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Relationship Between Hydrologic and Metrological Droughts Using the Streamflow Drought Indices and Standardized Precipitation Indices in the Dez Watershed of Iran

Arash Adib[1] · **Fatemeh Tavancheh**[1]

Abstract

This research utilizes DrinC software and some codes developed in MATLAB software for calculating the drought indices and determination of trend of climatologic and hydrologic time series data using different nonparametric Mann–Kendall trend tests. The time series data used in this research include the minimum, mean and maximum monthly temperatures, monthly precipitation, and monthly flow discharge (from 1981 to 2012). These data are pertinent to the Dez watershed climatic and hydrometric stations in southwest Iran. Results of this research show that precipitation has no significant trend, but flow discharge has a decreasing trend. The trends of mean, maximum, and minimum temperatures are increasing in summer and autumn but decreasing in spring. In winter, the trend of minimum temperature is increasing, while the trend of mean and maximum temperatures is decreasing. Standardized precipitation index (SPI) and streamflow drought index (SDI) show that the number and intensity of short-term droughts (with 3 months time scale) are more than the number and intensity of long-term droughts (with 6, 9, and 12 month time scales). Correlation coefficient between SPI and SDI increases as the time scale is increased too.

Keywords Drought · The Dez watershed · The Mann–Kendall trend test · Standardized precipitation index (SPI) · Streamflow drought index (SDI)

1 Introduction

Climate change, global warming, and severe shortage of water resources in recent years have created important problems such as the generation of dust storms and the creation of severe economic and social damages for the Middle East countries. Therefore, trend analysis of hydrological and climatic phenomena such as temperature, precipitation, and flow discharge is a necessary task. A lot of studies conducted in different countries have analyzed the trends of precipitation [1, 2], temperature [3], and streamflow [4–6].

Unfortunately, the government officials and the managers consider long-term droughts and do not pay attention to short-term droughts and the immediate needs of people. In addition, they assume that flow discharges are only dependent on precipitation, but flow discharges are affected by various factors (precipitation, temperature, melting snow, etc.).

This study utilizes the nonparametric methods like Mann–Kendal test [7] and Theil–Sen (Theil, 1950; Sen, 1968) approach (TSA) [8]. The nonparametric methods are distribution-free, robust against outliers, and, according to [9], have a higher power for nonnormally distributed data.

In a number of studies, the Mann–Kendal test was applied for trend analysis of the climatologic and hydrologic time series data [10–21].

In addition, two drought indices, namely Standardized Precipitation Index (SPI) and Streamflow Drought Index (SDI), have been used to analyze the relationship between meteorological and hydrological droughts. Recently, researchers have studied about the SPI and SDI drought indices [22–25]. Some hydrologists combined different drought indices for the evaluation of the relation between various droughts such as studying about the relation between

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meteorological and agricultural droughts in California and North Carolina in the USA [26].

A study [5] used the MK test for trend analysis of the monthly flow discharge of different hydrometric stations in the west of Iran and determined the correlation between precipitation and flow discharge in these stations.

In this research, the relation between metrological and hydrological drought indices (SPI and SDI) is studied, while the previous studies on the Dez watershed area have only considered one type of drought either metrological or hydrological or they have only evaluated trend of a hydrological or meteorological phenomenon such as [27, 28]. Studies [27, 28] only considered trend of temperature and SPI drought index in the Dez watershed, respectively. The relation between SPI and SDI shows the relation between the meteorological and the hydrological droughts. For this purpose, three stations (the Telezang, Dorud, and Keshvar stations) with different heights are considered. A novelty of this research is the evaluation of effects of height on the relation between SPI and SDI and the relation between precipitation and flow discharge in different months of the year. For this purpose, droughts were divided into two types: short-term and long-term droughts. In addition, the relation between SPI- SDI and precipitation- flow discharge is investigated.

2 The Dez Watershed

The Dez watershed is between 48°10′ and 50°21′E and 31°34′ and 34°7′N. The area of this watershed is 21,720 km^2 including 17,365 km^2 at the upstream of the Dez dam and its minimum, mean, and maximum height

are 190, 1676, and 4124 m. Seven hydrometric stations for measurement flow discharge are:

1—Sepid Dasht Sezar on the Sezar River (48°53′E, 33°13′N and elevation 970 m); 2—Sepid Dasht Zaz on the Zaz River (48°52′E, 33°14′N and elevation 980 m); 3—Telezang on the Dez River (48°46′E, 32°49′N and elevation 463 m); 4—Dorud on the Tiereh River (49°4′E, 33°28′30″N and elevation 1450 m); 5—Dareh Takht on the Marbereh River (49°23′E, 33°23′N and elevation 1820 m); 6—Cham Chit on the Sabzeh River (48°58′E, 33°23′N and elevation 1290 m); 7—Keshvar on the Sorkab River (48°42′18″E, 33°8′57″N and elevation 770 m).

Eleven meteorological stations for measurement precipitation are:

1—The Dez dam (48°27′E, 32°33′N and elevation 525 m); 2—Telezang (48°46′E, 32°49′N and elevation 463 m); 3—Broojerd (48°46′E, 33°53′N and elevation 1560 m); 4—Vanaaei (48°36′E, 33°55′N and elevation 1980 m); 5—Dorud (49°4′E, 33°28′30″N and elevation 1450 m); 6—Cham Zaman (49°24′E, 33°24′N and elevation 1830 m); 7—Kamandan (49°25′5″E, 33°18′N and elevation 1930 m); 8—Dareh Takht (49°22′5″E, 33°21′36″N and elevation 1890 m); 9—Keshvar (48°42′18″E, 33°8′57″N and elevation 770 m); 10—Kazem Abad (49°41′30″E, 33°8′59″N and elevation 2000 m); 11—Marvak (49°3′E, 33°40′N and elevation 1560 m).

Meteorological station for measurement temperature is: Tang 5 Bakteari (48°46′E, 32°56′N and elevation 540 m).

Figure 1 shows the geographical location of hydrometric and meteorological stations of the Dez watershed.

Fig. 1 Locations of some of stations in the Dez watershed
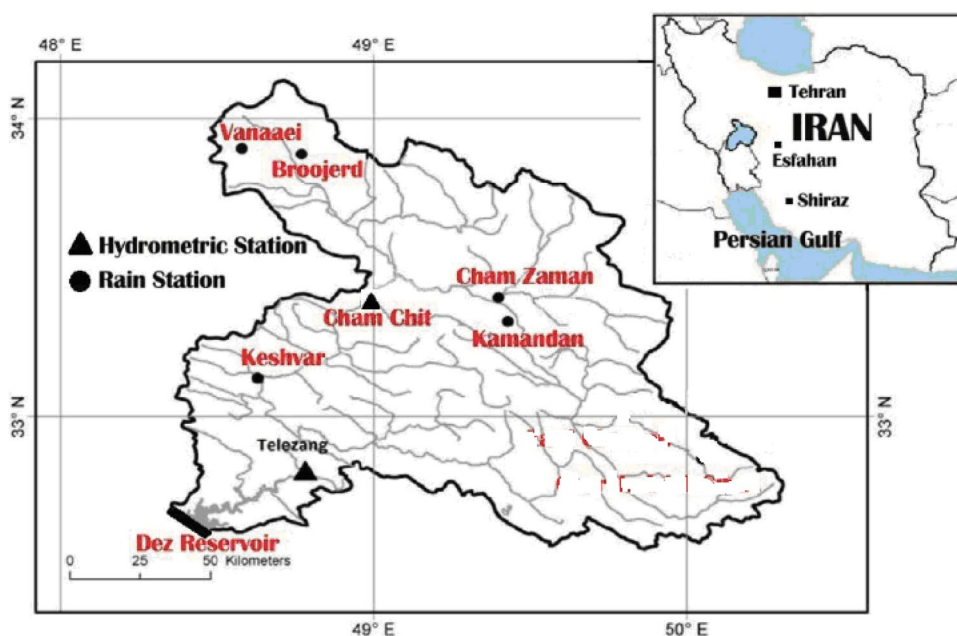
The major rivers of this watershed are the Dez, Sezar, Zaz, Bakteari, Tiereh, Marbereh, Sabzeh, and Sorkab rivers. Mean annual flows of these rivers are:

Dez (260 CMS), Sezar (116 CMS), Zaz (19.2 CMS), Bakteari (160 CMS), Tiereh (4.7 CMS), Marbereh (10.5 CMS), Sabzeh (7.31 CMS), and Sorkab (5.7 CMS).

Figure 2 shows the schematic connections between the Dez River and its branches.

Mean annual temperature is 24.2 °C in Tang 5 Bakteari. The difference between mean annual rainfalls of the climatic stations of the Dez watershed is high. Minimum and maximum annual rainfalls are 496.9 mm (in the Dez Dam station) and 995.9 mm (in the Keshvar station), respectively.

3 Research Methodology

This study includes the following steps:

1. preparation of the time series data of precipitation, temperature, and flow discharge in different stations at the upstream of the Dez dam;
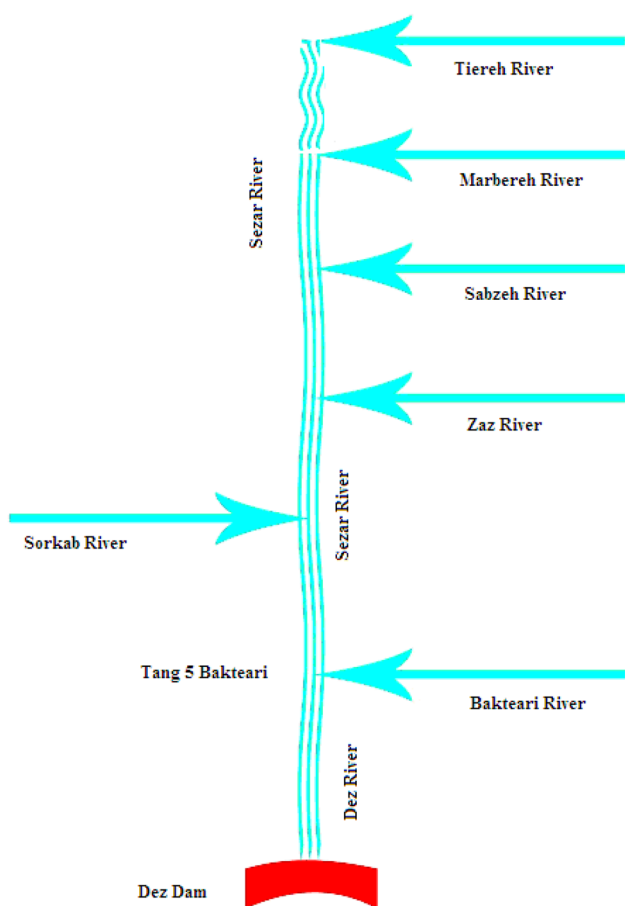

Fig. 2 Schematic connections between the Dez River and its branches

2. evaluation of quality of data (homogeneity and lack of change point);
3. trend analysis of precipitation, temperature, and flow discharge time series data by different MK test and TSA estimator;
4. calculation of SPI and SDI for different time scales;
5. comparison between SPI and SDI and determination of their correlation coefficient for different time scales.

Based on the mentioned stages, the required materials and methods of research methodology were selected and their details are explained in the following:

- Preparation of daily precipitation, temperature, and flow discharge data:

The data used in this study are concerned with 7 hydrometric stations (for daily flow discharge data), 11 climatic stations (for daily precipitation data), and 1 climatic station (for daily temperature data). The sources of these data are databases of the Iranian Ministry of Energy and the Iran Meteorological Organization. These stations do not have a simultaneous time period. Therefore, the data of their common time period are extracted. No data were missing in this common time period (from 1981 to 2012).

- Applied methods for the detection of homogeneity and lack of change point in time series data:

The run test determines homogeneity and randomness of time series data. In this test, values above the median are distinguished as positive and values below the median are distinguished as negative. A run is defined as a series of consecutive positive (or negative) values. The test statistic is:

$$Z = \frac{R - \bar{R}}{S_R} + 1, \tag{1}$$

where R is the number of runs, $\bar{R} = \frac{2n_1 n_2}{n_1 + n_2} + 1$, and $S_R^2 = \frac{2n_1 n_2 (2n_1 n_2 - n_1 - n_2)}{(n_1 + n_2)^2 (n_1 + n_2 - 1)}$ n_1 and n_2 are the number of positive and negative values in the time series data. For n_1 and $n_2 > 10$, if $|Z| > 1.96$, time series data are homogenous (non-randomness) at the 5% significance level.

The Pettitt's test shows change points in time series data. The Pettitt's test is a nonparametric test that requires no assumption about the distribution of data. The Pettitt's test is an adaptation of the tank-based Mann–Whitney test that allows identifying the time at which the shift occurs. The statistic used for the Pettitt's test is computed as follows: Let $D_{ij} = -1$ if $(x_i - x_j) < 0$, $D_{ij} = 0$ if $(x_i - x_j) = 0$, $D_{ij} = 1$ if $(x_i - x_j) > 0$:

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=i+1}^{T} D_{ij}, \tag{2}$$

where T is the number of data in time series data.

The Petitt's statistic is:

$$K_T = \max|U_{t,T}|. \tag{3}$$

The significance probability of K_T is:

$$p\text{value} \approx 2\exp\left(\frac{-6K_T^2}{T^3 + T^2}\right). \tag{4}$$

If p value ≤ 0.05, time series data have change point at the 5% significance level.

- The different Mann–Kendall trend test (MK) and TSA estimator:

The Mann–Kendall trend test (MK1):

The MK test is the rank-based nonparametric test [7]. Test statistic S is:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \text{sgn}(x_j - x_i), \tag{5}$$

where x_i and x_j are the sequential data values, n is number of the data, and sgn is a function:

$$sgn(y) = \begin{cases} 1 & \dots & \text{if}(y > 0) \\ 0 & \dots & \text{if}(y = 0) \\ -1 & \dots & \text{if}(y < 0) \end{cases}. \tag{6}$$

The Trend slope (Theil and Sen's median slope):

Theil–Sen's estimator estimated the slope of N pairs of data points [8] and calculated them as $Qi = (x_j - x_k) / (j - k)$ for $i = 1\dots N$.

Where: x_j and x_k are data values at times j and k, $(j > k)$. The median of these N values of Q_i is Sen's estimator of slope.

The Mann–Kendall test with trend-free pre-whitening (MK2):

This method was stated by [9, 29].

The procedure of this method is:

1. Computation of the lag-one ($k = 1$) autocorrelation coefficient (r1);
2. If $\frac{-1 - 1.645\sqrt{n-2}}{n-2} \leq r_1 \leq \frac{-1 + 1.645\sqrt{n-2}}{n-2}$ (n is number of data), then the data are assumed to be serially independent at 10% significance level (CL = 90%) and no pre-whitening is required.
3. Computation of nonparametric TSA slope (β) and remove the trend from the series.
4. Computation of the lag-1 autocorrelation of the detrended series.
5. Remove the lag-one autoregressive component (AR(1)) from the detrended series.
6. The trend is added to the residual series (preparation of a mixed series).

The significance of the trend of the mixed series is determined by the Mann–Kendall test.

The modified Mann–Kendall tests (MK3):

The modified Mann–Kendall test, proposed by [30], considers all the significant autocorrelation structure in a time series. In this method, modified variance is used for calculating the Mann–Kendall z [29].

- The applied drought indices:

Standardized precipitation index (SPI):

Research [31] published computational details of SPI and a guideline for application of SPI. The SPI is a dimensionless probability index, and its computational steps for a given location and time scale are:

a. Data sets are fitted to a probability density function (PDF). The selection of the suitable parametric distribution is very important. This subject can affect accuracy of the SPI values. Research [31] recommended gamma distribution, but other parametric distributions may be appropriate for SPI.
b. Calculation of the cumulative probability of a rainfall event.
c. Then, the cumulative probability distribution is converted to a standard normal distribution (mean = 0 and variance = 1). This standard normal distribution shows the SPI value [32, 33].

Based on SPI, different states are defined. Seven states are considered from extremely wet to extreme drought (Table 1).

Streamflow drought index (SDI):

Research [34] developed SDI drought index for the evaluation of severity of droughts. They used monthly streamflow discharge for this index.

Table 1 Different states based on SPI

State	Criterion
Extremely wet	SPI ≥ 2
Severely wet	$1.5 \leq \text{SPI} \leq 1.99$
Moderately wet	$1 \leq \text{SPI} \leq 1.49$
Normal	$-0.99 \leq \text{SPI} \leq 0.99$
Moderate drought	$-1.49 \leq \text{SPI} \leq -1$
Severe drought	$-1.99 \leq \text{SPI} \leq -1.5$
Extreme drought	SPI ≤ -2

Based on SDI, states of hydrological droughts are defined. Five states are considered from 0 (nondrought) to 4 (extreme drought); see Table 2.

For 3 month time scale, the considered four periods are: January–March, April–June, July–September, and October–December. For 6 months time scale, the considered two periods are: January–June and July–December. For 9 month time scale, the considered two periods are: January–July and April–December. For 12 month time scale, January–December is considered. Cumulative values of precipitation or flow discharge at each period are calculated for different years (X_T). The drought index at each period is $(X_T - \overline{X_T})/S_{X_T}$. S_{X_T} is standard deviation of cumulative values of precipitation or flow discharge at each period. For different time scales at each year, the minimum value of drought index must be selected. For example for 3 month time scale at each year, four values are calculated and minimum value among four values is selected as 3 months drought index at this year.

For the determination of correlation coefficient between precipitation and flow discharge or SPI and SDI, this research uses the Pearson correlation coefficient:

$$r = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}}. \tag{7}$$

4 Results and Discussion

- Preparation of monthly and annual precipitation, temperature, and flow discharge data:

Table 2 Definition of states of hydrological droughts based on SDI

State	Description	Criterion
0	Nondrought	$SDI \geq 0$
1	Mild drought	$-1 \leq SDI < 0$
2	Moderate drought	$-1.5 \leq SDI < 1$
3	Severe drought	$-2 \leq SDI < -1.5$
4	Extreme drought	$SDI < -2$

Time scales and correlation between SPI and SDI and correlation between precipitation and flow discharge

The summation of the daily precipitation data at each month is the value of the monthly precipitation and summation of the monthly precipitations at each year is the annual precipitation. The mean of the daily temperature and flow discharge data at each month is the value of the mean of monthly temperature and flow discharge, and the mean of the monthly temperatures and flow discharges at each year is the value of the mean of annual temperature and flow discharge. The minimum and maximum temperatures at each month and year are minimum and maximum monthly and annual temperature, respectively .

- Detection of homogeneity and lack of change point in time series data:

The run test showed that time series data (both annual and monthly data) are homogenous ($|Z| > 1.96$) at the 5% significance level. The Pettitt's test illustrates that time series data (both annual and monthly data) did not have any change points (p value ≥ 0.05) at the 5% significance level.

- Results of different MK tests and TSA estimator for trend analysis of precipitation, temperature and flow discharge time series data:

The precipitation time series data:
The MK test shows that precipitation time series data does not have any trend in eight climatic stations. Other stations (The Telezang, the Keshvar, and the Dez dam climatic stations) have a trend in March (Table 3).

The MK tests illustrate that precipitation time series data have an increasing trend in October and November, and a decreasing trend from December to May in the Telezang, the Keshvar, and the Dez dam climatic stations. The maximum decreasing trend occurred in March. In other words, TSA estimator shows that the precipitation time series data have a positive slope in fall and a negative slope in winter and spring at these climatic stations.

The temperature time series data in Tang 5 Bakteari:
(a) The mean temperature:
Various MK tests show that the mean temperature time series data have a decreasing trend in April and May, and an increasing trend from October to December and August and September. The TSA estimator illustrates a positive

Table 3 Z value, significance level of trend, and TSA's slope of precipitation time series data in March

Climatic station	MK1 test Z value (significance level %)	MK2 test Z value (significance level %)	MK3 test Z value (significance level %)	TSA's slope (mm/year)
The Dez dam	−2.69 (1%)	−2.69 (1%)	−2.69 (1%)	−1.623
Keshvar	−1.87 (10%)	–	–	−2.882
Telezang	−1.97 (5%)	−1.97 (5%)	−1.97 (5%)	−2.557

slope in fall and summer and a negative slope in winter and spring. The Maximum positive slope is 0.154 °C/year (in November) and maximum negative slope is − 0.12 °C/year (in April). Rising temperature increases evaporation (especially in the Khuzestan province). As this province is at the sea level, the winds transfer the water evaporated in this province to the highlands such as the Dez watershed leading to an increase in rainfall in this watershed. In addition, this station is close to the Telezang, Keshvar, and the Dez dam climatic stations. These stations are adjacent to the reservoir of the Dez dam. A temperature rise can increase the evaporation from the reservoir of the dam which leads to an increase in rainfall in fall (unlike winter and spring). However, the effects of the Dez dam reservoir on farther and higher stations are negligible.

(b) The minimum temperature:

The different MK tests show that the minimum temperature time series data have an increasing trend from October to December and March. The TSA estimator illustrates a positive slope in fall, winter, and summer, and a negative slope in spring. Maximum positive slope is 0.205 °C/year (in October) and maximum negative slope is − 0.033 °C/year (in June). This indicates the regional warming.

(c) The maximum temperature:

The different MK tests show that the maximum temperature time series data have an increasing trend from October to December and from July to September and decreasing trend from February to April. The TSA estimator illustrates a positive slope in fall and summer and a negative slope in winter and spring. Maximum positive slope is 0.13 °C/year (in October) and maximum negative slope is − 0.271 °C/year (in April). In other words, climatic conditions become tighter.

The flow discharge time series data:

The MK1, MK2, and MK3 tests show that 52, 35, and 44 flow discharge time series data have significant trend (Table 4).

Table 4 Significance level of trend of flow discharge time series data (determined by the different MK tests) and sign of trend line slope (determined by TSA estimator)

Hydrometric station	Test	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Sepid Dasht Sezar	MK1	0.05	0.05	0.1	–	–	0.05	0.01	0.05	–	–	–	–	0.05
	MK2	0.1	0.05	0.1	0.05	0.05	0.01	0.01	0.05	0.05	–	–	0.1	0.05
	MK3	–	0.05	0.1	–	–	0.1	0.01	–	–	–	–	–	0.1
	Sign of trend	–	–	–	–	–	–	–	–	–	–	–	–	–
Sepid Dasht Zaz	MK1	–	–	–	–	–	–	0.1	0.01	0.01	0.05	–	–	–
	MK2	–	–	–	–	–	–	0.1	–	0.01	–	–	–	–
	MK3	–	–	–	–	–	–	0.1	0.05	0.05	0.1	–	–	–
	Sign of trend	–	+	+	+	+	–	–	–	–	–	–	–	–
Telezang	MK1	0.05	0.1	–	0.1	0.1	0.05	0.01	0.05	0.01	0.05	0.05	0.05	0.05
	MK2	–	0.1	–	0.1	–	0.05	0.01	–	0.1	–	–	0.01	–
	MK3	0.1	0.1	–	0.1	–	0.05	0.01	0.1	0.05	0.1	0.1	0.1	–
	Sign of trend	–	–	–	–	–	–	–	–	–	–	–	–	–
Dorud	MK1	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.05	0.05	–	0.05	0.01
	MK2	–	0.05	0.01	0.01	–	0.1	–	0.05	–	0.01	–	0.01	–
	MK3	0.1	0.01	0.01	0.05	0.05	0.05	0.01	0.05	0.1	0.1	–	–	0.1
	Sign of trend	–	–	–	–	–	–	–	–	–	–	–	–	–
Dareh Takht	MK1	0.1	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.1	0.05	0.01
	MK2	0.1	0.01	–	–	–	0.01	–	–	–	0.05	0.05	0.01	–
	MK3	0.1	0.1	0.01	0.05	0.05	0.05	0.01	0.05	0.05	0.05	–	0.1	0.05
	Sign of trend	–	–	–	–	–	–	–	–	–	–	–	–	–
Cham Chit	MK1	0.05	–	–	–	0.1	–	–	–	–	–	–	–	–
	MK2	0.05	–	–	–	–	–	–	–	–	–	–	–	–
	MK3	–	–	–	–	–	–	–	–	–	–	–	–	–
	Sign of trend	+	+	+	+	+	+	–	–	–	–	+	+	–
Keshvar	MK1	–	–	–	–	0.1	0.01	–	–	–	–	–	–	–
	MK2	–	–	–	–	0.1	–	–	–	–	0.01	–	–	–
	MK3	–	–	–	–	0.1	0.05	–	–	–	–	–	–	–
	Sign of trend	+	+	–	–	–	–	–	–	–	–	–	+	–

As the MK1 test considers the autocorrelation between data, it has more significant trends. Table 4 illustrates that flow discharge is decreasing in the Dez watershed. The slope of trend line of flow discharge time series data in the Sepid Dasht Sezar, Telezang, Dorud, and Dareh Takht hydrometric stations is negative at the different months of the year. The Sepid Dasht Sezar, Telezang, Dorud, and Dareh Takht hydrometric stations are on the Sezar, Dez, Tiereh, and Marbereh rivers, respectively. The watersheds of these rivers include both mountainous and plains regions. The flow discharge of these rivers depends on snow cover area in their watersheds. Global warming has reduced snow cover area in these regions considerably. The most reduction of flow discharge is 12.18 CMS/year in April for the Telezang hydrometric station. As the Telezang hydrometric station is located at the end of the Dez watershed, the flow discharge of this station is more than other stations. Therefore, the reduction in flow discharge of this station is more than other stations.

The slope of the trend line of flow discharge time series data in the Sepid Dasht Zaz, Keshvar, and Cham Chit is negative and positive at the different months of the year. The Sepid Dasht Zaz, Keshvar, and Cham Chit hydrometric stations are on the Zaz, Sorkab, and Sabzeh rivers, respectively. The watersheds of these rivers include mountains. In Sepid Dasht Zaz and Keshvar, a significant trend of flow discharge occurs at months in which the slope of trend line of flow discharge time series data is negative.

The watershed of the Cham Chit hydrometric station is mountains and small. Therefore, a significant trend of flow discharge occurs at months in which the slope of the trend line of flow discharge time series data is positive. In the below box chart (Fig. 3), the results of the MK test (Z values) are shown for monthly flow discharge time series data of rivers in the Dez watershed.

Figure 3 illustrates the decreasing trend of flow discharges, especially in March and April, and median of Z values is negative for all months. The flow discharge is strongly dependent on snow cover area in April and March and reaches its maximum value in those months too.

- Results of drought indices (SPI and SDI).

From 1981 to 2012 (31 years), droughts have occurred. SPI and SDI are tools for determination of the number and intensity of the occurred droughts.

Table 5 shows the number of specified severe and extreme droughts by SPI in different meteorological stations and time scales. The calculated SPI3, SPI6, SPI9, and SPI12 for the Telezang station are illustrated in Fig. 4 during the period 1981–2012.

Table 6 shows the number of specified severe and extreme droughts by SDI in different hydrometric stations and time scales. The calculated SDI3, SDI6, SDI9, and SDI12 for the Telezang station are illustrated in Fig. 5 during the period 1981–2012.

Fig. 3 Box chart for Z values of monthly flow discharge time series data in the Dez watershed (1981–2012)
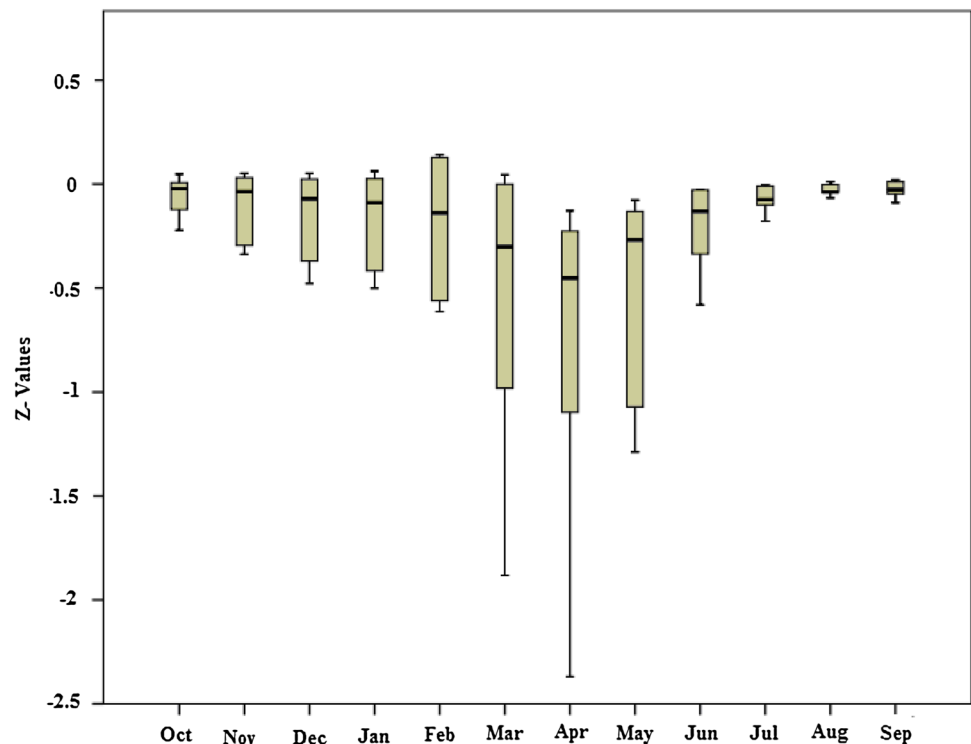
Table 5 Number and percentages of severe and extreme droughts of various time scales in different climatic stations of the Dez watershed using SPI

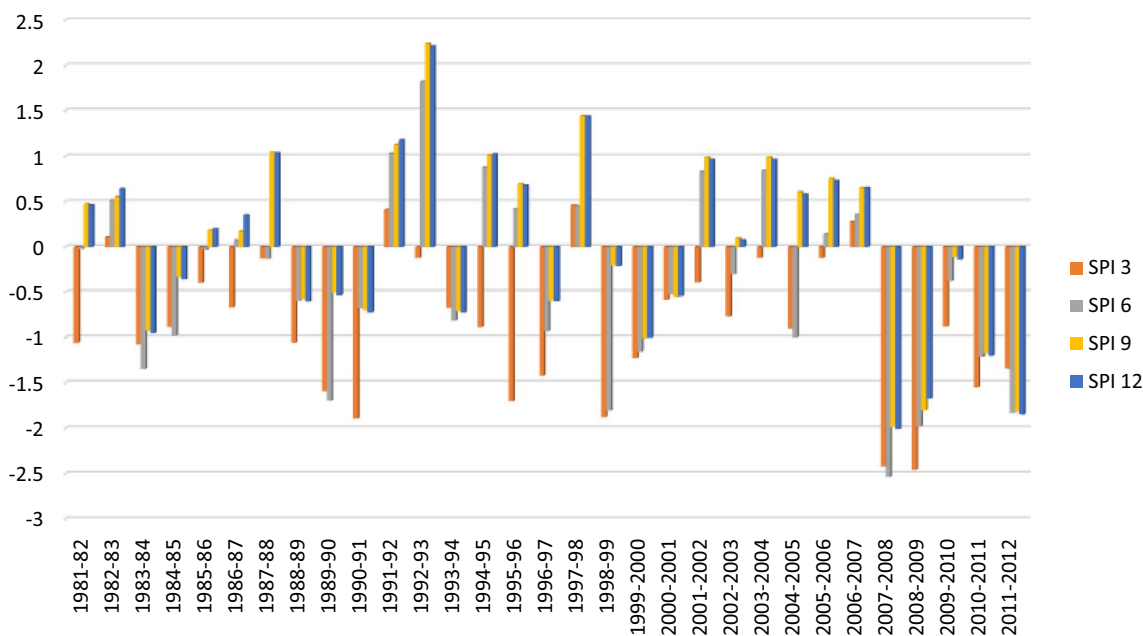| Climatic station	State	3 month number (%)	6 month number (%)	9 month number (%)	12 month number (%)
The Dez dam	Severe drought	4 (12.9)	3 (9.68)	3 (9.68)	3 (9.68)
	Extreme drought	2 (6.45)	2 (6.45)	0 (0)	0 (0)
Telezang	Severe drought	5 (16.13)	4 (12.9)	3 (9.68)	2 (6.45)
	Extreme drought	2 (6.45)	1 (3.23)	0 (0)	1 (3.23)
Broojerd	Severe drought	5 (16.13)	3 (9.68)	1 (3.23)	1 (3.23)
	Extreme drought	0 (0)	1 (3.23)	1 (3.23)	1 (3.23)
Vanaaei	Severe drought	4 (12.9)	3 (9.68)	1 (3.23)	1 (3.23)
	Extreme drought	1 (3.23)	1 (3.23)	0 (0)	0 (0)
Dorud	Severe drought	3 (9.68)	2 (6.45)	1 (3.23)	1 (3.23)
	Extreme drought	2 (6.45)	1 (3.23)	1 (3.23)	1 (3.23)
Cham Zaman	Severe drought	7 (22.58)	3 (9.68)	2 (6.45)	2 (6.45)
	Extreme drought	1 (3.23)	1 (3.23)	1 (3.23)	1 (3.23)
Kamandan	Severe drought	2 (6.45)	1 (3.23)	1 (3.23)	1 (3.23)
	Extreme drought	3 (9.68)	3 (9.68)	1 (3.23)	1 (3.23)
Dareh Takht	Severe drought	3 (9.68)	2 (6.45)	3 (9.68)	3 (9.68)
	Extreme drought	3 (9.68)	2 (6.45)	0 (0)	0 (0)
Keshvar	Severe drought	3 (9.68)	2 (6.45)	4 (12.9)	4 (12.9)
	Extreme drought	3 (9.68)	2 (6.45)	0 (0)	0 (0)
Kazem Abad	Severe drought	4 (12.9)	3 (9.68)	1 (3.23)	1 (3.23)
	Extreme drought	1 (3.23)	1 (3.23)	1 (3.23)	0 (0)
Marvak	Severe drought	1 (3.23)	2 (6.45)	1 (3.23)	3 (9.68)
	Extreme drought	4 (12.9)	2 (6.45)	2 (6.45)	1 (3.23)

Fig. 4 Calculated SPIs for different time scales in the Telezang station (1981–2012)

Table 6 Number and percentages of severe and extreme droughts of various time scales in different hydrometric stations of the Dez watershed using SDI

| Hydrometric station	State	3 month number (%)	6 month number (%)	9 month number (%)	12 month number (%)
Sepid Dasht Sezar	Severe drought	5 (16.13)	5 (16.13)	3 (9.68)	3 (9.68)
	Extreme drought	1 (3.23)	0 (0)	0 (0)	0 (0)
Sepid Dasht Zaz	Severe drought	3 (9.68)	3 (9.68)	1 (3.23)	1 (3.23)
	Extreme drought	2 (6.45)	1 (3.23)	2 (6.45)	2 (6.45)
Telezang	Severe drought	4 (12.9)	3 (9.68)	2 (6.45)	3 (9.68)
	Extreme drought	0 (0)	0 (0)	0 (0)	0 (0)
Dorud	Severe drought	5 (16.13)	2 (6.45)	1 (3.23)	1 (3.23)
	Extreme drought	1 (3.23)	0 (0)	1 (3.23)	1 (3.23)
Dareh Takht	Severe drought	2 (6.45)	0 (0)	0 (0)	0 (0)
	Extreme drought	0 (0)	0 (0)	0 (0)	0 (0)
Cham Chit	Severe drought	6 (19.35)	4 (12.9)	2 (6.45)	2 (6.45)
	Extreme drought	0 (0)	0 (0)	0 (0)	0 (0)
Keshvar	Severe drought	5 (16.13)	2 (6.45)	2 (6.45)	2 (6.45)
	Extreme drought	0 (0)	1 (3.23)	0 (0)	0 (0)
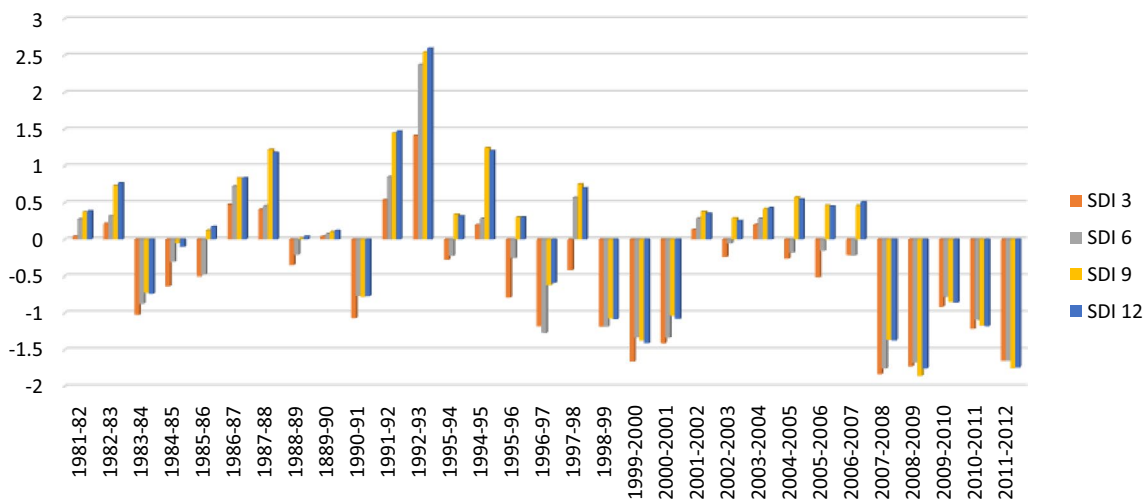
Fig. 5 The calculated SDIs for different time scales in the Telezang station (1981–2012)

Tables 5 and 6 show that, in short time scales (especially 3 months), the number of droughts is more than those of long time scales. Also for short time scales, Figs. 4, 5 illustrate that the average of SPI and SDI is less than those of long time scales. However, the maximum of SPI and SDI for long time scales is more than those of short time scales during the wet period. In the drought period and for short time scales, the value of indices, especially SPI, is less than those of long time scales. Some of the short time scales droughts include months with zero precipitation and a minimum flow discharge. This increases the number and severity of droughts and decreases the value of SPI and SDI.

By evaluation of SDI, it is observed that the severity and the number of droughts in the Dareh Takht hydrometric station is less than other climatic stations. This station is at the highest elevation, 1820 m, in the Dez watershed. In addition, the Sepid Dasht Zaz has the most number of extreme droughts and the least value of SDI. This station is located on the Zaz River, a small river in the Dez watershed. The elevation of this station, 980 m, is a moderate elevation, while the severity of droughts in highlands is less than those of other parts of watershed. In addition, at stations at low elevation, around the Dez dam, the severity of drought is reduced due to the presence of the reservoir of the Dez dam. This is the case for SPI too. The Dorud, 1450 m, and

Table 7 Correlation coefficient between flow discharge and precipitation in different months

Station	Correlation coefficient											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Telezang	0.03	0.603	0.639	0.502	0.686	0.644	0.501	0.787	0.055	0	0.118	− 0.042
Dorud	0.276	0.563	0.375	0.092	0.349	0.349	0.2	0.77	0.177	0	0	− 0.059
Keshvar	0.112	0.701	0.559	0.457	0.481	0.774	0.607	0.798	0.263	0	− 0.103	− 0.224

Marvak, 1560 m, climatic stations have moderate elevation and the severity of drought is more than those of other stations.

- Correlation coefficient between flow discharge and precipitation.

Table 7 shows the correlation coefficient between flow discharge and precipitation in three stations: the Telezang, Dorud, and Keshvar stations.

In summer, the correlation coefficient between flow discharge and precipitation is negative and negligible (the value of precipitation is zero in summer). Maximum correlation coefficient between flow discharge and precipitation is less than 0.8. This proves the dependence of flow discharge on snow cover area in the Dez watershed. In May, correlation coefficient between flow discharge and precipitation is maximum (the value of precipitation is maximum in May). Also, as the elevation is increased, the correlation coefficient between flow discharge and precipitation is reduced. The Dorud station has the least value of correlation coefficient.

- Relationship between SPI and SDI

The relation between SDI and SPI in three stations is shown in Table 8.

By increasing time scale, the correlation coefficient between SPI and SDI increases. Long time scales includes months in which the correlation between precipitations and flow discharges is high (wet months from November to May). Tables 7 and 8 state this fact and this matter confirms that the correlation between precipitation and flow discharge in wet months is more than those of dry months.

The highest amount of correlation coefficient between SPI and SDI is as to the Telezang station. The height of this station is 463 m; therefore, the flow discharge at this station is highly dependent on precipitation level. While the lowest amount of correlation coefficient between SPI and SDI occurs in the Dorud station. The elevation of this station is 1450 m; therefore, its flow discharge has a high dependence on the snow cover area.

5 Conclusion

In the Dez watershed, the different MK test and TSA estimator illustrated that the temperature and precipitation are rising, but flow discharge is declining. The reason is the reduction of snow cover area in the mountains of the Dez watershed (as results of [5]). In addition, the number and severity of short-time droughts (@@3 months) is more than those of long-term droughts (12 months). As the time scale is increased, the correlation coefficient between flow discharge and precipitation (SPI and SDI) decreases, especially in higher stations. The values of the correlation coefficient between precipitation and flow discharge are almost equal to those obtained by [5].

The Dez watershed is at upstream of the Dez dam and much of this watershed area is mountainous. Therefore, in this watershed, dams have not regulated flow discharge of rivers and fluvial flows have natural regime. Rivers of this watershed supply fluvial flow of the Dez River (Iran's second largest river). The Dez River supplies drinkable, and agricultural and industrial water demands of western provinces of Iran as the Khuzestan and the Lorestan provinces. In recent years, the Iranian government has desired to study the transfer of part of the water of the Dez River to the central provinces of Iran. Studies which study about the drought of this watershed can help the Iranian government in decision-making about water transfer to central parts of Iran and preventing social tensions between people that live in the west and the center of Iran.

Table 8 Correlation coefficient between SDI and SPI

Station	Telezang				Dorud				Keshvar			
Time scale (months)	3	6	9	12	3	6	9	12	3	6	9	12
R^2 between SPI and SDI	0.46	0.681	0.808	0.809	0.033	0.163	0.294	0.302	0.447	0.574	0.723	0.731

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