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

Ali Reza Nafarzadegan¹,², Hossein Ahani¹*, Vijay P. Singh³ and Mehrzad Kherad¹

¹Management Center for Strategic Projects, Fars Organization Center of Jahad-e-Agriculture, Shiraz, Iran
²PhD Student, Faculty of Agriculture and Natural Resources, Hormozgan University, Bandar Abbas, Iran
³Department of Civil and Environmental Engineering and Department of Biological and Agricultural Engineering, Texas A & M University, Scoates Hall, College Station, USA

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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

*Corresponding author: Management Center for Strategic Projects, Fars Organization Center of Jahad-e-Agriculture, Shiraz, Iran, Tel: +98 917 705 3538, E-mail: ahani.hos@gmail.com
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 ($E_{\text{pan}}$) and $E_T$ have decreased and that increases in relative humidity and decreases in radiation were correlated with a decreasing trend in $E_T$. Wang et al. (2007) analyzed the $E_{\text{pan}}$ and $E_T$ trends in the upper and mid-lower Yangtze River basin of China from 1961 to 2000. They found that $E_{\text{pan}}$ and $E_T$ decreased during summer months, contributing the most to the total annual reduction. The decreasing trends in $E_{\text{pan}}$ and $E_T$ 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 $E_{\text{pan}}$ and $E_T$ across the Tibetan Plateau during the period 1966 to 2003. They found that $E_{\text{pan}}$ and $E_T$ 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 $E_T$ 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 $E_T$ over different sites in Iran.

The first objective of this study was to investigate annual and seasonal trends in $E_T$ during 1966–2005 at 10 stations in southern Iran (with centrality of Fars province). The temporal variability of $E_T$ 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 $E_T$ 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 $E_T$.

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 $E_T$ 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 $E_T$ using the FAO-56 Penman-Monteith (PMF-56).

Hence, it was decided to include more stations from outside of the Fars borders. The
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_{\text{max}}), minimum (T_{\text{min}}) and mean air temperature (T_{\text{mean}}), wind speed (\text{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.
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.

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

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Station</th>
<th>$T_{\text{max}}$ ($^\circ$C)</th>
<th>$T_{\text{min}}$ ($^\circ$C)</th>
<th>$T_{\text{mean}}$ ($^\circ$C)</th>
<th>RH (%)</th>
<th>$U_2$ (m s$^{-1}$)</th>
<th>n (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abadan</td>
<td>32.91 ± 0.89</td>
<td>18.08 ± 0.70</td>
<td>25.51 ± 0.72</td>
<td>44.76 ± 3.09</td>
<td>2.47 ± 0.40</td>
<td>8.41 ± 0.57</td>
</tr>
<tr>
<td></td>
<td>Ahvaz</td>
<td>32.9 ± 0.77</td>
<td>17.80 ± 1.16</td>
<td>25.35 ± 0.83</td>
<td>42.96 ± 3.10</td>
<td>1.96 ± 0.40</td>
<td>8.35 ± 0.52</td>
</tr>
<tr>
<td></td>
<td>Bandar-Abbas</td>
<td>32.16 ± 0.65</td>
<td>21.61 ± 0.63</td>
<td>26.88 ± 0.58</td>
<td>65.50 ± 2.77</td>
<td>2.20 ± 0.57</td>
<td>8.49 ± 0.44</td>
</tr>
<tr>
<td></td>
<td>Bushehr</td>
<td>29.54 ± 0.77</td>
<td>19.79 ± 0.63</td>
<td>24.67 ± 0.65</td>
<td>65.21 ± 2.48</td>
<td>2.43 ± 0.46</td>
<td>8.49 ± 0.49</td>
</tr>
<tr>
<td></td>
<td>Esfahan</td>
<td>23.31 ± 0.92</td>
<td>9.42 ± 0.71</td>
<td>16.37 ± 0.64</td>
<td>37.80 ± 3.21</td>
<td>1.43 ± 0.33</td>
<td>8.96 ± 0.34</td>
</tr>
<tr>
<td></td>
<td>Fasa</td>
<td>27.68 ± 0.96</td>
<td>10.9 ± 1.17</td>
<td>19.29 ± 0.83</td>
<td>39.23 ± 4.26</td>
<td>1.24 ± 0.47</td>
<td>9.22 ± 0.34</td>
</tr>
<tr>
<td></td>
<td>Kerman</td>
<td>24.67 ± 0.84</td>
<td>6.71 ± 0.84</td>
<td>15.69 ± 0.79</td>
<td>32.56 ± 4.17</td>
<td>2.31 ± 0.57</td>
<td>8.69 ± 0.46</td>
</tr>
<tr>
<td></td>
<td>Shahrekord</td>
<td>20.20 ± 0.99</td>
<td>3.39 ± 0.88</td>
<td>11.8 ± 0.83</td>
<td>46.37 ± 3.05</td>
<td>0.93 ± 0.33</td>
<td>8.65 ± 0.3</td>
</tr>
<tr>
<td></td>
<td>Shiraz</td>
<td>25.77 ± 0.77</td>
<td>9.99 ± 1.34</td>
<td>17.88 ± 0.91</td>
<td>40.42 ± 3.43</td>
<td>1.74 ± 0.29</td>
<td>9.19 ± 0.36</td>
</tr>
<tr>
<td></td>
<td>Yazd</td>
<td>26.60 ± 0.81</td>
<td>11.83 ± 0.93</td>
<td>19.22 ± 0.81</td>
<td>30.98 ± 3.53</td>
<td>1.98 ± 0.47</td>
<td>8.83 ± 0.38</td>
</tr>
</tbody>
</table>
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 ET₀ 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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**Figure 2** Time series plots of $T_{mean}$, RH, $U_2$ and $n$ at Fasa and Shiraz stations (located in the Fars Province).
(Allen et al., 1998) was used to calculate ET₀ for the period of study Eq. (1):

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

where ET₀ 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); \(\Delta\) is the slope vapor pressure curve (kPa °C⁻¹); and \(\gamma\) is the psychometric constant (kPa °C⁻¹).

2.3 Multivariate linear regression

To evaluate the relative significance of climate variables for the calculated ET₀, 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 ET₀. Next, trends in the climatic variables were analyzed in order to understand their effect on the ET₀ 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 \((x_1, \ldots, x_n)\) 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:

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

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

$$Var(S) = \frac{n(n-1)(2n+5) - \sum t(t-1)(2t+5)}{18}$$ (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 \(i\)th group. In cases where the sample size \(n > 10\), the standard normal variable \(Z\) is computed using Eq. (5):

$$Z = \frac{S - 1}{\sqrt{Var(S)}} \quad \text{if } S > 0$$
$$Z = 0 \quad \text{if } S = 0$$
$$Z = \frac{S + 1}{\sqrt{Var(S)}} \quad \text{if } S < 0$$ (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 \(\alpha\) 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
Kahya, 2006). In this study, a significance level of $\alpha = 0.05$ 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):

$$D = 1 - \frac{6 \sum (R(X_i) - i)^2}{n(n-1)}$$

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):

$$E(D) = 0$$

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

The P-value of the SR statistic ($D$) of the observed cumulative 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:

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

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

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:

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

where $\Phi(|Z|)$ is the cumulative distribution function of the standard normal distribution $Z \sim N(0, 1)$.

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:

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

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 nonexistence of trend in $ET_0$ and in variables affecting it.
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 ET0 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 ET0 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≤0.01) except for Esfahan (p<0.1). Also, RH was significantly related to winter ET0 at all the stations (p≤0.01), except for Kerman (p<0.1).

<table>
<thead>
<tr>
<th>Series</th>
<th>Confidence level</th>
<th>T_max</th>
<th>T_min</th>
<th>T_mean</th>
<th>RH</th>
<th>U_2</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>95%</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>9</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>99%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Spring</td>
<td>95%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>99%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Summer</td>
<td>95%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>99%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Autumn</td>
<td>95%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>99%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Annual</td>
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<td>0</td>
<td>0</td>
<td>6</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>99%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>
Significant influences of air temperatures ($T_{\text{min}}$, $T_{\text{mean}}$ and $T_{\text{max}}$) 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 $E_{\text{T}0}$ and air temperature. Eventually it should be noted that $U_2$, $R\bar{H}$ and $n$ were more influential in the $E_{\text{T}0}$ calculation during winter.

Furthermore, there were significant correlations between spring and summer $E_{\text{T}0}$ series and the corresponding values of $U_2$ and $n$ for all the stations ($p<0.01$). In addition, significant correlations for $R\bar{H}$ were observed for all the stations ($p<0.01$), excluding Fasa station ($p<0.05$). Results of MLR for autumn $E_{\text{T}0}$ series indicated that only $U_2$ had a significant influence at all the stations ($p<0.01$). Similarly, $R\bar{H}$ and $n$ were significantly related to the autumn $E_{\text{T}0}$ in 90% and 30% of the stations ($p<0.01$), respectively. Analysis of the impact of climatic variables on the annual $E_{\text{T}0}$ series indicated significant correlations for $U_2$ and $R\bar{H}$ 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 $E_{\text{T}0}$ 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 $E_{\text{T}0}$ 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 $E_{\text{pan}}$ 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 $E_{\text{T}0}$ 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 $E_{\text{T}0}$ trend. The important role of air temperature in evapotranspiration mechanism must be noted that authors are aware of, but the MLR results for the considered time-scales for this study area showed that the $E_{\text{T}0}$ 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 ($U_2$, $R\bar{H}$ and $n$) seemed to have more leading role in the conditions and types (non-significant, decreasing or increasing) of trends in $E_{\text{T}0}$. Dinapashoh et al. (2011) also witnessed wind speed as the main contributory parameter for the observed $E_{\text{T}0}$ trends over different parts of Iran. Similar attributions have been reported for the decreases in $E_{\text{T}0}$ and $E_{\text{pan}}$ (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
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 ET₀ and related changes in U₂, 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 ET₀, U₂, RH and n are given in Table 4. Based on the considered parametric and non-parametric methods, the winter ET₀ 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 U₂. The remaining 2 stations (Bushehr and Fasa) indicated decreasing trends in winter ET₀.

There were non-significant trends in winter ET₀, RH, U₂ and n at Bandar-Abbas station, except that a decreasing trend in U₂ detected by the parametric methods also occurred at Ahvaz station. Since the Lilliefors test showed no normality in the U₂ series, it seems the degree of normality of distribution influenced U₂ 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 U₂ 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 U₂ had an important influence on the winter ET₀ trend at Bushehr station; but at Abadan station, the U₂ effect was offset by n. As mentioned above, Fasa station as well as Bushehr station showed downward trends in winter ET₀. In this case, despite the role of downward trends in U₂, the increasing trend in RH was the other factor affecting the ET₀ variation. On the other hand, the increasing trend in RH at Shahrakord station counteracted the effect of increasing trends in U₂ and n on the ET₀ variation and led to non-significant trends in winter ET₀.

In addition to U₂ 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 ET₀ at Kerman station, thus, the non-significant ET₀ variations at Kerman station should be due to the decreasing and increasing trends in U₂ and n, respectively. For Esfahan and Shiraz stations, it seems that decreasing trends in winter RH and U₂ neutralized each other and eventually resulted in non-significant trends in winter ET₀. Also the non-significant trends in winter U₂ and RH at Yazd station probably was the main reason for insignificant trends in winter ET₀.
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 ET₀ (Table 5). Meanwhile, Bandar-Abbas station indicated no significant trends in spring U₂, RH and n.

<table>
<thead>
<tr>
<th>Station</th>
<th>Abadan</th>
<th>Ahvaz</th>
<th>Bandar-Abbas</th>
<th>Bushehr</th>
<th>Esfahan</th>
<th>Fasa</th>
<th>Kerman</th>
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NS: Non-significant trend, D: Decreasing trend, I: Increasing trend, M-K: Mann-Kendall, SR: Spearman’s rho, Pr: Pearson, LR: Linear regression
Table 5 Trend estimates of parametric and non-parametric methods for spring RH, U₂, n and ET₀ (at the significance level of 0.05). The P-values of non-significant trends are presented where the different trends are observed.

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<th>Bushehr</th>
<th>Esfahan</th>
<th>Fasa</th>
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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 ET₀ 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 U₂ 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 ET₀ 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 U₂.

All four trend tests had detected decreasing trends in spring U₂ 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 U₂...
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, U₂, n and ET₀ (at the significance level of 0.05). The P-values of non-significant trends are presented where the different trends are observed.

<table>
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<th>Station</th>
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<th>Esfahan</th>
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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, U₂ and n, but the trend results of autumn ET₀ 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 ET₀ should be due to the existence of the downward trends in U₂, but it seems the decreasing trends in U₂ at Shiraz station did not play a prominent role in the autumn ET₀ variations.
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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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.

### 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.](image-url)
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.

<table>
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<tr>
<th>Station</th>
<th>Variable</th>
<th>Abadan</th>
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<th>Bandar-Abbas</th>
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<th>Fasa</th>
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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...
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 $\alpha=0.05$. 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.

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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
(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 ET0 distributions in this study area. Considering the dominancy of non-significant ET0 trends found in this study and decreasing trends of precipitation at the considered stations (Tabari and Hosseinzadeh Talaei, 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)

علي‌ضا نفرادگان(۱) ، حسین آهنی(۲) ، وی پی سینگ(۳) و مهرزاد خرد(۴)

چکیده تبخیر و تعرق یکی از مهم‌ترین اجزای چرخه هیدرولوژی است که مستقیماً تحت تأثیر شرایط آب و هوای است. در این مطالعه روندهای فصلی و سالانه تبخیر و تعرق مرجع و متغیرهای اقلیمی کلیدی موثر بر آن در ۱۰ ایستگاه واقع در جنوب ایران (با مرکزی استان فارس) در دوره زمین‌شناسی ۱۹۶۶ تا ۲۰۱۵ میلادی بررسی شد. ابتدا رگ‌سوزی چند متغیره جهت شناسایی متغیرهای اقلیمی اصلی موثر بر تبخیر و تعرق به کار رفته بود. سپس هرچند تبخیر و تعرق، روندهای فصلی و سالانه در این متغیرهای اقلیمی تهیه با استفاده از روش‌های ماتریس‌الگوریتم، استنباط، هم‌سنجی پیرسون و تحلیل رگ‌سوزی خطی بررسی شد تا سهم آنها در روند زمانی تبخیر و تعرق ذیل زمانی و ارتباطات آن تایید شود. نتایج نشان داد که متغیرهای اقلیمی انرژی گازاتر بر تبخیر و تعرق جدی‌تری بر سرعت خورشیدی تأثیر داشت. در نتیجه، تأثیر‌های اقلیمی بر روی روندی و تغییراتی که تبخیر و تعرق تجربه کرده‌اند، نشان دهنده تأثیر طویل‌مدتی اقلیمی بر روی تبخیر و تعرق می‌باشد. نتایج نشان داد که متغیرهای اقلیمی انرژی گازاتر بر تبخیر و تعرق جدی‌تری بر سرعت خورشیدی تأثیر داشت. در نتیجه، تأثیر‌های اقلیمی بر روی روندی و تغییراتی که تبخیر و تعرق تجربه کرده‌اند، نشان دهنده تأثیر طویل‌مدتی اقلیمی بر روی تبخیر و تعرق می‌باشد. نتایج نشان داد که متغیرهای اقلیمی انرژی گازاتر بر تبخیر و تعرق جدی‌تری بر سرعت خورشیدی تأثیر داشت. در نتیجه، تأثیر‌های اقلیمی بر روی روندی و تغییراتی که تبخیر و تعرق تجربه کرده‌اند، نشان دهنده تأثیر طویل‌مدتی اقلیمی بر روی تبخیر و تعرق می‌باشد. نتایج نشان داد که متغیرهای اقلیمی انرژی گازاتر بر تبخیر و تعرق جدی‌تری بر سرعت خورشیدی تأثیر داشت. در نتیجه، تأثیر‌های اقلیمی بر روی روندی و تغییراتی که تبخیر و تعرق تجربه کرده‌اند، نشان دهنده تأثیر طویل‌مدتی اقلیمی بر روی تبخیر و تعرق می‌باشد. نتایج نشان داد که متغیرهای اقلیمی انرژی گازاتر بر تبخیر و تعرق جدی‌تری بر سرعت خورشیدی تأثیر داشت. در نتیجه، تأثیر‌های اقلیمی بر روی روندی و تغییراتی که تبخیر و تعرق تجربه کرده‌اند، نشان دهنده تأثیر طویل‌مدتی اقلیمی بر روی تبخیر و تعرق می‌باشد. نتایج نشان داد که متغیرهای اقلیمی انرژی گازاتر بر تبخیر و تعرق جدی‌تری بر سرعت خورشیدی تأثیر داشت. در نتیجه، تأثیر‌های اقلیمی بر روی روندی و تغییراتی که تبخیر و تعرق تجربه کرده‌اند، نشان دهنده تأثیر طویل‌مدتی اقلیمی بر روی تبخیر و تعرق می‌باشد. نتایج نشان داد که متغیرهای اقلیمی انرژی گازاتر بر تبخیر و تعرق جدی‌تری بر سرعت خورشیدی تأثیر داشت. در نتیجه، تأثیر‌های اقلیمی بر روی روندی و تغییراتی که T

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