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Trend analysis and detection of precipitation fluctuations in arid and semi-arid regions

H. Khosravi[a*], F. Sajedi-Hosseini[b], M. Nasrollahi[c], H.R. Gharechaei[a]

[a] *Faculty of Natural Resources ,University of Tehran ,Karaj, Iran*
[b] *Department of Watershed Management Engineering, Sari University of Agricultural Sciences and Natural Resources, Sari, Iran*
[c] *Semnan University, Semnan, Iran*

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Abstract

The most important impacts of climate change relate to temperature and precipitation. Precipitation is particularly important, because changes in precipitation patterns may lead to floods or droughts in different areas. Also, precipitation is a major factor in agriculture and in recent years interest has increased in learning about precipitation variability for periods of months to annual and seasonal trends and change points had been analyzed for 22 rainfall stations in Fars province during 1972 to 2011. Mann-Kendall non-parametric test and Sen's method had been used to determine positive or negative trends; also Pettitt test, Standard normal homogeneity test, Buishand range test, Von Neumann ratio, for detection of change points in the time series had been implemented. The TFPW approach had been used in order to decline the effects of autocorrelation and serial correlation on Mann-Kendall test. The results of Mann-Kendall test and Sen's Method showed decreasing trend for all rainfall stations except for the Monje station. But, no significant trends were observed in all stations. Also, the results indicated that the precipitation has not occurred nonhomogeneity; whereas all test indicated there is no change point on precipitation time series. No change and abrupt shift were visible in the precipitation time series except in winter for Ali Abad Khafr; and Ali Abad Khafr; Tangab and Ramjerd based on pettitt test and Standard normal homogeneity test, respectively.

Keywords*:* Fars Province; Mann-Kendall test; Pettitt test; Precipitation; Variability

1. Introduction

Rainfall is one of the most important climatic variables in which its drastic changes can lead to droughts (Choubin *et al.* 2014; Sigaroodi *et al.* 2014; Choubin *et al.* 2016b), widespread floods (Choubin *et al.* 2016a; Choubin *et al.* 2017), and death in the worst cases. Analyzing the trend of rainfall and its abrupt changes prepare valuable information in order to improve Strategies of water resource management, environmental protection, agricultural production, or in general economic development of the region (Gocic and Trajkovic, 2013). Hence, in recent years several studies on precipitation trends analysis have been done around the world and showed it has high importance.

Studying annual and seasonal rainfall on 32 stations during 1833-1996 was showed a decreasing trend across Italy in annual scale but this decreasing was significant just in south-central Italy. In seasonal scale was found a significant decreasing trend in spring on the south-central part and in autumn season on northern part (Buffoni *et al.* 1999). Changes in annual rainfall and number of rainy days per month and annual in 20 stations using Mann–Kendall test showed there was no significant climate change in arid and semi-arid regions in Iran (Modarres and Silva, 2007). Temporal and spatial patterns of precipitation in the Yellow River basin in China were investigated during 1960-2006. The results showed decreasing trend in all stations (Liu *et al.* 2008). Hejam et al. (2008) were investigated the trend of annual and

* Corresponding author. Tel.: +98 26 32223044
Fax: +98 26 32223044
E-mail address: hakhosravi@ut.ac.ir

seasonal rainfall changes in the central basin of Iran. They were found; in most cases, Mann–Kendall test and Sen's slope estimator have the same performance in terms of trend determination. Annual and monthly rainfall trend on 10 stations in Portugal using Mann-Kendall test, Sen's non-parametric method represented the sequence of positive and negative trends in seasonal and annual rainfall (Lima *et al.* 2010). Zagros Mountains between1961-2001 was found that most runoff trend in the basin was related to changes the amount of rainfall (Masih *et al.* 2011). Tabari *et al.* (2011) showed there was no trend in annual rainfall in western, south and southwest of Iran during years 1966-2005. Moghaddamneia *et al.* (2012) trend changes in the maximum amounts of rainfall in 24 hours and mean annual rainfall in Mazandaran province using regional Mann-Kendall test was determined in a 30-year period. Results showed that mean annual rainfall had an increasing trend at the significant level of 1%. Wijngaard *et al.* (2003) conducted an extensive analysis of daily European station series (1901 to 1999) of surface air temperature and precipitation with respect to homogeneity. Marť nez *et al.* (2009) applied three location specific homogeneity tests - the standard normal homogeneity test (SNHT), the Buishand range test and the Pettitt test to detect break year in annual maximum temperature and annual maximum temperature series of Spain. When two out of three tests detect the same year at a certain confidence level, the year was assumed as the breaking year. Karabork *et al.* (2007) performed two absolute homogeneity tests in 212 meteorological stations for the precipitation time series, which were SNHT and Pettitt test. Stations were considered inhomogeneous if at least one of the tests rejects the homogeneity at the significance level 5%. Urkes *et al.* (2008) used for determining whether the time-series are homogeneous or not, the non-parametric K–W test. Turkes (1999) were accomplished statistical evaluations of homogeneity for the annual and seasonal precipitation total series, and annual aridity index and temperature series by the nonparametric K–W test for the homogeneity of means of the sub-periods.

With regard to the potential of Fars province in agriculture sector and rainfall as the most effective climatic variable, doing of this study is important. Hence, the purpose of current study was determining annual and seasonal precipitation trend, abrupt changes using Mann-Kendall non-parametric test, Sen's method, and Pettitt test after a decline in the effects of autocorrelation and serial correlation (TFPW) on series time.

2. Materials and Methods

2.1. The Location of Study Area

Fars province is one of the 31 provinces of Iran and its center is Shiraz. It is located in 50° 36' to 55° 35' eastern longitudes and 27° 3' to 31° 40' northern latitudes. The province of Fars covers an area of 122608 square kilometers. It is one of the most important provinces in terms of Agriculture by covering 15891 square kilometers (12.5% of the total area of the province). The mean annual rainfall is about 330 millimeters in a 20-year period is calculated. Abarkooh Plain has the minimum amount of rainfall (150 mm) and maximum amount was measured in Bonrood Zangane (1200 mm) on the north of Arzhan plain. In this study, monthly data of 22 rain gage stations through 40 years period (1972-2011) was used. Since before any analysis of hydrological, ensuring the accuracy and quality of data is essential therefore stations of the following conditions have been analyzed. 1. Having the same length 2. Lacking data missing or wrong 3. Covering the province in terms of geographical and climatic distribution, Figure 1 shows the spatial distribution of the gauge stations in Fars province map.

2.2. Temporal Trend Analysis Method

Removal of the Autocorrelation Component Method

It has been reported many times that the existence of serial correlation may lead to an erroneous rejection of the null hypothesis (Kulkarni and Von Storch 1995; Yue *et al.* 2002). Pre-whitening is one of the most common approaches for removing the impact of serial correlation on a dataset prior to applying the Mann-Kendall trend test and abrupt change point detection. Pre-whitening has first been proposed by Kulkarni and Von Storch (1995), in this study, a modified pre-whitening method, namely trend free pre-whitening (TFPW), was applied in the dataset with significant autocorrelation to eliminate the effect of serial correlation (Yue *et al.*, 2002).

Mann-Kendall test

The non-parametric Mann-Kendall test (Mann 1945; Kendall 1975) has been widely used as an effective tool for identifying monotonic trends in hydrometeorological and other related variables such as water quality, stream flow, air temperature, precipitation, and drought in different regions across the world (Modarres and Silva, 2007).

For a time series X {x1, x2 , …, xn},in which n>10, the standard normal statistic Z is estimated as follows:

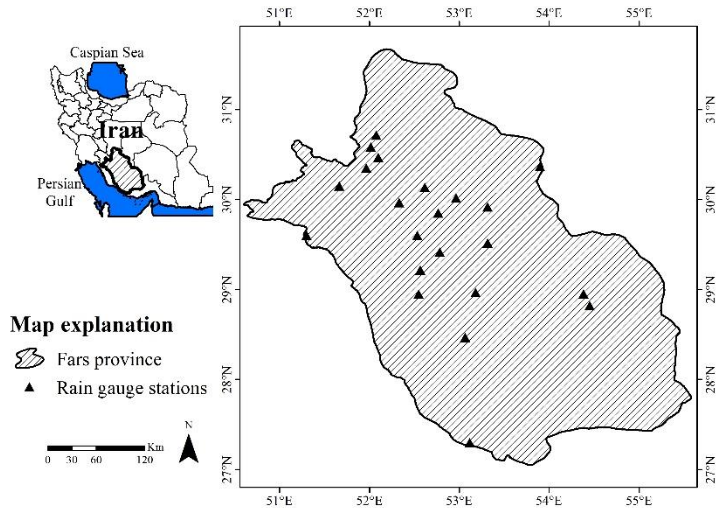

Fig. 1. The map of Fars province

$$z = \begin{cases} \frac{s-1}{\sqrt{var(s)}}, & if\ s > 1 \\ 0, & if\ s > 0 \\ \frac{s+1}{\sqrt{var(s)}}, & if\ s > 1 \end{cases} \tag{1}$$

Where

$$S = \sum_{i=2}^{n}\sum_{j=1}^{i-1} sgn(X_i - X_j) \tag{2}$$

$$\text{sign}(x_i - x_j) = \begin{cases} +1 & \text{if } (x_i - x_j) > 0 \\ 0 & \text{if } (x_i - x_j) = 0 \\ -1 & \text{if } (x_i - x_j) < 0 \end{cases} \tag{3}$$

$$var(s) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{n} tp(p)(p-1)(2p+5)}{18} \tag{4}$$

Where P is the extent of any given tie and ∑ denotes the summation of all ties. The statistic Z follows the standard normal distribution. At a 5% significance level, the null hypothesis of no trend is rejected if |Z| > 1.96. A positive value of Z denotes an increasing trend, and the opposite corresponds to a decreasing trend (Mann 1945; Kendall 1975).

Sen's Slope Estimator

If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple nonparametric procedure developed by Sen (1968). The slope estimates of N pairs of data are first computed by

$$Q_i = \frac{x_j - x_k}{j-k} \quad for\ \ i = 1,\ ....,\ N \tag{5}$$

where xj and xk are data values at times j and k(j > k), respectively. The median of these N values of Qi is a Sen's estimator of the slope. If N is odd, then Sen's estimator is computed by

$$Q_{med} = Q_{[\frac{N+1}{2}]} \tag{6}$$

If N is even, then Sen's estimator is computed by

$$Q_{med} = \frac{1}{2}(Q_{[\frac{N}{2}]} + Q_{[\frac{N+2}{2}]}) \tag{7}$$

Finally, Qmed is tested with a two-sided test at the 100(1 _ a) % confidence interval and the true slope may be obtained with the nonparametric test (Partal and Kahya, 2006).

Pettitt test

Identifying change point is one of the most important statistical methods for streamflow series analysis to investigate the effects of climate change and human activities. The non-parametric method, which was developed by Pettitt (1979), was used to determine the occurrence of a change point in this study and has been widely adopted to detect the abrupt change points in hydrological as well as climatic records (Mavromatis and Stathis 2011). This method detects a significant change in the mean of a time series when the exact time of the change is unknown. The test uses a version of the Mann–Whitney statistic Ut, N, which verifies whether two samples x1, …, xi and xi+1,…, xn are from the same population. The test statistic Ut, N is given by:

$$U_{t,T} = \sum_{i=2}^{n}\sum_{j=1}^{i-1} \mathrm{sgn}(X_i - X_j) \quad (8)$$

$$\mathrm{sign}(x_i - x_j) = \begin{cases} +1 & \text{if } (x_i - x_j) > 0 \\ 0 & \text{if } (x_i - x_j) = 0 \\ -1 & \text{if } (x_i - x_j) < 0 \end{cases} \quad (9)$$

The test statistic counts the number of times that a member of the first sample exceeds a member of the second sample. The null hypothesis of Pettitt's test is the absence of a changing point. Its statistic k (t) and the associated probabilities used in significance testing are given as (Pettitt 1979):

$$K_T = Max|U_{t,T}|, 1 \le t < T \quad (10)$$

$$P_{OA} = 2exp\left\{{-6(K^+)^2}/{(T^3 + T^2)}\right\} \quad for\, T \to \infty \quad (11)$$

If P<0.05, a significant change point exists, the time series is divided into two parts at the location of the change point.

Standard normal homogeneity test

Alexandersson (1986) describes a statistic T (k) to compare the mean of the first k years of the record with that of the last n - k years:

$$T_0 = \max_{1\le a<n} T_{(a)} = \max_{1\le a<n}(a\bar{z}_1{}^2 + (n-a)\,a\bar{z}_2{}^2) \;with\; a = 1, 2, \ldots, n$$

$$\bar{z}_1 = \frac{1}{a}\sum_{i=1}^{a}\frac{(Y_i - \bar{Y})}{s} \quad (12)$$

$$\bar{z}_2 = \frac{1}{n-a}\sum_{i=a+1}^{a}\frac{(Y_i - \bar{Y})}{s} \quad (13)$$

The mean of the first k years and the last n _ k years of the record is compared. T (k) reaches its maximum value when a break is located at the year K. The distribution of T (k) according to years is depicted in the graphs to represent the results. The test statistic T If T0 is defined as:

$$T_0 = \max_{1\le a<n} T_{(a)} \quad (14)$$

If T0 exceeds the critical value, the null hypothesis will be rejected. As seen in Table VII, the critical values are Dependent on the sample size. The SNHT is more sensitive to breaks near the beginning and the end of a series relatively easily.

Buishand range test

In this test, the adjusted partial sums are defined as

$$S_0^* = 0 \text{ and } S_k^* = a_0 + \sum_{i=1}^{k}(Y_i - \bar{Y}) \quad k = 1, \ldots, n \quad (15)$$

When a series is homogeneous the values of S_k^* will fluctuate around zero, because no systematic deviations Of the Yi values with respect to their mean will appear. If a break is present in year K, then S_k^* reaches a maximum (negative shift) or minimum (positive shift) near the year k = K .The (S_k^* / s) / $\sqrt{n}$ is depicted in the graphs representing the results of this test. The significance of the shift can be tested with the 'rescaled adjusted range' R, which is the difference between the maximum and the minimum of the s values scaled by the sample standard deviation:

$$R = (\max_{0\le K<n} S_k^* - \min_{0\le k<n} S_k^*)/s \quad (16)$$

Von Neumann ratio

The von Neumann ratio N is defined as the ratio of the mean square successive (year to year) difference to the variance (Von Neumann, 1941):

$$N = \frac{\sum_{i=1}^{n-1}(Y_i - Y_{i+1})^2}{\sum_{i=1}^{n-1}(Y_i - \bar{Y})^2} \quad (17)$$

3. Results and Discussion

Results of the Mann-Kendall test on the study of seasonal and annual rainfall data of 22 rain-gauge stations on in Fars province showed a decreasing trend on precipitation regime across the province except for Monej station. On the monthly scale, just Monj station in all seasons had a decreasing trend and on the annual scale all stations except for Chubekhle, Dehkade-shahid and Monej. However, none of the stations in any time scales has been a significant trend (Table 1). The results of Sen's slope estimator for gauge stations in Fars province on seasonal and annual time scales showed in autumn the most decreasing and increasing trend was related to Chity station (-2.042) and

Ramjerd (0.663) respectively. in winter all station except for monje (0.722) showed a decreasing trend and the most decreasing trend was related to the Tangab station (-4.645) (Table 2). Mol-ghaedi station had the most decreasing trend (-1.359) in spring. results showed slope trend wasn't observed in summer due to lack of precipitation in most stations. determining annual trend showed all stations had decreasing slope except for Chubekhle, Dehkade-shahid and Monje. the most negative slope was related to the Tangab station (-5.699). Based on the obtained results, in most cases, Mann–Kendall test and Sen's slope estimator have the same performance in terms of trend determination. Results of Pettitt test, standard normal homogeneity test, Buishand range test, von Neumann ratio for determining change point and abrupt shifts on mean series time showed among all 22 studied stations just Ali-Abad-Khafr in 1982, Tangab 2005, Ramjerd 2006 had change point in winter (Fig. 2).

Table 1 and 2, shows the results of the Mann-Kendall test and Sen's slope estimator of the 22 station consequently, with statistically significant (1, 5 and 10 % levels) increasing or decreasing trends in annual and seasonal precipitation series. Also, the direction of the trend for annual precipitation by Mann-Kendall test was represented in figure 3.

Table 1. Results of trend analysis by Mann-Kendall test for seasonal and annual precipitation

Station	Autumn	Winter	Spring	Summer	Annual
Ali-abad Khafr	0.032	-0.217	-0.041	-0.133	-0.178
Arsanjan	-0.021	-0.010	-0.066	-0.111	-0.097
Band-bahaman	-0.036	-0.086	0.015	-0.320	-0.122
Chamriz	0.012	-0.172	-0.057	-0.138	-0.151
Chity	-0.151	-0.135	-0.090	-0.215	-0.250
Choubekhle	-0.01	-0.042	0.018	-0.053	0.015
Darbe ghaleh	0.107	-0.153	0.054	0.117	-0.080
Dashtbal	-0.006	-0.089	-0.040	-0.038	-0.048
Dehkade-shahid	-0.032	-0.028	0.000	-0.123	0.049
Dobaneh	-0.037	-0.122	-0.013	0.083	-0.086
Gousangan	-0.071	-0.191	-0.082	0.083	-0.155
Gouzoon	0.111	-0.282	-0.056	0.136	-0.188
Hossein-abad	0.045	-0.113	-0.041	-0.208	-0.060
Jamal-beig	-0.006	-0.089	-0.040	-0.038	-0.047
Karzin	0.096	-0.158	0.016	-0.115	-0.083
Kharameh	-0.031	-0.333	-0.057	-0.018	-0.023
Mol-ghaedi	-0.092	-0.153	-0.192	-0.052	-0.205
Monje	0.176	0.125	0.02	0.246	0.153
Pol-e-khan	0.026	-0.044	-0.072	-0.260	-0.008
Ramjerd	0.101	-0.014	-0.051	-0.110	-0.035
Shiraz	-0.041	-0.092	-0.094	-0.208	-0.067
Tangab	-0.111	-0.332	-0.056	-0.082	-0.225

Table 2. Results of trend analysis by Sen's slope estimator for seasonal and annual precipitation

Station	Autumn	Winter	Spring	Summer	Annual
Ali-abad Khafr	0.011	-2.470	0.174	0.000	-2.900
Arsanjan	-0.038	-0.995	-0.286	0.000	-1.361
Band-bahaman	-0.020	-1.618	0.113	0.000	-2.126
Chamriz	0.163	-2.580	-0.450	0.000	-3.139
Chity	-2.042	-2.870	-0.333	0.000	-4.921
Choubekhle	-0.146	-1.153	0.205	0.000	0.796
Darbe ghaleh	0.333	-1.750	0.183	0.033	-0.938
Dashtbal	-0.067	-1.644	-0.225	0.000	-1.144
Dehkade-shahid	-0.513	-0.400	0.000	0.000	0.671
Dobaneh	0.407	-1.186	-0.094	0.000	-1.583
Gousangan	-0.017	-0.198	-0.082	0.083	-5.233
Gouzoon	0.111	-0.389	-0.056	0.136	-4.074
Hossein-abad	0.404	-1.579	-0.188	0.000	-0.907
Jamal-beig	-0.006	-0.089	-0.040	-0.038	-1.144
Karzin	0.536	-1.200	0.000	0.000	-1.313
Kharameh	-0.031	-1.952	-0.225	0.000	-2.828
Mol-ghaedi	-0.221	-3.268	-1.359	0.000	-5.407
Monje	0.333	0.722	0.000	0.000	1.400
Pol-e-khan	0.128	-0.469	-0.405	0.000	-0.111
Ramjerd	0.663	-1.500	-0.291	0.000	-0.394
Shiraz	0.307	-1.107	-0.486	0.000	-0.018
Tangab	-0.212	-4.465	-0.836	0.000	-5.699

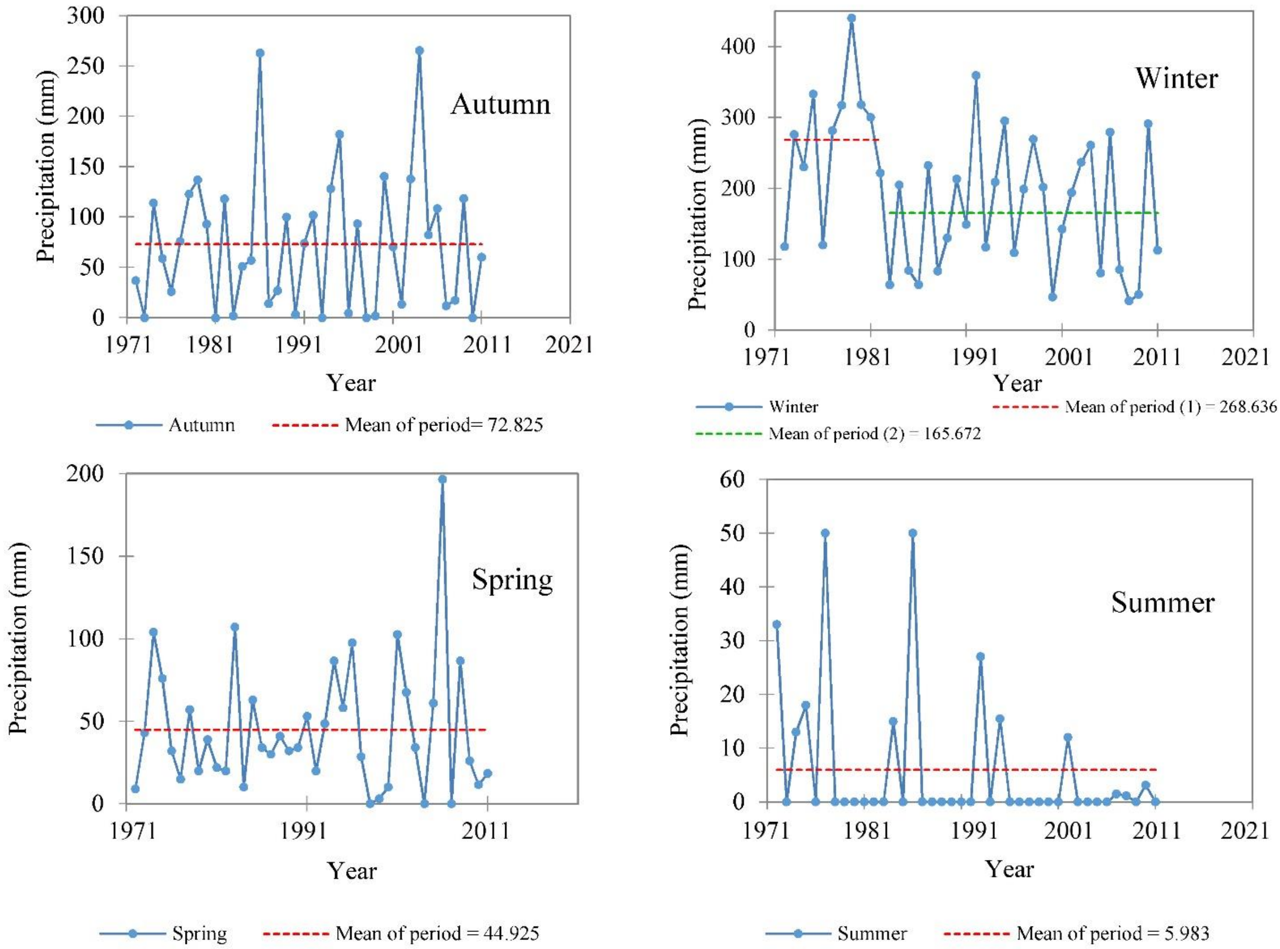

Fig. 2. Pettitt test results for identifying change points in seasonal time scale for the Aliabad-Abad Khafr station

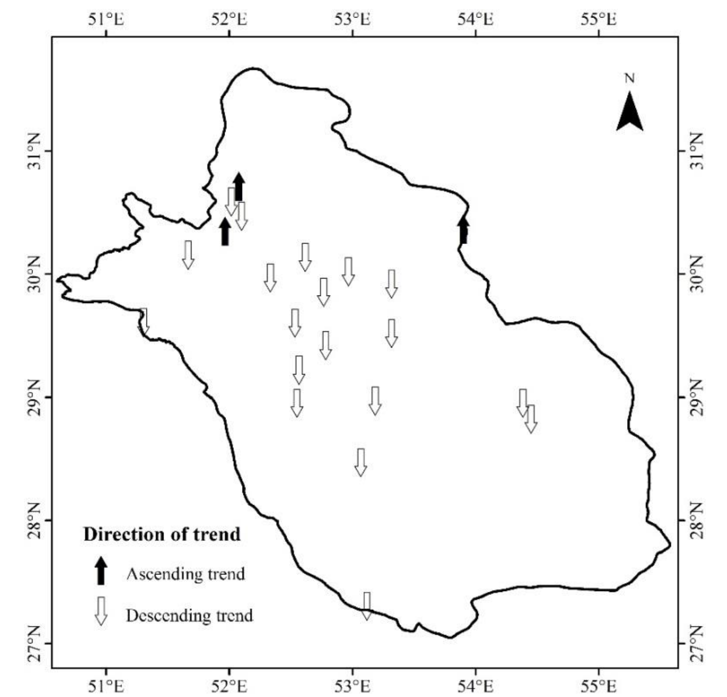

Fig. 3. Direction of trend in each station: flashes indicate direction of the trend for annual precipitation by Mann-Kendall test

4. Conclusion

A regional approach was used for this study with the purpose of better discriminating temporal trends and change points. In this study the trends of annual and seasonal precipitation over Fars province were determined using the Mann–Kendall test and the Sen's slope estimator for the period 1972–2011. Then, the standard normal homogeneity test (Alexandersson, 1986), the Buishand range test (Buishand, 1982), the Pettitt test (Pettitt, 1979) and the von Neumann ratio test (Von Neumann, 1941) to detection of change points in the time series had been investigated. TFPW approach had been used in order to decline the effects of autocorrelation and serial correlation on Mann-Kendall test. The results of Mann-Kendall test showed in seasonal scale, winter precipitation of Tangab station (-0.322), and in annual scale precipitation of Chity station (-0.250) had the most decreasing trends. The Sen's slope estimator method also showed the most decreasing trend both in seasonal and annual scales was related to Tangab station (-4.645 and -5.699 respectively). In some cases, results of trend by the two test was different, as values had a low difference. These cases was consistent with previous studies (Choubin *et al.* 2013; Hejam *et al.* 2008; Gocic and Trajkovic, 2013; Tabari and Hosseinzadeh Talaee, 2011). The results of Mann-Kendall test and Sen's method showed decreasing trend for all rainfall station except for the Monj. But no significant trends were observed in the rainfall and was consistent with previous studies (Kaviani and Asakere, 2003; Nasiri and Modarres, 2007; Tabari *et al.* 2011). These results can be used for the design of rain gauge networks, hydrological forecasting and for other applications in the Fars province. The results of Pettitt test for detection of change points and abrupt shifts in the time series revealed just Aliabad Khafr in the winter season in 1983 had change point among all 22 studied stations. In this station mean rainfall time series per-change and post-change were 268.636 and 165.672 mm respectively. It showed that mean rainfall in post-change period 102.964 mm was increased. Abrupt changes and shifts in more stations was consistent with Mann–Kendall test and Sen's slope estimator in terms of no significant trends in time series.

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