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Parametric and Non-Parametric Trend of Reference Evapotranspiration and its key influencing climatic variables (Case study: Southern Iran)

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ABSTRACT Evapotranspiration is one of the most important components of the hydrological cycle which is directly influenced by atmospheric conditions. This study investigated annual and seasonal trends in reference evapotranspiration (ET_0) and its key influencing climatic variables during 1966-2005 at 10 stations in southern Iran (with centrality of Fars province). First, multivariate regression analysis was performed to identify the major meteorological variables affecting ET_0. Second, annual and seasonal trends in climatic variables as well as ET_0 were assessed using the Mann-Kendall test, Spearman's rho, the Pearson correlation and linear regression to evaluate their contribution to the temporal trend in ET_0. Results suggested that the more effective variables for ET_0 were wind speed (U_2), relative humidity (RH) and sunshine hours (n). Also, the majority of trends in seasonal and annual ET_0 were non-significant and after that decreasing and increasing trends had higher frequencies. In addition, distributions of relative frequencies of trend types at all considered time-scales were similar for both parametric and non-parametric techniques. Hence, the disagreement between parametric and non-parametric trend results did not depend on the degree of normality in the annual and seasonal ET_0 distributions in the study area.

Key words: *Climate variables, Lilliefors test, Normality degree, Trend analysis*

1 INTRODUCTION

Evapotranspiration is one of the most important components of the hydrological cycle which is directly influenced by meteorological conditions. Reference evapotranspiration (ET_0), defined as the potential evapotranspiration of a hypothetical surface of green grass of uniform height, actively growing and adequately watered, is an essential variable for scheduling irrigation systems, computing water balance models (Gong *et al.*, 2006) and efficient water resources management (Gao *et al.*, 2012).

Analysis of long-term changes in climatic elements is a fundamental task in studies on climate change detection (Huth and Pokorna, 2004) and also in long-term agricultural planning. Both parametric (i.e., Pearson

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correlation) and non-parametric trend detection methods (i.e., Mann-Kendall test and Spearman rank correlation) yield similar significance levels for a wide variety of climatic elements (Huth, 1999).

Chattopadhyay and Hulme (1997) showed that in spite of the general increase in temperature in recent decades over the Indian region, both pan evaporation (E_{pan}) and ET_0 have decreased and that increases in relative humidity and decreases in radiation were correlated with a decreasing trend in ET_0. Wang *et al.* (2007) analyzed the E_{pan} and ET_0 trends in the upper and mid-lower Yangtze River basin of China from 1961 to 2000. They found that E_{pan} and ET_0 decreased during summer months, contributing the most to the total annual reduction. The decreasing trends in E_{pan} and ET_0 were also reported in USA (Peterson *et al.*, 1995; Hobbins *et al.*, 2004), former Soviet Union (Peterson *et al.*, 1995), Australia and New Zealand (Roderick and Farquhar, 2004, 2005), and China (Thomas, 2000; Liu *et al.*, 2004; Xu *et al.*, 2006; Wang *et al.*, 2012).

Zhang *et al.* (2007) evaluated E_{pan} and ET_0 across the Tibetan Plateau during the period 1966 to 2003. They found that E_{pan} and ET_0 significantly decreased at 47% and 38% of the observatories, respectively, though the air temperature at most of the sites significantly increased ($p<0.05$); the wind speed and sunshine hours significantly decreased at 85% and 43% of the observatories ($p<0.05$), respectively.

In Iran, Tabari *et al.* (2011a) investigated annual, seasonal and monthly trends in ET_0 during 1966-2005 in the western half of Iran. They witnessed a positive annual trend in more than 70% of the stations, but the trends were found to be significant at about 30% of the stations. Dinpashoh *et al.* (2011) and Kousari and Ahani (2012), using non-parametric statistical tests (the Mann–Kendall and the Kendall's rank correlation), found both statistically significant increasing and decreasing trends in ET_0 over different sites in Iran.

The first objective of this study was to investigate annual and seasonal trends in ET_0 during 1966–2005 at 10 stations in southern Iran (with centrality of Fars province). The temporal variability of ET_0 was analyzed using the Mann-Kendall test, Spearman's rho, the Pearson correlation and linear regression. In order to identify the key variables associated with the changes in the FAO-56 Penman Monteith ET_0 in the study area (the second objective), multivariate linear regression (MLR) was used. Then, as the second objective, temporal trends (and trend magnitudes) of the recognized meteorological variables were surveyed in order to evaluate their effects on the trends in ET_0.

It is commonly expressed that because the non-parametric methods are distribution-free techniques, they will be more suitable than the parametric tests for detecting trends in climatic variables. The third objective of the present study was to probe whether the degree of normality in the distribution of ET_0 affects the disagreement between parametric and non-parametric trend results (the above cited studies except Huth and Pokorna, 2004 did not investigate this issue in the trend analysis of climate variables) in southern Iran.

2 MATERIALS AND METHODS

2.1 Study area

The main focus of this study is on the Fars province. It should be noted that only two meteorological stations (Shiraz and Fasa) in Fars province have reliable long-term records of variables required for estimating ET_0 using the FAO-56 Penman-Monteith (PMF-56). Hence, it was decided to include more stations from outside of the Fars borders. The

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selected meteorological stations (8 stations) have approximately uniform dispersion surrounding the Fars borders (Figure 1). The most effective atmospheric systems over the study area are the active Mediterranean and Sudanese systems in autumn and winter. This territory (southern Iran with the centrality of Fars province) is one of the most important agricultural regions in Iran. Agriculture plays a significant role in production and supply of employment and food in Iran (Ahani *et al.*, 2012).

Fars Province in south Iran is located between 27° 03´ to 31° 42´ northern latitude and 50° 30´ to 55° 36´ eastern longitude. Its average annual rainfall varies between 100 mm in the southern parts and more than 400 mm in the northern parts of the province (Soufi, 2004). Fars has remarkable contribution in Iran's agricultural production. For many years, Fars has been a highly ranked province in crop production, especially wheat. The aridity index (UNESCO, 1979) was applied for classifying climates of the stations used in this study (Table 1).

Data from 10 meteorological stations (Table 1), including daily observations of maximum (T_{max}), minimum (T_{min}) and mean air temperature (T_{mean}), wind speed (U_2), relative humidity (RH), and sunshine hours (n) for the period of 1966–2005, were used in this study (IRIMO, 2007). Basic statistics of these variables are summarized in Table 2.

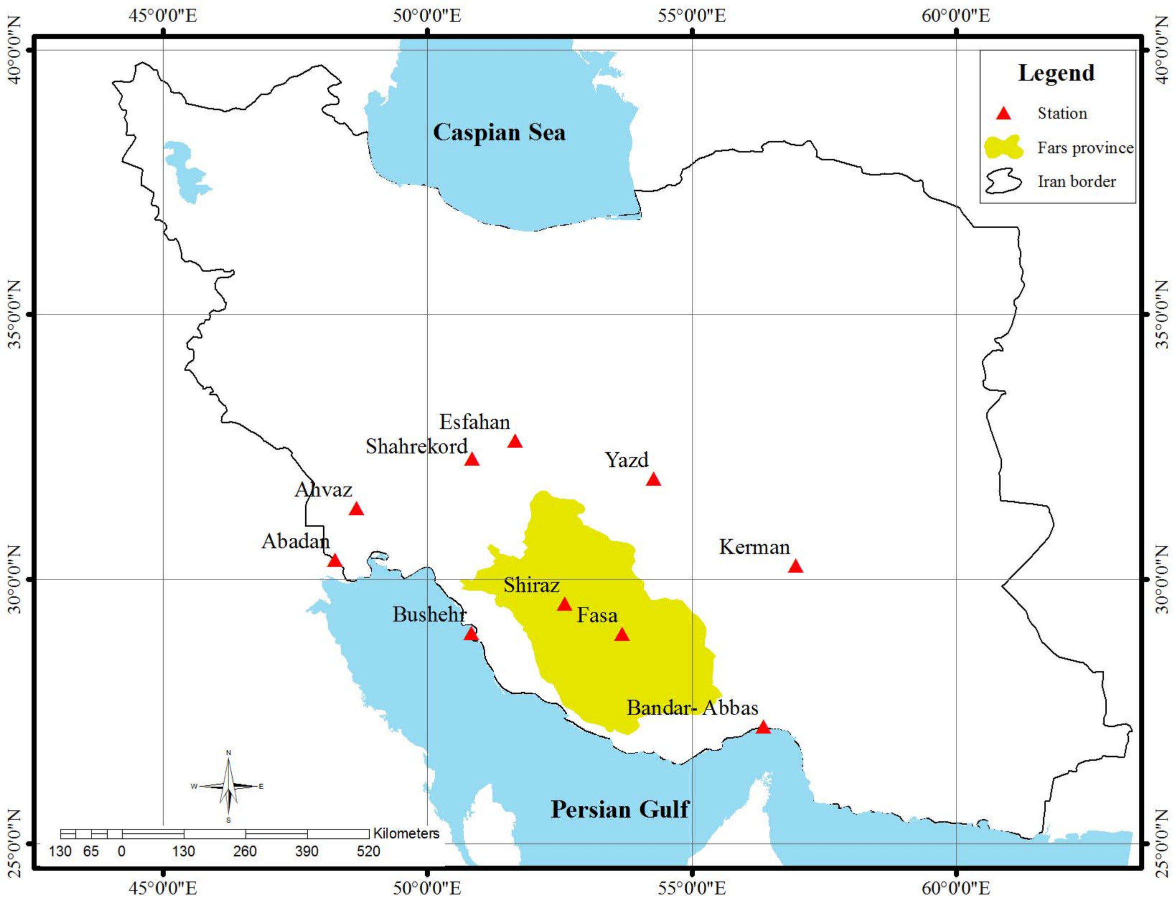

Figure 1 Geographic location of the study region and the stations.

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Based on the De Martonne (1926) climatic classification, the Fars province mostly has arid and semi-arid climate (Nafarzadegan *et al.*, 2012). As shown in Table 1, all considered stations have arid or semi-arid climate. Thus they are compatible with the dominant climate of Fars province.

The time series of mean air temperature, wind speed, relative humidity and sunshine hours at Fasa and Shiraz stations are shown in Figure 2 in order to help visualize the general trends in Fars province.

Table 1 Geographic characteristics and climate at the stations used in the study.

Station	Longitude (E)	Latitude (N)	Elevation (m)	Climate
Abadan	48° 15′	30° 22′	6	Arid
Ahvaz	48° 40′	31° 20′	22	Arid
Bandar-Abbas	56° 22′	27° 13′	10	Arid
Bushehr	50° 50′	28° 59′	19.6	Arid
Esfahan	51° 40′	32° 37′	1550	Arid
Fasa	53° 41′	28° 58′	1288	Arid
Kerman	56° 58′	30° 15′	1753	Arid
Shahrekord	50° 51′	32° 17′	2048	Semi-arid
Shiraz	52° 36′	29° 32′	1484	Semi-arid
Yazd	54° 17′	31° 54′	1237	Arid

Table 2 Mean values with standard deviation of the variables used in this study at different stations during 1966-2005.

Variable / Station	T_{max} (°C)	T_{min} (°C)	T_{mean} (°C)	RH (%)	U_2 ($m\ s^{-1}$)	n (hours)
Abadan	32.91 ± 0.89	18.08 ± 0.70	25.51 ± 0.72	44.76 ± 3.09	2.47 ± 0.40	8.41 ± 0.57
Ahvaz	32.9 ± 0.77	17.80 ± 1.16	25.35 ± 0.83	42.96 ± 3.10	1.96 ± 0.40	8.35 ± 0.52
Bandar-Abbas	32.16 ± 0.65	21.61 ± 0.63	26.88 ± 0.58	65.50 ± 2.77	2.20 ± 0.57	8.49 ± 0.44
Bushehr	29.54 ± 0.77	19.79 ± 0.63	24.67 ± 0.65	65.21 ± 2.48	2.43 ± 0.46	8.49 ± 0.49
Esfahan	23.31 ± 0.92	9.42 ± 0.71	16.37 ± 0.64	37.80 ± 3.21	1.43 ± 0.33	8.96 ± 0.34
Fasa	27.68 ± 0.96	10.9 ± 1.17	19.29 ± 0.83	39.23 ± 4.26	1.24 ± 0.47	9.22 ± 0.34
Kerman	24.67 ± 0.84	6.71 ± 0.84	15.69 ± 0.79	32.56 ± 4.17	2.31 ± 0.57	8.69 ± 0.46
Shahrekord	20.20 ± .99	3.39 ± 0.88	11.8 ± 0.83	46.37 ± 3.05	0.93 ± 0.33	8.65 ± 0.3
Shiraz	25.77 ± 0.77	9.99 ± 1.34	17.88 ± 0.91	40.42 ± 3.43	1.74 ±0.29	9.19 ± 0.36
Yazd	26.60 ± 0.81	11.83 ± 0.93	19.22 ± 0.81	30.98 ± 3.53	1.98 ±0.47	8.83 ± 0.38

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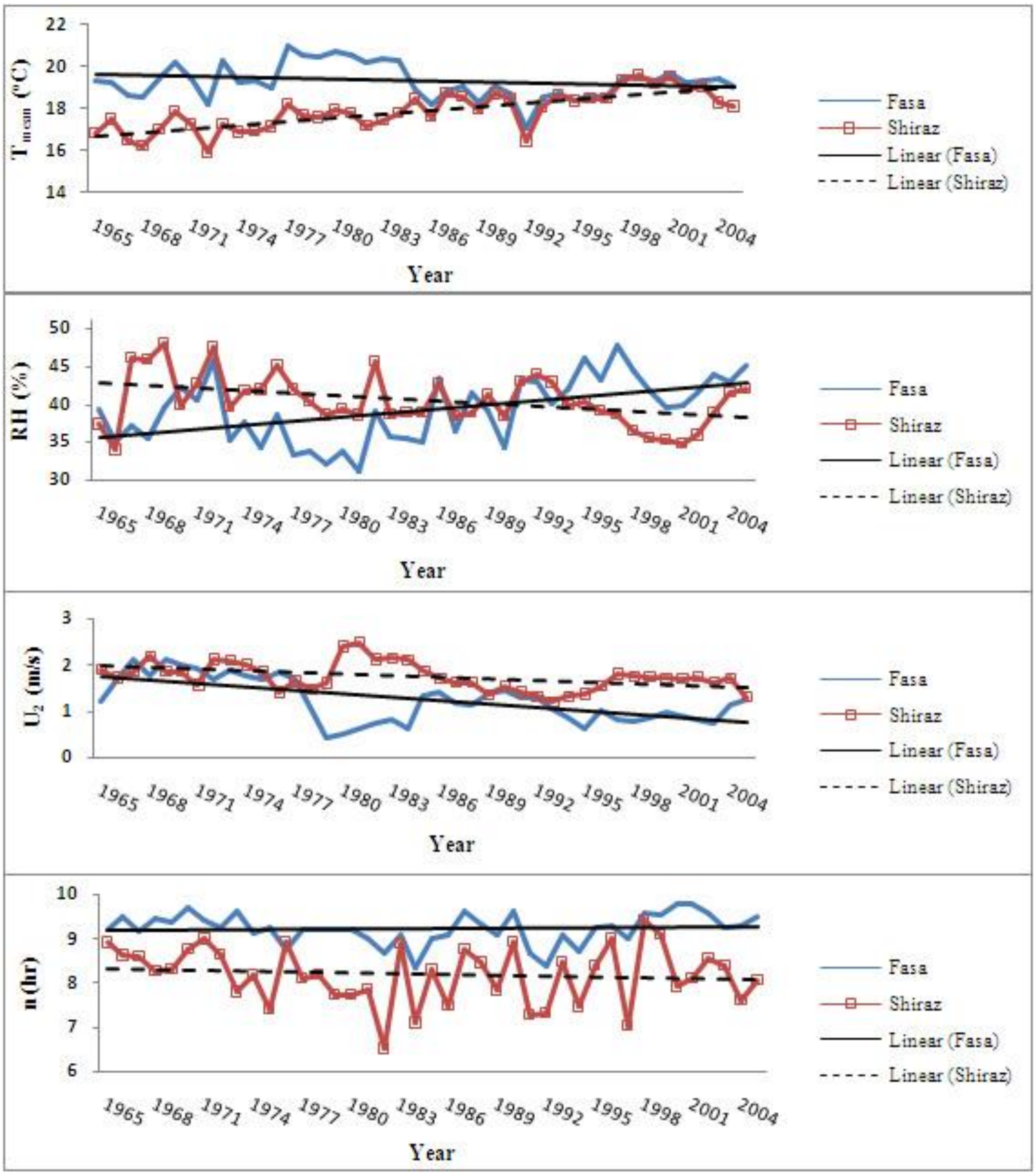

Figure 2 Time series plots of T_{mean}, *RH*, U_2 and *n* at Fasa and Shiraz stations (located in the Fars Province).

2.2 Evapotranspiration Computation

The Penman–Monteith method is recommended by FAO (Food and Agricultural Organization of the United Nations) and ASCE (American Society of Civil Engineers) as the sole and standard method for calculating reference evapotranspiration wherever the required input data are available (e.g., Allen *et al.*, 1998; ASCE 2005). This method is physically-based and can be used globally without any need for additional adjustments of parameters (Gong *et al.*, 2006). Some researchers employed Penman-Monteith method for Iran and tried to identify the main metrological variables influencing ET_0 in different climates of Iran (Dinpashoh *et al.* 2011; Tabari *et al.*, 2011b; Kousari and Ahani, 2012). In this study, the FAO-56 Penman-Monteith standard method

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(Allen *et al.*, 1998) was used to calculate ET_0 for the period of study Eq. (1):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma(900/(T+273))U_2(e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \quad (1)$$

where ET_o denotes the crop reference evapotranspiration (mm day^{-1}); R_n is the net radiation at crop surface (MJ m^{-2} day^{-1}); G is the soil heat flux density (MJ m^{-2} day^{-1}); T is the mean daily air temperature at a 2 m height (°C); U_2 is the wind speed at a 2 m height (m s^{-1}); e_s is the saturation vapor pressure (kPa); e_a is the actual vapor pressure (kPa); (e_s - e_a) is the saturation vapor pressure deficit (kPa); Δ is the slope vapor pressure curve (kPa °C^{-1}); and γ is the psychometric constant (kPa °C^{-1}).

2.3 Multivariate linear regression

To evaluate the relative significance of climate variables for the calculated ET_0, a sensitivity analysis was performed. There are several approaches available for sensitivity analysis. In this study, multiple linear regression (MLR) was applied to seasonal and annual series of maximum, minimum and mean air temperatures, wind speed, relative humidity, sunshine hours, and ET_0. Next, trends in the climatic variables were analyzed in order to understand their effect on the ET_0 trend.

2.4 Statistical tests

2.4.1 Mann-Kendall test

The non-parametric Mann-Kendall (M-K) test is widely used for detecting trends in hydrological and meteorological parameters (e.g., Modarres and da Silva, 2007; Wang *et al.*, 2008; Mishra and Singh, 2010; Zhang *et al.*, 2011). The test does not require the data to be distributed normally. Further, the test has a low sensitivity to abrupt breaks in the time series (Jaagus, 2006), and can test trends in a time series without requiring normality or linearity (Wang *et al.*, 2008). According to this test, the null hypothesis H_0 states that the depersonalized data (x_1, . . .,x_n) is a sample of n independent and identically distributed random variables. The alternative hypothesis H_1 of a two-sided test is that the distributions of x_k and x_j are not identical for all k, $j \leq n$ with $k \neq j$. The test statistic S, which has mean zero and a variance computed by Eq. (4), is calculated using Eqs. (2) and (3), and is asymptotically normal:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right) \quad (2)$$

$$\operatorname{sgn}\left(x_j - x_k\right) = \begin{cases} +1 & if \quad (x_j - x_k) > 0 \\ 0 & if \quad (x_j - x_k) = 0 \\ -1 & if \quad (x_j - x_k) < 0 \end{cases} \quad (3)$$

$$Var(S) = \frac{\left[n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)\right]}{18} \quad (4)$$

where n is the number of data points, m is the number of tied groups (a tied group is a set of sample data having the same value), and t_i is the number of data points in the ith group. In cases where the sample size n >10, the standard normal variable Z is computed using Eq. (5):

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(s)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \dfrac{S+1}{\sqrt{Var(s)}} & if \quad S < 0 \end{cases} \quad (5)$$

Positive values of Z indicate increasing trends, while negative values of Z indicate decreasing trends. When testing either increasing or decreasing monotonic trends at an α significance level, the null hypothesis is rejected for an absolute value of Z greater than $Z_{1-\alpha/2}$, obtained from the standard normal cumulative distribution Tables (Partal and

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Kahya, 2006). In this study, a significance level of α= 0.05 was applied.

2.4.2 Spearman's rho test

Spearman's rho (SR) test is another non-parametric rank-order test used in this study. Given a sample data set {X_i, $i= 1, 2, \ldots, n$}, the null hypothesis H_0 of the SR test against trend tests is that all X_i are independent and identically distributed; the alternative hypothesis is that X_i increases or decreases with j, that is, trend exists. The test statistic is given by Sneyers, (1990) and Yue *et al.* (2002):

$$D = 1 - \frac{6\sum_{i=1}^{n}[R(\mathrm{Xi}) - \mathrm{i}]^2}{n(n^2-1)} \tag{6}$$

where $R(X_i)$ is the rank of the i observation X_i in the sample of size n.

Under the null hypothesis, the distribution of D is asymptotically normal with the mean and variance as follows (Sneyers, 1990):

$$E(D) = 0 \tag{7}$$

$$V(D) = \frac{1}{n-1} \tag{8}$$

The P-value of the SR statistic (D) of the observed sample data is estimated using the normal cumulative distribution function (CDF) as its statistics are approximately normally distributed with mean of zero and variance of $V(D)$ for the SR statistic. Using the following standardization:

$$Z_{SR} = \frac{D}{\sqrt{V(D)}} \tag{9}$$

The standardized statistic Z follows the standard normal distribution Z~ N (0, 1).

The P-value (probability value, p) of both the M-K statistic (S) and the SR statistic (D) of sample data can be estimated using the normal CDF:

$$P = 0.5 - \Phi(|Z|)\ (Z = Z_{M\text{-}K}, Z_{SR}) \tag{10}$$

$$\Phi(|Z|) = \frac{1}{\sqrt{2\pi}}\int_0^{|Z|} e^{-t^2/2}\,dt \tag{11}$$

If the P-value is small enough, the trend is quite unlikely to be caused by random sampling. At the significance level of 0.05, if $p \leq 0.05$, then the existing trend is considered to be statistically significant (Yue *et al.*, 2002).

2.4.3 Pearson correlation

The Pearson correlation is a parametric technique for evaluating the degree of linear association or correlation between two independent variables. It is similar to Spearman's rho, except that it operates on the raw data rather than the ranks of the data (Gauthier, 2001). So, it can apply as well as the Mann-Kendall test and Spearman's rho (non-parametric methods) for detecting trends in a time series. The Pearson correlation (r) can be expressed as:

$$r = \frac{\sum_{i=1}^{N}(x-\bar{x})(y-\bar{y})}{\sqrt{\sum_{i=1}^{N}(x-\bar{x})^2\sum_{i=1}^{N}(y-\bar{y})^2}} \tag{12}$$

where x is the year; y is the estimated ET_0 by the PMF-56 or sensitive climatic variables; and $\bar{x}$ and $\bar{y}$ are their mean values in the annual and seasonal scales. The Pearson method was used to determine the existence or non-existence of trend in ET_0 and in variables affecting it.

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2.4.4 Linear regression

Linear regression analysis as well as the other suggested methods was applied for analyzing trends in the time series. The main statistical parameter drawn from regression analysis, the slope indicates the mean temporal change in the variable under study. Positive values of the slope show increasing trends, while negative values of the slope indicate decreasing trends. The total change during the period under observation was obtained by multiplying the slope by the number of years (Tabari and Marofi, 2011; Tabari *et al.*, 2011a).

2.4.5 Normality Test

As the Kolmogorov-Smirnov (K-S) test indicates rather poor performance in detecting the normality of distributions, i.e., its ability to detect when a sample comes from a non-normal distribution is relatively low (Thode, 2002), the K-S test with Lilliefors significance correction (Lilliefors test) was employed for this purpose. However, the value of the K-S test statistic can be used as an exploratory, not confirmatory tool (cf. Busuioc and von Storch, 1996): for this purpose one assumes that the higher the degree of the normality, the lower the value of the K-S statistic (Huth and Pokorna, 2004).

3 RESULTS AND DISCUSSION

3.1 Sensitivity analysis with MLR

In order to identify the key meteorological variables that are responsible for observed ET0 trends at stations, multiple linear regression (MLR) analysis was carried out (using SPSS) by considering the seasonal and annual ET_0 time series as a dependent variable and six meteorological variables (namely, T_{max}, T_{min}, T_{mean}, RH, U_2 and n) as independent variables. The results are summarized in Table 3.

Results of MLR for the winter ET_0 series showed a significant correlation for the U_2 series for all the stations ($p<0.01$). Similarly, the n series had a significant influence for all the stations ($p\leq0.01$) except for Esfahan ($p<0.1$). Also, RH was significantly related to winter ET_0 at all the stations ($p\leq0.01$), except for Kerman ($p<0.1$).

Table 3 Number of stations with the significant correlation between ET_0 and related climatic variables based on multivariate linear regression.

Series	Confidence level	No. of stations with significant correlation					
		T_{max}	T_{min}	T_{mean}	RH	U_2	n
Winter	95%	1	1	1	9	10	9
	99%	0	0	0	9	10	9
Spring	95%	0	0	0	9	10	10
	99%	0	0	0	9	10	10
Summer	95%	0	0	0	9	10	10
	99%	0	0	0	8	10	10
Autumn	95%	0	0	0	9	10	3
	99%	0	0	0	9	10	3
Annual	95%	0	0	0	6	10	7
	99%	0	0	0	6	10	6

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Significant influences of air temperatures (T_{min}, T_{mean} and T_{max}) were detected only at Bushehr station (p<0.05). It is interesting to note that MLR indicated no relation at the significance probability levels of 0.01 between winter ET_0 and air temperature. Eventually it should be noted that U_2, *RH* and *n* were more influential in the ET_0 calculation during winter.

Furthermore, there were significant correlations between spring and summer ET_0 series and the corresponding values of U_2 and *n* for all the stations (p<0.01). In addition, significant correlations for *RH* were observed for all the stations (p≤0.01), excluding Fasa station (p<0.05). Results of MLR for autumn ET_0 series indicated that only U_2 had a significant influence at all the stations (p<0.01). Similarly, *RH* and *n* were significantly related to the autumn ET_0 in 90% and 30% of the stations (p≤0.01), respectively. Analysis of the impact of climatic variables on the annual ET_0 series indicated significant correlations for U_2 and *RH* at all and 60% of the stations (p<0.01), respectively; and also there was a significant relation for *n* at 70% of the stations (p<0.05). It seems appropriate to state that Zhang *et al.* (2009) regressed ET_0 against air temperature, solar radiation, wind speed and air humidity for each station across the Qinghai-Tibetan Plateau (1971-2004) and concluded that all four climate variables had significant influence on the ET_0 variations at most of the stations. Using multiple regression analysis, Jhajharia *et al.* (2009) also suggested that mainly two parameters, i.e., sunshine duration followed by wind speed, strongly influenced the E_{pan} changes at various sites in northeast India.

The MLR results in this study area revealed that the most effective parameter on the seasonal and annual ET_0 series (estimated with PMF-56) was wind speed, followed by relative humidity and sunshine hours. Trends in these variables may help evaluate their effect on the ET_0 trend. The important role of air temperature in evapotranspiration mechanism It must be noted that authors are aware of, but the MLR results for the considered time-scales for this study area showed that the ET_0 variations were not affected significantly by the changes in air temperature. In other words, while the underlying factor for the occurrence of evapotranspiration is air temperature, in this study, the other factors (U_2, *RH* and *n*) seemed to have more leading role in the conditions and types (non-significant, decreasing or increasing) of trends in ET_0. Dinpashoh *et al.* (2011) also witnessed wind speed as the main contributory parameter for the observed ET_0 trends over different parts of Iran. Similar attributions have been reported for the decreases in ET_0 and E_{pan} (or evaporation) over some parts of China (Chen *et al.*, 2006; Xu *et al.*, 2006; Zhang *et al.*, 2007; Zhang *et al.*, 2009; Wang *et al.*, 2012), the majority of sites in India (Chattopadhyay and Hulme, 1997; Bandyopadhyay *et al.*, 2009), northeast India (Jhajharia *et al.*, 2009, 2012), Canadian Prairies (Burn and Hesch, 2007) and most parts of Australia (Roderick *et al.*, 2007). Donohue *et al.* (2010) also expressed that the overall contribution from the increase in temperature was almost entirely cancelled out by the decrease in wind speed alone over Australia.

Such seemingly unreasonable results like negative correlation between pan evaporation and actual evaporation, especially in arid and semi-arid conditions, have also been expressed by some investigators (Brutsaert and Parlange, 1998; Golubev *et al.*, 2001; Hobbins *et al.*, 2004). In this context, Burn and Hesch (2007) emphasized that the mechanisms causing the observed trends in evaporation are not clearly understood and although there is widespread agreement that global temperatures are increasing (IPCC, 2001), there are many

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meteorological factors that can result in an increase or a decrease in evaporation.

3.2 Trends at seasonal and annual time scales

Seasonal and annual ET_0 and related changes in U_2, *RH* and *n* for 10 stations were evaluated using two parametric (Pearson correlation and linear regression) and two non-parametric techniques (Mann-Kendall and Spearman's rho), as shown in Tables 4 to 8. It should be expressed that all trend results are presented at a significance level of 0.05. The magnitudes of observed trends were determined according to the linear regression slope (Tabari *et al.*, 2011b) wherever it was necessary. The magnitudes of trends can be determined with both parametric and non-parametric trend tests (Huth and Pokorna, 2004).

3.2.1 Winter

Results of the trend tests for winter ET_0, U_2, *RH* and *n* are given in Table 4. Based on the considered parametric and non-parametric methods, the winter ET_0 showed non-significant trends at 8 stations (except for Bushehr and Fasa). Among these 8 stations, five stations (Abadan, Ahvaz, Bandar-Abbas, Kerman and Yazd) had non-significant trends in *RH*, three stations in *n* (Bandar-Abbas, Esfahan and Shiraz stations) and only Yazd station in U_2. The remaining 2 stations (Bushehr and Fasa) indicated decreasing trends in winter ET_0.

There were non-significant trends in winter ET_0, *RH*, U_2 and *n* at Bandar-Abbas station, except that a decreasing trend in U_2 detected by the parametric methods also occurred at Ahvaz station. Since the Lilliefors test showed no normality in the U_2 series, it seems the degree of normality of distribution influenced U_2 at Bandar-Abbas and Ahvaz stations. Hence, in these cases non-parametric methods should be employed.

Unlike Bandar-Abbas and Ahvaz stations, the rest of the stations located on the northern coast of the Persian Gulf (Abadan and Bushehr stations) had significant trends in U_2 with a magnitude of -0.16 and -0.25 m s^{-1} per decade, respectively. Meanwhile, Abadan and Ahvaz stations indicated increasing trends (0.14 and 0.34 *hour* per decade) in *n*. It can be noted that U_2 had an important influence on the winter ET_0 trend at Bushehr station; but at Abadan station, the U_2 effect was offset by *n*. As mentioned above, Fasa station as well as Bushehr station showed downward trends in winter ET_0. In this case, despite the role of downward trends in U_2, the increasing trend in *RH* was the other factor affecting the ET_0 variation. On the other hand, the increasing trend in *RH* at Shahrekord station counteracted the effect of increasing trends in U_2 and *n* on the ET_0 variation and led to non-significant trends in winter ET_0.

In addition to U_2 at Bandar-Abbas and Ahvaz stations, parametric and non-parametric techniques presented different estimates of trends for *n* at Kerman station and to some extent at Yazd station; however, with the reduction in the confidence level to 90%, results of the non-parametric methods became similar to those of the parametric methods. Therefore, such cases were not considered as major disparities between the trend estimates.

As the results of MLR revealed that *RH* had a non-significant effect on winter ET_0 at Kerman station, thus, the non-significant ET_0 variations at Kerman station should be due to the decreasing and increasing trends in U_2 and *n*, respectively. For Esfahan and Shiraz stations, it seems that decreasing trends in winter *RH* and U_2 neutralized each other and eventually resulted in non-significant trends in winter ET_0. Also the non-significant trends in winter U_2 and *RH* at Yazd station probably was the main reason for insignificant trends in winter ET_0.

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3.2.2 Spring

According to all four methods, more than half of the stations (Abadan, Ahvaz, Bandar-Abbas, Bushehr, Shiraz and Yazd) showed insignificant trends in spring ET_0 (Table 5). Meanwhile, Bandar-Abbas station indicated no significant trends in spring U_2, *RH* and *n*.

Table 4 Trend estimates of parametric and non-parametric methods for winter *RH*, U_2, *n* and ET_0 (at the significance level of 0.05). The *P*-values of non-significant trends are presented where different trends are observed.

Variable \ Station		Abadan	Ahvaz	Bandar-Abbas	Bushehr	Esfahan	Fasa	Kerman	Shahrekord	Shiraz	Yazd
RH	M-K	NS	NS	NS	NS	D	I	NS	I	D	NS
	SR	NS	NS	NS	NS	D	I	NS	I	D	NS
	Pr	NS	NS	NS	NS	D	I	NS	I	D	NS
	LR	NS	NS	NS	NS	D	I	NS	I	D	NS
U_2	M-K	D	NS (0.20)	NS (0.11)	D	D	D	D	I	D	NS
	SR	D	NS (0.21)	NS (0.08)	D	D	D	D	I	D	NS
	Pr	D	D	D	D	D	D	D	I	D	NS
	LR	D	D	D	D	D	D	D	I	D	NS
n	M-K	I	I	NS	NS	NS	NS	NS (0.08)	I	NS	NS (0.06)
	SR	I	I	NS	NS	NS	NS	NS (0.06)	I	NS	I
	Pr	I	I	NS	NS	NS	NS	I	I	NS	I
	LR	I	I	NS	NS	NS	NS	I	I	NS	I
ET_0	M-K	NS	NS	NS	D	NS	D	NS	NS	NS	NS
	SR	NS	NS	NS	D	NS	D	NS	NS	NS	NS
	Pr	NS	NS	NS	D	NS	D	NS	NS	NS	NS
	LR	NS	NS	NS	D	NS	D	NS	NS	NS	NS

NS: Non-significant trend, D: Decreasing trend, I: Increasing trend, M-K: Mann-Kendall, SR: Spearman's rho, Pr: Pearson, LR: Linear regression

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Table 5 Trend estimates of parametric and non-parametric methods for spring *RH*, U_2, *n* and ET_0 (at the significance level of 0.05). The *P*-values of non-significant trends are presented where the different trends are observed.

Variable \ Station		Abadan	Ahvaz	Bandar-Abbas	Bushehr	Esfahan	Fasa	Kerman	Shahrekord	Shiraz	Yazd
RH	M-K	D	NS	NS	D	NS	NS (0.06)	NS	NS	D	NS
	SR	D	NS	NS	D	NS	I	NS	NS	D	NS
	Pr	D	NS	NS	D	NS	I	NS	NS	D	NS
	LR	D	NS	NS	D	NS	I	NS	NS	D	NS
U_2	M-K	NS	D	NS	D	D	D	D	I	NS	D
	SR	NS	D	NS	D	D	D	D	I	NS	D
	Pr	NS	D	NS	D	D	D	D	I	NS	D
	LR	NS	D	NS	D	D	D	D	I	NS	D
n	M-K	I	I	NS	NS	NS (0.05)	NS	I	I	I	I
	SR	I	I	NS	NS	I	NS	I	I	I	I
	Pr	NS (0.09)	I	NS	NS	I	NS	I	I	NS (0.06)	I
	LR	NS (0.09)	I	NS	NS	I	NS	I	I	NS (0.06)	I
ET_0	M-K	NS	NS	NS	NS	D	D	NS (0.07)	I	NS	NS
	SR	NS	NS	NS	NS	D	D	NS (0.07)	I	NS	NS
	Pr	NS	NS	NS	NS	D	D	D	I	NS	NS
	LR	NS	NS	NS	NS	D	D	D	I	NS	NS

NS: Non-significant trend, D: Decreasing trend, I: Increasing trend, M-K: Mann-Kendall, SR: Spearman's rho, Pr: Pearson, LR: Linear regression

It seems that no trends in ET_0 at Ahvaz and Yazd stations were due to the interaction of decreasing (-0.19 and -0.20 m s^{-1} per decade) and increasing (0.31 and 0.20 *hour* per decade) trends in U_2 and *n*, respectively. Also in cases like these, the role of non-significant trends in *RH* (Ahvaz, Bandar-Abbas, Esfahan, Kerman, Shahrekord stations) should not be completely ignored. At Abadan and Shiraz stations, the absence of significant trends in ET_0 could be due to the interaction of the detected trends in *RH* and *n* and furthermore should be due to the inducing role of insignificant trends in U_2.

All four trend tests had detected decreasing trends in spring U_2 at Bushehr, Esfahan, Fasa, Kerman and as expressed above Ahvaz and Yazd stations (six stations). At Esfahan and specially Fasa station, the decisive role of downward trends in U_2

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causing decreasing trends in ET_0 seemed reasonable. Thus, despite the existence of increasing trends in *n*, U_2 and ET_0 at Esfahan showed exactly the same trends. On the other hand, the MLR results indicated that *RH* had no significant role in the calculation of spring ET_0 at Fasa, and so increasing trends in *RH* could not have played an important role in the trends of spring ET_0 at Fasa station. It is worth noting that at the 90% confidence level, the Mann-Kendall test as well as the other three methods showed increasing trends in spring *RH* and *n* at Fasa and Esfahan stations. Unlike Fasa station, the downward trend in *RH* at Bushehr station played an important role to neutralize the decreasing trend in U_2 and led to insignificant variations in spring ET_0.

The parametric methods discerned significant (downward) trends and the non-parametric techniques indicated non-significant trends in spring ET_0 at Kerman station. As the Lilliefors test showed no normality, we focused in this case on the outcomes of non-parametric methods. So, despite a decreasing trend in U_2 (-0.35 m s^{-1} per decade), it seems that the increasing trend in *n* (0.36 *hour* per decade) was of enough magnitude to deal with the effect of U_2 and eventually led to insignificant trends in spring ET_0 at Kerman station.

3.2.3 Summer

Similar to spring ET_0, summer ET_0 (Table 6) indicated non-significant trends at six stations (Abadan, Ahvaz, Bandar-Abbas, Bushehr, Shiraz and Yazd stations) at the 90% confidence level. Bandar-Abbas station showed non-significant trends in summer. No trends in summer ET_0 at Bushehr and Shiraz stations could be detected, perhaps due to the absence of significant trends in *RH* and *n*. In other words, decreasing trends in U_2 at Bushehr and Shiraz stations could not play a decisive role in summer ET_0. All stations, except for Abadan, had non-significant trends in summer *RH*. Since Abadan station as well as Ahvaz station showed non-significant and increasing trends in U_2 and *n*, respectively, thus the *RH* effect on the emergence of upward trends in ET_0 at Abadan station should be regarded. In addition, the observed increasing trend but of low magnitude (0.10 *hour* per decade) in *n* at Yazd station could not induce an upward trend in ET_0.

The trend results in summer *RH*, U_2, *n* and ET_0 (Table 6) at Esfahan, Fasa, Kerman and Shahrekord stations could confirm the consequential role of U_2 on the summer ET_0 trends in the northern and eastern parts of Fars province.

3.2.4 Autumn

The results of parametric and non-parametric trend tests for the autumn *RH*, U_2, *n* and ET_0 series (Table 7) showed that four stations (Abadan, Ahvaz, Bandar-Abbas and Yazd) had non-significant trends in none of the studied variables (except downward trends in U_2 at Ahvaz station that was detected by the parametric methods). The Lilliefors test revealed no normality in autumn U_2 at Ahvaz station as well as winter ones. So, the parametric method based results for U_2 were ignored for Ahvaz station. On the other hand, such a difference between the results in U_2 at Shahrekord station was observed (Table 7). However, at the 90% confidence level both the parametric and non-parametric methods indicated the same trends in U_2 at this station. It seems that for reasons such as less than an influential magnitude (0.09 m s^{-1} per decade) and a neutralizing effect of U_2, there were no observed significant trends in autumn ET_0 at Shahrekord station.

Table 6 Trend estimates of parametric and non-parametric methods for summer *RH*, U_2, *n* and ET_0 (at the significance level of 0.05). The *P*-values of non-significant trends are presented where the different trends are observed.

Variable \ Station		Abadan	Ahvaz	Bandar-Abbas	Bushehr	Esfahan	Fasa	Kerman	Shahrekord	Shiraz	Yazd
RH	M-K	D	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SR	D	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Pr	D	NS	NS	NS	NS	NS	NS	NS	NS	NS
	LR	D	NS	NS	NS	NS	NS	NS	NS	NS	NS
U_2	M-K	NS	NS	NS	D	D	D	D	I	D	NS
	SR	NS	NS	NS	D	D	D	D	I	D	NS
	Pr	NS	NS	NS	D	D	D	D	I	D	NS
	LR	NS	NS	NS	D	D	D	D	I	D	NS
n	M-K	I	I	NS	NS	I	NS	I	NS	NS	I
	SR	I	I	NS	NS	I	NS	I	NS	NS	I
	Pr	I	I	NS	NS	I	NS	I	NS	NS	I
	LR	I	I	NS	NS	I	NS	I	NS	NS	I
ET_0	M-K	NS (0.07)	NS	NS	NS	D	D	D	I	NS	NS
	SR	NS (0.06)	NS	NS	NS	D	D	D	I	NS	NS
	Pr	I	NS	NS	NS	D	D	D	I	NS	NS
	LR	I	NS	NS	NS	D	D	D	I	NS	NS

NS: Non-significant trend, D: Decreasing trend, I: Increasing trend, M-K: Mann-Kendall, SR: Spearman's rho, Pr: Pearson, LR: Linear regression

The outcomes of Table 7 also reveal that autumn *n* had non-significant trends at all the stations. Moreover, Bushehr, Esfahan and Shiraz stations had the same trend results for autumn *RH*, U_2 and *n*, but the trend results of autumn ET_0 at Bushehr and Esfahan stations when compared with Shiraz station were different, based on all trend tests except for the Mann-Kendall test. However, these results were the same at the 90% confidence level. At Bushehr and Esfahan stations, the observed decreasing trends in autumn ET_0 should be due to the existence of the downward trends in U_2, but it seems the decreasing trends in U_2 at Shiraz station did not play a prominent role in the autumn ET_0 variations.

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Table 7 Trend estimates of parametric and non-parametric methods for autumn *RH*, U_2, *n* and ET_0 (at the significance level of 0.05). The *P*-values of non-significant trends are presented where the different trends are observed.

Variable \ Station		Abadan	Ahvaz	Bandar-Abbas	Bushehr	Esfahan	Fasa	Kerman	Shahrekord	Shiraz	Yazd
RH	M-K	NS	NS	NS	NS	NS	I	I	I	NS	NS
	SR	NS	NS	NS	NS	NS	I	I	I	NS	NS
	Pr	NS	NS	NS	NS	NS	I	NS (0.09)	I	NS	NS
	LR	NS	NS	NS	NS	NS	I	NS (0.09)	I	NS	NS
U_2	M-K	NS	NS (0.43)	NS	D	D	D	D	NS (0.07)	D	NS
	SR	NS	NS (0.55)	NS	D	D	D	D	NS (0.07)	D	NS
	Pr	NS	D	NS	D	D	D	D	I	D	NS
	LR	NS	D	NS	D	D	D	D	I	D	NS
n	M-K	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	SR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Pr	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	LR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ET_0	M-K	NS	NS	NS	D	D	D	NS (0.06)	NS	D	NS
	SR	NS	NS	NS	D	D	D	D	NS	NS (0.05)	NS
	Pr	NS	NS	NS	D	D	D	D	NS	NS (0.08)	NS
	LR	NS	NS	NS	D	D	D	D	NS	NS (0.08)	NS

NS: Non-significant trend, D: Decreasing trend, I: Increasing trend, M-K: Mann-Kendall, SR: Spearman's rho, Pr: Pearson, LR: Linear regression

The trend results in the autumn *RH*, U_2 and *n* at Fasa and Kerman stations were almost similar and at the 90% confidence level became completely the same. These cases suggested the decisive effect of U_2 on the autumn ET_0 variations at Bushehr and Esfahan stations and also complementary roles of U_2 and *RH* at Fasa and Kerman stations (which encompass an important portion of Eastern Fars Province). Generally, it seems that the most sensitive variable in the determination of the autumn ET_0 trends in the study area is U_2 and to a lesser degree *RH*. This is compatible with the MLR results for autumn, especially where the negligible role of *n* has been suggested as compared with U_2 and *RH*.

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3.2.5 Annual

The annual ET_0 variations at the stations are shown in Figure 3. The range of average annual ET_0 in the study area is between 1144 *mm* at Shahrekord station and 2215 *mm* at Abadan station.

The annual trends found by parametric and non-parametric methods (Table 8) showed decreasing dominancy in the ET_0 trends at Bushehr, Esfahan, Fasa and Kerman stations.

The results also indicate that 8 stations (all stations except Fasa and Shiraz) exhibited the dominant insignificant trends in annual *RH*. At Bushehr and Esfahan and especially Kerman (despite detected increasing trends in *n*) stations, a clear effect of downward trends in U_2 in causing decreasing trends in annual ET_0 was detectable. On the other hand, Table 8 reveals that *RH* as well as U_2 had an important role in the annual ET_0 trends at Shiraz and to some extent at Fasa station. Similar to seasonal ET_0, annual ET_0 and related U_2, *RH* and *n* showed high frequencies of non-significant trends at Bandar-Abbas station. Meanwhile, five stations (Abadan, Ahvaz, Kerman, Shahrekord and Yazd stations) indicated the same trend types (increasing) for annual *n*. However, it seems these increasing trends did not have exercise a significant influence on the annual ET_0 variation.

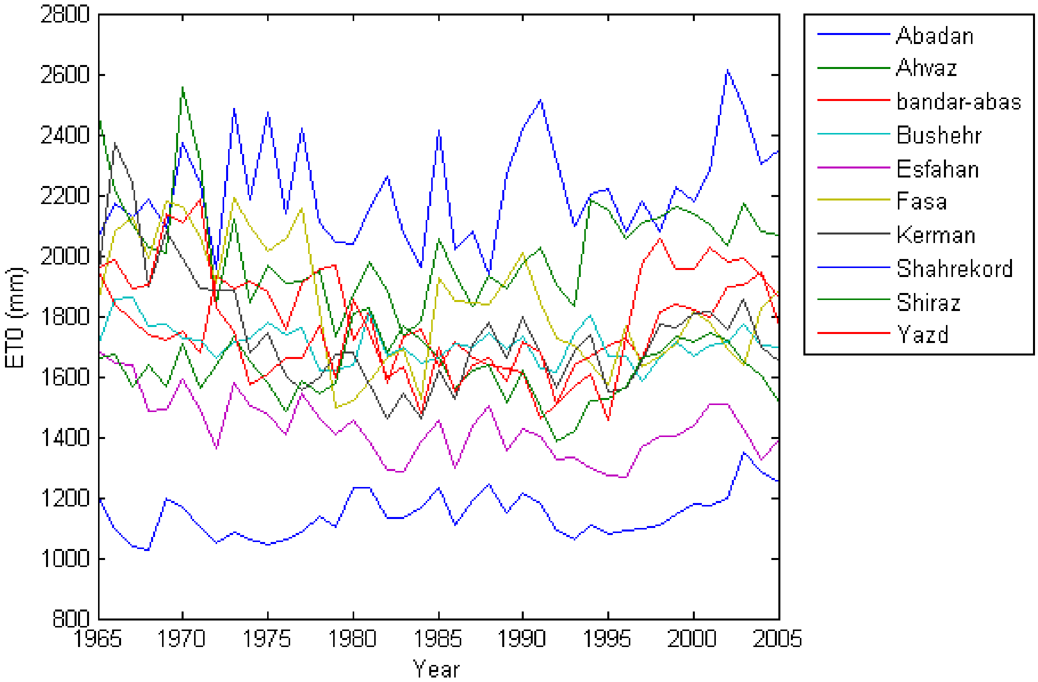

Figure 3 Annual ET_0 variations at the stations used in the study.

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Table 8 Trend estimates of parametric and non-parametric methods for annual *RH*, U_2, *n* and ET_0 (at the significance level of 0.05). The *P*-values of non-significant trends are presented where the different trends are observed.

Variable \ Station		Abadan	Ahvaz	Bandar-Abbas	Bushehr	Esfahan	Fasa	Kerman	Shahrekord	Shiraz	Yazd
RH	M-K	NS (0.06)	NS	NS	NS	NS	I	NS	NS (0.052)	D	NS
	SR	NS (0.08)	NS	NS	NS	NS	I	NS	I	D	NS
	Pr	D	NS	NS	NS	NS	I	NS	NS (0.07)	D	NS
	LR	D	NS	NS	NS	NS	I	NS	NS (0.07)	D	NS
U_2	M-K	NS	NS (0.49)	NS	D	D	D	D	I	D	NS
	SR	NS	NS (0.35)	NS	D	D	D	D	I	D	NS
	Pr	NS	D	NS	D	D	D	D	I	D	NS
	LR	NS	D	NS	D	D	D	D	I	D	NS
n	M-K	I	I	NS	NS	NS	NS	I	I	NS	I
	SR	I	I	NS	NS	NS	NS	I	I	NS	I
	Pr	I	I	NS	NS	NS	NS	I	I	NS	I
	LR	I	I	NS	NS	NS	NS	I	I	NS	I
ET_0	M-K	NS	NS	NS	NS (0.07)	D	D	NS (0.06)	I	NS	NS
	SR	NS	NS	NS	D	D	D	D	I	NS	NS
	Pr	NS	NS	NS	D	D	D	D	I	NS	NS
	LR	NS	NS	NS	D	D	D	D	I	NS	NS

NS: Non-significant trend, D: Decreasing trend, I: Increasing trend, M-K: Mann-Kendall, SR: Spearman's rho, Pr: Pearson, LR: Linear regression

There was a major disparity (the difference remained even at the 90% confidence level) in the trend results of annual U_2 at Ahvaz station. The Lilliefors test recognized no normality in the annual U_2 distribution at Ahvaz station. In this case like the previous ones, relying on the outcomes of non-parametric methods was more reasonable. Results of trend tests for annual ET_0, U_2, *RH* and *n* at Abadan and Ahvaz stations (located in the west of Fars province) were almost the same. This suggests that the appearance of insignificant trends in annual ET_0 at Abadan and Ahvaz stations as well as Shiraz station (central parts of the study area) could be due to the greater influence of U_2 and *RH* than of *n*. In general, results of annual and summer ET_0 at Abadan and Ahvaz stations showed a high degree of similarity for all variables.

Furthermore, there were increasing trends in annual and summer ET_0 only at Shahrekord station. This should be due to the increasing trends in U_2 and *n* at Shahrekord station. Results of MLR revealed that annual U_2 and *n* were more effective variables for the ET_0 variation at

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Shahrekord and Yazd stations. However, trend analysis at Yazd station revealed that U_2 series had a more significant role in the annual ET_0 trends as compared to *n*.

3.3 Frequency of various ET_0 trends

The relative frequency of seasonal and annual ET_0 trend types (non-significant, decreasing and increasing) detected by parametric and non-parametric methods are presented in Table 9. According to the results of both groups of methods, the most number of trend types for seasonal and annual ET_0 were non-significant (50-80%) and after that decreasing (20-40%) and increasing (0-20%) trends had higher frequencies.

Thus, the relative frequencies of the recorded trend types in all considered variables had very similar distributions for both parametric and non-parametric techniques. These results are in good agreement with the results of Huth and Pokorna (2004) who studied the seasonal and annual means of some climatic variables, such as daily mean temperature, wind components, relative humidity and sunshine hours for the period 1961-1998 and found that the degree of normality possessed by seasonal and annual series did not influence systematically the agreement between the parametric and non-parametric results. In this context, it should be regarded that recognized trend types by the Pearson correlation (parametric) and Spearman's rho (non-parametric) at the significance level of 0.05 were the same in 96% of the cases. Also, the percentage of cases with similar trend types at the significance level of 0.01 was identical for α=0.05. Hence, the difference between parametric and non-parametric trend results did not depend on the degree of normality in annual and seasonal ET_0 distributions.

Table 9 Relative frequencies of seasonal and annual ET_0 trends detected by parametric and non-parametric techniques.

Trend type / Series	Non-significant (%)		Decreasing (%)		Increasing (%)	
	Parametric	Non-parametric	Parametric	Non-parametric	Parametric	Non-parametric
Winter	80	80	20	20	0	0
Spring	60	70	30	20	10	10
Summer	50	60	30	30	20	10
Autumn	60	60	40	40	0	0
Annual	50	60	40	30	10	10

4 CONCLUSIONS

This study investigates annual and seasonal trends in ET_0 during the past four decades at 10 stations in southern Iran (with centrality of Fars province). Multivariate linear regression shows that the key variables in the temporal changes of ET_0 in the study area are wind speed, relative humidity and sunshine hours, respectively. Then, annual and seasonal trends in these variables as well as ET_0 are detected using the Mann-Kendall test, Spearman's rho, the Pearson correlation and linear regression to evaluate their contributions to the temporal variations in ET_0. In general, results of seasonal and annual time scales show that U_2 and *RH* have more influence on the ET_0 trends than does *n*.

Results reveal that non-significant trends are the most frequent trend type for seasonal and annual ET_0 in the study area. Meanwhile, the trend types detected by the Pearson correlation

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(parametric) and Spearman's rho (non-parametric) are the same in 96% of the cases. Hence, disagreements between the parametric and non-parametric trend results do not depend on the degree of normality in the annual and seasonal ET_0 distributions in this study area. Considering the dominancy of non-significant ET_0 trends found in this study and decreasing trends of precipitation at the considered stations (Tabari and Hosseinzadeh Talaee, 2011), further research is needed to clarify the causes of increasing aridity in the last decades in the study area.

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روند پارامتری و ناپارامتری تبخیر و تعرق مرجع و متغیرهای اقلیمی کلیدی موثر بر آن (مطالعه موردی: جنوب ایران)

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چکیده تبخیر و تعرق یکی از مهم‌ترین اجزای چرخه هیدرولوژی است که مستقیماً تحت تاثیر شرایط آب و هوایی است. در این مطالعه روندهای فصلی و سالانه تبخیر و تعرق مرجع (ET_0) و متغیرهای اقلیمی کلیدی موثر بر آن در ۱۰ ایستگاه واقع در جنوب ایران (با مرکزیت استان فارس) در دوره زمانی ۱۹۶۶ تا ۲۰۰۵ میلادی بررسی شد. ابتدا رگرسیون چند متغیره جهت شناسایی متغیرهای اقلیمی اصلی موثر بر تبخیر و تعرق به‌کار برده شد. سپس هم‌چون تبخیر و تعرق، روندهای فصلی و سالانه در این متغیرهای اقلیمی نیز با استفاده از روش‌های من-کندال، اسپیرمن، همبستگی پیرسون و تحلیل رگرسیون خطی بررسی شد تا سهم آنها در روند زمانی تبخیر و تعرق ارزیابی گردد. نتایج نشان داد که متغیرهای اقلیمی تاثیرگذارتر بر تبخیر و تعرق سرعت باد (U_2)، رطوبت نسبی (RH) و ساعات آفتابی (n) بوده‌اند. هم‌چنین اکثر روندهای فصلی و سالانه برای تبخیر و تعرق غیرمعنی‌دار بودند و بعد از آن بالاترین فراوانی به ترتیب برای روندهای کاهشی و افزایشی مشاهده گردید. به علاوه توزیع فراوانی نسبی این روندها در هر یک از بازه‌های زمانی در نظر گرفته شده، برای روش‌های پارامتری و ناپارامتری شبیه بود. بنابراین در منطقه مورد مطالعه، تفاوت بین نتایج روندیابی روش‌های پارامتری و ناپارامتری به درجه نرمالیته توزیع سری‌های فصلی و سالانه تبخیر و تعرق بستگی نداشته است.

کلمات کلیدی: آزمون لیلیفورس، تحلیل روند، درجه نرمالیته، متغیرهای اقلیمی

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