t+5)}{18} \tag{8}$$

$$VAR(S) = \frac{n(n-1)(2n+5)}{18} \tag{9}$$

Where n refers to the number of observational data, m refers the number of series with at least one duplicate data, and t denotes the frequency of the same valuable data also.

Finally, the lower and upper limits of the confidence interval are calculated using the following equations:

$$\begin{cases} M_1 = \dfrac{n' + C_a}{2} \\ M_2 = \dfrac{n' - C_a}{2} \end{cases} \tag{10}$$

Where n' denotes the number of slopes obtained by Eq. 8.

Now we extract the M_1th and the M_2 +1th of slopes among the calculated slopes. If the zero ranges between the two extracted slopes above, the H_0 is accepted and the lack of trend in the data series is confirmed. Otherwise, the H_0 is rejected and the trend is accepted at the confidence level. Finally, in order to obtain the B value in equation (1), N number of differences $x_i - Qt_i$ is calculated. Then the median values give an estimate of B (Alijani et al. 2011).

Discussion

Initially, the seasonal and annual precipitation of all stations studied using the standardized precipitation index (SPI) converts to quantitative values of this index and the frequency of each of the different classes of droughts was determined based on five categories: no drought, normal, moderate drought, severe drought, and extreme drought. Spatial distribution of three classes of moderate, severe and extreme drought indicates that throughout the whole range of Iran during the thirty years studied, 4 to 9 droughts with different classes have experienced, but there is no clear spatial pattern for the frequency of these droughts on an annual scale for Iran. The reason for the absence of a specific spatial pattern could be due to the wide, complex topography and turbulence of Iran's precipitation in two dimensions of time and space. In total, during the 30 study years (1986-2016), two Arak and Anzali stations with 9 times drought experience had the highest frequency, and the Abadan, Qazvin, Caravan, Semnan and Zahedan stations with 4 times drought experience were the least frequent (Figure 2).

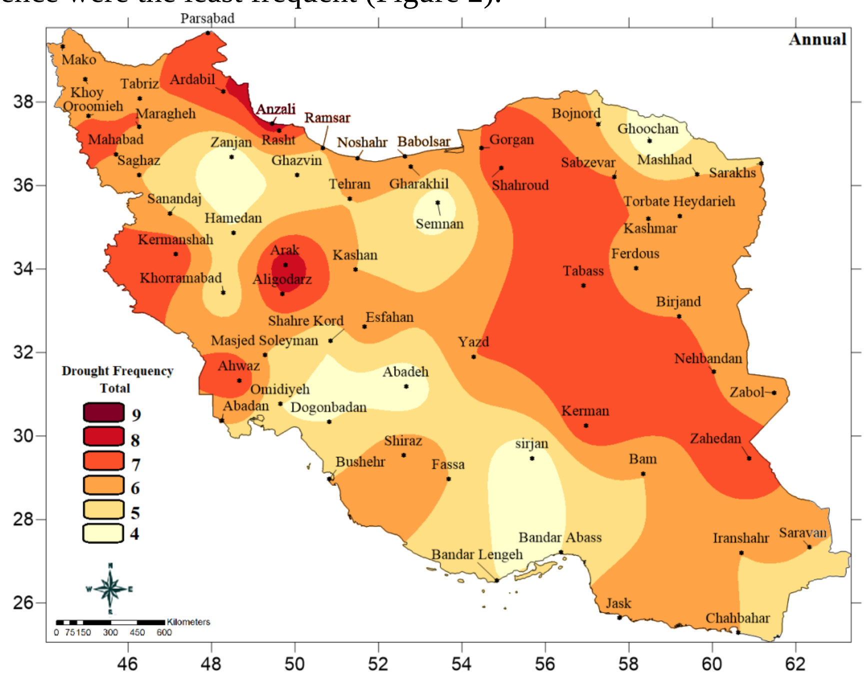

Figure 2. Spatial distribution of the sum-frequency of three classes of moderate, severe and extreme droughts for the period 1983-2013 in Iran

Spatial distribution of the sum-frequency of different classes of drought in Iran on a seasonal scale indicates different spatial patterns for this scale from droughts. In the fall season, the highest and lowest frequency of droughts has been concentrated in the southeast and center of Iran, respectively. Chabahar station with 17 times and Ahvaz station with 1 time are largest and lowest values, respectively. The reason for this frequency in the southeast of Iran is related to the precipitation regime of this region, which is a winter precipitation regime. In the autumn, precipitation has not been found at all in this area for many years (its diagrams have not been provided). But in winter, when most of Iran's area has a winter precipitation regime, the spatial distribution pattern of droughts in Iran changes, which the highest frequency of droughts is observed in the west, northwest, and northeast, and the least frequency, is observed in the south and center of Iran. In the spring, the highest frequency of droughts belonged to the northwest of Iran in Mako and Ardabil with 8 cases and the lowest frequency of droughts belonged to four stations of Bam, Fassa, Iranshahr, and Sirjan in the southern half of Iran with 1 case.

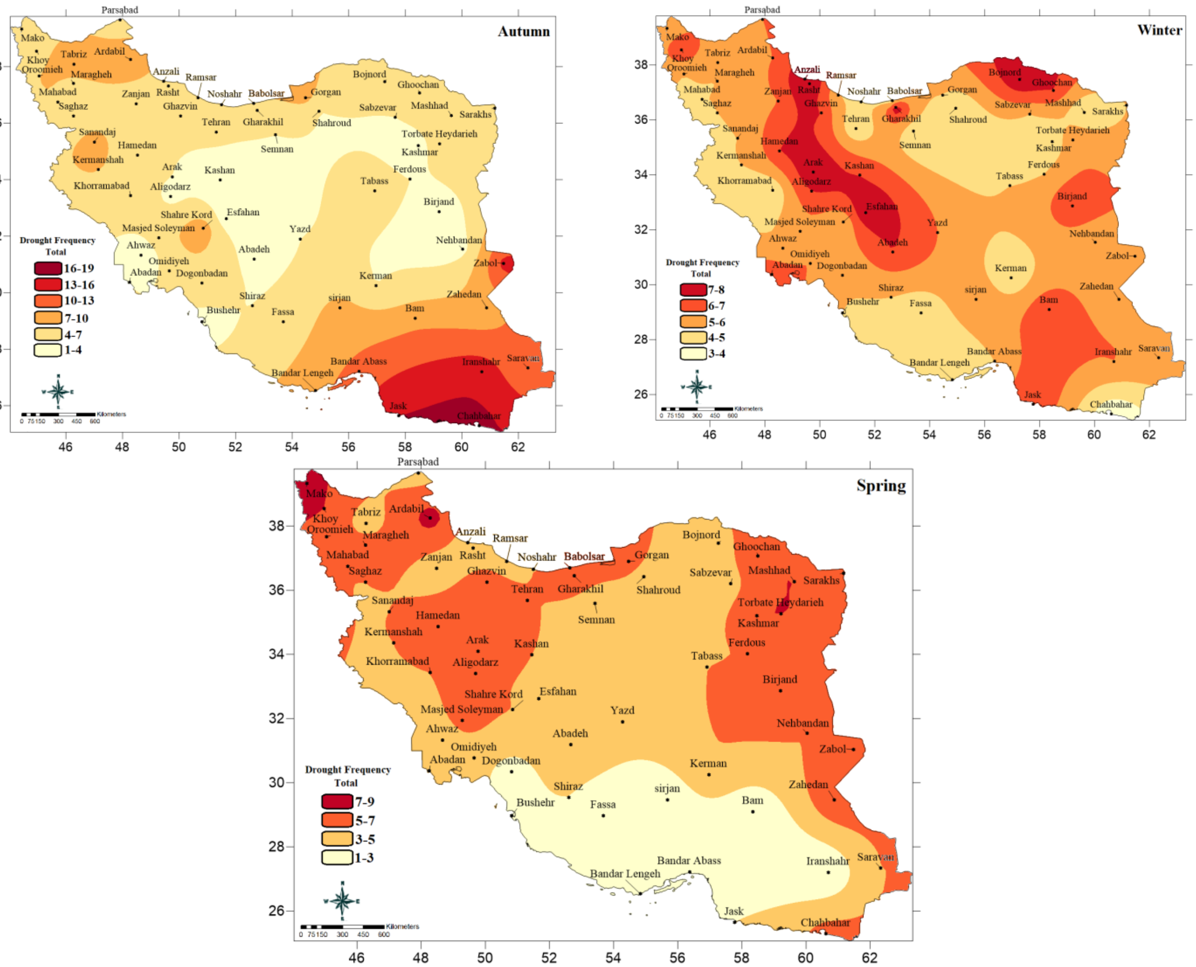

Figure 3. Spatial distribution of total frequency of three classes of moderate, severe and extreme drought, top left: autumn, top right: winter and down: spring season for the period 1983-2013

The trend of changes of Iran's drought severity in two annual and seasonal scales was evaluated by Sen’s slope estimator for all stations. Results of slope values of the annual drought variations for all 63 stations were studied. In this map, blue and yellow colors are assigned as declining and increasing trend, respectively. The significance of the slope of the changing trend is also indicated by circles in three colors. Stations, where the trend of their changes was significant at the probability level of $\alpha = 0.1$, have been marked black circle, those that were significant at probability level of $\alpha = 0.05$, have been marked brown circle and eventually, stations whose trend has been meaningful at the probability level of $\alpha = 0.01$, are marked with a red circle (from now on, to provide more uniform analysis, all the maps drawn from this template follow). As can be seen from Figure 4, only eight stations distributed in the Iranian region have an increasing trend in the severity of droughts, and in none of the three probabilistic levels, the significance of their trend has not been confirmed, but apart from these eight stations, all the remaining stations of the trend changes of the severity of their droughts have been declined. Of these stations, the trend of only 20 stations has been significant at different levels of probability, most concentrated in the northeast, southwest, northwest, and south (Figure 4). Table 1 show the characteristics of all stations where their trend is meaningful.

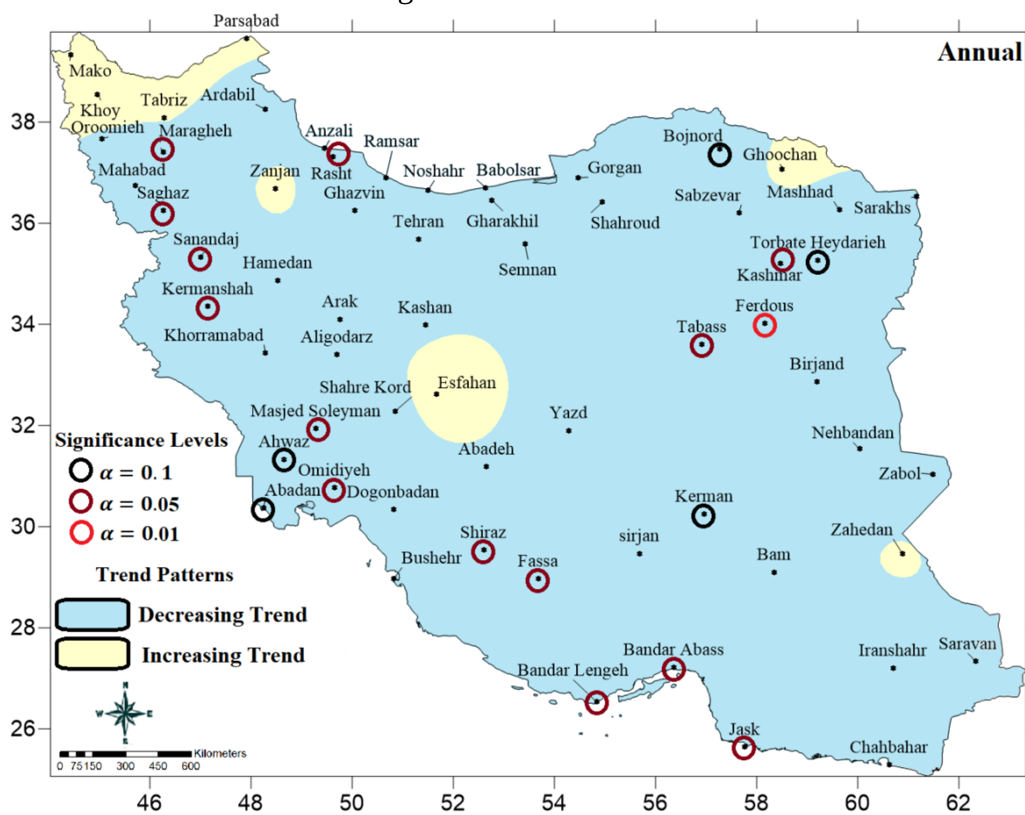

Figure 4. Trend slope estimates for the severity of droughts at an annual scale with their significant level during 1986-2016

Table 1. Statistical characteristics of the change trend the drought severity at an annual scale for stations with a significant statistical trend

Station Name	Trend Slope Values	Significance Levels	Station Name	Trend Slope Values	Significance Levels
Ahwaz	-0.035	0.1	**Maragheh**	-0.047	0.05
Kerman	-0.035	0.1	**Jask**	-0.047	0.05
T. Heydarieh	-0.036	0.1	**Rasht**	-0.047	0.05
Bojnord	-0.041	0.1	**Kashmar**	-0.047	0.05
Abadan	-0.047	0.1	**Omidyeh**	-0.047	0.05
Sanandaj	-0.040	0.05	**B. Abass**	-0.048	0.05
Saghez	-0.041	0.05	**M. Soleyman**	-0.049	0.05
B. Lengeh	-0.043	0.05	**Tabass**	-0.050	0.05
Kermanshah	-0.044	0.05	**shiraz**	-0.052	0.05
Fassa	-0.045	0.05	**Ferdous**	-0.069	0.01

The trend of changes in the severity of droughts at a seasonal scale was the next step in the analysis, which was considered. In the fall season, the pattern of change is much different than the pattern of annual change. In this season, except for the southeast and southern shores of the Caspian Sea, whose trend has been decreasing, the rest of Iran has experienced an increase in the trend of their drought severity (Figure 5). But all these trends have not been meaningful at the defined levels of probability. Stations with a decreasing trend have not confirmed their significance at any level of probability. However, 11 stations with an increasing trend, the significance of the trend of changes were confirmed at two probabilistic levels of α = 0.1 and α = 0.05. An interesting point in this regard is how the spatial arrangement of stations with a significant trend has been taken central Iran to form an incomplete ring (Figure 5). In Table 2, the names of stations with a significant trend and the slope rate of change are presented.

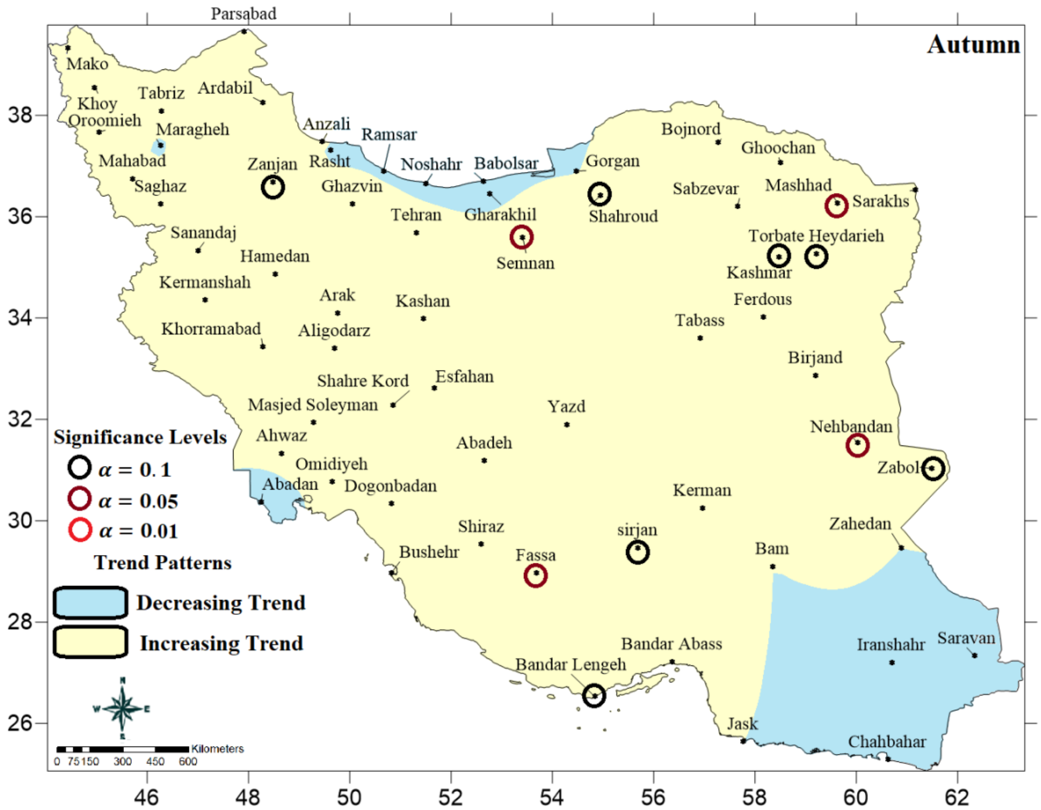

Figure 5. The trend slope of variations in the severity of droughts in Iran in autumn with their significant level for the period 1986-2016.

Table 2. Statistical characteristics of the variation trend of the severity of droughts in autumn for stations with a significant statistical trend

Station Name	Trend Slope Values	Significance Levels	Station Name	Trend Slope Values	Significance Levels
Zabol	0.009	0.1	**Shahroud**	0.045	0.1
Sirjan	0.016	0.1	**Nehbandan**	0.026	0.05
B. Lengeh	0.026	0.1	**Fassa**	0.026	0.05
Kashmar	0.031	0.1	**Semnan**	0.046	0.05
T. Haydarieh	0.035	0.1	**Mashhad**	0.054	0.05
Zanjan	0.045	0.1			

Considering that Iran's precipitation regime, with the exception of the southern shores of the Caspian Sea, is a winter-spring precipitation regime, the trend of changes in the severity of droughts in this season can play an important role in water resource management in Iran. The spatial pattern of the trend of changes in the severity of droughts in this season is very similar to the pattern of the trend of changes in the severity of annual droughts. This similarity can be attributed to the high precipitation of winter in total annual precipitation in Iran. With the exception of several stations (Zahedan, Semnan, Sarakhs, Gorgan, Noshahr, and Pars Abad), which do not show a certain spatial arrangement and are scattered throughout Iran, most stations have shown a decreasing trend in the severity of droughts (Figure 6). According to Figure 6, the apparent spatial arrangement is clearly observed at stations where their trend has been significant at various levels of probability. This particular spatial arrangement was not very noticeable in other seasons. Stations in northeastern Iran and along the Zagros Mountains (with northwest-southeast direction) are stations whose declining trend has been confirmed at various levels of probability. Stations in the southeast, central Iran and the southern shores of the Caspian Sea have been declining their trend, but their significance has not been confirmed at any level (Figure 6). Table 3 lists the names of stations with significant trends and their trend slope.

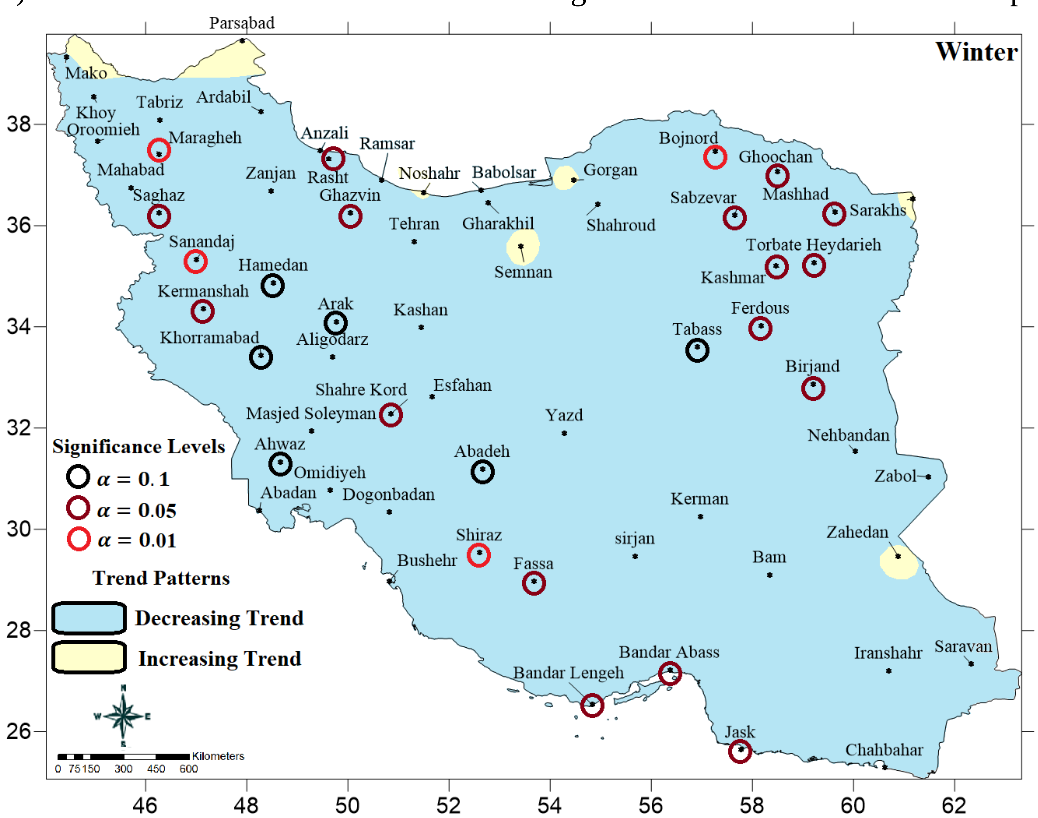

Figure 6. Map of the trend slope of changes in the severity of droughts in winter with their significant level for the period 1986-2016.

Table 3. Statistical characteristics of the trend of the variation of the severity of droughts in winter for stations with a significant statistical trend

Station Name	Trend Slope Values	Significance Levels	Station Name	Trend Slope Values	Significance Levels
Abadan	-0.037	0.1	**Mashhad**	-0.045	0.05
Tabass	-0.040	0.1	**Fassa**	-0.047	0.05
Hamedan	-0.041	0.1	**T. Haydarieh**	-0.047	0.05
Khorramabad	-0.041	0.1	**Ferdous**	-0.048	0.05
Ahwaz	-0.043	0.1	**Birjand**	-0.048	0.05
Arak	-0.044	0.1	**B. Abass**	-0.050	0.05
Saghez	-0.036	0.05	**B. Lengeh**	-0.052	0.05
Kermanshah	-0.038	0.05	**Ghazvin**	-0.057	0.05
Sabzevar	-0.038	0.05	**Jask**	-0.058	0.05
Shahre Kord	-0.040	0.05	**Maragheh**	-0.055	0.01
Ghoochan	-0.042	0.05	**Shiraz**	-0.056	0.01
Kashmar	-0.043	0.05	**Bojnord**	-0.060	0.01
Rasht	-0.044	0.05	**Sanandaj**	-0.068	0.01

The spatial pattern of the trend of the changes in the severity of droughts in spring is roughly similar to the annual spatial patterns and winter season (Figure 7). Spring droughts in the 55 studied stations have a negative trend and have an increasing trend in 8 stations. Among these eight stations, the only trend of the Mako station in the northwest has been significant at the probability level of $\alpha = 0.05$. Northwest, southwest, and northeast were the only parts of Iran that some of their stations have a significant decreasing trend (Figure 7). Table 4 shows the statistical characteristics of stations with a significant trend for the spring.

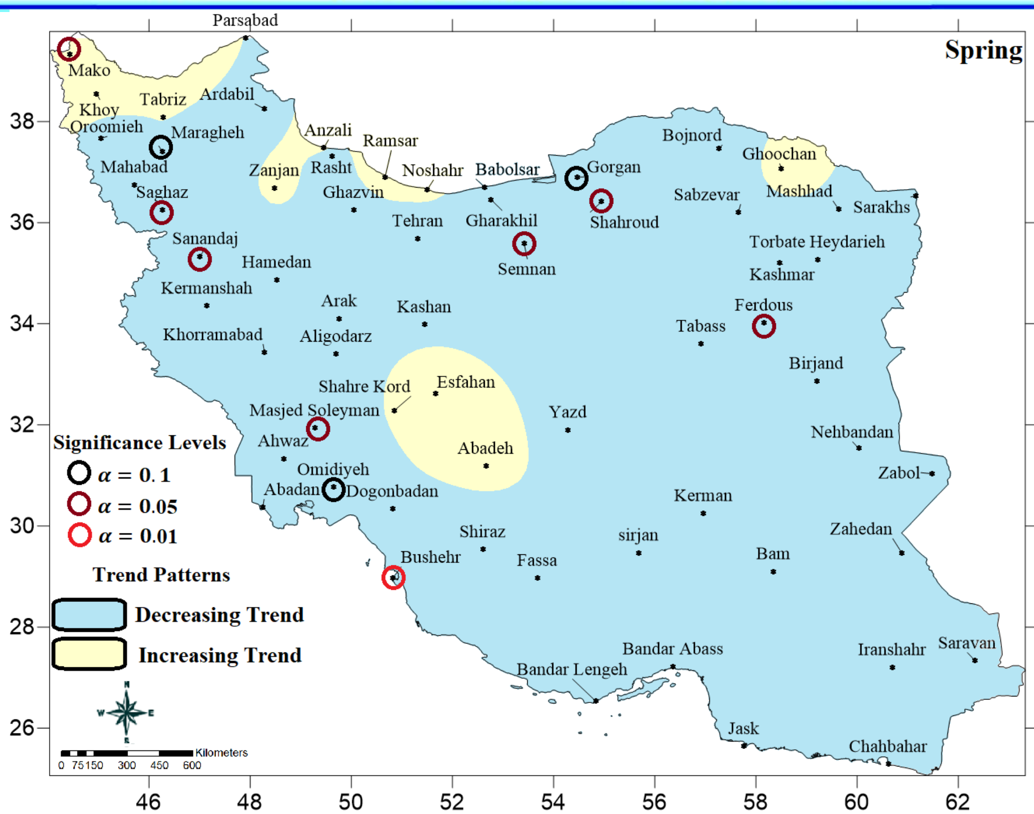

Figure 7. Map of the trend slope of changes in the severity of droughts in Iran in spring with their significant level for the period 1986-2016.

Table 3. Statistical characteristics of the trend of the changes of the severity of droughts in spring for stations with a significant statistical trend

Station Name	Trend Slope Values	Significance Levels	Station Name	Trend Slope Values	Significance Levels
Omidiyeh	-0.031	0.1	**M. Soleyman**	-0.037	0.05
Maragheh	-0.035	0.1	**Saghez**	-0.040	0.05
Gorgan	-0.044	0.1	**Sanandaj**	-0.041	0.05
Mako	0.051	0.05	**Ferdous**	-0.046	0.05
Shahroud	-0.030	0.05	**Bushehr**	-0.043	0.01
Semnan	-0.036	0.05			

Conclusion

Today, competition for the access to water resources has become one of the most important current issues in the world. In the near future, an issue that will capture most of the world's regions, especially the Middle East, will be facing new challenges. The results of this study showed that the trend of changes in the severity of drought in Iran from season to other season and from a time scale to other time scale was very different. In the autumn, the trend of changes in the severity of drought in Iran, with the exception of the south coast of the Caspian Sea and the southeast has been increasing trend and declined in both winter and spring. In other words, in the autumn, the severity of the drought in Iran has been increased and in both winter and spring has decreased. On an annual scale, the trend of changes in the severity of drought has also shown a declining trend for most areas of Iran. So these changes can be the first signs of a change in the pattern of droughts in Iran, which must be taken seriously. As this change surely causes a change in the distribution of water resources in Iran, therefore, changes to the new water resource management scenarios should take place.

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