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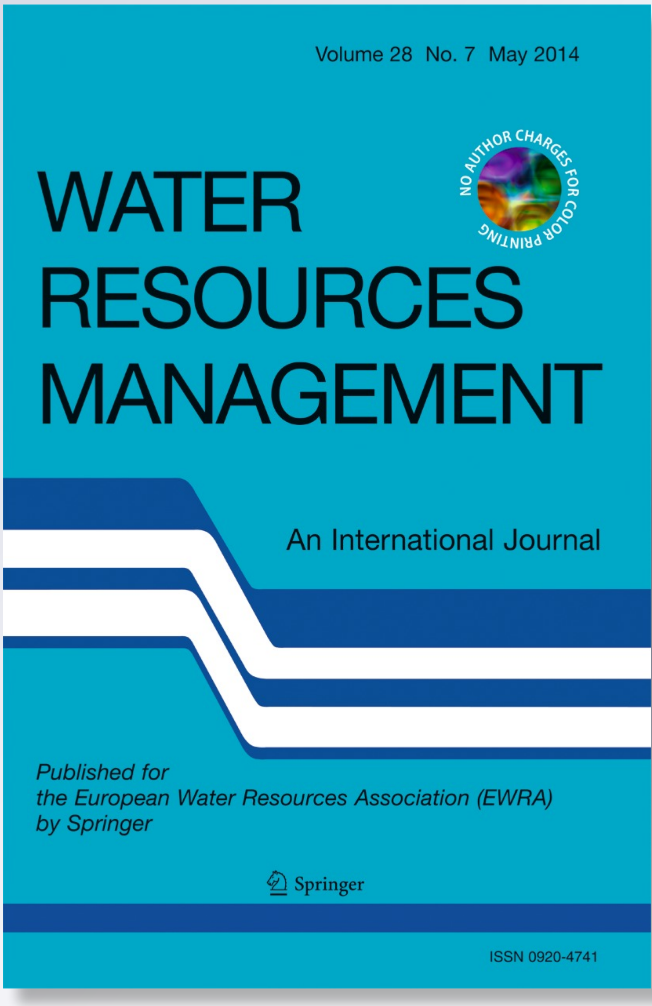

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Trend Detection of Drought in Arid and Semi-Arid Regions of Iran Based on Implementation of Reconnaissance Drought Index (RDI) and Application of Non-Parametrical Statistical Method

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Abstract Drought is known as one of the main natural hazards especially in arid and semi-arid regions where there are considerable issues in regard to water resources management. Also, climate changes has been introduced as a global concern and therefore, under conditions of climate change and global warming, the investigation of drought severity trend in regions such as Iran which is mainly covered by arid and semi-arid climate conditions is in the primary of importance. Therefore, in this study, based on the application of Reconnaissance Drought Index (RDI) for assessment drought severities, and also the implementation of non-parametric Mann- Kendall statistics and Sen's slope estimator, the trends in different time series of RDI (3, 6, 9, 12, 18 and 24 monthly time series) were investigated. 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. Decreasing trend in RDI time series means the increasing trend in drought severities. Since the water resources especially ground water in most cases are affected by long term droughts, therefore, increasing trend in drought intensities in long term ones can be a threat for water resources management in surveyed areas.

Keywords Arid and semi-arid · Drought · Iran · RDI · Trend

1 Introduction

It is anticipated that with increasing in the global temperature and occurring of climate change phenomenon, the temporal and spatial patterns of hydrological parameters such as

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precipitation and evapotranspiration are also changed. The changes in these patterns can be effective on hydrological extremes such as floods or droughts. In terms of droughts, they 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 a natural but temporary imbalance of water availability caused majority by low precipitation and thus resulting in lower availability of water resources (Tsakiris et al. 2013). In fact, it is a departure from the average or normal conditions in which shortage of water adversely impact ecosystem functioning and the resident populations of people. Droughts have been experienced in different severities by wide range of people in different parts of the world. In most cases drought is known as one of the main concerns of managers, decision makers and governments, therefore, considerable attempts have been made by experts, researchers and scientists in order to monitor its severities to be able to present appropriate reactions as drought mitigation activities. These concerns are more considerable in arid and semi-arid regions such as Iran where there are many restrictions in regard to having sufficient water resources. These regions and their fragile ecosystems are more vulnerable to droughts. Not only water scarcity, but also land degradation in Iran basins has become a major issue during the past decades, resulted from soil fertility decrease due to land use change, soil degradation and erosion, overgrazing of rangelands, and groundwater exploitation (Ahani et al. 2013).

In addition to the mentioned problems, climate changes and global warming (IPCC 2007) can appear as a threat to intensify these issues. The researchers in Iran have surveyed climatic parameters in different time series especially temperature (Kousari et al. 2011; Kousari and Asadi Zarch 2011; Tabari et al. 2011), precipitation (Modarres and de Paulo Rodrigues da Silva 2007; Soltani et al. 2012), relative humidity (Kousari et al. 2011; Kousari and Asadi Zarch 2011) and near surface wind speed (Kousari et al. 2013). Especially about temperature, it must be added that some works show increasing trend in average air temperature of Iran especially in central and eastern parts. While, during recent years climate change impacts have been combined with drought effects and caused serious problems in different parts of the world (Dastorani and Afkhami 2011). Such climate changes have a major impact on hydrological cycles and consequently on available water resources, flooding, drought frequencies and natural ecosystems (Raziei et al. 2005). Therefore, the analysis of drought intensities and their trend detection during last decades is an important and essential work which can not be easily underestimated.

Drought severity is conventionally assessed by drought indices (Vangelis et al. 2013). According to Kharraz et al. (2012) in the international publications different indices have been discussed and applied among which are the Percent of Normal, Deciles, Palmer Drought Severity Index (PDSI), Palmer Hydrological, Drought Severity Index (PHDI), Palmer Moisture Anomaly Index (Z-Index), Surface Water Supply Index (SWSI), Standardized Precipitation Index (SPI), Rainfall Anomaly Index (RAI), Reconnaissance Drought Index (RDI), Run Analysis, Crop Moisture Index, Soil Moisture Anomaly Index, Normalized Difference Vegetation Index (NDVI), Water Stress Indicator (WSI) and 'Socio-economic vulnerability to drought' Index. However, Selection of an integrated index for quantifying drought severity is a challenge for decision makers in developing water resources and operation management policies (Karamouz et al. 2009). Consideration to different indices completely depends on situations. In the other words, available data in aspect of quality, quantity and diversity, knowledge of experts, researchers and specialists, importance of subject and accessibility to sufficient hardware and software are the most important factors which determine the optimum option.

Also, it should be noted that every method has its advantages and disadvantages. Sometimes, a simple method can be more effective when there is a limitation of sufficient data availability, than the complex methods. There is no doubt that in the conditions of having more available data, intermediate procedures which consider more parameters to represent drought severities can be considered too. As stated by Vangelis et al. 2013, recently, a powerful drought index, the Reconnaissance Drought Index (RDI), which was first introduced by Tsakiris and colleagues in National Technical University of Athens (Tsakiris et al. 2007a; Tsakiris et al. 2007b; Tsakiris and Vangelis 2005) is gaining wide acceptance mainly in the arid and semiarid climatic regions. RDI (Tsakiris and Vangelis 2005) have been considered by some researchers especially for monitoring drought conditions (Asadi Zarch et al. 2011; Khalili et al. 2011; Kirono et al. 2011; Tsakiris et al. 2011; Tsakiris et al. 2007b). Since this index considers precipitation and potential evapotranspiration, drought trend detection by RDI can reveals important results for researchers and decision makers in Iran and neighboring regions.

In spite of the importance of drought trend detection under conditions of climate changes and global warming, there are a few works in Iran. Bari Abarghouei et al. (2011) surveyed the changes and trend of drought under the current global climate changes, by non-parametric Mann–Kendall statistical test for 42 synoptic stations at different places of Iran. The obtained results have indicated a significant negative trend of SPI time series in many parts of Iran, especially the South-East, West and South-West regions of the country (Bari Abarghouei et al. 2011).

Although, there are many studies for trend analysis in regard to evapotranspiration (Dinpashoh et al. 2011; Eslamian et al. 2011; Kousari and Ahani 2012; Tabari et al. 2011) and precipitation (Ahani et al. 2012; Ahani et al. 2013; Kousari et al. 2011; Modarres and de Paulo Rodrigues da Silva 2007; Tabari and Talaee 2011) as two main components of RDI, there is no study in regard this drought index. Therefore, in this study, the RDI trends in different time series (3, 6, 9, 12, 18 and 24 monthly time series) have been considered.

2 Material and Methods

2.1 Study Area and Relevant Data

Iran, with about 1,648,000 km^2 area, is located in the south west of Asia, approximately between 25°00′N and 38°39′N latitudes and between 44°00′E and 63°25′E longitudes. Generally, Iran is categorized as having arid (BW) and semi-arid (BS) climates based on the Koppen climatic classification (Ahrens 1998). The two main mountain chains in Iran are Alborz and Zagros. Alborz Mountains extends from the north to the west and east Iran, while, Zagros Mountains extends from the northwest to the southern part of Iran (Dinpashoh et al. 2011). These two main mountain chains play effective role in weather conditions of Iran.

In Iran the main source of water is precipitation, which normally amounts to 251 mm or 413 billion cubic meters annually. This precipitation depth is less than one-third of worldwide average precipitation (831 mm) and about one-third of the average precipitation in Asia (732 mm) (Malekinezhad 2009). Annual rainfall ranges from less than 50 mm in the deserts to more than 1,600 mm on some parts of the Caspian Plain. Approximately 90 % of the country is arid or semiarid. Overall, about two-thirds of the country receives less than 250 mm of rainfall per year. More than 50 % of the rain falls in winter and a few amount of precipitation occurs in summer. While 1 % of the world population lives in Iran, our share of renewable freshwater is only 0.36 % (Malekinezhad 2009).

Figure 1 shows Iran's boundaries in addition to the distribution of 25 synoptic stations used in this study. These stations have a good distribution with sufficient length of meteorological data (31 years), which can support drought trend studies spatially and temporally. Table 1 indicates the general characteristic of 25 surveyed stations such as elevation, latitude, longitude, the average of precipitation and the climate zone status in aspect to aridity (Kousari and Ahani 2012).

Since the RDI considers the proportion of precipitation to PET, at first precipitation data were gathered and the PET was computed. The missing data was substituted with the corresponding long-term mean (Dinpashoh et al. 2011). ET0 was estimated using the PM-56 equation (Allen et al. 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma[900/(T+273)]U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,U_2)} \quad (1)$$

Where the ET0 is reference evapotranspiration using the FAO PM-56 method (mm day^{-1}), Rn is the daily net radiation (MJ m^{-2} day^{-1}), G is the daily soil heat flux (MJ m^{-2} day^{-1}), T is the mean daily air temperature at a height of 2 m (°C), U_2 is the daily average wind speed at a height of 2 m (m s^{-1}), e_s is the saturation vapour pressure (kPa), e_a is the real vapour pressure (kPa), Δ is the slope of the saturation vapour pressure versus the air temperature curve (kPa $°C^{-1}$), and γ is the psychrometric constant (kPa °C−1) (Rahimikhoob 2010). In this study according to Rahimikhoob 2010, the daily values of Δ, R_n, e_s, and e_a were calculated using the equations (for albedo, α=0.23 for green vegetation surface) given by Allen et al. (1998). The soil heat flux (G) was accepted to be zero over the calculation time step period (24 h; Allen et al. 1998). The measured relative humidity, T max and T min values were used to calculate e_a and e_s. The daily solar radiation (R_s) was calculated using the Angstrom formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration. Equation 39 in Allen et al. (1998) was used to calculate the net outgoing long-wave radiation (Rahimikhoob 2010). More details in regard to this equation can be found in FAO Irrigation and Drainage Paper 56 by Allen et al. 1998. ET0 values were computed at the monthly time scale for each synoptic station.

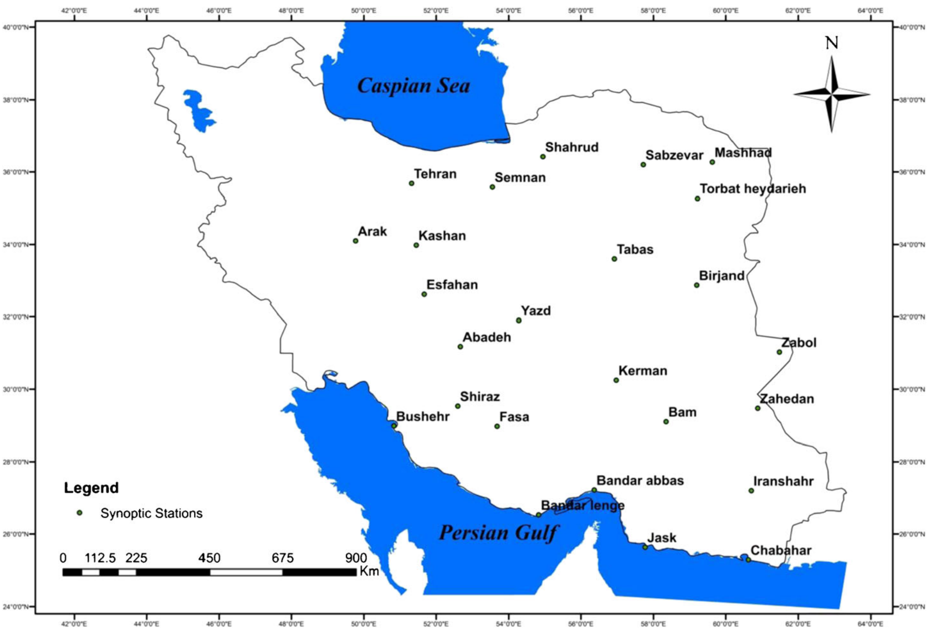

Fig. 1 The spatial distribution of selected synoptic station at Iran

Table 1 General characteristic of surveyed 25 stations

Station name	Elevation from free sea surface level (m)	Average of annual PET (mm)	Average of annual precipitation (mm)	Precipitation (mm)/PET(mm)	Zone
Abadeh	2,030	1,486	143	0.10	Arid
Arak	1,708	1,222	323	0.26	Semi-arid
Bam	1,067	2,040	59	0.03	Hyper-arid
Bandar abbas	98	1,866	153	0.08	Arid
Bandar lenge	23	1,682	206	0.12	Arid
Birjand	1,491	1,691	172	0.10	Arid
Bushehr	196	1,575	277	0.16	Arid
Chabahar	8	1,395	118	0.08	Arid
Esfahan	1,550	1,469	127	0.09	Arid
Fasa	1,288	1,223	317	0.22	Semi-arid
Iranshahr	591	1,768	112	0.05	Arid
Jask	5	1,131	139	0.08	Arid
Kashan	982	1,668	137	0.12	Arid
Kerman	1,753	1,395	142	0.09	Arid
Mashhad	999	1,738	271	0.21	Semi-arid
Sabzevar	978	1,615	205	0.13	Arid
Semnan	1,131	1,309	146	0.11	Arid
Shahrud	1,345	1,274	163	0.13	Arid
Shiraz	1,484	1,641	348	0.21	Semi-arid
Tabas	711	1,639	88	0.05	Arid
Tehran	1,191	1,577	246	0.16	Arid
Torbat heydarieh	1,451	1,356	288	0.21	Semi-arid
Yazd	1,237	1,743	64	0.04	Arid
Zabol	489	2,814	63	0.02	Hyper-arid
Zahedan	1,370	1,870	75	0.04	Arid

2.2 Reconnaissance Drought Index (RDI)

According to Asadi Zarch et al. (2011), Reconnaissance Drought Index (RDI) was characterized as a general meteorological index for the drought assessment. The RDI is considered in three ways: the initial value (α_k), normalized RDI (RDI_n) and standardized RDI (RDI_{st}). The initial value (α_k) is presented in an aggregated form using a monthly time scale and may be calculated on a monthly, seasonal or annual basis. The α_k can be calculated by the following equation:

$$a_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, \mathrm{i} = 1 \text{ to } \mathrm{N} \tag{2}$$

Where P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration within the month "j" of hydrological year "i" that usually starts from October in Iran. Hence, for October K=1 and N were the total number of experimental years.

Equation 2 could be calculated for any period of the year. It could also be recorded starting from any month of the year except October, if necessary. A second expression, the Normalized RDI (RDI_n) was computed using the following equation, in which it is evident that the parameter $\overline{a}_k$ is the arithmetic mean of a_k values.

$$RDI_n^{(i)} = \frac{a_k^{(i)}}{\overline{a}_k} - 1 \tag{3}$$

The initial formulation of RDI_{st} (Tsakiris and Vangelis 2005) used the assumption that α_k values follow the log natural (ln) distribution. So, RDI_{st} was calculated as:

$$RDI_{st(k)}^{(i)} = \frac{y_k^{(i)} - \overline{y}_k}{\widehat{\sigma}_{yk}} \tag{4}$$

In which, y_k is the $\ln(\alpha_k^{(i)})$, $\overline{y}_k$ was the arithmetic mean of y_k and $\widehat{\sigma}_{yk}$ is the standard deviation. Based on an extended research on various data from several locations and different time scales, it was concluded that α_k values follow both the *ln* and the gamma distribution values at almost all locations and time scales. But in most of the cases, the gamma distribution was proved to be more successful.

According to Tsakiris et al. (2008) and also Asadi Zarch et al. (2011) it has been proved that the calculation of RDI_{st} could be performed better by fitting the gamma probability density function (pdf) at the given frequency distribution of α_k, following the procedure described below. Like SPI computation by Gamma approach, this method tends to solve the problem of calculating RDI_{st} for the small time scales, such as monthly, which may include zero-precipitation values (α_k=0), for which Eq. (3) could not be applied (Tsakiris et al. 2008). The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{a-1} e^{-x/\beta} \quad for: x > 0 \tag{5}$$

Where α>0 is a shape factor; β>0, a scale factor and x>0 is the amount of precipitation (Tsakiris et al. 2008). Γ (α) is the gamma function, defined as:

$$\Gamma(\alpha) = \int_0^\infty y^{\alpha-1} e^{-y} dy \tag{6}$$

Fitting of distribution to data requires the estimation of α and β as following:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{7}$$

$$\beta = \frac{\overline{x}}{\alpha} \tag{8}$$

Where

$$A = \ln\left(\overline{x}\right) - \frac{1}{n}\sum_{i=1}^{n} \ln(x_i) \tag{9}$$

For n observations. The resulting parameters were then used to find the cumulative probability of an observed precipitation event for the given month or any other time scale:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \tag{10}$$

Substituting t for $\frac{x}{\beta}$ reduces the Eq. 6 to incomplete gamma function

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-t} dt \tag{11}$$

Since, the gamma function is undefined for $x=0$ and a precipitation distribution may contain zeros, where the cumulative probability becomes:

$$H(x) = q + (1-q)G(X) \tag{12}$$

Where q is the probability of zero precipitation and $G(x)$ is the cumulative probability of the incomplete gamma function. If m be the number of zeros in a α_k time scales, then q could be estimated by m/n. The cumulative probability $H(x)$ is then transformed to the standard normal random variable z with mean zero and the variance of one (Abramowitz and Stegun 1965), which is the value of RDI_{st} (Tsakiris et al. 2008). During the present analysis, RDI calculations were performed by MATLAB software (Asadi Zarch et al. 2011).

2.3 Trend Detection

According to Duhan and Pandey (2013) there are various parametric and non-parametric tests which were used for identifying trends in hydro-meteorological time series. However, from recent studies it is found that nonparametric tests are mostly used for non-normally distributed and censored data, including missing values, which are frequently encountered in hydrological time series. For trend detection non-parametrical Mann-Kendall test (Kendall 1975; Mann 1945) is one of the most common methods and has bas been widely applied in determination of the trend in hydro-climatic time series (Ahani et al. 2012; Arora et al. 2005; Chen et al. 2007; Dinpashoh et al. 2011; Kousari et al. 2013; Tabari and Talaee 2011; Zhang et al. 2006; Zhu and Day 2005).

Therefore in this study the non-parametric rank-based MK test (Kendall 1975; Mann 1945) was considered to detect trends of precipitation maxima values in different time scales. According to Zhai and Feng (2008), it has a number of advantages such as (i) the data do not need to conform to a particular distribution, thus extreme values are acceptable Hirsch et al. (1993), (ii) missing values are allowed (Yu et al. 1993), (iii) 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 (iv) in time series analysis, it is not necessary to specify whether the trend is linear or not (Silva 2004; Sneyers 1990; Yu et al. 1993).

For trend detection, MK statistics was used after the removal of the significant lag-1 serial correlation effect (Yue and Wang 2002) from all the extreme precipitation time series by pre-whitening. MK statistics is well known method and described by many researcher. Therefore, the details of this method have not been presented here.

2.4 Sen's Slope Estimator

Sen's slope estimator was applied in order to assess the amount of changes of RDI values in different time series. As stated Kahya and Kalaycı (2004), if a time series shows linear trend, the true slope (change per unit time) can be determined by using a simple nonparametric method developed by Sen (1968). Sen's slope estimator the same as MK statistics is a well-known statistical test and more details in regard to these statistical functions can be found in Ahani et al. (2012), Dinpashoh et al. (2011) and Tabari et al. (2011). The total change during the observed period was obtained by multiplying the slope by the number of years (Tabari and Talaee 2011). In this study, Sen's slope estimator was applied on all RDI time series.

3 Results

Figures 2, 3, and 4 show the different time series (3, 6, 9, 12, 18 and 24 monthly RDI) for the synoptic meteorological stations of Bushehr, Yazd and Zahedan, respectively. In these figures, the dashed lines show the fitted first order linear trend for each time series. The increasing trends of RDI time series in Bushehr station can be seen in Fig. 2. The increasing slopes of the trend lines can be seen from the short term time series to long term ones. By contrast the Bushehr station, the decreasing trends of RDI time series can be found for Yazd and Zahedan Stations. However, same as Bushehr station, the steepness of trend line increasing from the short term time series to long term types.

Table 2 indicates the Z parameter results of MK test in for different time series of RDI. * symbol illustrates the including upward trends (Z parameter more than 1.96) and downward trends (Z parameter less than −1.96), α<0.05. Both downward and upward trends can be seen in these two tables.

Analysis of the results of this table reveals that the percentages of significant trends are 32 %, 44 %, 60 %, 68 %, 72 % and 72 % for 3, 6, 9, 12, 18 and 24 RDI time series, respectively. However, for these time series, 32 %, 44 %, 56 %, 56 %, 60 and 60 % are attributed to downward trends and remaining percentages equal to 0 %, 0 %, 4 %, 12 %, 12 % and 12 % are related to positive trends. These findings illustrate the frequent significant trends mostly decreasing ones for these time series. However, from the short term time series to long term ones, the frequencies of significant trends are increased.

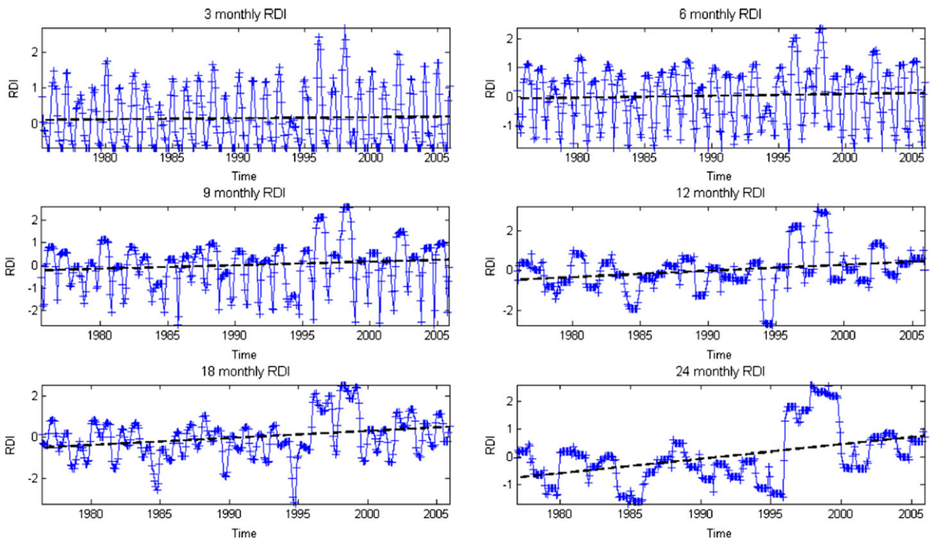

Fig. 2 3, 6, 9, 12, 18 and 24 monthly RDI time series for the synoptic meteorological station of Bushehr

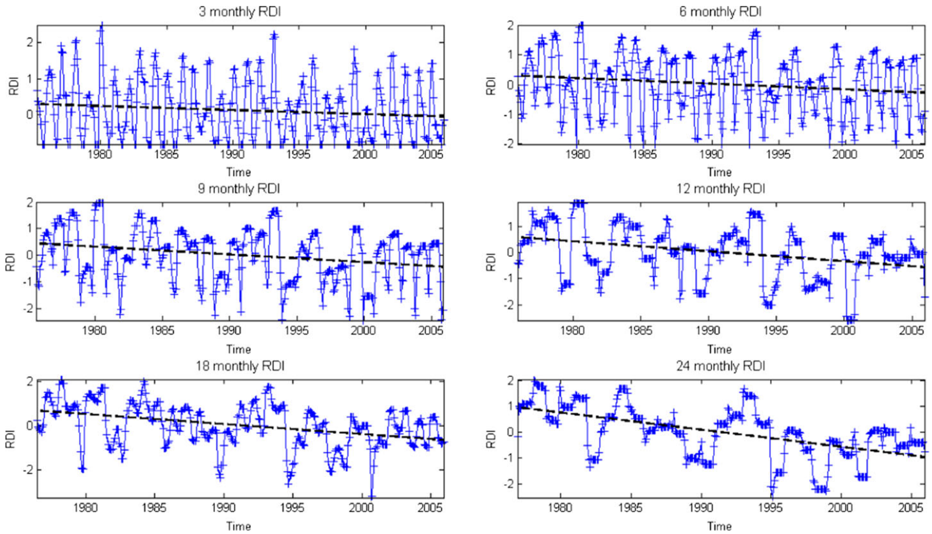

Fig. 3 3, 6, 9, 12, 18 and 24 monthly RDI time series for the synoptic meteorological station of Yazd

Table 3 shows the Sen's slope values of changes for different RDI time series. As well as the results of the frequency of trends show that the slope of changes are more considerable for long term time series of RDI than short term types.

For 3, 6, 9, 12, 18 and 24 RDI time series, most decreasing trends are equal to (−) 0.00017, (−) 0.00029, (−) 0.00038, (−) 0.00055, (−) 0.00055 and (−) 0.00071 per month, respectively. By multiplying these values on the total period of data the total changes can be detected. For example, for maximum Sen's slope of 24 monthly RDI time series, the total change is about (−) 2.5.

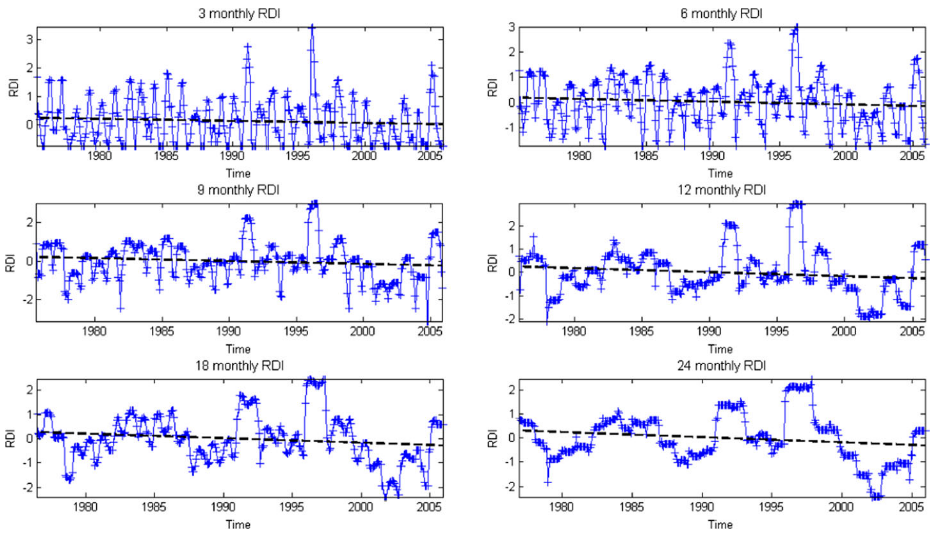

Fig. 4 Different time series (3, 6, 9, 12, 18 and 24 monthly RDI) for the synoptic meteorological station of Zahedan

Table 2 Z factor derived by application of the MK test on different RDI time series for all synoptic stations. Z values more than 1.96 represent upward significant trend, less than −1.96 show the decreasing trend at $\alpha<0.05$

Station name	RDI 3	RDI 6	RDI 9	RDI 12	RDI 18	RDI 24
Abadeh	−0.56	−0.14	0.87	1.12	1.97*	2.74*
Arak	−0.95	−1.71	−2.94*	−4.48*	−4.46*	−6.06*
Bam	−1.84	−3.06*	−5.11*	−6.65*	−7.30*	−9.18*
Bandar abbas	−1.97*	−2.60*	−3.67*	−4.79*	−4.41*	−4.75*
Bandar lenge	−2.08*	−2.95*	−4.01*	−4.56*	−4.54*	−4.48*
Birjand	−1.12	−1.01	−1.09	−0.87	−1.20	−1.79
Bushehr	0.02	1.12	2.79*	4.85*	4.86*	6.34*
Chabahar	−4.21*	−4.12*	−4.75*	−5.47*	−5.82*	−5.74*
Esfahan	−0.62	−0.22	0.50	1.04	0.83	1.85
Fasa	−1.33	−0.43	0.08	−0.02	0.09	−0.51
Iranshahr	−4.61*	−5.73*	−6.61*	−7.22*	−6.95*	−6.64*
Jask	−4.81*	−5.35*	−6.98*	−8.61*	−7.68*	−6.87*
Kashan	−0.42	−0.50	−0.84	−1.59	−1.12	−0.94
Kerman	−1.17	−1.62	−2.45*	−3.80*	−4.01*	−5.76*
Mashhad	−2.14*	−4.10*	−7.53*	−10.51*	−10.83*	−14.08*
Sabzevar	−1.93	−2.98*	−5.24*	−8.19*	−7.99*	−11.94*
Semnan	−1.48	−2.56*	−4.54*	−7.46*	−8.03*	−13.50*
Shahrud	−0.52	−0.27	0.49	2.14*	0.84	0.97
Shiraz	−0.74	0.02	1.34	2.29*	2.56*	3.26*
Tabas	−1.78	−0.87	0.06	0.60	0.42	1.46
Tehran	−0.30	−0.82	−1.31	−1.80	−2.72*	−5.79*
Torbat heydarieh	−0.88	−1.94	−3.75*	−6.38*	−5.77*	−10.09*
Yazd	−2.03*	−3.14*	−4.31*	−6.23*	−7.78*	−11.56*
Zabol	−1.51	−1.52	−1.79	−1.68	−1.67	−1.78
Zahedan	−2.03*	−2.43*	−3.13*	−3.83*	−3.54*	−3.56*

* significant level is $\alpha<0.05$

Figures 5, 6, and 7 contains the subfigures which each one exhibits the spatial distribution of increasing, decreasing and non-significant trends for particular RDI time series (3, 6, 9, 12, 18 and 24 monthly time series). In these maps, solid up pointing triangles show positive (increasing) significant trend at 95 %. Solid down pointing triangles show (negative) decreasing significant trend at 95 %. Not filled ones represent no significant trends). The maps in regard to 3, 6, 9 and 12 monthly RDI time series indicate that the most non-significant trends are located in the west parts of study areas while the significant ones are suited in the central and particularly eastern regions. To some extent, the positive trends mostly located in the south western of study areas.

4 Discussion

Results showed the frequent downward trends of RDI time series during three past decades in arid and semi-arid areas of Iran. Also, the long term RDI time series revealed more frequent trends than short term ones. It is clear that the decreasing trend of RDI indicates the more severity of drought occurrences. Unlike SPI which uses only precipitation time series, RDI

Table 3 Sen's slope estimator results of RDI time series (per months)

Station name	RDI 3	RDI 6	RDI 9	RDI 12	RDI 18	RDI 24
Abadeh	−0.0001	−0.0001	0.0004	0.0005	0.0011	0.0013
Arak	−0.0004	−0.0009	−0.0015	−0.0022	−0.0024	−0.0034
Bam	−0.0004	−0.0015	−0.0026	−0.0034	−0.0040	−0.0048
Bandar abbas	0.0000	−0.0012	−0.0017	−0.0023	−0.0024	−0.0024
Bandar lenge	0.0000	−0.0012	−0.0021	−0.0024	−0.0025	−0.0028
Birjand	−0.0001	−0.0005	−0.0005	−0.0003	−0.0006	−0.0007
Bushehr	0.0000	0.0006	0.0013	0.0018	0.0024	0.0030
Chabahar	−0.0008	−0.0017	−0.0022	−0.0024	−0.0029	−0.0033
Esfahan	−0.0001	0.0000	0.0003	0.0005	0.0005	0.0010
Fasa	−0.0003	−0.0002	0.0000	0.0000	0.0001	−0.0002
Iranshahr	−0.0017	−0.0029	−0.0035	−0.0038	−0.0040	−0.0038
Jask	−0.0008	−0.0023	−0.0036	−0.0045	−0.0045	−0.0047
Kashan	0.0000	−0.0003	−0.0004	−0.0008	−0.0006	−0.0005
Kerman	−0.0003	−0.0008	−0.0011	−0.0017	−0.0021	−0.0029
Mashhad	−0.0011	−0.0021	−0.0038	−0.0055	−0.0055	−0.0071
Sabzevar	−0.0009	−0.0015	−0.0025	−0.0040	−0.0041	−0.0059
Semnan	−0.0007	−0.0013	−0.0022	−0.0032	−0.0040	−0.0058
Shahrud	−0.0003	−0.0001	0.0003	0.0008	0.0004	0.0006
Shiraz	0.0000	0.0001	0.0007	0.0010	0.0013	0.0018
Tabas	−0.0004	−0.0003	0.0000	0.0000	0.0002	0.0005
Tehran	−0.0002	−0.0004	−0.0007	−0.0009	−0.0014	−0.0031
Torbat heydarieh	−0.0004	−0.0009	−0.0018	−0.0032	−0.0030	−0.0045
Yazd	−0.0004	−0.0015	−0.0021	−0.0030	−0.0038	−0.0053
Zabol	0.0000	−0.0005	−0.0009	−0.0008	−0.0010	−0.0013
Zahedan	−0.0003	−0.0012	−0.0016	−0.0019	−0.0018	−0.0016

considers the proportion of precipitation to ET0. Therefore, these more severities can be attributed to more complex conditions and can be referred to some factors involving upward trend in ET0 and its related parameters such as temperature, sunshine duration and wind speed by contrast to decreasing trend in precipitation or P/ET0. In addition to increase of drought frequency, increasing of drought magnitude and drought duration can be considered as other causes of such downward trends of RDI time series. Moreover, drought event intrinsically is multivariate and its severity, areal extent, duration, inter-arrival time and return periods in drought analysis should be taken in account (Zhang et al. 2012).

Therefore, based on the results of this study it is rather difficult to find the participations and weights of the mentioned factors on the RDI trends. But previous studies in Iran especially the researches which have focused on trends in precipitation, ET0, P/ET0 or aridity index (AI) as well as drought indices particularly SPI can promote and enhance our understanding in regard to these events. For example, more frequent increasing trends of ET0 time series (Ahani et al. 2013; Dinpashoh et al. 2011; Kousari and Ahani 2012) than downward ones can be play important role in decreasing trends of RDI time series. Also, there are a few evidences describing the downward trend of precipitation time series (Modarres and Sarhadi 2009; Tabari and Talaee 2011) in Iran. Some of them illustrate the frequency of non-significant trends at least for annual precipitation especially in arid and semiarid regions (Ahani et al. 2013; Kousari and Asadi Zarch 2011; Kousari

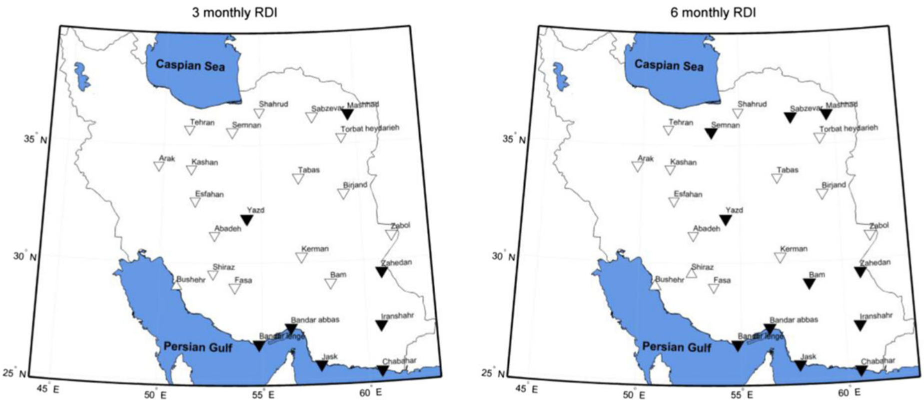

Fig. 5 Spatial distribution of increasing, decreasing and non-significant trends for different RDI time series (3, and 6 monthly time series)

et al. 2011; Soltani et al. 2012) or mixed trends of increasing and decreasing rainfall (Modarres and de Paulo Rodrigues da Silva 2007). Some studies have emphasized that there are decreasing or increasing trends in annual, seasonal and monthly rainfall but most of them are not significant trends (Soltani et al. 2012). To some extent, the results for AI trend in arid and semi-arid regions of Iran (Ahani et al. 2013) is similar to those for precipitation and there are no considerable significant trend for this parameter too.

While the studies associated with the trends of precipitation have revealed the frequent non-significant type, an investigation of climatic drought trend in Iran based on SPI by Bari Abarghouei et al. 2011 demonstrated that meteorological drought has been increased in different parts of Iran. Nearby, they reported the same results of SPI trend with the current RDI analysis. Also, Asadi Zarch et al. 2011 showed considerable correlations between RDI and SPI in different time series in Iran. Therefore, the similar reported trend of SPI by Bari Abarghouei et al. 2011 and the RDI in current study can refer to this high correlation reported by Asadi Zarch et al. 2011 and also it determines that the common input parameter between RDI and SPI i.e. precipitation plays key role in general trend of both indices.

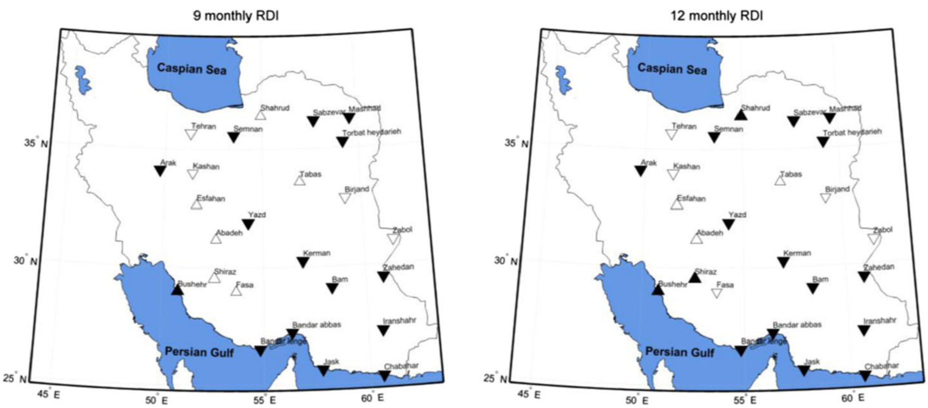

Fig. 6 Spatial distribution of increasing, decreasing and non-significant trends for different RDI time series (9, and 12 monthly time series)

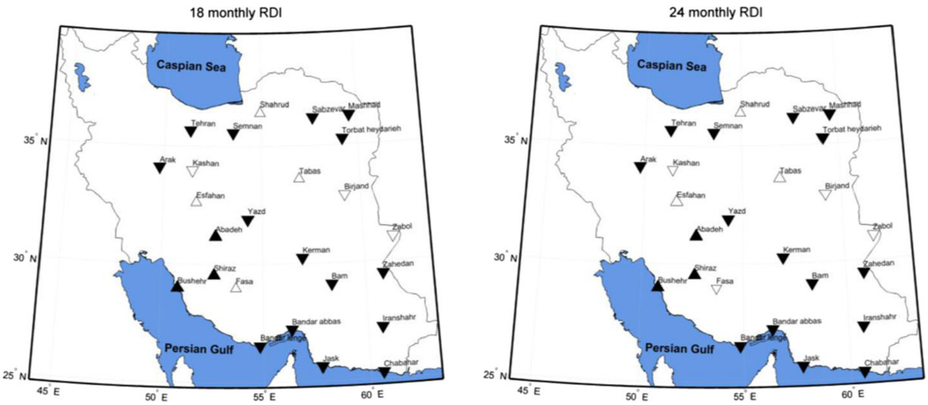

Fig. 7 Spatial distribution of increasing, decreasing and non-significant trends for different RDI time series (18 and 24 monthly time series)

Since the running sum of precipitation and P/ET0 are implemented for SPI and RDI, respectively, it can be said that during the study period, the cumulative precipitation and also cumulative values of P/ET0 have had decreasing trend. Also, the results of these study showed that the prolonged time series of RDI indicated more frequent downward trends. While, the 3 monthly RDI time series contained lowest negative significant trend. As it was previously mentioned, most studies in Iran revealed the frequent non-significant trend of precipitation and it justifies the rare significant trend of 3 monthly RDI time series and therefore, it can be concluded that the prolonged time series of RDI are stronger to reveal the trends in the time series. RDI uses the running sums of P/ET0 values and by increasing the term of RDI time series, it becomes smoother and also the more P/ET0 values during a time series are contributed to form the prolonged RDI values. Therefore, detection of a particular trend is more feasible in long term RDI time series.

Although the application of RDI and non-parametrical MK statistics revealed valuable findings in regard to drought trend in arid and semi-arid regions of Iran, deriving more detailed results comes across to some issues which should be taken in account. This restriction refers to temporal resolution of the monthly drought indices. Monthly time scales suffer from weaker temporal resolution than daily time series. There are many criticizes for application of monthly precipitation data for drought studying (for example Cindrić et al. (2010); She et al. (2012)). Although the indices which consider monthly time series are simple and have wide application, since they just implement accumulated values of climatic parameters during a month (form example sum of precipitation or ET0), they can not distinguish the effects of various occurrences in the approximately 30 days. For instance, the contributions of three precipitation occurrences each one equal to 5 mm seems similar to a storm thoroughly equal to 15 mm. while, their contribution to water resources charging are different especially in arid and semiarid regions where heavy precipitation occurrences have more chance for percolation and infiltration to deeper ground water zones. In such cases, the precipitation intensities are also important and it is believed that concentrations of heavy precipitation in watershed areas and their arrivals to regions with high capacity of deeper infiltration can be more effective for harvesting water resources than low amounts of precipitations. Perhaps it can be said that the temporal resolution is the most important restriction of application of monthly time scales and therefore, the temporal resolution of precipitation and ET0 occurrences should be taken in to the account. Anyway, every method or index has its capabilities and limitations and in application of every index all these aspects should be considered.

Based on above statement it can be said that the enhancing and increasing of our understanding about different aspects of drought needs more studies and investigations. Drought is a complicated phenomenon and finding its trends, relations to other climatic parameters and climate changes needs more comprehensive studies and the current study and similar ones are in fact the bases for these efforts in the future.

5 Conclusions

In this study RDI trends were investigated with different methods in monthly time scale (3, 6, 9, 12, 18 and 24 monthly time series) from 1975 to 2005. First, RDI time series were trended by non-parametric MK test and then mapped. Second, Sen's slope estimator was used to determine the extremes of positive or negative RDI trends. As conclusion it should be said that frequent decreasing trends in RDI time series is a sign of more hazardous circumstances for water resources management. RDI is a simple but valuable drought index which considers both precipitation and evapotranspiration as the main input and output of the hydrological cycles, respectively. These situations are more remarkable in arid and semiarid regions where the lower values of precipitation are accompanied with high demand of evapotranspiration. The decreasing trend of RDI time series which may be resulted from decreasing trend in precipitation, increasing trend in evapotranspiration or downward trend in P/ET0 values means more severe conditions for water resources management. Of course the effects of other parameters' trends on RDI should be followed in future studies. Anyway, occurrence of more frequent and severe droughts is a real threat for water resources harvesting as well as storages.

Last but not least, the results of this study indicated that long term time series of RDI had more considerable decreasing trends than short term ones. Considering this fact that the water resources especially ground waters are more affected by long term droughts than short term types, it can be concluded that the ground water recharging has been influenced by these downward trends during past decades and the executive managers, specialists, decision makers and researchers in regard to water resources management should consider to this fact and these trends should be taken in account.

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