Detection of abrupt shift and non-parametric analyses of trends in runoff time series in Dez River Basin

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**ABSTRACT

The present study aims to investigate the homogeneity of runoff time series and also to review the existence of trends in Tale Zang hydrometric station (the hydrometric station in the entrance of Dez Reservoir) runoff, using 61 years (1956–2016) daily observatory data. Pettit test, which is a common method in investigating the homogeneity of time series, was used to identify change points. Both Mann-Kendall and auto-correlated Mann-Kendall tests were applied to analyze the existence or non-existence of trends in each annual, seasonal, and monthly time series observed in a runoff. In time series, significant trends in 95% level of confidence were recognized, upper and lower limit values were presented for Sen’s slope and it was tested for the increasing or decreasing trends in nature. Based on the results of this study, the significant change point in 95% level of confidence was recognized in Annual, Spring, Summer, Autumn, March, May, June, July, August, September, and October in 1997, 1997, 1999, 1997, 1999, 1999, 1999, 1997, 2000, 2007, 2008, respectively. Analyzing the existence of a trend in 95% level of confidence indicated that in Spring, and in March, September, and October, for both Mann-Kendall and auto-correlated Mann-Kendall tests, the trend is significant and additive until the change point.

**Key words:** non-parametric test, Pettit test, runoff, Sen’s slope

**HIGHLIGHTS

- Investigating the changes in long term runoff time series in Tale Zang hydrometric for the first time.
- Investigating the magnitude of the change point or trend in 95% level of confidence.
- Studying existence or nonexistence of trend before and after change point of confidence.
- Determining the upper and lower limits of Sen’s slope.
- Assisting to water resource planners to make appropriate decisions.

**INTRODUCTION

Climate change and human activities have a significant influence on different components of the hydrology cycle (Milly \textit{et al.} 2002; Ishak \textit{et al.} 2013; Chen \textit{et al.} 2019; Esha & Imteaz 2019; Ashrafi \textit{et al.} 2020a, 2020b; Mohammadi \textit{et al.} 2020a, 2020b, 2021). In recent decades, about 31 percent of 145 main rivers in the world have indicated significant statistical changes in their annual flow (Zhai & Tao 2017; Dinpashoh \textit{et al.} 2019). In arid and semi-arid regions, water resources demand mostly relates to agriculture. Population increase in the future results in higher demand for irrigation, industry, and drinking. It is expected that the hydrological system response to these changes may be regarded as a significant option for climate change (Mirza \textit{et al.} 1998; Marofi \textit{et al.} 2012; Lotfifard \textit{et al.} 2019). Some researchers have concentrated on identifying nonstationary changes in hydrological long-term time series (Wang \textit{et al.} 2015; Deng & Chen 2017; Zhai & Tao 2017). In addition, understanding the reasons for runoff change in a changing environment to confront drought or flood and also prevent unpredicted changes in the future is very important (Casse & Gosset 2015; Farajpanah \textit{et al.} 2020). Lots of previous studies have addressed changes in runoff average or changes in hydrological trend (Zuo \textit{et al.} 2012; Rougé \textit{et al.} 2013; Feng \textit{et al.} 2016; Gao \textit{et al.} 2016; Biazar & Ferdosi 2020; Esmaeili-Gisavandani \textit{et al.} 2021). Different techniques have been utilized to recognize possible changes including the Mann-Kendall

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test, Bayesian inference, and Pettit test (Reeves et al. 2007) in which significant changes in average values are defined as abrupt shifts for hydrological time series (Verbesselt et al. 2010; Rougé et al. 2013). Abrupt changes may be related to some anthropogenic activities including construction of reservoirs and dams, regulation of water flow, and a rapid increase in water consumption (Zhang et al. 2015; Cloern et al. 2016; Kam & Sheffield 2016; Wu et al. 2017). An abrupt change point is often considered a breakpoint. Usually, hydrological records, have been influenced a little by human beings’ activities before reaching breakpoint; but after that human intense activity affects them seriously. Furthermore, a significant gradual trend may occur in nonstationary hydrological time series. The most effective human interventions consist of a gradual increase in population, hydraulic engineering, and soil surface coverage (Zhang et al. 2015; Cloern et al. 2016; Kam & Sheffield 2016). Some human activities (such as reservoirs’ hydrologic regulations) may change seasonal or annual characteristics of a flow (current) (White et al. 2005). By the way, flow periodical changes derived from human activities don’t attract much attention, although they play a significant role in providing regional water and hydropower generation (Koch et al. 2011; Stojković et al. 2014).

Villarini et al. (2011) suggested that the change point test should be applied on time series before evaluating hydrological time series trends. An abrupt shift in average and variance may be related to climate regime change (Potter 1976; Hare & Mantua 2000; Alley et al. 2003; Swanson & Tsonis 2009). The abrupt shift in average may also be related to anthropogenic factors such as dam and reservoir system construction, land coverage and use change, agricultural works, and river water displacement (Potter 1979; Villarini et al. 2009).

Dez river basin, as a strategic basin, plays a key role in the development of the southwest of Iran through providing drinking, and agricultural water. The largest rivers of this basin include Dez, Sezar, Bakhtiari, Tiereh, Marbereh, Sabzan, and Sorkhab (Adib & Tavancheh 2019). Height differences in the region and Zagros mountains have influenced regional climate regimes and caused relative heterogeneity in Dez river basin climate characteristics (Marofi et al. 2012).

Dez dam has the most stable hydropower plant in Iran which besides supplying the agricultural and drinking demands, contributes to power generation in Iran’s cross country (national) network. Therefore the water level in reservoirs and its management is very important for the reservoir operators. Hence, estimating changes in the reservoir input and updating the rule curve of the Dez dam requires special attention. In this regard, it seemed necessary for present research to study the trend of the change in runoff entering the Dez reservoir. The last hydrometric station entering the Dez reservoir is Tale Zang station. This station is one of the best hydrometric stations considering the length of statistical period and quality of registered data and its data has been utilized in the present research.

The present research studies the following issues:

1. Do long-term time series (annual, seasonal, and monthly) in Tale Zang hydrometric station runoff have to change points or not?
2. How much is the magnitude of this change point or trend (in 95% level of confidence)?
3. Studying existence or nonexistence of trend before and after change point in runoff time series (in 95% level of confidence).
4. Determining the upper and lower limits of Sen’s slope in modes in which trend exists and also specifying its additive or subtractive nature.

MATERIALS AND METHODS

The present research used 61 years of daily runoff data of the Tale Zang hydrometric station located in the Dez basin. 17 data sets including annual (1 data set), seasonal (4 data sets- 1 data set for each season), and monthly (12 data sets- one data set for each month) were generated. For each data set, the homogeneity test (Pettit test) was performed in a 95% level of confidence to recognize the existence or non-existence of breakpoint. To study the existence or non-existence of trends in each time series (data sets), Mann-Kendall and auto-correlated Mann-Kendall tests were utilized. Trend study for all datasets in which breakpoint is evident is performed in two stages (for data until breakpoint and for data after breakpoint until the end). In data sets in which Mann-Kendall and auto-correlated Mann-Kendall tests of the trend are significant in 95% level of confidence, Sen’s slope certain upper and lower limits are calculated and presented, and according to them, it will be expressed if the trend is increasing or decreasing and their level of significance will be explained and results will be analyzed (Figure 1).

The utilized data

In the present research, daily rainfall amount belonging to the 1956–2016 period was used and from the mentioned annual, seasonal, and monthly time series amount of runoff was calculated and tested. To determine change points and specify monotonic trends, the process was analyzed. Each time series include 61 data. The data sets used in this research are complete and
lack the missing data. This data set is specific because there are not so many hydrometric stations in Iran with 61 years’ gapless data and most hydrometric stations in Iran include a much lower registered statistical period compared to Tale Zang station (the case study in present research). Tale Zang station is considered one of the first-class stations located in the Dez river basin (Heidarnejad & Gholami 2012). This station is the entrance hydrometric station of Dez Reservoir (Valipour et al. 2012). The geographical location of the Tale Zang hydrometric station in the Dez river basin is indicated in Figure 2.

The region understudy
Dez River drainage basin, as a grade three basin, is considered a subset of the great Karun basin and in larger classification, it is located in Perian Gulf and Oman Sea basin subsets. Of the main cities in this river, one may mention Dezful, Andimeshk,
and Shush. Dez River drainage basin is located in the central sections of the Zagros mountains (in Iran). The total area of this basin is about 23,230 square kilometers and the highest and lowest height of the basin relative to the mean sea level are 4,065 and –60 respectively. The slope of the basin is from north to south (Figure 2). Dez river includes the main rivers, i.e. Sezar and Bakhtiari, which join Karun river in Band-e-Ghir and then lead to the formation of Great Karun (Ashrafi et al. 2020a, 2020b).

The average annual temperature of the basin is 24.2 centigrade degrees. The average annual rainfall of the Dez river basin in different stations was different in a way that the long-term average changes interval for the basin’s annual rainfall in
different stations indicate values between 479 and 1,029 millimeters. The average basin slope is about 12.1% and in upstream slope becomes relatively steep (slope in 10% of the basin is more than 19.5 percent). The source of basin rainfalls is the clouds deriving from Mediterranean sea currents. The dominant regime of the region is snowfall and major atmospheric falls in autumn and winter take the form of snow. Melting snow from the end of winter to the end of spring provides the main part of the annual water of the basin’s surface rainfalls. The climate of the basin is classified in the cold and dry categories (Esmaelzadeh et al. 2015; Adib & Tavancheh 2019).

**Statistical methods**

Heterogeneity in time series may cause misinterpretation of limit events (Rahman et al. 2017) and mislead interpretation of trends. Abrupt shifts in average are one of the usual results of heterogeneity in time series’ data (Rahman et al. 2017). The importance of the homogeneity test has been indicated by Buffoni et al. (1999) and also Reiter et al. (2012). Their results showed that the homogeneity test has better performance in recognizing heterogeneity in datasets and determining change points in time series, compared to other methods. There are different methods to indicate abrupt shifts from which the Pettit test is considered an expanded nonparametric method for recognizing heterogeneity in datasets and determining change points in time series (Arikan & Kahya 2019). World Meteorological Organization suggests using Mann-Kendall’s non-parametric trend for identifying significant statistical biases in the environmental dataset (Irannezhad et al. 2016). Using the Man-Kendall trend test, due to its simplicity and power, is common for analyzing climate and hydrologic time series and may distinguish the missed values (Gavrilov et al. 2016). The Man-Kendall trend test, which is a non-parametric test, is usually used to diagnose monotonic trends of environmental data set (Pohlert 2016). In the Mann-Kendall test, it is not required to assume data normality (Helsel & Hirsch 2002). Hamed & Rao (1998) developed a modified Mann-Kendall test for auto-correlated data. As an example, a function of this modified method has been developed by Amir-Ataee et al. (2016). Yue et al. (2002), too, studied the power of the Mann-Kendall test in hydrological time series.

**Homogeneity test**

In the present research, Pettit’s test (1979) was selected to distinguish heterogeneity in time series analysis. In Pettit (1979) research, a non-parametric approach has been developed for analyzing change points which are still used extensively. This test calculates transferring data average in different significance levels of hypothesis test (Liu et al. 2012; LotfiRad et al. 2018; Adib et al. 2021). The Null hypothesis states that all data is homogenous, and there is an alternative hypothesis that opposes this hypothesis and indicates that there is one change in data average. The present research was accomplished in a 5% (p-value) empirical level of significance.

**Mann-Kendall trend and Sen’s slope estimation tests**

Mann-Kendall trend test is based on Mann (1945) and Kendall (1975) research (Kis et al. 2017) and is close to Kendall correlation coefficient ranking. Here the equation of this method is introduced and a detailed explanation expressed by Gilbert (1987) and Hipel & McLeod (1994) is as follows: To determine the monotonic trend in a time series, the Null hypothesis (H0) of Mann-Kendall states that there is no monotonic trend in the intended level of significance. The alternative hypothesis (Ha) in this test indicates that data, during time passage, follow a monotonic tendency explained in Equation (1):

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

(1)

In the above equation, \( j > k \) and

\[
\begin{align*}
k & = 1, 2, \ldots, n - 1 \\
j & = 2, 3, \ldots, n
\end{align*}
\]

n indicates the number of data.
\[ \text{sgn}(x_i - x_k) \text{ is calculated according to Equation (2).} \]

\[ \text{sgn}(x_i - x_k) = \begin{cases} +1 & \text{if } \sqrt{x_k} > 0 \\ 0 & \text{if } \sqrt{x_k} = 0 \\ -1 & \text{if } \sqrt{x_k} < 0 \end{cases} \quad (2) \]

Kendall (1975) proved that \( S \) has normal distribution following Equation (3) asymptotically.

\[ \text{E}(S) = 0 \]
\[ \text{Var}(S) = \left\{ n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right\} / 18 \quad (3) \]

In the above equation:
- \( g \) is the number of the tied groups in the data set;
- \( t_p \) is the data number in the tied group’s \( p^{th} \);
- \( n \) is the number of data in the time series.

A positive value indicates that the trend is increasing and in contrast, a negative value for \( S \) indicates that in the time we have had decreasing. For \( n > 10 \) (i.e. more than 10 observation), \( Z \) standard normal random variable may be utilized for hypothesis test (Equation (4)): additive

\[ Z = \begin{cases} \frac{S - 1}{\text{Var}(s)^{1/2}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S + 1}{\text{Var}(s)^{1/2}} & \text{if } S < 0 \end{cases} \quad (4) \]

\( S \) has direct and close relation with Kendall’s rank correlation coefficient (\( \tau \)) and so \( \tau \) test is equivalent to the \( S \) test (Equation (5)):

\[ \tau = \frac{s}{D} \quad (5) \]

where \( D \) is the possible number of observation pairs of total \( n \) observations (Equation (6)).

\[ D = \binom{n}{2} \quad (6) \]

The hypothesis test method was used in \( a = 50\% \) level of significance as a two-tailed test in which the Null hypothesis indicates that there is no monotonic trend in time series (\( H_0: \tau = 0 \)) and the alternative hypothesis suggests the existence of a significant monotonic trend in time series (\( H_a: \tau \neq 0 \)). The empirical level of significance for the \( p \)-value was determined.

The existence of positive autocorrelation in data increases the possibility of trend identification when in fact there is no trend and vice versa (Hamed & Rao 1998). The influence of autocorrelation in data is often ignored. Hamed & Rao (1998) assumed a suitable modified non-parametric test for autocorrelated data and developed a precise explanation of the modified Mann-Kendall trend test for autocorrelated data. In the present research, the mentioned modified Mann-Kendall test was utilized to consider the uncertainty of existence or non-existence of trend in the Mann-Kendall method. The modified Mann-Kendall version acts according to \( S \) variance correction \( S = (\text{Var}'(s)) \) (Hamed & Rao 1998; Taxak et al. 2014) (Equation (7)).

\[ \text{Var}'(s) = \text{Var}(S) \frac{n}{n_i^2} \quad (7) \]
In each data set with a change point, just one change point existed. Table 2 presents the average of runoff values until and after the change point (for data sets in which change point has been recognized) and runoff average for modes in which shown in Figure 3.

Age and has divided the data set in each mentioned data set to two sectors. Displacement in runoff average in change point is change points in the even no displacement occurred during data measurement years. It seems that the main cause for the existence of found archive information about historical worrying registered values, no evident reason for these change points is found and sets in which change point was observed, the number of change points was just one case. After extensive research in the April, November, and December were homogenous and no break point was distinguished (Table 1). In all other 11 data sets relating to winter and January, February, Summer, Autumn, March, May, June, July, August, September, and October data sets respectively in 1997, 1997, 1999, 1999, 1999, 1997, 2000, 2007 and 2008. In all data sets with change point, the average was downward and the most frequent year in which breakpoint was recognized was 1997. Data sets relating to winter and January, February, April, November, and December were homogenous and no break point was distinguished (Table 1). In all other 11 data sets in which change point was observed, the number of change points was just one case. After extensive research in the archive information about historical worrying registered values, no evident reason for these change points is found and even no displacement occurred during data measurement years. It seems that the main cause for the existence of found change points in the findings of this research is climate change which has resulted in displacement in registered runoff average and has divided the data set in each mentioned data sets to two sectors. Displacement in runoff average in change point is shown in Figure 5.

As stated before, from among 17 datasets understudy, in 11 data sets, change point in runoff average trend was recognized. Two-tailed Pettit test was utilized while null hypothesis stated that there is no shift (displacement) in data average and alternative hypothesis states that a certain datum may be distinguished for chang point and data set average is displaced in the statistical point of view, a significance empirical level (p values) is indicated in Table 1. According to obtained results, from the statistical point of view, a significant change point may be distinguished in 95% level of confidence for Annual, Spring, Summer, Autumn, March, May, June, July, August, September, and October data sets respectively in 1997, 1997, 1999, 1997, 1999, 1999, 1997, 2000, 2007 and 2008. In all data sets with change point, the average was downward and the most frequent year in which breakpoint was recognized was 1997. Data sets relating to winter and January, February, April, November, and December were homogenous and no break point was distinguished (Table 1). In all other 11 data sets in which change point was observed, the number of change points was just one case. After extensive research in the archive information about historical worrying registered values, no evident reason for these change points is found and even no displacement occurred during data measurement years. It seems that the main cause for the existence of found change points in the findings of this research is climate change which has resulted in displacement in registered runoff average and has divided the data set in each mentioned data sets to two sectors. Displacement in runoff average in change point is shown in Figure 5.

Correction coefficient \( \frac{n}{n^*} \) is evaluated as follows (Hamed & Rao 1998; Taxak et al. 2014) (equation 8):

\[
\frac{n}{n^*} = 1 + \frac{2}{n^2(n-1)(n-2)} \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2) \rho_s(i)
\]  

(8)

In the above equation, \( \rho_s(i) \) is the autocorrelation among ranks of calculated observations after subtracting a non-parametric trend estimator such as Sens’s slope and \( n^* \) is the number of the most effective number of observations to calculating autocorrelation in data; just \( \rho_s(i) \) ranked significant values are utilized for \( \text{Var}(S) \) which, in the case of positive autocorrelation, will be underestimated (Hamed & Rao 1998; Taxak et al. 2014).

To distinguish non-parametric trends, Sen’s slope estimator (Sen 1968) is used. This non-parametric method may calculate the change in time unit (direction and volume). Sen’s method should be constant during time uses a linear model to estimate trend slope and variance of residuals (Da Silva et al. 2015). First, \( N' \) slope estimates were calculated \( Q \) according to Equation (9).

\[
Q = \frac{x_{i'} - x_i}{i' - i}
\]

where \( x_{i'} \) and \( x_i \) are data values at \( i' \) and \( i \) times, respectively; where \( i' > i \). \( N' \) is the number of data pairs in which \( i' > i \).

In the case there is just one datum in each time period, Equation (10) will apply.

\[
N' = \frac{n(n-1)}{2}
\]

(10)

where, \( n \) is a number of time periods (Gilbert 1987; Gocic & Trajkovic 2013).

\( N' \) values related to \( Q \) are classified from small to large and \( Q \) median amounts indicate trend slope. The advantage of this method is that it limits the effect of outliers on the slope (Shadmani et al. 2012) and is free from statistical limitations.

**RESULTS AND DISCUSSION**

**Homogeneity test based on annual, seasonal, and monthly time series**

Two-tailed Pettit test was utilized while null hypothesis stated that there is no shift (displacement) in data average and alternative hypothesis states that a certain datum may be distinguished for chang point and data set average is displaced in the breakdown. The significance empirical level (p values) is indicated in Table 1. According to obtained results, from the statistical point of view, a significant change point may be distinguished in 95% level of confidence for Annual, Spring, Summer, Autumn, March, May, June, July, August, September, and October data sets respectively in 1997, 1997, 1999, 1997, 1999, 1999, 1997, 2000, 2007 and 2008. In all data sets with change point, the average was downward and the most frequent year in which breakpoint was recognized was 1997. Data sets relating to winter and January, February, April, November, and December were homogenous and no break point was distinguished (Table 1). In all other 11 data sets in which change point was observed, the number of change points was just one case. After extensive research in the archive information about historical worrying registered values, no evident reason for these change points is found and even no displacement occurred during data measurement years. It seems that the main cause for the existence of found change points in the findings of this research is climate change which has resulted in displacement in registered runoff average and has divided the data set in each mentioned data sets to two sectors. Displacement in runoff average in change point is shown in Figure 5.

As stated before, from among 17 datasets understudy, in 11 data sets, change point in runoff average trend was recognized. In each data sets with a change point, just one change point existed. Table 2 presents the average of runoff values until and after the change point (for data sets in which change point has been recognized) and runoff average for modes in which change point didn’t exist in the data set. According to the results presented in Table 2, in heterogeneous modes, the main difference in the data set average is in May which is equal to 167.3 and indicates that until change point, runoff average is 452.1 m³/sec and after change point, it reaches 284.8 m³/sec. Also, the least difference in data set average belongs to October, meaning that until change point, runoff average is 74.9 m³/sec and after change point, it becomes 59.9 m³/sec.
Mann-Kendall trend test based on annual, seasonal, and monthly amounts

Table 3 presents non-parametric p-values of the Mann-Kendall trend test to distinguish monotonic trends. Trends are analyzed using the Mann-Kendall test and the modified Mann-Kendall test (Hamed & Rao 1998) to study the possibility of the presence of autocorrelation in hydrological data. In data sets in which change point was found according to Pettit test, Mann-Kendall and autocorrelated Mann-Kendall tests, both before and after the change points, were reviewed in 95% level of confidence.

From a statistical aspect, the increasing trend of annual runoff is found to be significant based on Mann-Kendall and autocorrelated Mann-Kendall tests, both until the change point and after the change point. The runoff increasing trend in spring is found to be significant according to both Mann-Kendall and autocorrelated Mann-Kendall tests until the change point but after the change point no significant trend was observed. Also, the runoff increasing trend in March, September and October is significant before the change point, but after the change point, no significant trend change was observed. In other data sets, too, before and after breakpoint no trend was observed (Table 3). The important point in the obtained results is that homogeneity and Mann-Kendall results support and overlap each other. For example, in none of the data sets in which no change point is found in data set, no trend was recognized by the Mann-Kendall test, either.

Sen’s slope change interval

In Table 4, lower and upper limits of Sen’s slope for significant trends (distinguished in past stages), have been presented in 95% level of confidence. Sen’s slope calculations in annual data sets until change point (2008), in both normal Mann-Kendall and autocorrelated Mann-Kendall cases (AMAU, MAU), indicate the 1.49–2.09 m³ increase of runoff for each year. But after change point in both Mann-Kendall and autocorrelated Mann-Kendall cases (AMAA, MAA), explain 8.18–8.92 m³ increase of runoff. In spring, in both normal Mann-Kendall and autocorrelated Mann-Kendall tests, before the change point, i.e. 2007 (AMSPU, MSPU), the values obtained for Sen’s slope were similar. Between 1956–2007, a 3.75–2.15 m³/sec increase was recognized for each year in spring. Until the change point in March data set, i.e. 1999 in both Mann-Kendall and autocorrelated Man-Kendall trend tests (AMMU, MIMU), between 1956–1999, a 5.82–8.27 m³/sec increase was recognized for each month. In March and September, in both Mann-Kendall and autocorrelated Mann-Kendall trend tests, before the change point, i.e. 1997 (AMSEU, MSEU) values obtained for Sen’s slope were equal. Between 1956–1997, a 0.48–0.75 m³/sec increase for runoff has been identified. Until the change point of October data set (i.e, 1997), in both Mann-Kendall and

### Table 1 | Results of Pettit homogeneity test (p values of the significant change points in italics)

<table>
<thead>
<tr>
<th>Change point at year</th>
<th>p value (Two-tailed)</th>
<th>Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual</td>
<td>2008</td>
<td>0.026</td>
</tr>
<tr>
<td>Spring</td>
<td>2007</td>
<td>0.031</td>
</tr>
<tr>
<td>Summer</td>
<td>2000</td>
<td>0.04</td>
</tr>
<tr>
<td>Autumn</td>
<td>1997</td>
<td>0.024</td>
</tr>
<tr>
<td>Winter</td>
<td>……</td>
<td>0.124</td>
</tr>
<tr>
<td>Jan</td>
<td>……</td>
<td>0.268</td>
</tr>
<tr>
<td>Feb</td>
<td>……</td>
<td>0.198</td>
</tr>
<tr>
<td>Mar</td>
<td>1999</td>
<td>0.025</td>
</tr>
<tr>
<td>Apr</td>
<td>……</td>
<td>0.126</td>
</tr>
<tr>
<td>May</td>
<td>1999</td>
<td>0.011</td>
</tr>
<tr>
<td>Jun</td>
<td>1999</td>
<td>0.005</td>
</tr>
<tr>
<td>Jul</td>
<td>1997</td>
<td>0.007</td>
</tr>
<tr>
<td>Aug</td>
<td>1999</td>
<td>0.035</td>
</tr>
<tr>
<td>Sep</td>
<td>1997</td>
<td>0.001</td>
</tr>
<tr>
<td>Oct</td>
<td>1997</td>
<td>0.001</td>
</tr>
<tr>
<td>Nov</td>
<td>……</td>
<td>0.445</td>
</tr>
<tr>
<td>Dec</td>
<td>……</td>
<td>0.094</td>
</tr>
</tbody>
</table>
Figure 3 | Significant change points and downward shifts in the mean in the runoff amounts.
### Table 2 | Average runoff before and after the change point in case of annual, Seasonal & monthly

<table>
<thead>
<tr>
<th>Runoff average</th>
<th>Until the change point</th>
<th>After the change point</th>
<th>Difference</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual</td>
<td>255.7</td>
<td>114.1</td>
<td>141.6</td>
<td>239.2</td>
</tr>
<tr>
<td>Spring</td>
<td>358.6</td>
<td>195</td>
<td>163.6</td>
<td>331.8</td>
</tr>
<tr>
<td>Summer</td>
<td>436.6</td>
<td>301</td>
<td>135.6</td>
<td>396.6</td>
</tr>
<tr>
<td>Autumn</td>
<td>113</td>
<td>82.7</td>
<td>30.3</td>
<td>103.1</td>
</tr>
<tr>
<td>Winter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Feb</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mar</td>
<td>519.83</td>
<td>353.77</td>
<td>166.1</td>
<td>470.8</td>
</tr>
<tr>
<td>Apr</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>May</td>
<td>452.1</td>
<td>284.8</td>
<td>167.3</td>
<td>402.7</td>
</tr>
<tr>
<td>Jun</td>
<td>244.5</td>
<td>157.58</td>
<td>86.92</td>
<td>218.8</td>
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<tr>
<td>Jul</td>
<td>155.3</td>
<td>107</td>
<td>48.3</td>
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<tr>
<td>Aug</td>
<td>103.9</td>
<td>76.28</td>
<td>27.62</td>
<td>95.75</td>
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<tr>
<td>Sep</td>
<td>79.1</td>
<td>63.6</td>
<td>15.5</td>
<td>74.1</td>
</tr>
<tr>
<td>Oct</td>
<td>74.9</td>
<td>59.9</td>
<td>15</td>
<td>70</td>
</tr>
<tr>
<td>Nov</td>
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<td>119.5</td>
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<tr>
<td>Dec</td>
<td></td>
<td></td>
<td></td>
<td>186.6</td>
</tr>
</tbody>
</table>

### Table 3 | Results of the simple and autocorrelated Mann-Kendall (MK) trend tests (the p value of the significant monotonic tendency is in italics)

<table>
<thead>
<tr>
<th>Two-tailed test until the change point if any</th>
<th>Two-tailed test after the change point if any</th>
</tr>
</thead>
<tbody>
<tr>
<td>MK p value</td>
<td>Autocorrelated MK p value</td>
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<tr>
<td>Annual</td>
<td>0.019</td>
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<tr>
<td>Spring</td>
<td>0.021</td>
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<tr>
<td>Summer</td>
<td>0.102</td>
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<tr>
<td>Autumn</td>
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<tr>
<td>Winter</td>
<td>0.538</td>
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<tr>
<td>Jan</td>
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<td>Feb</td>
<td>0.723</td>
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<tr>
<td>Mar</td>
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<td>Apr</td>
<td>0.818</td>
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<td>May</td>
<td>0.194</td>
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<tr>
<td>Jun</td>
<td>0.064</td>
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<td>Jul</td>
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<td>Aug</td>
<td>0.143</td>
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<tr>
<td>Sep</td>
<td>0.029</td>
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<tr>
<td>Oct</td>
<td>0.016</td>
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<tr>
<td>Nov</td>
<td>0.704</td>
</tr>
<tr>
<td>Dec</td>
<td>0.245</td>
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</table>
autocorrelated Mann-Kendall trend tests (AMOU, MOU), between 1956–1997, 0.52–0.68 m³/sec increase of runoff was distinguished for each month.

In Figure 4, Sen’s slope change interval for each significant trend case (identified in the Mann-Kendall test) has been presented in a 95% level of confidence. Accordingly, the least change interval of Sen’s slope relates to AMOU and MOU and most change interval belongs to AMMU and MMU, but the upper limit of Sen’s slope, i.e. 8.92 m³/sec, belongs to AMAA and MAA.

### CONCLUSION

In the first phase of the present research, homogeneity of annual, seasonal, and monthly time series of the Tale Zang hydro-metric station runoff (hydrometric station in the entrance of Dez reservoir dam) was studied using Pettit’s test. Results of the Pettit test indicated that from 17 data sets of different time series (annual, seasonal, and monthly), 11 data sets are heterogeneous time series. In each time series with a change point, just one change point was recognized. In the second phase, the existence or nonexistence of trend in each time series was studied using Mann-Kendall and autocorrelated Mann-Kendall

![Figure 4](http://iwaponline.com/ws/article-pdf/doi/10.2166/ws.2021.357/948691/ws2021357.pdf)

**Figure 4** | Change bar related to Confidence intervals of Sen’s slope for the significant tendencies at 95% confidence level.
trend tests. In the cases with a change point time series, Mann-Kendall tests were calculated once until the change point and one after the breakpoint. And in the data sets that trend existed upper and lower limits of Sen’s slope were calculated and presented to clarify runoff changes level in that cases and determine the additive or subtractive nature of runoff.

Based on the results, a significant change point in a 95% confidence level was recognized in Annual, Spring, Summer, Autumn, March, May, June, July, August, September, and October data sets in 1997, 1997, 1999, 1999, 1999, 1999, 1999, 1997, 2000, 2007, and 2008. In all modes with change point in, the average was downward and the most frequent year in which break point was recognized was 2007. According to both Mann-Kendall and auto-correlated Mann-Kendall tests, until the change point and after that, trend is significant and increasing. The trend in a 95% level of confidence, in Spring and March, September and October under both the Mann-Kendall and the auto-correlated Mann-Kendall tests, the trend is additive and significant until the change point. The important point in the obtained results is that homogeneity and the Mann-Kendall test results support and overlap each other. For example, in none of the models in which no change point is found in the data set, no trend was recognized by the Mann-Kendall test, either. The least change interval of Sen’s slope relates to MOU and the greatest change interval of Sen’s slope belongs to MMU and AMMU, but greatest upper limit of Sen’s slope belongs to both MAA and AMAA with 8.92 m³/sec.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories. All data, models, and code are available from the corresponding author by request.

REFERENCES


Pohlert, T. 2016 *Non-parametric Trend Tests and Change-Point Detection*.


First received 5 August 2021; accepted in revised form 8 October 2021. Available online 19 October 2021.