Effect of Short-Term and Long-Term Persistence on Identification of Temporal Trends

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Abstract: In this study, the trends in precipitation in the northwest (NW) of Iran were identified using the four different versions of the Mann-Kendall method, i.e., the conventional Mann-Kendall method (MK1); the Mann-Kendall method following the removal of the effect of significant lag-1 autocorrelation (MK2); the Mann-Kendall method after the removal of the effect of all significant autocorrelation coefficients (MK3); and the Mann-Kendall method by considering the Hurst coefficient (MK4). Identification of trends was carried out on different time scales (monthly, seasonal, and annual) using the precipitation data of 50 years from 1955 to 2004 of the sixteen stations selected from the NW region of Iran. The Theil-Sen method was used to estimate the slopes of trend lines of precipitation series. Results showed that: (1) on a monthly time scale, the statistically significant Z-statistics were negative for all but one (July) month; and the strongest negative (positive) precipitation trend-line slope among all the negative (positive) cases was found to be $-0.89(0.38)$ mm/year at Bijar (Kermanshah) station in NW Iran; (2) on a seasonal time scale, the median of trend-line slopes was found to be negative in all four seasons; the winter and spring season's precipitation series witnessed negative trends for almost all the stations using all four different versions of the MK test; and in the summer and autumn seasons, both upward and downward trends were observed for most of the sites of NW Iran; (3) in an annual time scale, all stations had witnessed negative trends using both the MK1 and the MK4 tests. However, application of the MK4 instead of the MK1 reduced the absolute value of the Z-statistic for most of the time series. The strongest negative annual trend-line slope was -4.04 mm/year at Bijar station. Therefore, the observed decreases in precipitation in NW Iran in the recent half of the past century may have serious implications for water resources management under the warming climate with probably a higher rate of the population growth and the higher consumption of freshwater as a result of the rise in standards of living of the population of NW Iran. **DOI: 10.1061/(ASCE)HE.1943-5584.0000819.**

Author keywords: Autocorrelation coefficient; Hurst coefficient; Iran; Persistence; Precipitation; Trend.

Introduction

Understanding trends of hydrometeorological variables is important to the future development and sustainable management of water resources. Precipitation is one of the vital elements of the hydrological cycle, which is projected to change with variation in the concentration of atmospheric greenhouse gaseous. Several studies conducted precipitation trend analysis in different regions (Garbrecht et al. 2004; Kahya and Partal 2007; Kumar et al. 2009; Pal and Al-Tabbaa 2009; Tabari and Talaee 2011; De Martino et al. 2012). Most studies used nonparametric methods for trend analysis and a few studies used a linear regression test. The nonparametric methods were used in this study because the nonparametric methods are distribution-free, robust against outliers, and have a higher power for non-normally distributed data (Barua et al. 2013; Onoz and Bayazit 2003; Yue et al. 2002). The Mann-Kendall (MK) method (Mann 1945; Kendall 1975) is the most commonly used nonparametric method that is recommended for identification of monotonic trends in different hydrologic and climatologic time series by the World Meteorological Organization (WMO) (Yue et al. 2002). The serial dependence between observations should not exist when the original classic MK test (hereafter, referred as MK1) used for trend detection. Most of the studies used MK1 for trend detection, assuming no significant serial correlation between observations. However, some investigators have used the modified version of the MK test, when there is a significant lag-1 autocorrelation among observations. Existing significant lag-1 autocorrelation coefficient called as short-term persistence (STP).

A well-known modified procedure, hereafter referred to as the MK2, was used for treating data for the adverse effect of significant lag-1 autocorrelation (Yue and Wang 2002). In most of the hydrometeorological time series, significant autocorrelation with different time lags, in addition to lag-1, may exist among observations. Existence of more than one significant autocorrelation among data is called long-term persistence (LTP). In such a situation, application of MK1 and/or MK2 for trend analysis could yield unreliable results. In other words, the presence of positive autocorrelation overestimates the significance of both positive and negative trends, whereas negative autocorrelation underestimates the significance of both positive and negative trends. To incorporate the LTP behavior in the MK test, Hamed (2008) modified the classical form of the MK test, the MK3. Moreover, the Hurst phenomenon was

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identified as the major source of uncertainty in analyzing the hydrometeorological time series (Koutsoyiannis and Montanari 2007). According to Koutsoyiannis (2003), the presence of the LTP behavior in the data leads to the underestimation of serial correlation in the data structure and overestimation of significance of the Mann-Kendall test. Hamed (2008) proposed a method for trend analysis based on the Hurst phenomenon, hereafter referred to as the MK4.

No study is available in the literature on trend analysis of precipitation in NW Iran incorporating the STP and LTP. The primary aims of this study are: (1) to detect the trends in annual, seasonal, and monthly precipitation time series of NW Iran using the MK1, the MK2, the MK3, and the MK4; (2) to compare the results obtained through the four versions of the MK test; and (3) the estimation of precipitation trend-line slopes using the Theil-Sen approach (TSA) (Sen 1968; Theil 1950a, b, c) over NW Iran.

Materials and Methods

Site Selection and Rainfall Data

The study area is a mountainous region located in NW Iran and is located approximately between 34°00′ N and 39°20′ N latitudes and between 44°09′ E and 48°30′ E longitudes. The mean annual precipitation of the study area is approximately 280 mm. The mean annual air temperature varies from 8 to 15°C. The primary source of precipitation in the study area is from westerly Mediterranean systems. Dry summers and cold winters are characteristic of this area. The monthly precipitation data of sixteen stations was obtained from the Islamic Republic of Iran Meteorological Organization (IRIMO). Missing data was estimated using the normal ratio method (Xia et al. 1999). The quality of data was checked prior to the analysis. For this purpose, the rainfall time series was plotted and then visually inspected for possible higher outliers. If there were any unusual points, nearby stations corresponding plot was checked and possible errors were corrected. Contingency of data was checked using the double mass analysis. The randomness of the precipitation series of all sixteen stations of NW Iran was also tested using the turning point test (Lye and Lin 1994). The results of the randomness tests are not shown in this paper. All results indicate that the annual precipitation series is random for the stations of NW Iran. Fig. 1 shows the GIS-based map of the study area. Details of the annual rainfall statistics for selected stations are indicated in Table 1.

Methods Used for Trend Analysis

In this study, the TSA was used to estimate the trend-line slope of time series. The effect of short-term persistence (STP) and long-term persistence (LTP) in trend analysis were considered. The effect of the Hurst coefficient was also investigated in the trend analysis. Therefore, four different versions of MK method were used to detect trends. A brief description of these four versions of the MK test are described in the subsequent sections.

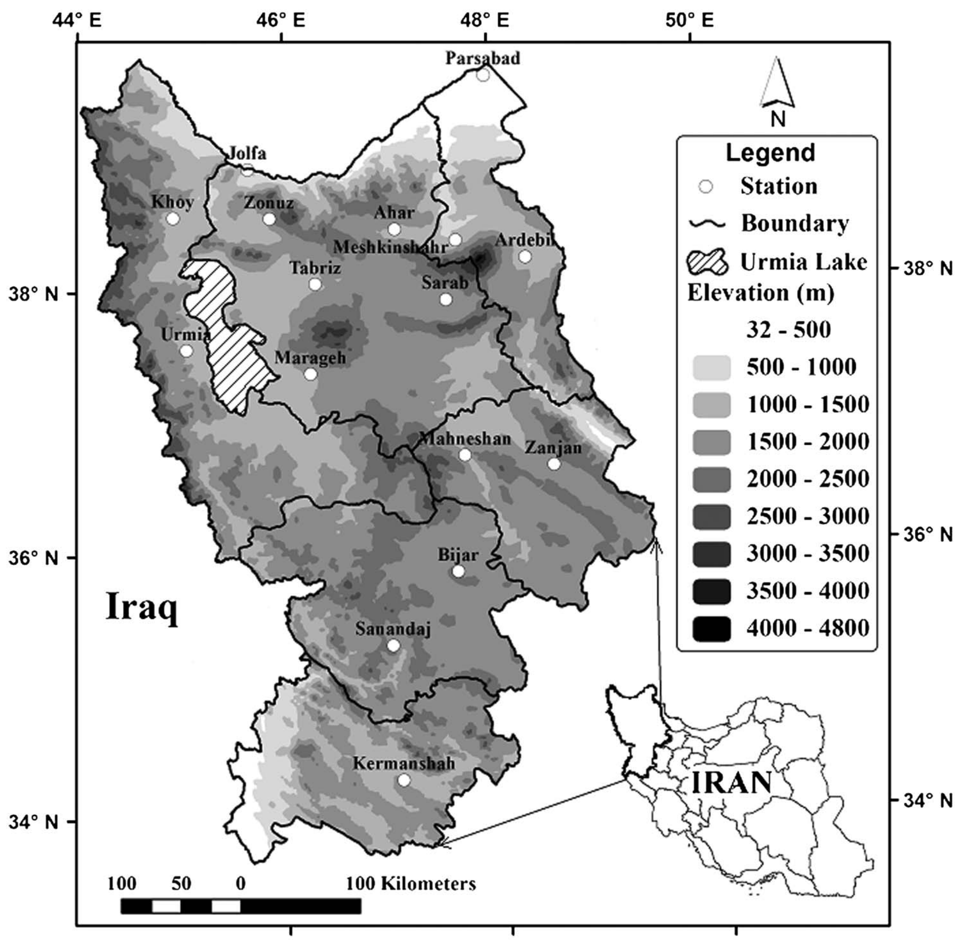

Fig. 1. GIS-based map of the study area and geographical location of the stations

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Table 1. Some Useful Statistics of Rainfall in the Selected Stations

Stations	Mean (annual) (mm)	SD (annual) (mm)	CS (annual) (mm)	Winter (%)	Spring (%)	Summer (%)	Autumn (%)
Ahar	312	73.2	0.95	25.2	41.9	7.6	25.4
Mahneshan	283	61.3	1.01	31.9	36.2	2.1	29.7
Ardebil	340	117.2	1.49	28.4	36.4	7.8	27.4
Zonuz	324	77.0	0.31	23.6	42.5	10.3	23.6
Sarab	263	75.9	0.66	22.6	43.6	10.2	23.5
Jolfa	215	55.8	0.00	22.7	44.0	8.3	25.0
Kermanshah	453	134.9	0.59	45.3	21.9	0.6	32.2
Khoy	297	78.3	0.38	25.2	43.5	8.2	23.2
Maragheh	324	82.2	0.38	32.7	36.6	2.3	28.4
Meshkinshahr	380	91.3	−0.13	23.4	47.0	9.8	19.8
Urmia	337	94.8	0.91	33.0	36.0	3.7	27.4
Parsabad	290	71.8	−0.54	25.8	32.4	12.5	29.3
Bijar	439	119.9	0.24	42.0	30.5	1.5	26.0
Sanandaj	451	126.6	0.14	45.0	24.5	0.6	29.9
Tabriz	291	86.4	0.98	29.6	39.0	5.6	25.8
Zanjan	299	74.7	0.03	34.0	34.4	4.8	26.8
Mean	331	88.8	0.46	30.7	36.9	6.0	26.4

Note: SD and CS denote the standard deviation and coefficient of skewness, respectively.

Trend Analysis Using the MK1 Test

The original Mann-Kendall method, MK1, carried out by computing the S statistic as

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

where n = number of observations; $x_j = j$th observation; and sgn(.) = sign function, which can be computed as follows:

$$\mathrm{sgn}(x_j - x_i) = \begin{cases} 1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{cases} \tag{2}$$

Under the assumption that the data are independent and identically distributed, the mean and variance of the S statistic in Eq. (1) given by Kendall (1975) as

$$E(S) = 0 \tag{3}$$

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \tag{4}$$

where m = number of groups of tied ranks, each with t_i tied observations. The original MK1 statistic, designated by Z, is computed as

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{V(S)}} & S < 0 \end{cases} \tag{5}$$

If $-Z_{1-\alpha/2} \leq Z \leq Z_{1-\alpha/2}$, then the null hypothesis of no trend was accepted at the significance level of α. Otherwise, the null hypothesis was rejected and the alternative hypothesis was accepted at the significant level of α.

Trend Analysis Using the Mk2 Test

Hamed and Rao (1998) suggested that positive (negative) autocorrelation will result in the increase (decrease) of S in Eq. (1) and will be underestimated (overestimated) by the original $\mathrm{Var}(S)$. Thus, if MK1 is conducted for testing trends in positively (negatively) autocorrelated data, it will show significant trends, when actually no trends exist. The influence of serial correlation on the MK test was eliminated by removing the lag-1 serial correlation component from the time series prior to applying the MK test to assess the influence of trend. This treatment was called *trend free prewhitening*. Then the MK test was used to detect trends in the residual (or prewhitened) series. For trend analysis using the MK2, the following steps were used:

1. The new time series as proposed by Kumar et al. (2009) was obtained as

$$x_i' = x_i - (\beta \times i) \tag{6}$$

where β = slope of trend line using the TSA and described later in the present study.

2. The r_1 value of the x_i' time data set was computed and used to determine the residual series as

$$y_i' = x_i' - r_1 \times x_{i-1}' \tag{7}$$

3. The value of $\beta \times i$ was added again to the residual data set as follows:

$$y_i = y_i' + (\beta \times i) \tag{8}$$

4. The y_i series was subjected to trend analysis using MK1.

Trend Analysis Using the MK3 Test

In this method, the effect of all significant autocorrelation coefficients is removed from a data set (Hamed and Rao 1998). For this purpose, a modified variance of S, designated as $V(S)^*$, was used as follows:

$$V(S)^* = V(S)\frac{n}{n^*} \tag{9}$$

where n^* = effective sample size. The n/n^* ratio was computed directly from the equation proposed by Hamed and Rao (1998) as

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2) r_i \tag{10}$$

where n = actual number of observations; and r_i = lag-i significant autocorrelation coefficient of rank i of time series. Once $V(s)^*$ was computed from Eq. (9), then it is substituted for $V(S)$ in Eq. (5). Finally, The Mann-Kendall Z was tested for significance of trend comparing it with threshold levels, i.e., 1.645 for 10%; 1.96 for 5%; and 2.33 for 1% levels of significance.

Trend Analysis Using the MK4 Test

The fourth version of the Mann-Kendall method was described by Kumar et al. (2009) and takes into account the Hurst coefficient, H, of a series for LTP. H is used as a measure of long-term memory, i.e., autocorrelation of the time series. A value of 0.5 for H indicates a true random walk, which implies that the time series has no memory for previous values of observations. A value of H between 0.5 (0) and 1 (0.5) indicates a time series with positive (negative) autocorrelation [e.g., an increase (decrease) between observations will probably followed by another increase (decrease)].

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In the present study, the following steps were carried out for applying the MK4:

1. Calculation of Hurst coefficient (H) by the following:
   - A new time series x_i' is computed from Eq. (6).
   - Using the ranks of x_i' designated by R_i, the standardized Z variate is computed as

$$Z_i = \phi^{-1}\left(\frac{R_i}{n+1}\right) \quad (11)$$

   where n = size of observation; and ϕ^{-1} = inverse of the normal distribution function.
   - Compute the elements of the Hurst matrix for a given H as follows:

$$C_n(H) = [\rho_{|j-i|}], \quad \text{for } i = 1{:}n, \quad j = 1{:}n \quad (12)$$

   where

$$\rho_l = \frac{1}{2}(|l+1|^{2H} - 2|l|^{2H} + |l-1|^{2H}) \quad \text{for } l > 1 \quad (13)$$

   where ρ_l = lag-l autocorrelation coefficient for a given H.
   - The accurate value of H can be computed by maximizing the log-likelihood function of H as follows:

$$\log L(H) = -\frac{1}{2}\log|C_n(H)| - \frac{Z^T[\boldsymbol{C_n}(\boldsymbol{H})]^{-1}\mathbf{Z}}{2\gamma_0} \quad (14)$$

   where Z^T = transpose of vector $\mathbf{Z}$ obtained from Eq. (11); γ_0 = variance of z_i and $C_n(H)$; and $\boldsymbol{C_n}(\boldsymbol{H})^{-1}$ = Hurst matrix and inverse of the Hurst matrix, respectively. These two last matrices can be obtained using Eq. (13). To maximize $\log L(H)$, assume H to be in the range of 0.5–0.98 and compute the mentioned function for a given H. Repeat this for other H values with 0.01 steps. The H yields the maximum value for $\log L(H)$ detected as the answer.
2. According to Hamed (2008), the mean and standard deviation of H are functions of n and can be computed as follows:

$$\mu_H = 0.5 - 2.87n^{-0.9067} \quad (15)$$

$$\sigma_H = 0.77654n^{-0.5} - 0.0062 \quad (16)$$

   Then, the Z_{cal} is computed as follows:

$$z_{\text{cal}} = \frac{H - \mu_H}{\sigma_H} \quad (17)$$

   This z_{cal} obtained from Eq. (17) was tested for significance of trend considering the 10% significance level. If z_{cal} was greater than the critical normal value (1.645), then continue as follows; otherwise, use only the MK1.
3. For significant H values, the modified variance for the S statistic was computed as recommended by Kumar et al. (2009) as follows:

$$V(S)^{H'} = \sum_{i<j}\sum_{k<l}\frac{2}{\pi}\sin^{-1}\left(\frac{\rho|j-l| - \rho|i-l| - \rho|j-k| + \rho|i-k|}{\sqrt{(2-2\rho|i-j|)(2-2\rho|k-l|)}}\right) \quad (18)$$

   where ρ_l is computed from Eq. (13) for a given H value. Because $V(S)^{H'}$ is a biased estimator, corrected it for bias as follows:

$$V(S)^H = V(S)^{H'} \times B \quad (19)$$

   where B = function of sample size, n, and can be computed as follows (Hamed 2008):

$$B = a_0 + a_1H + a_2H^2 + a_3H^3 + a_4H^4 \quad (20)$$

   where $a_0 - a_4$ are coefficients dependent on the size of the time series and can be found in (Kumar et al. 2009).

In the MK4 method, the $V(S)^H$ obtained from Eq. (20) was used as a $V(S)$ in the MK1. Then in order to detect the trend, the significance of Z was tested.

Theil-Sen's Estimator Approach

The slope of n pairs of data points was estimated using the TSA, which is given by the following relationship:

$$\beta = \text{Median}\left(\frac{x_j - x_l}{j-l}\right) \quad \forall\ 1 < l < j \quad (21)$$

According to Yue et al. (2002), the slope computed by TSA is a robust estimate of the magnitude of a trend.

Results and Discussion

Monthly Trends

Table 2 shows the Z-statistic values of precipitation of the selected stations in the monthly time scales using the four different versions of the MK. Using the MK1/MK2/MK3/MK4, approximately 77/70/77/77% of cases showed negative (either statistically significant or insignificant) trends, and all remaining cases showed opposite trends. In the monthly time scale, the statistically significant Z-statistics were negative in all but one (July) month. Results indicated that 25/24/21/17 out of 192 cases (13/12.5/10.9/8.9%) showed statistically significant negative trends at the 10% level by using the MK1/MK2/MK3/MK4. In contrast, only 3/2/3/1 cases (1.6/1.0/1.6/0.5%) showed statistically significant positive trends at the 10% level. All the positive significant trends were observed in the month of July, the hottest and driest month in the NW region of Iran. It showed that the number of negative trends were much more pronounced than the positive trends in precipitation series of NW Iran in a monthly time scale. It can be concluded that the number of statistically significant (both positive and negative) trends reduced considerably when MK4 was used instead of MK1 in the monthly time scale. To compare results for the 5% and 10% significance levels, the number of Z-statistics greater than 1.96 (for the 5% level) was counted for all four versions of the MK test. In a monthly time scale, 15/14/11/10 of 192 cases (i.e., 7.8/7.3/5.7/5.2%) exhibited significant trends ($P < 0.05$) by using the MK1/MK2/MK3/MK4. The percentage of significant trends were reduced from 13% ($P < 0.05$) to 7.8% ($P < 0.10$) on using the 5% level of significance instead of the 10% level of significance by the MK1 test. Similar results were obtained for three other versions of the MK test. For example, significant trends for MK2 reduced from 12.5% ($P < 0.05$) to 7.3% ($P < 0.10$). Approximately 5% reduction was witnessed in total signifcant negative trends obtained through the four different versions of the MK test on using the 5% level of significance instead of the 10% level of significance.

Fig. 2 shows the three sample correlograms of the monthly rainfall sets at Ardebil (in April), Jolfa (in January), and Urmia (in March) stations. Two autocorrelations exist (in lags 2 and 7) for the rainfall time series in the month of April over Ardebil, whose values were greater than the upper limit of the 95% confidence

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Table 2. *Z*-Statistic Values of Monthly Precipitation Using MK1/MK2/MK3/MK4 for NW Iran (1955–2006)

Station	January	February	March	April	May	June
Ahar	−1.1/−1.1/−1.1/−1.1	**−1.7**/**−1.7**/**−1.7**/**−1.7**	0.2/0.2/0.2/0.2	−0.1/−0.1/−0.1/−0.1	−0.2/−0.2/−0.2/−0.2	−1.4/−1.4/−1.4/−1.4
Mahneshan	−0.4/−0.4/−0.4/−0.4	**−2.2**[a]/**−2.2**[a]/**−2.2**[a]/**−2.2**[a]	−0.6/−0.6/−0.6/−0.6	−1.0/−1.0/−1.0/−1.0	−0.3/−0.3/−0.3/−0.3	**−2.5**[b]/**−2.5**[b]/**−2.5**[b]/**−2.5**[b]
Ardabil	−0.9/−0.9/−0.9/−0.9	−0.9/−0.9/−0.9/−0.9	−1.6/−1.6/−1.6/−1.6	**−2.2**[a]/**−1.9**/−1.5/**−2.2**[a]	−1.0/−1.0/−1.0/−1.0	**−2.1**[a]/**−2.1**[a]/**−2.1**[a]/**−2.1**[a]
Znoz	−1.4/−1.4/−1.4/−1.4	−1.2/−1.2/−1.2/−1.2	−1.6/−1.6/−1.6/−1.6	**−1.9**/**−1.9**/**−1.9**/**−1.9**	−1.3/−1.3/−1.3/−1.3	−1.0/−1.0/−1.0/−1.0
Sarab	1.2/1.2/1.2/1.2	**−2.2**[a]/**−2.2**[a]/**−2.2**[a]/**−2.2**[a]	−0.1/0.0/−0.3/−0.1	−0.7/−0.7/−0.7/−0.7	−0.4/0.2/−0.3/−0.4	−1.3/−1.3/−1.3/−1.3
Jolfa	**−1.9**/−1.6/−1.1/**−1.9**	**−1.8**/**−1.8**/**−1.8**/**−1.8**	−0.3/−0.3/−0.3/−0.3	−1.0/−1.0/−1.0/−1.0	−0.9/0.0/−0.7/−0.9	−1.0/−1.0/−1.0/−1.0
Kermanshah	0.5/0.5/0.5/0.5	0.1/0.1/0.1/0.1	0.4/0.4/0.4/0.4	**−2.9**[b]/**−2.8**[b]/**−1.9**/**−2.9**[b]	−1.1/−1.1/−1.1/−1.1	−1.3/0.5/−1.1/−0.4
Khoy	−1.5/−1.5/−1.5/−1.5	**−1.8**/**−1.8**/**−1.8**/**−1.8**	−0.7/−0.7/−0.7/−0.7	−0.4/−0.4/−0.4/−0.4	−1.3/−1.3/−1.3/−1.3	−0.9/−0.9/−0.9/−0.9
Maragheh	−0.2/−0.2/−0.2/−0.2	−1.0/−1.0/−1.0/−1.0	0.2/0.2/0.2/0.2	−1.2/−1.1/−1.0/−1.2	−1.2/−1.2/−1.2/−1.2	−1.2/−1.2/−1.2/−1.2
Meshkinshahr	0.1/0.1/0.1/0.1	−0.5/−0.5/−0.5/−0.5	−0.4/−0.4/−0.4/−0.4	−0.9/−0.9/−0.9/−0.9	−0.1/−0.1/−0.1/−0.1	−1.4/−1.4/−1.4/−1.4
Urmia	−0.7/−0.7/−0.7/−0.7	**−1.7**/**−1.9**/−1.4/**−1.7**	0.4/0.4/0.4/0.4	−0.9/−0.5/−0.7/−0.9	−0.9/−0.9/−0.9/−0.9	**−1.9**/**−1.9**/**−1.9**/**−1.9**
Parsabad	**−2.7**[b]/**−2.7**[b]/**−2.7**[b]/**−1.2**	−0.8/−0.8/−0.8/−0.8	0.4/0.4/0.4/0.4	−1.0/−1.0/−1.0/−1.0	−0.7/−0.7/−0.7/−0.7	−0.6/−0.6/−0.6/−0.6
Bijar	**−3.5**[b]/**−3.5**[b]/**−3.5**[b]/**−3.5**[b]	**−2.2**[a]/**−2.2**[a]/**−2.2**[a]/**−2.2**[a]	−1.0/−1.0/−1.0/−1.0	**−2.4**[b]/**−2.3**[b]/**−1.8**/**−1.1**	−0.3/−0.3/−0.3/−0.3	−0.5/−0.2/−0.4/−0.2
Sanandaj	−0.8/−0.8/−0.8/−0.8	−0.3/−0.3/−0.3/−0.3	−1.3/−1.3/−1.3/−1.3	−0.6/−0.3/−0.5/−0.6	−0.6/−0.6/−0.6/−0.6	−1.6/−1.6/−1.6/−0.6
Tabriz	−1.5/−1.6/−1.2/−0.7	**−2.8**[b]/**−2.8**[b]/**−2.8**[b]/**−2.8**[b]	−1.5/−1.5/−1.5/−1.5	−1.0/−1.0/−1.0/−1.0	−0.7/−0.7/−0.7/−0.7	−1.5/−1.5/−1.5/−1.5
Zanjan	−1.1/−1.1/−1.1/−1.1	−1.2/−1.2/−1.2/−1.2	0.3/0.3/0.3/0.3	−1.5/−1.5/−1.5/−1.5	−1.1/−1.1/−1.1/−1.1	0.0/0.0/0.0/0.0
	July	August	September	October	November	December
Ahar	0.3/0.3/0.3/0.3	−0.7/−0.7/−0.7/−0.7	−0.8/−0.8/−0.8/−0.8	0.0/0.0/0.0/0.0	0.2/0.2/0.2/0.2	−0.2/−0.2/−0.2/−0.2
Mahneshan	−0.2/−0.2/−0.2/−0.2	**−2.3**[b]/−1.2/**−1.9**/−0.9	**−3.0**[b]/**−3.0**[b]/**−3.0**[b]/−1.2	−1.2/−1.2/−1.2/−1.2	−1.1/−1.1/−1.1/−1.1	0.5/0.5/0.5/0.5
Ardabil	**2.4**[b]/**2.4**[b]/**2.4**[b]/**2.4**[b]	0.6/0.6/0.6/0.6	−1.4/−1.4/−1.4/−1.4	−0.2/−0.2/−0.2/−0.2	0.1/0.1/0.1/0.1	−0.6/−0.6/−0.6/−0.6
Znoz	−0.5/−0.5/−0.5/−0.5	−0.3/−0.3/−0.3/−0.3	**−1.9**/−1.4/−1.5/**−1.9**	−0.3/−0.3/−0.3/−0.3	−0.4/−0.4/−0.4/−0.4	0.2/0.2/0.2/0.2
Sarab	0.9/0.9/0.9/0.9	−0.1/−0.1/−0.1/−0.1	−0.8/−0.8/−0.8/−0.8	−0.3/−0.3/−0.3/−0.3	0.4/0.4/0.4/0.4	0.0/0.0/0.0/0.0
Jolfa	−0.5/−0.5/−0.5/−0.5	−1.1/**−2.2**[a]/**−1.8**/−1.1	−1.4/−1.4/−1.4/−1.4	−0.6/−0.6/−0.6/−0.6	−0.7/−0.7/−0.7/−0.7	−0.5/−0.5/−0.5/−0.5
Kermanshah	**2.8**[b]/1.2/**2.4**[b]/0.5	−1.5/0.1/−1.1/−0.2	0.5/0.5/0.5/0.1	0.9/0.9/0.9/0.9	0.5/0.5/0.5/0.5	1.1/1.1/1.1/1.1
Khoy	−1.5/−1.5/−1.5/−1.5	−1.1/−1.1/−1.1/−1.1	−1.1/−1.1/−1.1/−1.1	−0.6/−0.6/−0.6/−0.6	−0.1/0.9/−0.1/0.0	0.0/0.0/0.0/0.0
Maragheh	−0.3/−0.3/−0.3/−0.1	−1.6/−1.6/−1.6/−0.6	**−1.7**/**−1.7**/**−1.7**/−0.8	−0.8/−0.8/−0.8/−0.8	0.3/1.4/0.3/0.3	0.2/0.2/0.2/0.2
Meshkinshahr	0.1/0.1/0.1/0.1	−0.6/−0.6/−0.6/−0.6	−1.5/−1.5/−1.5/−1.5	−0.7/−0.7/−0.7/−0.7	−0.3/−0.3/−0.3/−0.3	−0.3/−0.4/−0.4/−0.3
Urmia	−0.9/−0.9/−0.9/−0.9	−1.3/−1.3/−1.3/−0.4	**−2.1**[a]/**−2.1**[a]/**−2.1**[a]/−0.9	−0.6/−0.6/−0.5/−0.6	0.2/0.2/0.2/0.2	−0.1/−0.1/−0.1/−0.1
Parsabad	−0.8/−0.8/−0.8/−0.8	−0.1/−0.1/−0.1/−0.1	−0.7/−0.7/−0.7/−0.7	0.0/0.0/0.0/0.0	−0.1/−0.1/−0.1/−0.1	−0.6/−0.6/−0.6/−0.6
Bijar	**3.4**[b]/**2.1**[a]/**2.8**[b]/0.8	−0.4/−0.4/−0.4/−0.1	−0.7/−0.7/−0.7/−0.2	0.2/0.2/0.2/0.2	1.2/1.2/1.2/1.2	−0.5/−0.4/−0.4/−0.2
Sanandaj	1.4/1.4/1.4/0.3	**−1.9**/0.4/−1.4/−0.6	−1.3/0.6/−1.1/−0.3	0.2/0.2/0.2/0.2	0.7/0.7/0.7/0.7	0.9/0.9/0.9/0.9
Tabriz	0.9/0.9/0.9/0.9	0.3/0.3/0.3/0.1	−1.4/−1.4/−1.4/−0.6	−0.3/−0.3/−0.3/−0.3	−0.3/−0.3/−0.3/−0.3	0.8/0.8/0.8/0.8
Zanjan	0.3/0.3/0.3/0.3	−0.7/−0.7/−0.7/−0.3	**−2.1**[a]/**−2.1**[a]/**−2.1**[a]/−0.8	0.2/0.2/0.2/0.2	−0.2/−0.2/−0.2/−0.2	0.0/0.0/0.0/0.0

Note: Bold numbers indicate significance at the 10% level.
[a]Significance at the 5% level.
[b]Significance at the 1% level.

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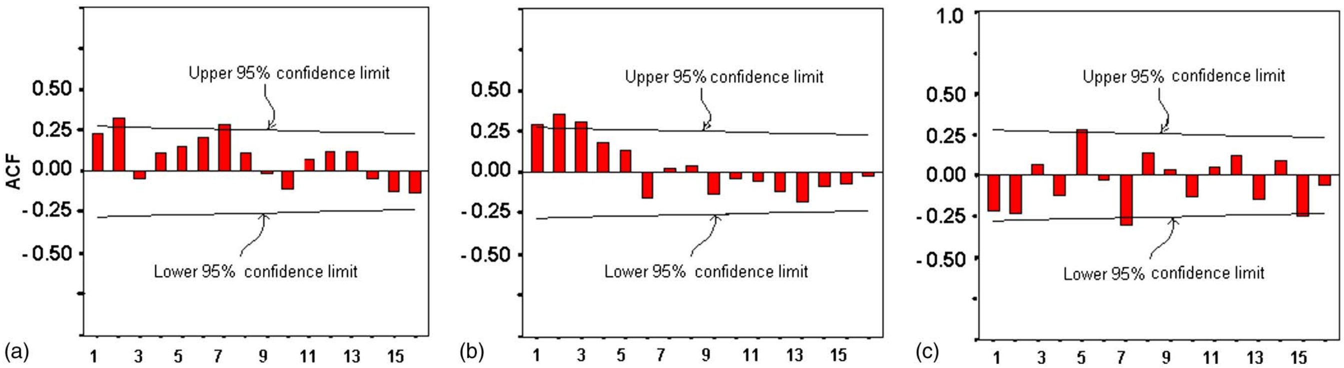

Fig. 2. Three sample corelograms of the monthly precipitation time series: (a) Ardebil (in April); (b) Jolfa (in January); (c) Urmia (in March); numbers in the horzinontal axes denote the lag numbers, vertical axes denote autocorellation coefficients, and two solid lines show 95% confidence limits

limit. Similarly at Jolfa, the first three autocorelation coefficients were significant for precipitation in January. The precipitation correlogram in March at Urmia showed at least three significant autocorrelation coefficients in the lags of 5, 7, and 15. These significant autocorrelation coefficients affect the *Z*-statistic to be changed from the MK1 to the MK4.

Seasonal and Annual Trends

Table 3 shows the *Z*-statistic values for the precipitation time series of the selected stations in the seasonal and annual time scales by using the four different versions of the MK. In the seasonal time scale, almost all stations exhibited decreasing trends in precipitation in all seasons. Strong negative trends in precipitation dominated primarily in the winter and spring seasons. In winter, the number of significant trends at the 10% level using MK1/MK2/MK3/MK4 were found to be 6/6/6/5, respectively. Using MK1 and MK4, fifteen stations (approximately 94%) showed decreasing trends in winter. Using MK1, of the sixteen stations that witnessed negative precipitation trends in winter, only six (37.5%) were statisticaly significant ($P < 0.10$). On the other hand, only five stations (31%) of all those that showed negative trends in winter were significant at the 10% level using MK4. In contrast, no station showed a statistically significant positive trend at the 10% level. Notably, only one station (Kermanshah) showed an increasing insignificant trend in winter. It can be concluded that decreasing precipitation trends are observed for almost all the stations in winter over NW Iran, and this is true for all the four versions of the MK tests. Table 3 shows that in winter season, the number of significant trends ($P < 0.05$) were 5/5/5/4 using the MK1/MK2/MK3/MK4 test. Comparing the trend results at the 5% level of significance with those at the 10% level of significance, leads to the conclusion that in the winter season, the percentage of negative significant precipitation series gets reduced from 36% ($P < 0.10$) to approximately 29.7% ($P < 0.05$) of all the selected stations.

In spring, the number of negative significant trends ($P < 0.10$) were found to be 5/3/3/3 using MK1/MK2/MK3/MK4. Results showed that all the stations had witnessed a negative sign in *Z*-statistics using the MK1 and that only five (approximately 31%) were statistically significant at the 10% level. Similarly, all the stations witnessed negative (either significant or insignificant) trends using MK4 in the spring season and that only three stations (approximately 19%) were statistically significant at the 10% level. In contrast, no station witnessed positive sign for *Z*-statistics using MK1 and MK4 in spring. Therefore, the number of statistically significant trends decreased from five to three on using the MK4

Table 3. *Z*-Statistic Values of Seasonal and Annual Precipitation Using MK1/MK2/MK3/MK4 for NW Iran (1955–2006)

Station	Winter	Spring	Summer	Autumn	Annual
Ahar	−1.1/−1.1/−1.1/−1.1	−1.4/−1.4/−1.4/−1.4	0.0/0.0/0.0/0.0	0.1/0.1/0.1/0.1	−1.1/−1.1/−1.1/−1.1
Mahneshan	−1.1/−1.1/−1.1/−1.1	−1.1/−1.1/−1.1/−1.1	−0.6/0.1/−0.5/−0.3	−0.5/−0.5/−0.5/−0.5	−1.5/−1.3/−1.2/−0.7
Ardabil	**−2.1**[a]/**−2.1**[a]/**−2.1**[a]/**−2.1**[a]	**−2.7**[b]/**−2.1**[a]/**−2.2**[a]/−1.2	0.1/0.1/0.1/0.1	−0.3/−0.3/−0.3/−0.3	**−2.0**[a]/**−2.0**[a]/**−2.0**[a]/−0.9
Znoz	**−2.3**[b]/**−2.3**[b]/**−2.3**[b]/**−2.3**[b]	**−1.7**/−1.2/−1.3/**−1.7**	−0.7/−0.7/−0.7/−0.7	−0.1/−0.1/−0.1/−0.1	**−1.8**/−1.4/−1.5/**−1.8**
Sarab	−0.2/−0.5/−0.5/−0.2	−0.6/−0.1/−0.6/−0.6	0.5/0.5/0.5/0.5	−0.1/−0.1/−0.1/−0.1	−0.7/−0.7/−0.7/−0.7
Jolfa	**−2.1**[a]/**−2.2**[b]/−1.4/−0.9	−0.1/−0.1/−0.1/−0.1	−1.5/−1.5/−1.5/−1.5	−0.3/−0.3/−0.3/−0.3	**−1.7**/−1.1/−1.2/−0.8
Kermanshah	0.7/0.7/0.7/0.7	**−2.7**[b]/**−2.7**[b]/**−2.7**[b]/−1.2	1.4/1.4/1.4/0.5	1.3/1.3/1.3/1.3	−0.1/−0.1/−0.1/−0.1
Khoy	−1.5/−1.5/−1.5/−1.5	−1.2/−1.2/−1.2/−1.2	−1.5/−1.5/−1.5/−1.5	−0.4/−0.4/−0.4/−0.4	**−2.1**[a]/−1.5/**−1.8**/**−2.1**[a]
Maragheh	−0.3/−0.3/−0.3/−0.3	−1.5/−1.2/−1.2/−1.5	0.0/0.0/0.0/0.0	0.0/0.3/0.0/0.0	−0.7/−0.4/−0.5/−0.3
Meshkinshahr	−0.3/−0.3/−0.3/−0.1	−0.8/−0.8/−0.8/−0.8	−0.5/−0.5/−0.5/−0.5	−0.5/−0.5/−0.5/−0.5	−1.0/−1.0/−1.0/−1.0
Urmia	−1.2/−1.2/−1.2/−1.2	−1.6/−1.1/−1.2/−1.6	−1.1/−1.1/−1.1/−1.1	−0.4/−0.4/−0.4/−0.4	**−1.7**/−1.2/−1.4/**−1.7**
Parsabad	−1.0/−1.0/−1.0/−1.0	−0.7/−0.7/−0.7/−0.7	−0.7/−0.4/−0.9/−0.7	0.4/0.6/0.3/0.2	−1.0/−0.5/−0.6/−0.4
Bijar	**−3.6**[b]/**−3.7**[b]/**−2.5**[b]/**−3.6**[b]	**−2.5**[b]/**−2.4**[b]/**−2.0**[a]/**−2.5**[b]	1.6/1.6/1.2/0.7	0.0/0.0/0.0/0.0	**−3.6**[b]/**−3.1**[b]/**−2.1**[a]/−1.6
Sanandaj	**−1.9**/**−1.9**/**−1.9**/**−1.9**	−1.0/−1.0/−1.0/−1.0	0.2/0.2/0.2/0.1	1.2/1.2/1.2/1.2	−0.8/−0.5/−0.6/−0.4
Tabriz	**−2.7**[b]/**−2.8**[b]/**−2.3**[b]/**−2.7**[b]	−1.6/−1.6/−1.6/−1.6	−1.0/−1.0/−1.0/−1.0	−0.1/−0.1/−0.1/−0.1	**−2.5**[b]/**−1.9**/**−1.9**/**−2.5**[b]
Zanjan	−1.4/−1.2/**−2.1**[a]/−1.4	**−1.7**/−1.1/−1.4/**−1.7**	0.0/0.0/0.0/0.0	0.2/0.2/0.2/0.2	−1.3/−1.3/−1.3/−1.3

Note: Bold numbers indicate significance at the 10% level.
[a]Significance at the 5% level.
[b]Significance at the 1% level.

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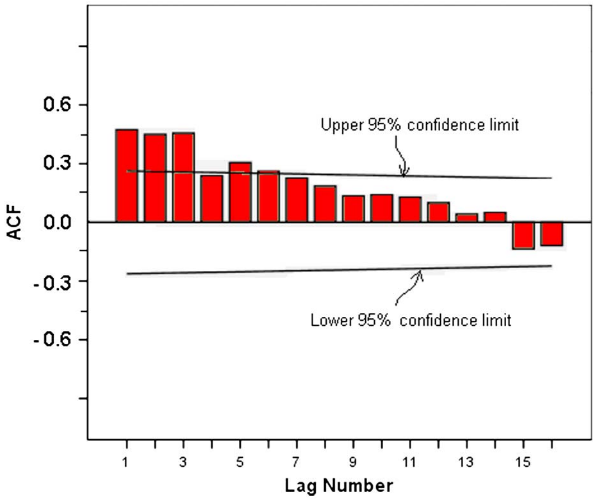

Fig. 3. Corelogram of the annual precipitation time series of Bijar station in NW Iran; numbers in the horzinontal axes denote the lag numbers, vertical axes denote autocorellation coefficients, and two solid lines show 95% confidence limits

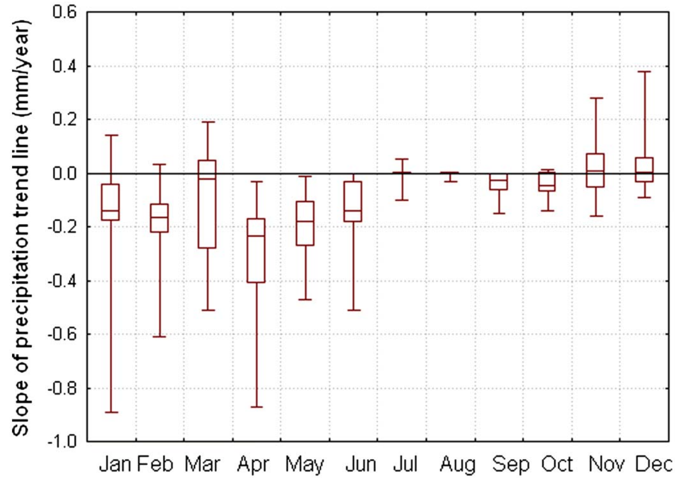

Fig. 4. Box plot of Theil-Sen's slopes for monthly precipitation time series of NW Iran (1955–2005)

instead of the MK1 in the spring; and the number of statistically significant trends decreased from five to three on using the the MK4 test instead of the MK1 test in spring. In the spring season, the number of negative significant trends ($P < 0.05$) was found to be 3/3/3/1 using the MK1/MK2/MK3/MK4 test. The number of negative significant trends gets reduced from five (three) to three (one) on using the MK1 (the MK4) test at the 5% level of significance instead of the 10% level of significance; however, it remained unchanged on using both the MK2 and MK3 tests, possibly resulting from steeper downward slopes, and thus significant at both 5% and 10% levels of significance.

In summer and autumn, no station witnessed a statistically significant trend, either negative or positive, at the 5 and 10% levels using the four different versions of the MK test (Table 3).

In annual time scale, the number of significant trends at the 10% level using the MK1/MK2/MK3/MK4 were 7/3/4/4. Using the MK1 (MK4) test, all (all) of the 16 stations witnessed decreasing trends; from these sixteen stations, only seven (four) stations observed statistically significant negative trends in precipitation at the 10% level. Therefore, it may be concluded that the number of significant trends reduced considerably using the MK4 instead of the MK1. In annual time scale, the number of significant trends ($P < 0.05$) were 4/2/2/2 using the MK1/MK2/MK3/MK4 test. Therefore, it can be concluded that using 5% instead of 10% as a significant level the percentages of stations (having negative significant trends) reduces from 28 to approximately 15.5%.

Fig. 3 shows the correlogram of the precipitation time series in the annual time scale at Bijar station. The autocorelation coefficients in lags 1, 2, 3, 5, and 6 were beyond the 95% confidence intervals. Such significant positive autocorelation coefficients showed long-term memory of the mentioned station in annual precipitation series, which affect the Z-statistics in all four versions of the MK test. The most important conclusion is that all stations of NW Iran experienced negative trends in annual precipitation by all four different versions of the MK approach.

Magnitude of Monthly Trends

Fig. 4 shows the box plot of Theil-Sen's slopes of precipitation time series in a monthly time scale over NW Iran. Notably, the line inside the boxes represents the median; however, the upper and lower lines of the boxes indicate the 75th and 25th percentile, respectively. Furthermore, the upper and lower part of the whiskers (vertical lines) indicates the respective maximum and minimum values of the slopes of the precipitation time series. According to Fig. 4, medians of almost all 12-month slopes are negative. The lowest point among 12 whiskers, i.e., vertical lines, occurred in the month of January (approximately −0.9 mm/year), followed by April (approximately −0.87 mm/year). This implies that the trend lines having the steepest negative slope occurred in January and April. In contrast, the highest point of whiskers occurred in the month of December (approximately +0.39 mm/year) followed by November (approximately 0.3 mm/year). In general, the maximum (minimum) distance between the lowest and highest points of whiskers was found in the month of January (August). This implies that the variance of the slopes of precipitation trend lines in the study area is highest in January and lowest in August.

Magnitude of Seasonal and Annual Trends

Fig. 5 shows the box plot of slopes estimated by TSA in seasonal and annual time scale. According to Fig. 5, the medians of slopes for all seasons and annual time scale were located below the zero line. The lowest (−2.36 mm/year) value of slope of precipitation trend line is found to occur in the winter season. The median of slopes in spring is lower compared with the other three seasons, indicating the presence of some kind of seasonality in the precipitation time series in the NW region of Iran.

In autumn, the maximum (minimum) value for precipitation trend-line slope was approximately $+0.69(-0.22)$ mm/year. In general, spring and winter precipitation showed a downward trend line in NW Iran. Approximately 66% of the annual rainfall series of NW Iran occurs in the winter and spring seasons (Dinpashoh 2006). Therefore, the reduction in winter and spring precipitation may cause water scarcity in the study area, which may adversly affect the water-related activities as well as the ecology of the region. The streamflows in NW Iran exhibited negative trends using the MK2 test in the recent three decades, and approximately half the hydrometeorological stations experienced significant decreasing trends in the winter and spring seasons (Dinpashoh 2010). This is in accordance with the findings of precipitation trends in the area under study. On an annual time scale, the range of slopes were between

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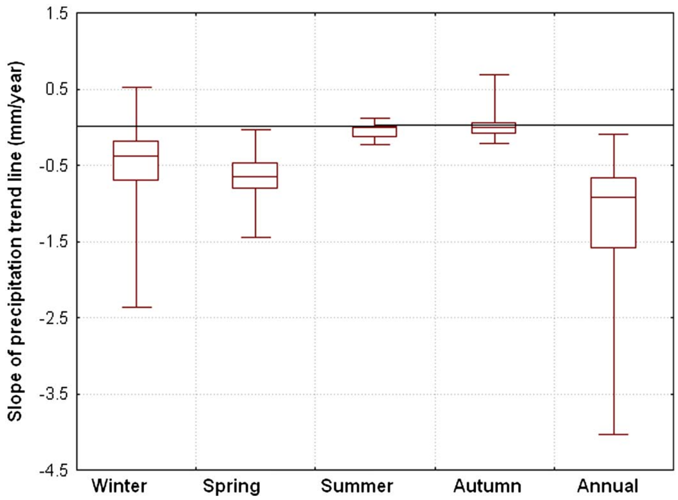

Fig. 5. Box plot of Theil-Sen's slopes for seasonal and annual precipitation time series of NW Iran (1955–2005)

(−)4.1 and (−)0.15 mm/year (see Fig. 5). The median of slopes in the mentioned time scale was approximately (−)0.85 mm/year. This was greater than that of the corresponding seasonal and monthly time scales.

Tabari and Talaee (2011) reported that approximately 60% of Iran's stations were characterized by nonsignificant negative annual precipitation trends, mostly from the NW region of Iran. Although in their study, the effect of sample size was applied to eliminate the effect of serial correlation in the MK test (i.e., LTP in MK3); however, the effects of the STP and the Hurst coefficient (MK4) were not investigated. Modarres and Sarhadi (2009) reported that approximately 67% of Iran's stations, mostly located in NW Iran, experienced decreasing annual precipitation trends. Both Modarres and Sarhadi (2009) and Tabari and Talaee (2011) used only a few sites from the NW region of Iran and did not consider the monthly precipitation data for their study. Furthermore, Modarres and Sarhadi (2009) used the MK test without taking into account the effect of the STP and/or the LTP in rainfall time series. According to Modarres and Sarhadi (2009, Fig. 3), nearly all the stations located in NW Iran exhibited downward trends. Some of these stations had witnessed significant negative trends, which is in conformity with the findings of this study for NW Iran.

Conclusions

In the present study, the trends in precipitation over NW Iran (1955–2004) were examined using the four different versions of the MK test on monthly, seasonal, and annual time scales. The effect of the short-term persistence, the long-term persistence, and the Hurst coefficient on identification of the trends was analyzed. The slopes of precipitation trend lines were estimated using the nonparametric Theil-Sen test. Results indicated that the decreasing trends in precipitation were more pronounced in the first 6 months of the year (January to June), which corresponds with the wet period of winter and spring seasons in NW Iran. The precipitation decreases in the aforementioned 6 months indicate the presence of seasonality in the precipitation over NW Iran, also affecting the trends in seasonal and annual precipitation. All selected 16 stations experienced decreasing trends in precipitation in an annual time scale. Approximately 28.1% of the total stations witnessed a decreasing trend ($P < 0.10$) using the four different versions of the MK test for annual precipitation series over NW Iran. Notably, the number of statistically significant trends decreased on using the MK4 test instead of the MK1 test in all three time scales, indicating that most of the absolute values of Z-statistics get reduced on removing the effect of the Hurst coefficent from the precipitation data. This is also true, to some degree, for the MK2 and the MK3 tests. The median of trend-line slopes were negative for the precipitation time series on annual, seasonal, and monthly time scales. The precipitation trends varied from (−)4.1 to (−)0.15 mm/year over NW Iran in an annual time scale. On seasonal time scale, the precipitation trends over NW Iran witnessed downward trends, especially in the winter and spring seasons. The decreasing trends in precipitation in the winter and spring seasons would lead to the water scarcity in the region because these two seasons are the primary rainy seasons over NW Iran. The adverse affects of the observed decreasing trends in precipitation may be expected for different water-related sectors, primarily the rainfed agriculture and the availability of freshwater in the NW region of Iran.

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