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Identification of Trend in Reference Evapotranspiration Series with Serial Dependence in Iran

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Abstract Monitoring the temporal variations of reference evapotranspiration (ET_o) and quantifying any trends offer valuable information for regional hydrology, agricultural water requirements and water resources management. This study aimed to examine the temporal trends in the Penman–Monteith ET_o in the west and southwest of Iran by using the Kendall and Spearman tests after eliminating the influence of significant lag-1 serial correlation from the ET_o time series. The magnitudes and starting years of significant ET_o trends were determined by the Mann-Kendall rank statistic and the Theil–Sen's estimator, respectively. For the study period of 1966–2005, a significant positive lag-1 serial correlation coefficient was observed at almost all the stations. The existence of the positive serial correlation in the ET_o series increased the possibility of the Kendall and Spearman tests to reject the null hypothesis of no trend while it is true. It was found that the Kendall test was more sensitive than the Spearman test to the existence of the positive serial correlation in the ET_o series. After removing the serial correlation effect with pre-whitening method, only three significant increasing ET_o trends were obtained at Khorram-Abad, Shahrekord and Zanjan stations at the rates of 0.16, 0.06 and 0.06 mm/day per decade, respectively. The significant increasing ET_o trends of Khorram-Abad, Zanjan and Shahrekord stations started in 1997, 1994 and 1998, respectively. The stepwise regression method showed that wind speed was the most dominating variable affecting on the significant changes of ET_o.

Keywords Kendall test · Penman-Monteith model · Pre-whitening · Spearman test · Serial correlation · Trend magnitude

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1 Introduction

Climate change due to the anthropogenic-driven emissions of greenhouse gases and land-use and land-cover changes has emerged as one of the important environmental issues of the 21st century. The global mean surface temperature has increased by 0.6°C over the last 100 years, with 1998 being the warmest year, and most of the increase in the global mean temperature has been observed in two distinct periods: 1910–1940 (0.35°C) and since 1970 (0.55°C) (Jhajharia et al. 2011). One major challenge of recent hydrological modeling activities is the assessment of the effects of climate change on the terrestrial water cycle (Bormann 2010). As a consequence of climatic changes, a significant impact on hydrological parameters, viz. runoff, evapotranspiration, soil moisture, ground water etc. is expected (Goyal 2004).

Evapotranspiration (ET) is the most important parameter for revealing the climate change and temporal-spatial patterns of parameters influencing the eco-hydrological processes, which control the evolution of the surface ecosystem. Moreover, assessment of climate change impacts on ET variability can be helpful in determining appropriate adaptation strategies for mitigating the probable damage from these impacts (Shadmani et al. 2011).

Climate observations of many climate stations report that temperature has increased in the last century (IPCC 2007), while the change in the components of the hydrological cycle such as ET shows regionally differentiated patterns of increase and decrease (e.g., Chattopadhyay and Hulme 1997; Thomas 2000; Chen et al. 2006; Xu et al. 2006; Gao et al. 2006, 2007; Zhang et al. 2007, 2009; Donohue et al. 2010; Liu et al. 2010; Li et al. 2010).

Recently, Yin et al. (2010) studied the trends in reference evapotranspiration (ET_o) across China during the period 1961–2008. The results showed the decreasing trends of ET_o in the whole country and in most climate regions except the cold temperate humid region in Northeast China. Abtew et al. (2011) showed that South Florida is experiencing increase in evaporation and evapotranspiration. In the other study, Jhajharia et al. (2011) investigated the trends in ET_o over the humid region of northeast India by using the Mann-Kendall test after removing the effect of serial correlation from the time series of ET_o by pre-whitening. They found that ET_o decreased significantly at annual and seasonal time scales for 6 sites in NE India and NE India as a whole.

In Iran, Tabari and Marofi (2011) analyzed the changes of observed pan evaporation (E_{pan}) and the associated variations in maximum, minimum and mean air temperatures and precipitation data for 12 stations in Hamedan province in western Iran from 1982 to 2003. Trend analysis was carried out by the Mann–Kendall test, the Sen's slope estimator and the linear regression method. They indicated a significant increasing trend in E_{pan} in 67% of the selected stations, and the increasing E_{pan} was strongly related to air temperature changes. Tabari et al. (2011a, b) studied the temporal trends in the ET_o series at the synoptic stations of Iran using the Mann–Kendall test, the Sen's slope estimator and the linear regression. The results showed that ET_o significantly increased at the majority of the stations, but the trends were found to be significant at about 30% of the stations. In the above mentioned studies in Iran, the influences of serial correlation on the trend tests were not considered.

The present study was undertaken to achieve the following purposes: (i) to detect the temporal trend of the Penman–Monteith ET_o at 15 synoptic stations located in the west and southwest of Iran by using the Kendall and Spearman tests, (ii) to consider the effect of serial correlation on the Kendall and Spearman tests with pre-whitening method, (iii) to estimate the magnitudes of the significant ET_o trends through the Theil–Sen's estimator, (iv) to determine the approximate year of starting of the significant ET_o trends using the Mann-Kendall rank statistic, and (v) to identify the most dominating climatic variables affecting ET_o using stepwise regression method.

2 Materials and Methods

2.1 Data Base

The weather data were collected from 15 synoptic stations located in the west and southwest of Iran. The geographical position of the selected stations is presented in Fig. 1 and Table 1. The weather data including mean, maximum and minimum air temperatures, relative humidity, dew point temperature, water vapour pressure, wind speed, atmospheric pressure, precipitation, solar radiation and sunshine hours for a period of 40 years (1966–2005) were obtained from IRIMO.

First of all data were quality-controlled with the double-mass curve analysis (Kohler 1949). The missing data were also substituted by the average between the data of the previous and the following year. When this standard was not possible to obtain, the recorded values in neighboring stations with high correlation (r greater than 0.8 at the 95% confidence level) were used to complete the climatic parameters records. Moreover, the solar radiation gaps were filled using the Angstrom equation (Allen et al. 1998).

$$R_s = (a_s + b_s \frac{n}{N})R_a \tag{1}$$

where R_a is the extraterrestrial radiation (MJ m^{-2} day^{-1}), n is the actual duration of sunshine (h), N is the maximum possible duration of sunshine or daylight hours (h), a_s is the regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n=0) and a_s+ b_s is the fraction of extraterrestrial radiation reaching the earth on clear days (n=N).

2.2 ET_o Calculation

The International Commission for Irrigation and Drainage (ICID) and Food and Agriculture Organization of the United Nations (FAO) have proposed using the Penman–Monteith

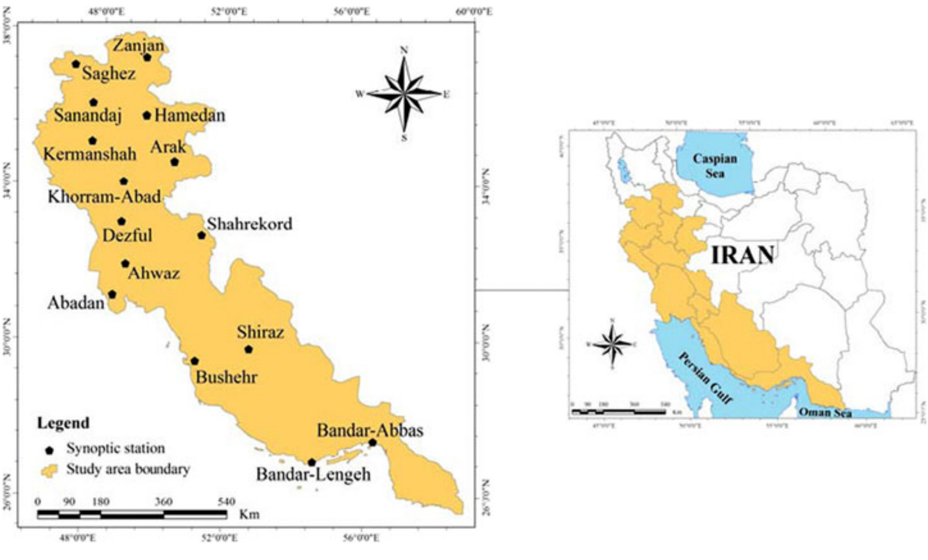

Fig. 1 Map of Iran with the locations of the 15 synoptic stations

Table 1 Details of the synoptic stations used in the study

Station	Longitude (E)	Latitude (N)	Elevation (m a.s.l.)
1. Zanjan	48° 29′	36° 41′	1663
2. Saghez	46° 16′	36° 15′	1523
3. Sanandaj	47° 00′	35° 20′	1373
4. Hamedan	48° 43′	35° 12′	1680
5. Kermanshah	47° 09′	34° 21′	1319
6. Arak	49° 46′	34° 06′	1708
7. Khorram-Abad	48° 17′	33° 26′	1148
8. Dezful	48° 23′	32° 24′	143
9. Shahrekord	50° 51′	32° 17′	2049
10. Ahwaz	48° 40′	31° 20′	23
11. Abadan	52° 40′	31° 11′	2030
12. Shiraz	52° 36′	29° 32′	1484
13. Bushehr	50° 50′	28° 59′	20
14. Bandar-Abbas	56° 22′	27° 13′	10
15. Bandar-Lengeh	54° 50′	26° 32′	23

method as the standard method for estimating ET_o (Allen et al. 1994a, b). The Penman–Monteith method assumes the ET_o as that from a hypothetical crop with an assumed crop height (0.12 m) and a fixed canopy resistance (70 sm^{-1}) and albedo (0.23), closely resembling the evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, and not short of water, which is given by Allen et al. (1998) as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean}+273} U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (2)$$

where ET_o is the reference crop evapotranspiration (mm day^{-1}), R_n is the net radiation (MJ m^{-2} day^{-1}), G is the soil heat flux (MJ m^{-2} day^{-1}), γ is the psychrometric constant (kPa $°C^{-1}$), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), and Δ is the slope of the saturation vapor pressure-temperature curve (kPa $°C^{-1}$), T_{mean} is the average daily air temperature (°C), and U_2 is the mean daily wind speed at 2 m (m s^{-1}). The computation of all data required for calculating ET_o followed the method and procedure given in Chapter 3 of FAO-56 (Allen et al. 1998).

2.3 The Techniques Used for Trend Analysis

Spearman Test The Spearman coefficient, r_s, is the correlation coefficient of the linear regression between the series i and y_i and it is obtained from the expression:

$$r_s = 1 - \left[6\sum (y_i - i)^2\right] / \left[n(n^2 - 1)\right] \quad (3)$$

where n is the number of data items in the series and i is the order of the elements in the original series. The distribution of r_s tends towards a normal distribution (bell curve) with a mean of zero.

In order to examine whether the null hypothesis, that there is no trend, can be rejected or not, it is necessary to calculate the probability

$$\alpha = P(|u| > |u(r_s)|) \tag{4}$$

$$u(r_s) = r_s(n-1)^{1/2} \tag{5}$$

This is calculated using a table of reduced normal distribution. If $\alpha<\alpha_0$, the null hypothesis is rejected for a significance level of α_0. If a trend is detected, it will be an increasing or decreasing trend, depending on whether $r_s>0$ or $r_s<0$ (del Rio et al. 2005).

Kendall Test Kendall's rank correlation (or τ test) is a commonly used test to assess the significance of trends in hydro-meteorological time series which is based on the proportionate number of subsequent observations that exceed a particular value (Kendall and Stuart 1973; Kottegoda 1980). For a sequence $x_1, x_2, \ldots, x_n$, the standard procedure is to determine the number of times, say, p, in all pairs of observations (x_i, x_j; j>i) that x_j is greater than x_i; the ordered (i, j) subsets are (i=1, j=2,3,. . .,n), (i=2, j=3,4,. . .,n), . . ., (i=n-1, j=n), n is the data set record length. There is a rising trend where succeeding values are throughout greater than preceding ones and p is given by $(n-1)+(n-2)+\ldots+1$ which is the sum of an arithmetic progression and is given by $\frac{n(n-1)}{2}$. If the observations are totally reversed, $p=0$ and, hence it follows that, for a trend free series,

$$E(p) = \frac{n(n-1)}{4} \tag{6}$$

The test is based on the statistic τ,

$$\tau = \frac{4p}{n(n-1)} - 1 \tag{7}$$

For random sequence $E(\tau)=0$ and $Var(\tau)$ is calculated by

$$Var(\tau) = \frac{2(2n+5)}{9n(n-1)} \tag{8}$$

The test defines the standard normal variant N as

$$N = \frac{\tau}{Var(\tau)^{0.5}} \tag{9}$$

N converges rapidly to a standard normal distribution as n increases. At a specified level of significance of α, standard N_α value can be obtained from the table of standard normal distribution. If $|N| > N_{\alpha/2}$, a positive N indicates an increasing trend in the time series, and a negative N indicates a decreasing trend (Ma et al. 2008).

Pre-whitening Approach The Kendall and Spearman tests require time series to be serially independent. von Storch (1995) suggested to use a pre-whitening approach to eliminate the influence of serial correlation on the Mann-Kendall test. Later, the pre-whitening approach was used for removing the effect of serial correlation on the other trend tests such as Mann-Whitney (Yue and Wang 2002) and Sen's slope estimator (Tabari and Hosseinzadeh Talaee 2011c). A serially correlated series is pre-whitened using the following formula (Yue and

Wang 2002):

$$Y_t = X_t - r_1 X_{t-1} \tag{10}$$

where r_1 is the lag-1 sample serial correlation coefficient, which is estimated using the following formula:

$$r_1 = \frac{(1/(n-1))\sum_{t=1}^{n-1}[X_t - E(X_t)][X_{t+1} - E(X_t)]}{\frac{1}{n}\sum_{t=1}^{n}[X_t - E(X_t)]^2} \tag{11a}$$

$$E(X_t) = \frac{1}{n}\sum_{t=1}^{n} X_t \tag{11b}$$

Theil–Sen's Estimator The magnitude of the trends in the ET_o time series was estimated using the non-parametric Theil–Sen's estimator (Theil 1950; Sen 1968) as follows:

$$\beta = Median\left(\frac{X_i - X_j}{i - j}\right), \quad \forall j < i \tag{12}$$

in which $1<j<i<n$. The estimator β is the median over all combination of record pairs for the whole data set and is thereby resistant to the effect of extreme values in the observations (Xu et al. 2003).

Mann-Kendall Rank Statistic Test The Mann-Kendall rank statistic test proposed by Sneyers (1990) is used for determining approximate year of beginning of the significant trend (e.g., del Rio et al. 2005; Partal and Kahya 2006; Croitoru et al. 2011). This test sets up two series, a progressive one and a backward one. If they cross each other, and then diverge and acquire specific threshold values, then there is a statistically significant trend. The point where they cross each other indicates the approximate year at which the trend begins (Mosmann et al. 2004).

3 Results and Discussion

The descriptive statistics of the ET_o values at the stations are given in Table 2. As shown, the ET_o values varied from 7 and 6.2 mm/day respectively at Abadan and Ahwaz stations to 3.4 mm/day at Shahrekord station. Furthermore, the highest coefficient of variation (CV) of the ET_o values was observed at Saghez and Khorram-Abad stations located in the west of the study area at the rates of 17.91% and 16.88%, respectively. On the contrary, the lowest CV of 4.32% was found at coastal Boushehr station.

Figure 2 illustrates lag-1 serial correlation coefficients for ET_o data at the study stations. It can be determined from Fig. 2 that the ET_o data had a positive lag-1 serial correlation coefficient at all of the stations. The positive correlations were found to be significant at the 95% confidence level at the whole stations except Abadan. Moreover, the highest serial correlations of 0.81 and 0.78 were obtained at Zanjan and Khorram-Abad stations respectively, while the lowest serial correlation of 0.24 was detected at Abadan station.

The results of the Kendall and Spearman tests on the ET_o series before and after the removal of serial correlation effects on the trend tests were summarized in Tables 3 and 4. As

Table 2 Descriptive statistics of the ET_o values at the stations

Station	Max. (mm/day)	Min. (mm/day)	Mean. (mm/day)	SD (mm/day)	CV (%)
Zanjan	4.5	2.7	3.5	0.458	13.09
Saghez	5.3	2.7	3.5	0.625	17.91
Sanandaj	4.8	3.0	4.0	0.433	10.89
Nozheh	5.2	3.5	4.3	0.366	8.55
Kermanshah	5.2	3.6	4.4	0.415	9.44
Arak	4.5	2.8	3.7	0.340	9.19
Khorram-Abad	5.4	31	4.0	0.677	16.88
Dezful	6.9	4.8	5.5	0.552	10.03
Shahrekord	4.3	3.0	3.4	0.319	9.37
Ahwaz	8.1	5.1	6.2	0.586	9.45
Abadan	8.5	5.9	7.0	0.621	8.87
Shiraz	5.9	4.2	5.0	0.373	7.46
Bushehr	5.6	4.6	5.1	0.220	4.32
Bandar-Abbas	6.3	4.7	5.7	0.477	8.36
Bandar-Lengeh	6.0	4.3	5.3	0.427	8.06

SD standard deviation; *CV* coefficient of variation

shown, the results of the trend tests were coincident at the majority of the cases. After eliminating serial correlation effect, the sign of the ET_o trend converted at some stations. For instance, the sign of the ET_o trend by the Kendall and Spearman tests at Nozheh station was negative before eliminating serial correlation effect, while the positive ET_o trend was obtained at the station after eliminating serial correlation effect. Such pattern was found at Bandar-Lengeh and Bandar-Abbas stations for the Kendall test.

In addition to converting the sign of the ET_o trends, the significance level of them changed in all the series after removing the effect of serial correlation by pre-whitening method (Tables 3 and 4). In general, by comparing the results of the trend tests before and after removing the effect of serial correlation, it is evident that the existence of the positive serial correlation in the ET_o series increased the possibility of the Kendall and Spearman tests to reject the null hypothesis of no trend while it is true. In some cases, changing the

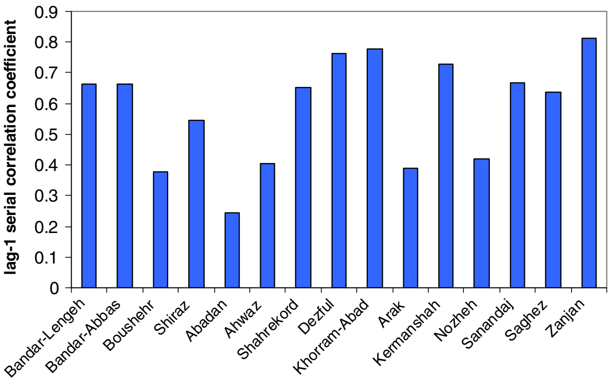

Fig. 2 Lag-1 serial correlation coefficients for the ET_o data at the stations

Table 3 Values of the statistics N of the Kendall test for the ET_o series before and after eliminating serial correlation effects

Station	Before eliminating serial correlation effects		After eliminating serial correlation effects	
	N	*P-value*	N	*P-value*
Zanjan	4.27	0.000	2.03	0.046
Saghez	1.63	0.105	1.95	0.054
Sanandaj	1.23	0.220	0.50	0.620
Nozheh	−0.03	0.981	0.41	0.690
Kermanshah	2.03	0.042	1.87	0.064
Arak	1.02	0.309	0.48	0.637
Khorram-Abad	2.33	0.020	2.84	0.005
Dezful	−3.90	0.000	−0.67	0.506
Shahrekord	3.70	0.000	2.05	0.043
Ahwaz	1.65	0.099	1.68	0.097
Abadan	1.24	0.222	1.24	0.222
Shiraz	−0.46	0.640	−0.46	0.654
Bushehr	−0.28	0.255	−1.02	0.315
Bandar-Abbas	−0.04	0.972	0.38	0.708
Bandar-Lengeh	0.41	0.682	−0.14	0.894

significance level of the trends caused converting significant ET_o trends to insignificant ones. According to both trend tests, the ET_o trends at Boushehr and Dezful stations were found to be significant before eliminating serial correlation effect, however, the trends

Table 4 Values of the statistics r_s of the Spearman test for the ET_o series before and after eliminating serial correlation effects

Station	Before eliminating serial correlation effects		After eliminating serial correlation effects	
	r_s	*P-value*	r_s	*P-value*
Zanjan	0.703	0.000	0.352	0.028
Saghez	0.295	0.064	0.301	0.063
Sanandaj	0.222	0.169	0.075	0.649
Nozheh	−0.010	0.952	0.089	0.590
Kermanshah	0.305	0.055	0.267	0.101
Arak	0.151	0.352	0.060	0.715
Khorram-Abad	0.418	0.007	0.430	0.006
Dezful	−0.590	0.000	−0.121	0.464
Shahrekord	0.574	0.000	0.321	0.046
Ahwaz	0.235	0.144	0.280	0.085
Abadan	0.197	0.229	0.198	0.229
Shiraz	−0.068	0.677	−0.057	0.730
Bushehr	−0.405	0.009	−0.168	0.306
Bandar-Abbas	0.007	0.964	0.060	0.718
Bandar-Lengeh	−0.034	0.831	−0.057	0.732

converted to insignificant after eliminating serial correlation effect. Such pattern was observed at Kermanshah station for the Kendall test. Furthermore, the confidence level of the ET_o trend at Shahrekord and Zanjan stations decreased from 99% to 95%. Such pattern was observed at Khorram-Abad station for the Spearman test. As a whole, the analysis showed that the Kendall test was more sensitive than the Spearman test to the existence of the positive serial correlation in the ET_o data. The significant upward trend of the ET_o series was found only at Zanjan, Khorram-Abad and Shahrekord stations. In fact, the significant upward ET_o trends were mainly observed in the mountainous regions of the study area. The decreasing the availability of water will decrease the natural vegetation in these mountainous areas which have adverse impacts on meat production, and therefore on agricultural economy. It should be noted that the ET_o trends were considered statistically significant when identified by both statistical tests. Figure 3 shows the time series of ET_o at Zanjan, Khorram-Abad and Shahrekord stations.

The magnitudes of the ET_o trends calculated by the Theil-Sen's estimator are shown in Fig. 4. The highest magnitudes of the ET_o trends were obtained at Khorram-Abad and Ahwaz stations at the rates of 0.16 and 0.12 mm/day per decade, respectively. When averaged over all 15 stations, the ET_o values of the study area increased by 0.047 mm/day per decade during 1966–2005. This results in increasing the amount of crop water requirements in the area where arid and semi-arid regions occupy most of the land.

The Mann-Kendall rank statistic was used to determine the approximate year of beginning of the significant ET_o trends. The u(d) and u′(d) plots for the ET_o series at Shahrekord, Zanjan and Khorram-Abad stations are shown in Fig. 5. As mentioned earlier, the point where u(d) and u′(d) curves cross each other indicates the approximate year at which the trend begins. According to the Mann-Kendall rank statistic, the starting years of the significant ET_o trends at Khorram-Abad, Zanjan and Shahrekord stations were 1997, 1994 and 1998, respectively.

In this study, the trends of the climatic parameters associated with ET_o were examined to possibly explain the underlying mechanisms of ET_o changes. The insignificant trends of the temperature and precipitation (P) series were found at Khorram-Abad and Shahrekord

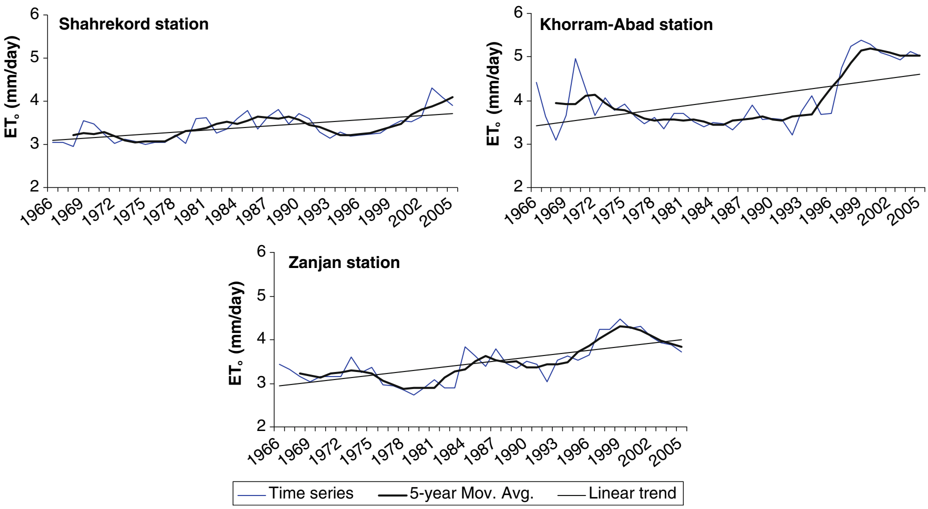

Fig. 3 Observed, 5-year moving average and trend line of annual ET_o at the stations with significant trends for the period 1966–2005

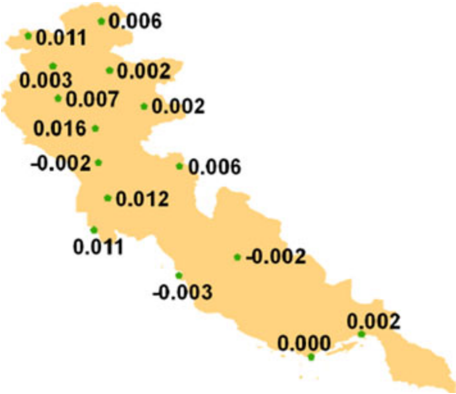

Fig. 4 Values of slope β (mm/year) for the annual ET_o (1966–2005)

stations (Tabari and Hosseinzadeh Talaee 2011a, Tabari et al. 2011c). Similarly, no significant trend was observed in the temperature series of Zanjan station (Tabari and Hosseinzadeh Talaee 2011a). The precipitation of Zanjan station significantly decreased at the 95% confidence level during 1966–2005 (Tabari and Hosseinzadeh Talaee 2011b). The u(d) and u′(d) plots for the P series at Zanjan station are illustrated in Fig. 6. The approximate starting year of the significant decreasing trend of the P series at the Zanjan station was 1997. The significant increasing trend of ET_o at the stations can be related to the variations of the other climatic parameters governing ET_o. To clarify it, the trends of relative humidity (RH), wind speed (U) and vapour pressure (e_a) at the stations were analyzed. The results of this study showed an insignificant trend in the RH and e_a series at Khorram-Abad and

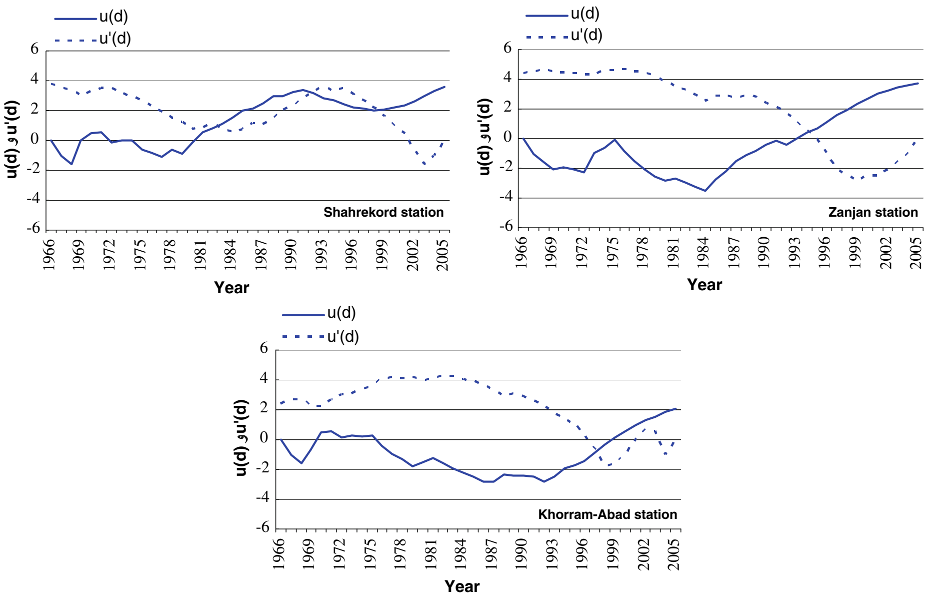

Fig. 5 Graphical representation of the series *u*(*d*) and the retrograde series *u′*(*d*) of Mann-Kendall rank statistic test for the ET_o series during1966–2005

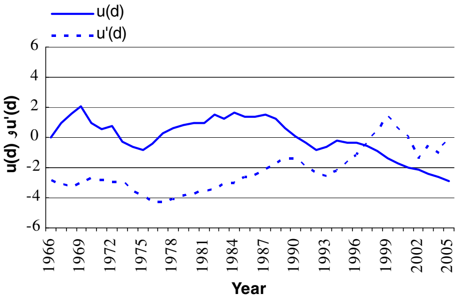

Fig. 6 Graphical representation of the series *u*(*d*) and the retrograde series *u'*(*d*) of Mann-Kendall rank statistic test for the P series at Zanjan station during1966–2005

Shahrekord stations, while wind speed significantly increased at the stations. Among the climatic parameters considered here, the increasing trend of U may have actually caused the increasing trend of the ET_o series at Khorram-Abad and Shahrekord stations. At Zanjan station, no significant trend was detected in the e_a series, whereas U and RH significantly increased at the station.

To identify the dominant variables associated with ET_o at the stations with significant ET_o trends (i.e., Zanjan, Khorram-Abad and Shahrekord stations), stepwise regression method was also used. Stepwise regression serves as a robust tool for the selection of the most dominating independent variables affecting the dependent variable. The determination of the most dominating variables is based on adding or deleting the variable/variables with the greatest impact on the residual sum of squares. In the stepwise regression method, ET_o was considered as the dependent variable and the climatic parameters, i.e. air temperature, precipitation, wind speed, vapour pressure and relative humidity as independent ones. As expected, wind speed was found to be the most dominating variable affecting on the observed changes of ET_o at all three stations (Table 5). Air temperature was the other important contributing variable for the observed trends in annual ET_o. On the contrary, relative humidity and precipitation were found to be the most insignificant causative variables for the observed ET_o changes.

Figure 7 illustrates the plots of the Mann-Kendall rank statistic for the U series of Shahrekord, Zanjan and Khorram-Abad stations. The u(d) and u′(d) plots for the U series of the stations were similar to those for the ET_o series. Based on Fig. 7, the significant increasing trend of U at Khorram-Abad station started in 1997 which is in accordance with the starting year of the ET_o trend at the station. Similar to the ET_o trend of Zanjan station, the

Table 5 The *p-value* of the relations between climatic parameters and ET_o in stepwise regression method (step 1)

Parameter/Station	Shahrekord	Zanjan	Khorram-Abad
Air temperature	**0.001**	**0.000**	0.364
Precipitation	0.542	**0.002**	0.364
Wind speed	**0.000**	**0.000**	**0.000**
Vapour pressure	**0.003**	**0.002**	0.104
Relative humidity	0.413	0.207	0.721

Bold values indicate significant relations

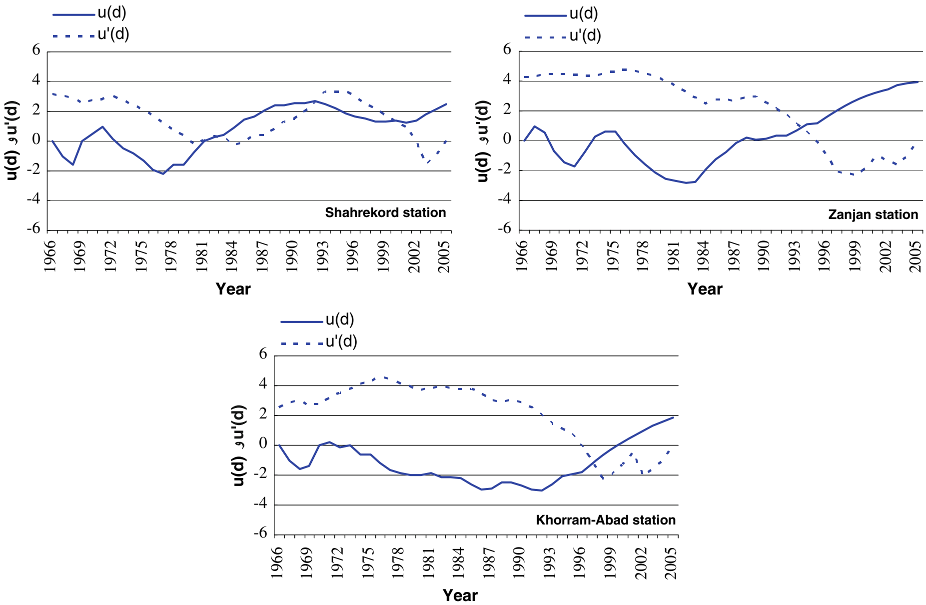

Fig. 7 Graphical representation of the series $u(d)$ and the retrograde series $u'(d)$ of Mann-Kendall rank statistic test for the U series during1966–2005

significant U trend at the station started in 1994. The approximate starting year of the significant U trend at Shahrekord station was 2001.

4 Summary & Conclusions

Analysis of the autocorrelated ET_o series at 15 synoptic stations in Iran over a 40-year study period allowed us to draw the following conclusions:

- There was a significant positive lag-1 serial correlation in the ET_o series at all the stations except Abadan. Although the existence of the positive serial correlation in the ET_o series increased the possibility of both trend tests to reject the null hypothesis of no trend, the Kendall test showed more sensitivity than the Spearman test to the existence of the positive serial correlation.
- Based on the Theil–Sen's estimator, the highest magnitudes of the ET_o trends were obtained at Khorram-Abad and Ahwaz stations at the rates of 0.16 and 0.12 mm/day per decade, respectively. On average, the ET_o values of the study area increased by 0.047 mm/day per decade.
- According to the Mann-Kendall rank statistic, the approximate years of beginning of the significant ET_o trends at Khorram-Abad, Zanjan and Shahrekord stations were 1997, 1994 and 1998, respectively.
- The stepwise regression analysis indicated that the most effective parameter influencing on the significant changes of ET_o was wind speed. In addition, wind speed significantly increased at the stations with the significant ET_o trends viz., Khorram-Abad, Zanjan and Shahrekord. The significant increasing U trends at Khorram-Abad, Zanjan and Shahrekord stations started in 1997, 1994 and 1998, respectively.

In general, the results of the trend tests before pre-whitening the ET_o data were extremely different from those after pre-whitening. Thus, the application of the Kendall and Spearman tests is recommended for detection of trend for the hydrological time series that do not have significant serial correlation. In the case that significant serial correlation exists in a time series, prior to trend analysis, the influence of the significant serial correlation should be removed from the series first.

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