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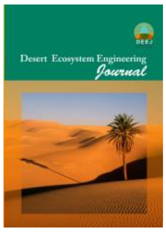

Drought Trend Assessment in Riverheads of Karkheh and Dez Basins based on Streamflow Drought Index (SDI)

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Abstract

The present study was conducted to study drought phenomenon based on the streamflow drought index (SDI) at hydrometric stations in riverheads of Karkheh and Dez Basins in Lorestan province. For this purpose, the monthly discharge data from 21 hydrometric stations were used over the period 1975-2011. The Mann-Kendall and Sen's methods were applied to explore the trends in the time series of 12 months. The results showed that detection of the drought trend has been almost the same in both methods such that 70% and 100% of stations in the Karkheh dam had significant trend based on the Mann-Kendall method and Sen's methods, respectively. However, these values in Dez dam for Mann-Kendall and Sen's Estimate methods were 58% and 78%, respectively. The stations of Daretakht (Marbareh), Dorud (Tire), and Dorud (Marbareh) in Dez dam basin suffered from the highest intensity trend of hydrological drought. The stations Doab (Vesseyan), Horo (Kaka Reza), and Tang Syab in Karkhe dam basin also had the highest intensity of hydrological drought. Based on these results, Karkheh dam has experienced more severity and a long time of water deficit in recent years. According to the location and distribution of the stations in the study area, these two studied dams have a particular spatial trend.

Keywords: Drought, Mann-Kendall**,** Sen's Estimate**,** Trend, SDI.

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1. Introduction

Due to population growth and the expansion of agriculture, energy, and industry sections, water demand has increased rapidly and water shortage has occurred in many parts of the world (Mishra & Sing, 2010). Compared to flood, drought monitoring has not been developed enough and it is often presented in the form of descriptive analysis (Azimi Hosseiny, 1999). Drought is a natural hazard resulted from a deficiency of precipitation from expected or "normal" but insufficient to meet the demands of the environment and human activities (Fathabadi et al. 2009). Drought can adversely affect any location, even humid continental regions such as the United Kingdom. In this regard, there is no possibility to prevent the occurrence of it (Dupigny-Giroux et al. 2001, Zehtabian et al. 2013). Among various types of droughts, the hydrological drought is the most important given the high dependence of many sections such as industrial, urban water supply, and hydropower generation on surface water resources (Vicente et al. 2011). Hydrological drought initially caused by rainfall deficits is normally associated with reservoirs or lake levels within a basin (Liu et al. 2012). In fact, hydrological droughts can have widespread impacts by reducing water supplies, deteriorating water quality, restricting water for irrigation, causing crop failure, reducing power generation, disturbing riparian habitats, limiting recreation activities, and affecting a diversity of economic and social activities (Mishra & Singh 2010). Therefore, analysis of different drought intensities and detection of their trends have been of great importance in recent decades. Several drought indices have been developed to characterize hydrological droughts (Tate & Gustard 2000; Smakhtin 2001; Heim 2002; Tallaksen & Van Lanen 2004).

The streamflow drought index (SDI) developed recently by Nalbantis (2008) is a very simple and effective index for hydrological droughts. Kwon and Kim (2010) assessed the hydrological drought in South Korea in a semi-distributed form using an equation modifying the Surface Water Supply Index (SWSI). Based on their results, the weekly-based SWSI evaluation showed accurately the continual drought condition while the monthly-based evaluation failed to catch the drought within a month. Pandey et al. (2008) defined the drought severity index (DSIe) as a function of the ratio of deficit flow volume to the corresponding volume at the truncation level and the ratio of the duration of deficit flow to the maximum possible duration of the independent streamflow drought event. Wu et al. (2008) studied statistical characteristics on streamflow drought event parameters and detected spatial and temporal trends in the streamflow drought in terms of frequency, duration, and severity in Nebraska. Tabari et al. (2013) investigated the hydrologic drought defined by the streamflow drought index (SDI) in the northwest of Iran. They found that some of the streamflow volume series did not follow the normal distribution. The efficiency of the lognormal, exponential, and uniform probability distributions was examined in order to choose the most suitable distribution and the lognormal distribution was used to fit the long-term streamflow data. Despite the importance of recognizing the hydrological drought trend in the main riverheads of big dams in Iran such as Karkheh and Karun dams, little studies have been done on this issue. For example, in a study, three hydrologic variables of mean daily discharge, maximum daily discharge, and peak discharge were analyzed by Sheikh et al. (2011) for detection of any probable trend. Using three non-parametric tests including Mann-Kendall, Spearman's Rho, and Thiel-Sen estimators, the trend of hydrologic variables in the Atrak River basin in the northeast of Iran was studied for 10 discharge-gauging stations. Maroofi and Tabari (2011) examined discharge changes of Maroon River in Khuzestan Province, Iran, using the Mann-Kendall and Sen's Estimator. They showed that the annual discharge in all investigated sites has been a downward trend in the last two decades. Fathiyan and Morid (2012) studied changes of temperature, rainfall, and discharge of river monthly and yearly in the basin of Lake Urmia using non-parametric Mann-Kendall, Thiel-Sen, and Sen-Ti estimators. Cagatay (2007) investigated the trends of annual and seasonal drought patterns based on regionally averaged surface humidity index (SHI) series in Turkey. For this purpose, two nonparametric approaches, i.e., the Mann-Kendall test and Sen's T-test, were used. Significant negative correlations were found for some regions.

The aim of this study is the assessment of the severity, frequency, and trend of drought in riverheads of Karkheh and Dez basins based on streamflow drought index (SDI) using two non-parametric tests including Mann-Kendall and Sen Estimator during the period 1975-2011.

2. Materials and methods

2.1. The study area

Lorestan Province is located in the Zagros Mountains in western Iran. It covers an area of 28,157 km^2 and is situated between 51° 44′ and 54° 30′ E longitude and 29° 7′ and 31° 15′ N latitude. The study area consists chiefly of mountains with numerous ranges and a part of the Zagros chain, running northwest to southeast. This mountain has formed due to convergent regime between the Arabian and Eurasian plates during Cenozoic (Rahimi et al. 2017). The central range has many summits that almost reach the line of perpetual snow, rising to 4000 m and more. It feeds the headwaters of Iran's most important rivers such as the Zayandeh Rood, Jarahi, Karun, Dez, Abi, and Karkheh. The higher ranges have many fertile plains and low hilly well-watered districts. Based on its climate, the province can be divided into three parts: the mountainous regions experience cold winters and moderate summers. In the central region, the spring season begins from mid-February and lasts until mid-May. Finally, southern areas are under the influence of the warm air currents of Khuzestan and have hot summers and relatively moderate winters. The climate is generally sub-humid continental with winter precipitation, majorly falling as snow. With an annual precipitation of 530 mm, this province has the highest precipitation in the south of the Alborz Mountains. About 12.5 billion cubic meters of water exits from the province. Annually, 63% of this amount exists mainly from Dez river and the rest of it exists from Karkheh basin. Fig. 1 presents the location of the study area and distribution of used hydrometric stations.

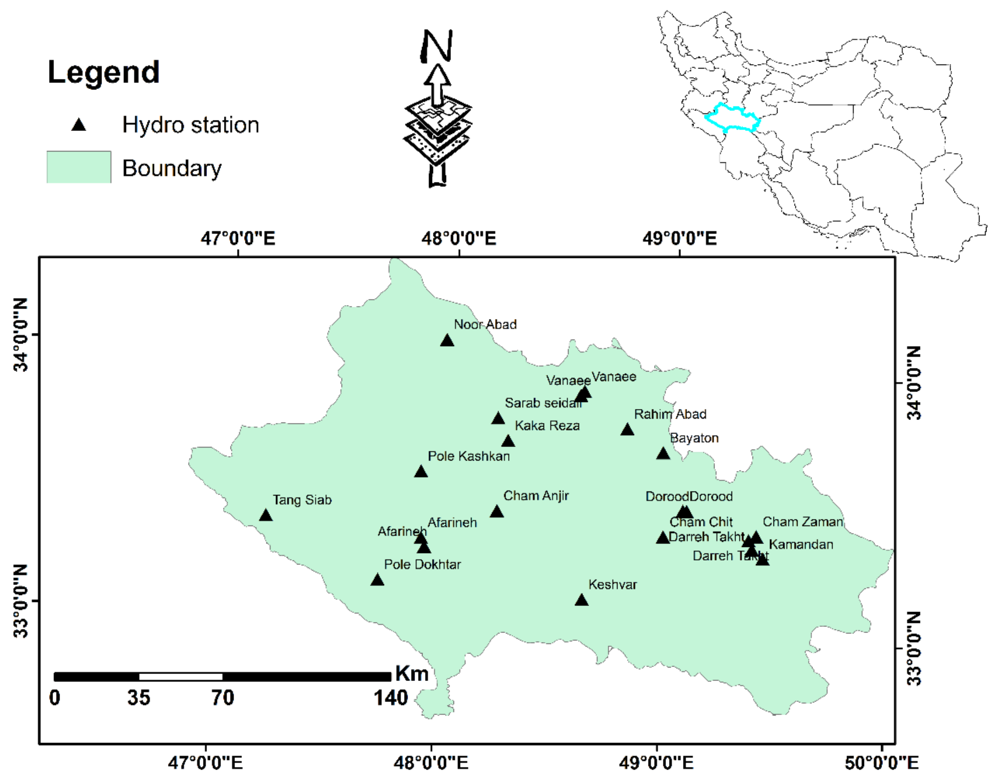

Figure 1: Geographic location of the study area and spatial distribution of the hydrometric stations

2.2. Methodology

First, the border of the study area and location of hydrometric and climatology stations were determined in GIS environment. The characteristics of the selected station are presented in Table 1. After selecting the appropriate statistical foundation to determine the different intensities of hydrological drought, following operations were performed on these data:

1: the data of each station was modified in terms of homogeneity using the test of double mass. Also, outlier's data test was conducted using water resources America method.

2: To restore the data, the correlation matrix was determined between all stations and incomplete stations and the then the incomplete stations were completed by using homogenous station data having the highest correlation with it.

3: SDI index was calculated based on monthly discharge for the station.

4: drought trend was analyzed using Mann-Kendall and Sen Slope estimator.

Table 1: The characteristics of the used stations

Row	Basin	Station	River	Longitude	Latitude	Area	Level of sea
1	Karkheh	Poldokhtar	Kashkan	4743	3310	9235.5	650
2	Dez	Kamandan	Kamandan	4926	3319	40.3	2080
3	Dez	Keshvar	Sourkhab	4838	3308	341.5	747
4	Karkheh	Kaka Reza	Hyrvd	4816	3343	1145	1530
5	Karkheh	Afrineh	Kashkan	4755	3318	6802.9	820
6	Karkheh	Afrineh	Kashkan	4754	3320	817.9	850
7	Dez	Byatvn	Byatvn	4858	3342	3513.1	1600
8	Karkheh	Cham Angir	Khorramabad	4814	3327	1635.7	1140
9	Dez	Cham Zaman	Azna	4924	3324	2006.9	1830
10	Dez	Dereh Takht	Dereh Takht	4923	3321	41	1940
11	Dez	Dereh Takht	Marbareh	4922	3323	2187.4	1800
12	Dez	Rahim Abad	Silakhor	4848	3347	988.5	1490
13	Karkheh	Syyed Ali	Doab Elster	4813	3348	776.6	1520
14	Karkheh	Nour Abad	Badavr	4758	3305	614.7	1780
15	Dez	Vanai	Sarab Safid	4836	3355	60.1	1980
16	Dez	Vanai	Galeh Roud	4835	3354	31.6	2000
17	Karkheh	Doab Vaisian	Kashkan	4753	3335	3729	1000
18	Dez	Droud	Tireh	4905	3329	2553	1450
19	Dez	Droud	Marbareh	4904	3329	3513.1	1450
20	Karkheh	Tang Syab	Dareh Dozdan	4712	3323	565	880
21	Karkheh	Cham Chit	Saab Buzeh	4859	3323	327.6	1290

2.2.1. Streamflow Drought Index (SDI)

The SDI was developed by Nalbantis (2008) for characterizing hydrological drought based on the concepts used for developing the SPI. To compute SDI, it is assumed that a time series of monthly streamflow volumes Qij is available where i denotes the hydrological year and j the month within that hydrological year. Based on this series, cumulative streamflow volume is computed as follows:

$$Vik = \sum_{i=1} Qij \qquad (1)$$

K=1,2,3,4,5,6

I=1,2…...

J=1, 2,…12

Where $V_{i,k}$ is the cumulative streamflow volume for the i-th hydrological year and the k-th reference period. The SDI is defined based on cumulative streamflow volumes $V_{i,k}$ for each reference period k of the i-th hydrological year as follows:

$$SDI_{ik} = \frac{V_{ik} - \overline{V_{ik}}}{S_k} \quad (2)$$

where V_k and S_k are respectively the mean and the standard deviation of cumulative streamflow volumes of reference period k as these are estimated over a long period of time. In this definition, the truncation level is set to V_k although other values could be used. Based on the SDI, five states of hydrological drought are defined, which are denoted by an integer number ranging from 0 (non-drought) to 4 (extreme drought). The states of hydrological drought are defined through the criteria of Table 2.

Table 2: Definition of states of hydrological drought based on SDI

Drought conditions	range	states
Without drought	$0 \le SDI$	0
Mild drought	$-1 \le SDI < 0$	1
Mid-drought	$-1.5 \le SDI < -1$	2
Extreme drought	$-2 \le SDI < -1.5$	3
Very extreme drought	$SDI \le -2$	4

2.2.2. Mann-Kendall Test = for Monotonic Trend

The purpose of the Mann-Kendall (MK) test is to assess statistically whether there is a monotonic upward or downward trend of the variable of interest over time. The MK test can be used in place of a parametric linear regression analysis, which can be used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be normally distributed; an assumption not required by the MK test, that is, the MK test is a non-parametric (distribution-free) test. The calculation steps of the test are as follows:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i=1} sign(X_i - X_j) \quad (3)$$

where Xi and Xj are arranged values of sample and n is the number of samples.

$$sign(X_i - X_j) \quad (4)$$

Compute the variance of S by Eq. 5 and 6:

$$sign(X_i - X_j) = -1, for (X_i - X_j) < 0$$

$$sign(X_i - X_j) = 0, for (X_i - X_j) = 0$$

$$sign(X_i - X_j) = 1, for (X_i - X_j) > 0$$

$$Var(s) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p 5)}{18} \quad (5)$$

$$E(s)=0 \quad (6)$$

where *tp* is the number of tied groups and t_p is the number of observations in the p^{th} group. The MK test statistics, *Z* MK, are computed as follows:

$$\frac{S-1}{\sqrt{Var(s)}}, if \rightarrow S > 0$$

$$0 \rightarrow if, S = 0$$

$$\frac{S-1}{\sqrt{Var(s)}}, if \rightarrow S < 0 \quad (7)$$

A positive/negative value of *Z* MK indicates that the data tend to increase/decrease with time. In this study, significance levels of 0.01 and 0.05 were used.

2.2.3. Sen's Estimate Approach

A non-parametric method to evaluate line slope is Sen Slope estimator method. The amount of trend using the technique presented by Thiel (1950) and Sen (1968) is estimated by using Eq. 8.

$$Q = Median(\frac{x_j - x_1}{j - i}), \forall i < j \quad (8)$$

where X_j and X_1 are the amounts of data at a time j and 1 (j> 1), respectively.

In Eq. (8), Q is an estimator of the trend line slope and x_l is the recorded value for viewing l^{th} number in the historical order.

3. Results and Discussion

Figures 2 and 3 show 12-month different time series of streamflow drought index (SDI) for hydrometric stations of Dez and Karkhe basins. In these figures, the dash presents Sen Slope estimator that is fitted to all series.

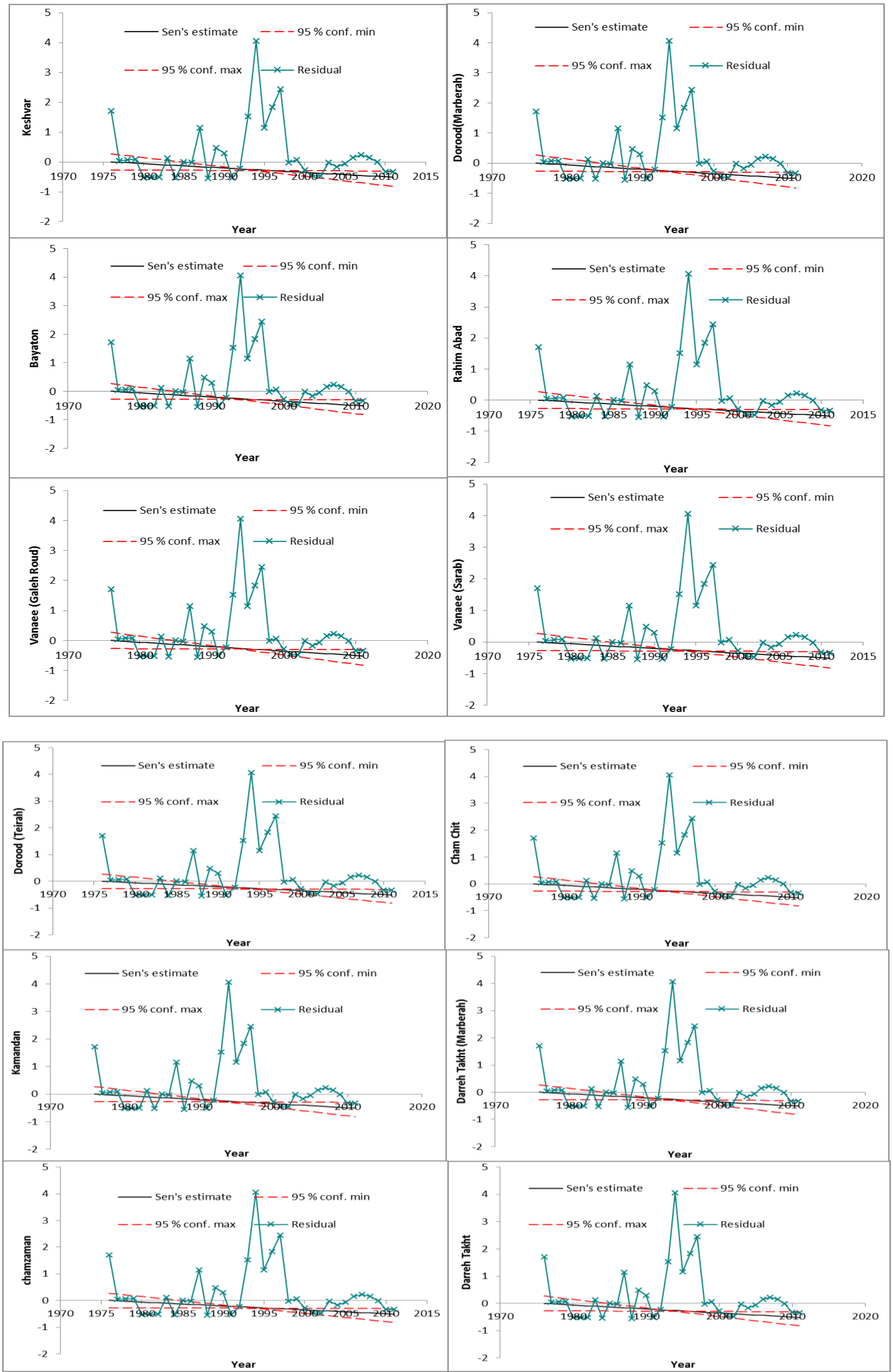

Figure 2: SDI twelve-month time series for stations in the Dez Basin

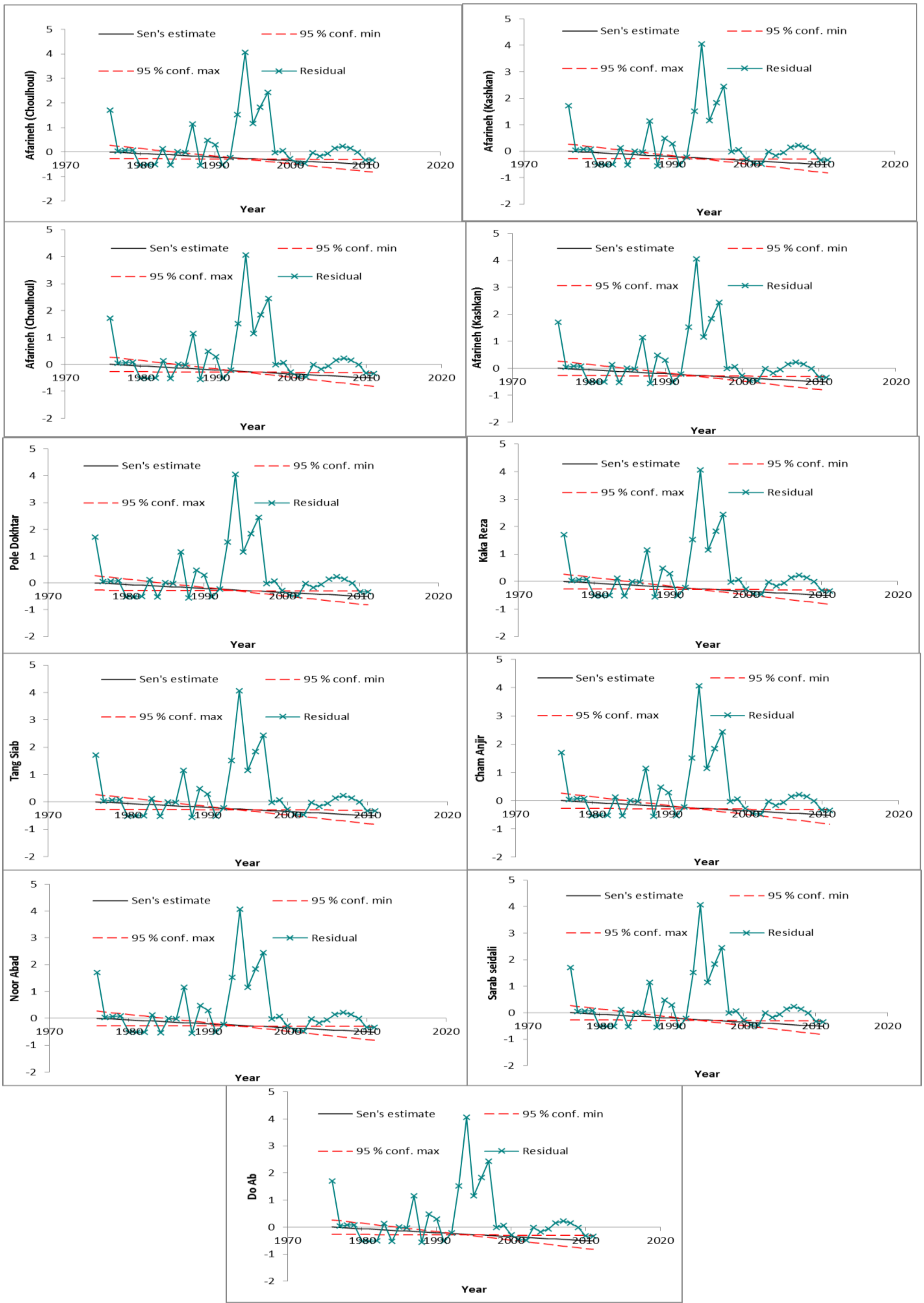

Figure 3: SDI twelve-month time series for stations in the Karkheh Basin

As shown in Fig. 2, Sen Slope estimator shows a trend of hydrological drought increase in all hydrometric stations located in riverheads of Dez Dam. However, these meaningful trends were examined by two parameters of Z (Mann-Kendall) and Q (estimator Sen), which yielded different results. These results are presented in Table 3.

Table 3: The results of the Z parameter in the non-parametric Mean-Kendall test and the Sen slope estimator (Q)

Dez basin			Karkheh basin		
Station	Test Z	Q	Station	Test Z	Q
Dorud Tire	-3.47 **	-0.05 *	Poldokdtar Pashkan	-2.11 *	-0.03
Abe Sabz	0.89	0.01	Afrineh Chvlhvl	-2.6 **	-0.04
Kamandan	-3.12 **	-0.05	Afrineh Kashkan	-2.63 **	-0.04
Dretakht	-1.78	-0.03	Horo (Kaka Reza)	-1.92	-0.03
AZNA Cham zaman	-2 *	-0.01	Tang Syab	-2.96 **	-0.05
Marbare	-3.69 **	-0.03 *	Cham Anjier	-2.96 **	-0.05
Keshvare sorkhab	-0.23	0	Nour Abad	-2.41 *	-0.04
Droud Marbare	-2.26 **	-0.03	Sarab-e Seyyed Ali	-1.27	-0.02
Byatoun	-0.35	-0.02	Doab (Vesseyan)	-3.58 **	-0.06 *
Rahim Abad Silakhor	-2.57 *	-0.04			
Vanai Galeh Roud	-2.3 *	-0.04			
Vanai (Sarab)	0.1	0			

Regarding the Z parameter, the time will increase and decrease if it is more than 1.96 and less than -1.96, respectively. The intended error is α<0.01. Based on Table 3, the trend increase for SPI index was also significant in Dorud (Tire), Kamandan, Dretakht, Marbareh, and Dorud Marbareh at 99% accuracy. Moreover, Z parameter although was positive in Cham Chit (Abe Sabz) and Vanai (Sarab), the reduction of drought trend was not significant. Therefore, 58% of hydrometric stations located in riverheads of Dez dam have a trend increase in hydrological drought.

Table 3 presents values of Sen Slope estimation for changes of time series of SDI12. However, only two stations of Dorud (Tire) and Daretakht (Marbareh) were significant at 95% accuracy. Thus, 75% of Dez basin stations have an increasing trend in hydrological drought based on the Sen Slope estimator.

Fig. 3 shows the results of 9 hydrometric stations located in the Karkheh dam basin. In this area, it was only in Sarab-e Seyyed Ali and Horo (Kaka Reza) stations that time series had no significant drought trend such that the values of the Z parameter were, -1.27 and -1.96, respectively. Therefore, 77% of hydrometric stations in Karkheh dam have a significant trend of hydrological drought based on Mann-Kendall. The results showed that detection of the trend in drought data have been frequently the same in both methods of Mann-Kendall and Sen Slope estimator (Table 3).

4. Conclusions

In this research, the annually hydrological drought, SDI 12, is investigated using Mann-Kendall test and Sen Slope estimator for hydrometric stations of Lorestan province, where there is a large part of Karkheh and Dez dam watershed. For this purpose, the monthly discharge data of 21 hydrometric stations were used over the period 1975-2011. A total of 12 stations were selected from Dez basin and others were from Karkheh basin.

According to the results, detection of the drought data trend has been frequently the same in both methods such that 70% of stations in Karkheh dam had a significant trend in the Mann-Kendall method and 100% in Sen’s Estimate approach. These values in Dez dam for Mann-Kendall and Sen’s Estimate methods were 58 and 78%, respectively. Daretakht (Marbareh), Dorud (Tire), and Dorud (Marbareh) stations in Dez dam basin suffered from the highest intensity trend of hydrological drought. Doab (Vesseyan), Horo (Kaka Reza), and Tang Syab stations in Karkhe dam basin also had the highest intensity of hydrological drought.

Karkheh dam has experienced more severity and duration of water deficit in recent years.

Two studied dams have a special spatial trend, due to the position and distribution of the stations in the study area. Thus, the trend was significant in riverheads of Karkheh except for Kaka Reza and Sarab-e Seyyed Ali stations. This trend is observed also for riverheads of Dez dam. Therefore, it can be stated that almost all the stations experienced an increasing trend of drought during the study period, which is concordant with the results of Eskandari Damaneh et al. (2016).

Also, results reported by Amiri et al. (2015), who investigated climate change by analyzing the Man-Kendall trend and drought index, showed that the causes of hydrological regime changes can be explained by trend analysis of climate indicators including temperature, precipitation, and drought and using Man-Kendall test. Our results were also consistent with the results presented by Maleki Najad et al. (2013), who analyzed the trend of rainfall and drought using Man-Kendall and Sen Slope estimator in Tehran province. They reported that Sen Slope estimator better indicated the precipitation rate and drought trend in annual scale compared to Man- Kendall test and also showed that drought increased over time in the region.

The current situation of water resources in Karkheh and Dez basins and also geographical and natural challenges such as successive droughts and climate change have caused serious problems in the balance of water resources and water demands. Droughts event can affect water resources in many aspects and cause the deficit. To make decisions involved in dealing with droughts hazard, it is necessary to monitor and assess droughts feature in terms of their severity and geographic extent. These issues must be considered by authorities for managing water resources and planning purposes.

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