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ORIGINAL PAPER

Trends in reference crop evapotranspiration in Urmia Lake basin

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Abstract
Evapotranspiration is one of the main important components of hydrologic cycle. Trend analysis of reference crop evapotranspiration (ET_0) provides useful information for understanding the crop water requirements associated with climate change. In this study, monotonic trends were analyzed in monthly, seasonal, and annual timescales at the nine stations selected from Urmia Lake basin. The Mann-Kendall method was used for trend detection. Significant autocorrelation coefficients were taken into account in analysis using the modified version of Mann-Kendall method. In order to estimate the slope of trend line, the Sen's estimator method was used. The ET_0 values estimated using the standard recommended form of the FAO-56 Penman-Monteith. The results showed that more than 66.6% of the annual ET_0 time series had positive trends which were significant at 0.10 level. The highest slope of annual ET_0 trends belonged to the station Marageh, which was equal to 17.34 mm/year. In the seasonal scale, all of the sites (except Tekab) exhibited significant upward trends for spring season in 0.1 level. In the monthly timescale, unless 6.5% of the tested time series, all of them had downward trends. Analysis of the impacts of climatic variables on trends in ET_0 showed that the reason for increasing trends in ET_0 was attributed to the increasing trends in both mean air temperature and wind speed, as well as the decreasing trend in the mean relative humidity. Wise use of fresh water in this fragile ecosystem is recommended for future sustainable agricultural activities.

Keywords Autocorrelation · Climate change · Mann-Kendall · Monotonic · Penman-Monteith · Sen's estimator

Introduction

Evapotranspiration is one of the main important components of the hydrologic cycle. Accurate estimation of this element is vital in scientific water management in arid and semiarid regions. Estimation of reference crop evapotranspiration (ET_0) is needed for estimation of many crop water requirements. This is accomplished in many practical cases by multiplying the ET_0 by crop coefficient denoted by K_c. An accurate estimate of ET_0 is important in various studies such as agriculture, design of irrigation and drainage systems, and reservoir operation practices (Gundekar et al. 2008). Nowadays, improving the efficiency of irrigation systems attracted by investigators as no more water available to use in agricultural systems can be achieved mainly by better understanding of ET_0 trends at different stations.

ET_0 is defined as the rate of ET from an extensive surface of 8–15-cm tall, green grass of uniform height, actively growing, completely shading the ground, and not short of water (Doorenbos and Pruitt 1977). Nowadays, many researchers believed that global warming is the reflection of the increasing rate of the greenhouse gas emission in the past decades. Almost all processes in the biosphere are influenced by climate change, because of its adverse effects on the human environment and water resources. Some reasons for climate change are related to human activities, such as increasing use of fossil fuel in industries, transport, and heating buildings. These activities have increased the concentration of greenhouse gases in the atmosphere. Therefore, climate change in different regions occurred, which in turn the human livelihood suffered its consequences. Moreover, climatic change affected adversely many agricultural activities in terms of production of crops such as cereal, fruit, and meat. In order to mitigate these effects, analysis of trends in climatic parameters as well as the ET_0 time series would be useful.

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In a broad classification, all the trend analysis methods can be grouped into the two approaches, namely parametric and non-parametric methods. The non-parametric methods are more interested in trend detection in climatologic and hydrologic studies. In these methods, trends are not influenced by outliers, considerably. Furthermore, there is no need for reconstruction of missing data in these methods. In addition, there is no need to obey observed data from a certain statistical distribution such as normal. Among the non-parametric methods, the Mann-Kendall (MK) scheme has been used widely in trend analysis of hydro-meteorological parameters (Gan 1998; Zhang et al. 2001; Darshana and Pandey 2013; Irmak et al. 2012, Fan and Thomas 2013; Liu and Zhang 2013; Jhajharia et al. 2014a, b; Dinpashoh et al. 2019a, b). Numerous studies were conducted on trend detection of ET_0 time series in the USA (Hobbins et al. 2004), China (Thomas 2000; Liu and Zeng 2004; Wang et al. 2007, 2017), and Australia and New Zealand (Roderick and Farquhar 2004, 2005). McVicar et al. (2012) in a comprehensive study reviewed the near-surface wind speed trends for the purpose of finding implications of evaporation decreasing all over the globe.

Thomas (2000) evaluated the trends in ET_0 (1954-1993) calculated using the Penman-Monteith (PM) method in China. Increasing trends observed in northwest and southeast of China. Based on his report, the main factor influencing the ET_0 is the sunshine hours. Trends in ET_0 were examined using the PM method in the Yangtze river basin (Xu et al. 2006). They showed that spatio-temporal trends in ET_0 are consistent with pan evaporation (E_{pan}) records. In addition, throughout the basin, a significant decreasing ET_0 trend observed in both ET_0 and E_{pan} records. Zhang et al. (2009) analyzed the trends in ET_0 (1971-2004) in the Gygayy-Taybtan (China) and reported a decreasing trend in this region. They suggest that the main climatic variables influencing the ET_0 are air temperature, relative humidity, wind speed, and sunshine hours at this territory. The trends in ET_0 time series in northeast part of India were studied by Jhajharia et al. (2011). They used the trend-free pre-whitened MK method for detection of the trends. They concluded that trends in seasonal ET_0 at this region were decreasing. According to the results of this study, solar radiation and wind speed are the two main climatic variables influenced the ET_0 in NE of India. Zhang et al. (2011) investigated the trends in ET_0, estimated by PM approach in China using the MK method. They reported that decreasing trends exhibited in annual and seasonal ET_0 time series at east, south, and northwest of China. Furthermore, radiation and relative humidity are found to be the two main meteorological variables that influenced the ET_0 in China. Abtew et al. (2011) examined the trends in ET_0 time series as well as the E_{pan} in the nine meteorological stations selected from South Florida. They also employed the PM method for ET_0 estimation and found the upward trends in the mentioned area. Jhajharia et al. (2015) estimated reference evapotranspiration over different places of Rajasthan (India) having semiarid and arid climates. Monia and Jhajharia (2016) reported that wind speed followed by relative humidity and sunshine hours were found to be the main causative parameters of the observed declining trends in ET_0 over Pilani (Rajasthan) under arid-type environments. Jhajharia et al. (2014a, b) also reported the existence of evaporation paradox in arid environments of northwest India based on the concurrence of declining trends in observed pan evaporation in the range of 20.40 to 41.0 mm/decade and a rising temperature in the range of 0.3–0.7 °C per decade over Jaisalmer (Rajasthan) station located in the great Thar Desert of India. In the most recently published article, trends in ET_0 and some climatic parameters have been analyzed in northwest China (Chao et al. 2020). Results indicated that annual ET_0 in the region, namely Ningxia Hui Autonomous Region (NX), NYR (Northern Yellow River Irrigation Area), and SMA (Southern Mountain Area) witnessed by upward significant trend, while the region called CAZ (Central Arid Zone) had downward trend.

In Iran, many studies were carried out on trend detection of hydro-meteorological variables in different regions (Mirabbasi and Dinpashoh 2012; Dinpashoh et al. 2014). However, less effort was attempted on the detection of trends in ET_0 time series especially in Urmia Lake basin. Sabziparvar and Shadmani (2011) studied the trends in ET_0 at the twelve stations selected from the arid and semiarid region of Iran. They concluded that in the monthly, seasonal, and annual timescales, the trends in ET_0 were upward and statistically significant ($P < 0.05$). Dinpashoh et al. (2011) examined the trends in ET_0 (1965–2005) in Iran using the information from the 16 selected stations over the country. They estimated the ET_0 using the PM method, and the MK method employed for detection of trends. The results showed that the number of stations in Iran with an increasing trend was more than the decreasing trend. In the monthly timescale, the number of sites with increasing trends was more than the opposite trends. In a similar study, Tabari et al. (2011) examined the trends in ET_0 time series at 20 stations selected across Iran. They used the information from 1966 to 2005 for trend detection carried out by MK method. They showed that there were positive trends in 70% of the selected stations in Iran. Using the two versions of the Mann-Kendall method, trends in ET_0 time series were investigated in Urmia Lake basin (Amirataee et al. 2016). Results revealed that increasing trends were dominated for most of the chosen stations using the traditional MK. However, the number of stations with significant increasing trends was lessen considerably after eliminating the significant autocorrelation coefficients. Using the Spearman's Rho trends in ET_0 time series in 30 synoptic stations selected from different climates in Iran, it was found that annual and seasonal trends were negative in arid and semiarid stations, while trends were positive for humid sites (Khanmohammadi et al. 2017).

In the Urmia Lake basin, which is located in northwest of Iran, there are several water-related problems. Construction of several dams on local rivers, overexploitation of groundwater for agricultural uses, and the increase in the mean air temperature amplified the water shortage in the basin. All of the rivers in the basin discharge their water into the mentioned lake embedded in the basin. In recent years, discharge of water into the lake diminished drastically, and therefore, this lake is exposed to shrinkage. Solving these problems is not easy and needs better understanding of basin hydrology. Therefore, the aim of this study is to examine the trends in ET_0 at the Urmia Lake basin using the MK method and its modified version for significant autocorrelation coefficients.

Materials and methods

The Urmia Lake basin is located in the northwest of Iran selected as the study area. The basin is approximately located between 44° 13′ E to 47° 53′ E longitude and 35° 40′ N to 38° 29′ N latitude. The area of this basin is about 52,700 km^2 which is equal to 3.2% of Iran's area. The average annual precipitation of this basin is about 398 mm. The mean daily data (1986–2010) of some climatic variables such as minimum air temperature ($T_{\min}$), maximum air temperature ($T_{\max}$), maximum relative humidity (RH_{max}), minimum relative humidity (RH_{min}), sunshine hour duration, and wind speed at 10-m height (U) were gathered from the Islamic Republic of Iran Meteorological Organization (IRIMO). The mentioned data as well as the geographic information of the stations (such as the altitudes and latitudes of the stations) were used to estimate the ET_0. Prior to computation of ET_0, the quality of data was checked carefully. In order to be assured that the values of $T_{\max}$ are greater than the corresponding $T_{\min}$, these two series were plotted in the same diagram and checked visually for possible outliers and/or disorder points. These two graphs should never cross each other, and the graph of $T_{\max}$ should be located above the $T_{\min}$ everywhere. In the cases of some existing unusual data points, such suspicious records were substituted by synthetic reconstructed data. For this purpose, the UK traditional method (Kashani and Dinpashoh 2012) was used to implement information of a nearby station. This method was used in reconstruction of missing data in $T_{\max}$, $T_{\min}$, and sunshine hour series employing the adjacent neighboring station data. On the other hand, all the recorded data of sunshine hours, RH_{max}, and RH_{min} time series were inspected for negative values. The mentioned method for reconstruction of air temperature was applied for such unusual values of sunshine hours, RH_{max}, and RH_{min} time series. The same method was used in detection of possible negative values in wind speed data of the stations. However, their reconstruction was performed by a simple linear regression scheme with the corresponding values of the nearby station records that had the largest positive coefficient of correlation.

In this study, seven stations were selected in Urmia Lake (around the Urmia Lake) for analysis. Figure 1 shows the study area and location of the stations. The De Martonne climatic classification system was used for the detection of the selected stations' climate and their aridity indices. In the De Martonne classification system, the type of the stations' climate was determined by the calculation of the aridity index "I" using the following equation (De Martonne 1926):

$$I = \frac{P}{T+10} \tag{1}$$

where P is the long-term mean annual precipitation (in mm), and T is the annual mean air temperature (in °C). The De Martonne index classification is presented in Table 1.

Geographical locations of the selected stations as well as their aridity index and climate types were indicated in Table 2. In order to estimate the ET_0 values of the stations, the standard FAO-56 PM method was used. This method is the recommended form of the PM approach (Allen et al. 1998). ET_0 of the stations was estimated by this method using the following equation (Allen et al. 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \tag{2}$$

where ET_0 is the reference crop evapotranspiration (mm/day), R_n is the net solar radiation at crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux (MJ m^{-2} day^{-1}), T is the mean air temperature at 2 m height (°C), u_2 is the wind speed at 2 m height (m/s), the term ($e_s - e_a$) is the saturation vapor deficit (kPa), Δ is the slope of the vapor pressure curve at the point of air temperature (kPa/°C), and γ is the psychometric constant (kPa/°C). In order to convert the wind speed from the 10-m height to 2 m, the following equation was used (Sentelhas et al. 2010):

$$u_2 = U_z \frac{4.87}{Ln(67.8z_w - 5.42)} \tag{3}$$

where U_z is the wind speed (ms^{-1}) at z meters height, and z_w is the height (m) of the anemometer pivot apparatus.

Trends in ET_0 time series (in monthly, seasonal, and annual timescales) were analyzed using the MK test (Mann 1945; Kendall 1975). The MK method has been widely used in analyzing trends of hydrological and meteorological series (Lettenmaier et al. 1994). A pre-requisite for using this test is the absence of significant autocorrelation coefficient in the data time series. The presence of a significant positive autocorrelation leads to an estimation of trend statistic parameters more than the actual values. In contrast, the existence of significant negative correlation makes estimation of trend

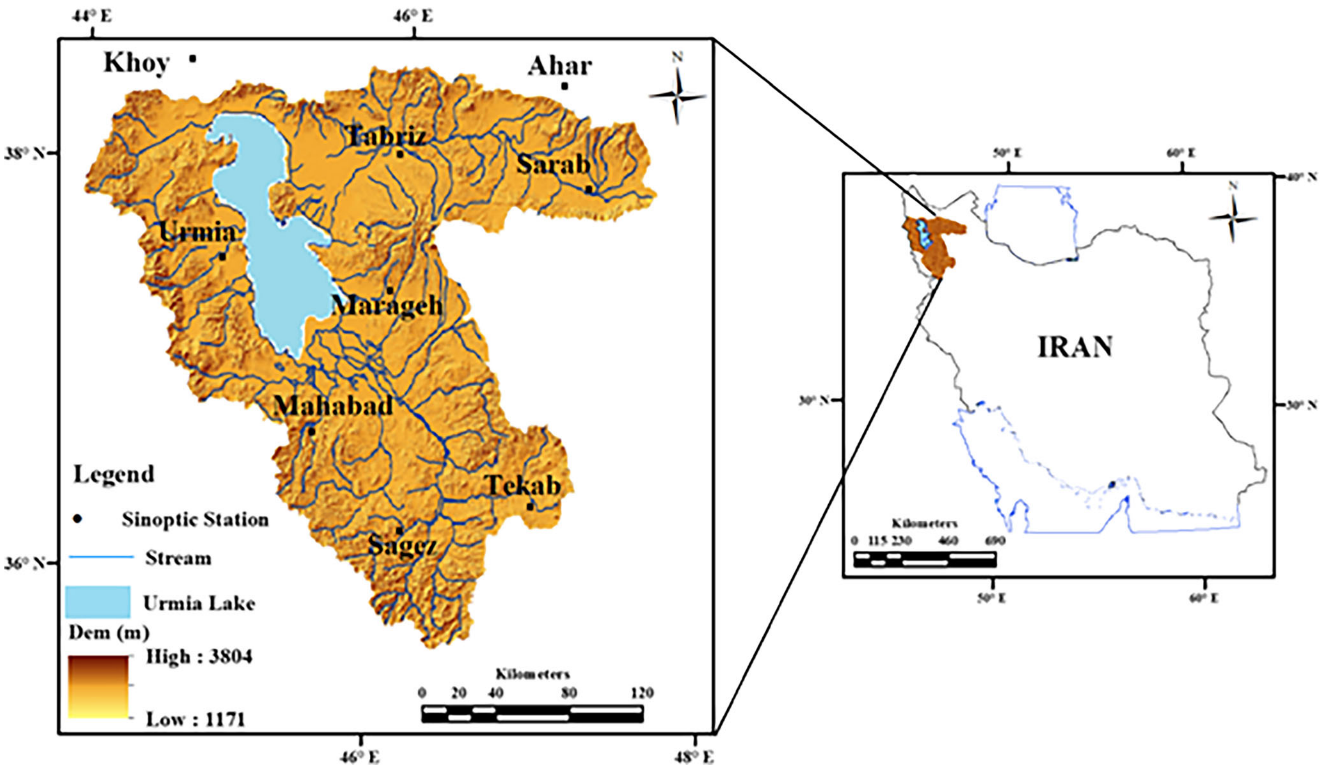

Fig. 1 The study area and the location of the selected stations in Urmia Lake basin

statistical parameters leads to an estimation of trend statistic less than the actual values (Lettenmaier et al. 1994). A modified version of MK method, including all significant autocorrelation coefficients (denoted by MK3 here), was used for the series with significant autocorrelation coefficient.

Mann-Kendall test

In the traditional MK (denoted by MK1) test, the first step is the calculation of the S statistics using the observations and employing the following equation (Mann 1945; Kendall 1975):

$$S = \sum_{i=1}^{n-1} \sum_{j=1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \tag{4}$$

Table 1 The De Martonne aridity index classification

Types of climate	Values of index I
Arid	$I < 10$
Semiarid	$10 \le I < 20$
Mediterranean	$20 \le I < 24$
Semi-humid	$24 \le I < 28$
Humid	$28 \le I < 35$
Very humid	$35 \le I < 55$
Extremely humid	$55 \le I$

where x_j is the value of jth data, n is the number of data, and sgn (θ) is the sign function, which is defined as:

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & if \quad \theta > 0 \\ 0 & if \quad \theta = 0 \\ -1 & if \quad \theta < 0 \end{cases} \tag{5}$$

If $n > 8$, the S statistics has a normal distribution having $E(S) = 0$ and following variance:

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \tag{6}$$

where t_i is the number of observations in the i^{th} tied class, and m is the total number of tied classes. The score of MK test or Z statistic is calculated as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{V(S)}} & S < 0 \end{cases} \tag{7}$$

Null hypotheses (H_0), i.e., there is no significant trend in the tested time series, was accepted if the condition $-Z_{1-\frac{\alpha}{2}} \le Z \le Z_{1-\frac{\alpha}{2}}$ is satisfied. Otherwise, the H_0 is rejected and the alternative hypothesis (H_1), i.e., there is a significant trend in time series, at the α significance level is accepted.

Table 2 Details of the geographical location of the selected stations

Station	Longitude	Latitude	Altitude (m)	Mean annual ET_0 (mm)	Aridity index (I)	Type of climate
Ahar	47° 04′	38° 26′	1390.5	1064.42	0.26	Semiarid
Khoy	44° 58′	38° 33′	1103	994.01	0.25	Semiarid
Mahabad	45° 43′	36° 46′	1385	1199.42	0.29	Semiarid
Marageh	46° 16′	37° 24′	1477.7	1371.41	0.25	Semiarid
Urmia	45° 05′	37° 32′	1315.9	1070.01	0.34	Semiarid
Sarab	47° 32′	37° 56′	1682	1024.63	0.24	Semiarid
Sagez	46° 16′	36° 15′	1522.8	1160.22	0.37	Semiarid
Tekab	47° 07′	36° 23′	1765	1122.63	0.35	Semiarid
Tabriz	46° 17′	36° 23′	1361	1379.69	0.22	Semiarid

Modified Mann-Kendall test

The MK1 test was modified by Hamed and Rao (1998), and described in details by Kumar et al. (2009), which is denoted here as MK3. In this test, the effect of all significant autocorrelation coefficients is removed from the time series. In order to test the trends using the MK3, it is necessary to calculate the modified variance of S, denoted by $V(S)^*$ using the following equation:

$$V(S)^* = V(S)\frac{n}{n^*} \tag{8}$$

where the ratio of $\frac{n}{n^*}$ is calculated from the following equation:

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)}\sum_{i=1}^{n-1}(n-i)(n-i-1)(n-i-2)r_i \tag{9}$$

where r_i is the i^{th} autocorrelation coefficient calculated from the following equation:

$$r_k = \frac{\frac{1}{n-k}\sum_{i=1}^{n-k}\left(x_i-\overline{x}\right)\left(x_{i+k}-\overline{x}\right)}{\frac{1}{n}\sum_{i=1}^{n}\left(x_i-\overline{x}\right)^2} \tag{10}$$

In MK3 test, the value obtained for $V(S)^*$ was used instead of $V(S)$ in Eq. (6).

In the present study, the significance of trends tested in 10, 5, and 1 percent levels.

Sen's estimator

In this study, the magnitude of trends is calculated using the Sen's estimator (Theil 1950; Sen 1968) method using the following equation:

$$\beta = \text{Median}\left(\frac{x_i-x_j}{i-j}\right)\forall j < i \tag{11}$$

where x_j and x_i are the jth and ith observations in the tested time series. The positive values of β represent the upward trends, whereas the negative values indicate the downward trends.

Results

Figure 2 shows the resulting correlograms of the monthly ET_0 time series at a representative station "Tabriz" in the first 8 months (i.e., from January to August), respectively. The correlograms in the cases of the last 4 months of a year, four seasons, and annual ET_0 time series are shown in Fig. 3. In these figures, the dashed lines depict the 90% confidence interval bounds. Also, the bars in these figures are correlation coefficients in different lag-times. As can be seen from these figures, the correlation coefficients in the most of the months were not significant at 10% level. However, in some of the correlograms, one or more of the autocorrelation coefficients exceeded the 90% confidence bounds. For example, in the monthly scale, the lag-1 and lag-2 correlation coefficients of the ET_0 (in March) exceed the upper bound. In addition, in the station Tabriz, in August, the lag-2 correlation coefficient exceeded the upper band. In the seasonal scale, the lag-1 serial correlation exceeded the upper band in winter and autumn seasons (Fig. 3). On the other hand, in the annual timescale, the lag-1 and lag-2 exceeded the upper 90% confidence level. Thus, it can be suggested that blindly using the conventional MK for these mentioned ET_0 series is not allowed. In these cases, for all the selected stations, the modified version of MK test called MK3 was used.

The resulting values of Z statistics obtained by using the MK1 (or MK3) in all the examined series are shown in Table 3. All the Z values, which are significant at 10% level, are shown by bold numbers in Table 3. Moreover, those values which were significant in the 0.05 and/or 0.01 levels are indicated by both bold numbers and by putting one or two asterisks on the values, respectively. Figure 4a shows the time

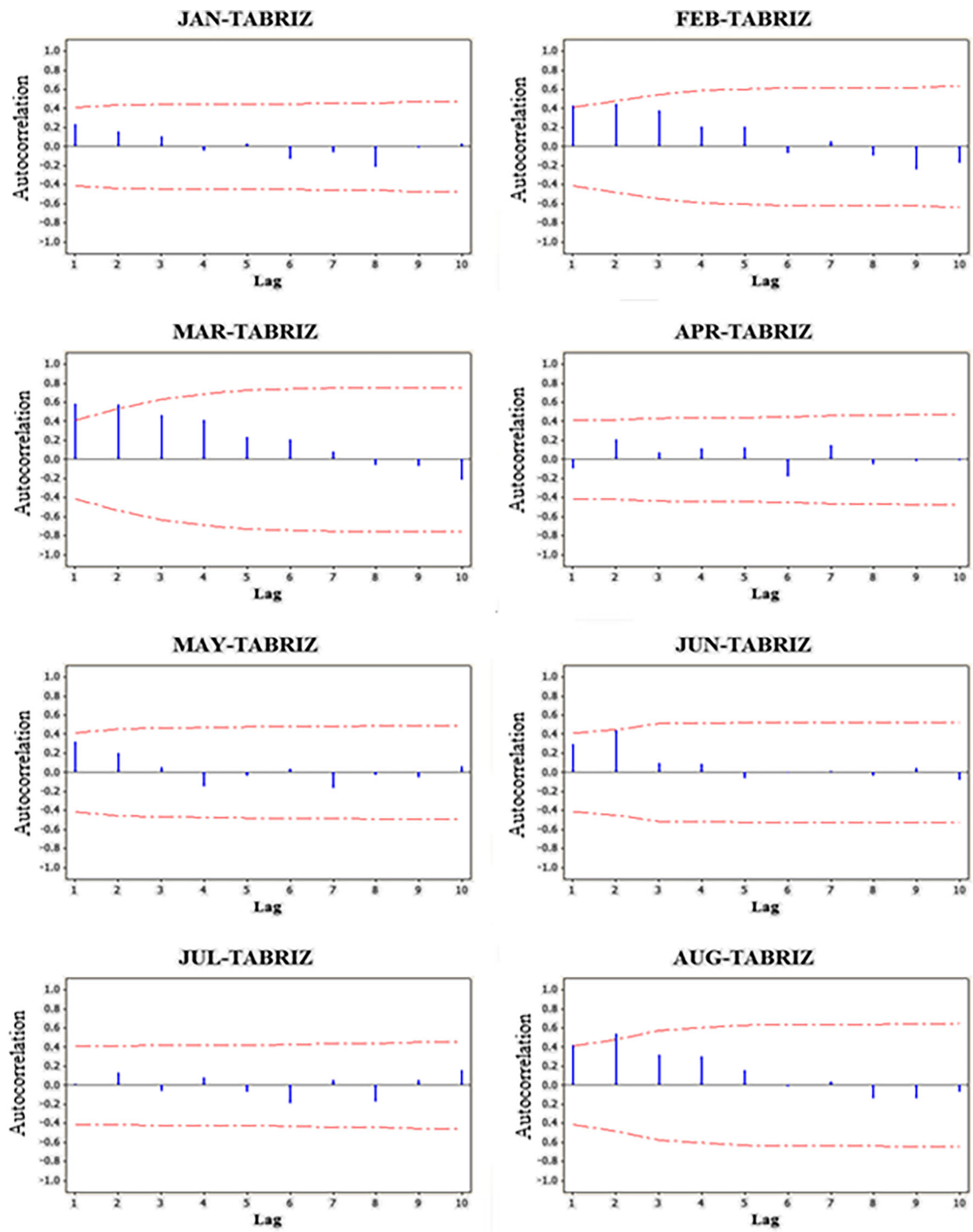

Fig. 2 The correlograms of the time series of monthly ET_0 (mm/month) for 8 months (January to August) in Tabriz station in the period 1986–2010

series of the air temperature trends in August at three representative stations, namely Mahabad, Sarab, and Khoy. As can be seen from the mentioned figure, the trends in air temperature are apparently upward for the three mentioned sites. The value of the Z statistics for the abovementioned stations was 3.64, 3.01, and 1.16, for the stations Mahabad, Sarab, and Khoy, respectively. The upward trends in the first two mentioned stations were found to be significant at the 1% level. Therefore, the air temperature can be said to be an effective parameter in increasing the ET_0 at the sites in August. Figure 4b shows the time series of spring, summer, and autumn mean air temperature series in the sample station Tabriz. As it can be observed from the figure, rising trends are obvious in seasonal air temperature series. The calculated values of Z

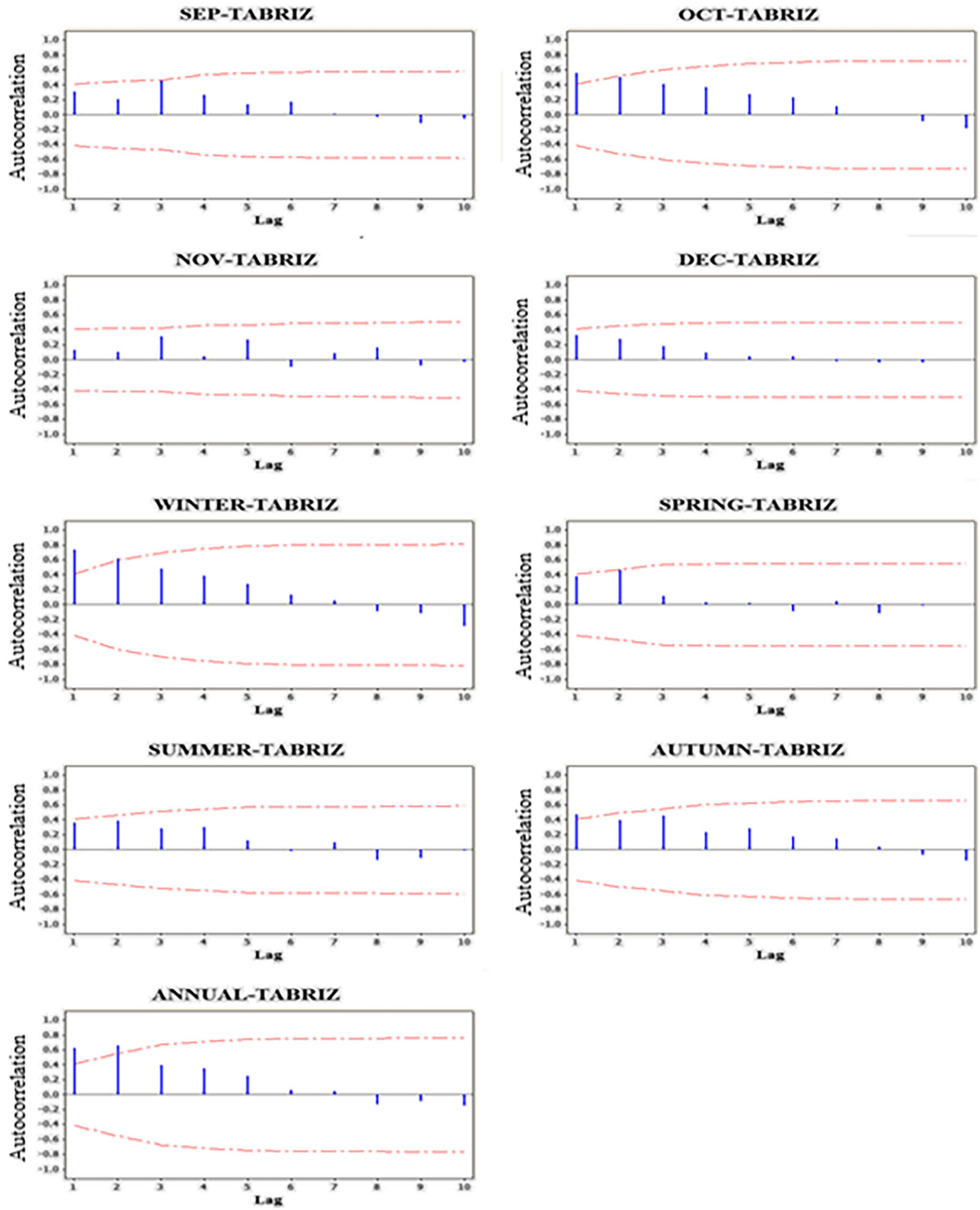

Fig. 3 The correlograms of the ET_0 time series in the last 4 months of the year (September to December), seasons and year in the station "Tabriz" (1986–2010)

statistics for the abovementioned time series in spring, summer, and fall seasons were 1.89, 2.74, and 2.49, respectively. Figure 4c shows the mean annual air temperature time series at three sample stations, namely Ahar, Mahabad, and Sarab. As can be seen from the figure, the mean annual air temperature witnessed an upward trend that implies the effectiveness of this parameter in ET_0 changes at the abovementioned sits. It is worthy to mention that, the values of Z statistics obtained for the annual mean air temperature were equal to 3.17, 2.56, and 3.74, in Mahabad, Ahar, and Sarab stations, respectively. All of the mentioned Z values were significant at 0.01 level.

As the wind speed trends may influence the ET_0 trends, therefore, trends of this climatic variable analyzed as well. Figure 5a indicates the diagram of mean August wind speed

Table 3 The obtained Z values of ET_0 time series by using the MK1 (or MK3) method in monthly, seasonal, and annual timescales for the selected stations in Urmia Lake basin

Station	Urmia	Tekab	Tabriz	Sarab	Sagez	Marageh	Mahabad	Khoy	Ahar
Month									
January	_1.73_	1.61	_2.03*_	1.01	0.91	_1.75_	0	_1.94_	0.84
February	_1.71_	_2.45**_	1.55	_1.75_	_2.36**_	_3.53**_	_1.75_	1.61	_1.68_
March	_3.32**_	_2.78**_	_1.72_	1.47	_1.78_	_1.79_	_3.29**_	_1.89_	_3.08**_
April	_2.50**_	0.07	_1.99*_	0.86	1.19	_2.13*_	_1.84_	_2.49**_	0.70
May	1.00	− 0.96	_2.26*_	− 0.99	− 0.63	_2.55**_	− 0.16	_1.94_	− 0.47
June	_2.15*_	0.35	_2.04*_	1.52	_1.84_	_2.20*_	_2.50**_	_1.96*_	1.03
July	_1.82_	− 1.19	_1.75_	_1.89_	1.47	_2.06*_	_2.36**_	_2.20*_	1.49
August	1.59	0.07	1.59	_2.61**_	1.24	_1.97*_	_2.73**_	_2.24*_	1.62
September	1.41	0.49	_3.20**_	0.96	1.30	1.48	_2.54**_	_2.05*_	0.42
October	_1.87_	_2.22*_	_2.04*_	_1.75_	1.61	_2.09*_	1.52	_1.94_	_2.10*_
November	_2.48**_	− 0.21	_3.16**_	0.30	0.44	_2.29*_	− 0.58	_3.43**_	0.61
December	_2.92**_	0.54	_3.20**_	0.30	0.82	_3.90**_	0.12	_3.15**_	0.42
Season									
Winter	1.49	_2.90**_	1.46	_2.55**_	_1.87_	_1.94_	_3.06**_	_1.75_	_2.76**_
Spring	_1.75_	− 0.35	_2.45**_	1.33	0.40	_1.83_	1.33	_3.34**_	1.03
Fall	1.61	0.26	_3.01**_	_3.15**_	1.53	_2.06*_	_3.01**_	_1.87_	_2.10*_
Summer	_1.68_	1.38	_2.10*_	_1.66_	_2.66**_	_2.22*_	0.86	_2.08*_	1.31
Annual	1.41	0.16	_1.74_	_2.64**_	1.41	_1.99*_	_2.64**_	_2.01*_	_2.90**_

Note: The values indicated in italics , with an asterisk, and with two asterisks denote to be significant at 10, 5, and 1 percent levels, respectively

time series in three representative stations, namely Mahabad, Sarab, and Khoy, respectively. As can be seen from this diagram, the mean August wind speed increased through the examined time period. The values of the Z statistics for the mentioned stations obtained equal to 4.64 (in Mahabad), 2.35 (in Sarab), and 1.35 (in Khoy). Results showed that increasing trends in wind speed experienced in almost all the sites, which influenced the ET_0 trends. Figure 5b shows the wind speed time series at the station Tabriz in three seasons, namely spring, summer, and fall (from left to right, respectively). As it can be seen, the rising trends in seasonal wind speed at Tabriz are obvious, which might be regarded to be a reason for the upward trends in seasonal ET_0. The values of the Z statistics obtained for the seasonal wind speed are equal to 2.84, 2.33, and 0.99, in spring, summer, and fall seasons, respectively. Figure 5c shows the annual wind speed time series at the three sample sites, namely Ahar, Mahabad, and Sarab. It can be deduced from this figure that this climatic variable had upward trends too. The values of the Z statistics were obtained to be equal to 2.38, 2.34, and 3.12 in the three stations, namely Mahabad, Ahar, and Sarab, respectively. All of the three Z values for the mentioned sites were significant at 0.01 level.

Figure 6a indicates the RH time series in August at the stations Mahabad, Sarab, and Khoy (from left to right at the first panel of the figure). In this diagram, it can be seen that decreasing trends in RH were detected for the sites. The values of the Z statistics for the above stations were equal to − 1.68 (in Mahabad), − 1.19 (in Sarab), and − 2.44 (in Khoy). Figure 6b shows the RH time series in the seasonal timescale at Tabriz station. As can be seen from the mentioned figure, there is an apparent decreasing trend in RH time series in spring, summer, and fall seasons. The values of the Z statistics for the abovementioned stations in the spring, summer, and fall were negative and equal to − 0.58, − 0.58, and − 1.19, respectively. Negative trends in RH impress the upward trends in ET_0. Figure 6c represents the annual RH time series (from left to right at the bottom panel) in the stations Ahar, Mahabad, and Sarab, respectively. It can be seen that apparent decreasing trends were experienced in the annual RH series of the sites. The values of the Z statistics for the abovementioned stations were equal to − 1.79, − 1.63, and zero in Mahabad, Ahar, and Sarab stations, respectively. The trends in the first two stations, i.e., Mahabad and Ahar, were significant at 0.10 level.

In Table 3, the bold numbers indicate that the trends are significant at 0.10 level. Bold numbers with an asterisk (or two asterisks) denote the time series was significant at 0.05 (or 0.01) level. In this basin, 32% of the time series showed significant serial correlation; therefore, the MK3 method was used for them instead of MK1. As can be deduced from Table 2, that in the monthly timescale, 60 out of the 108 time series (equal to 55% of whole monthly series) had positive significant ET_0 trends ($P < 0.10$). In the seasonal scale, the

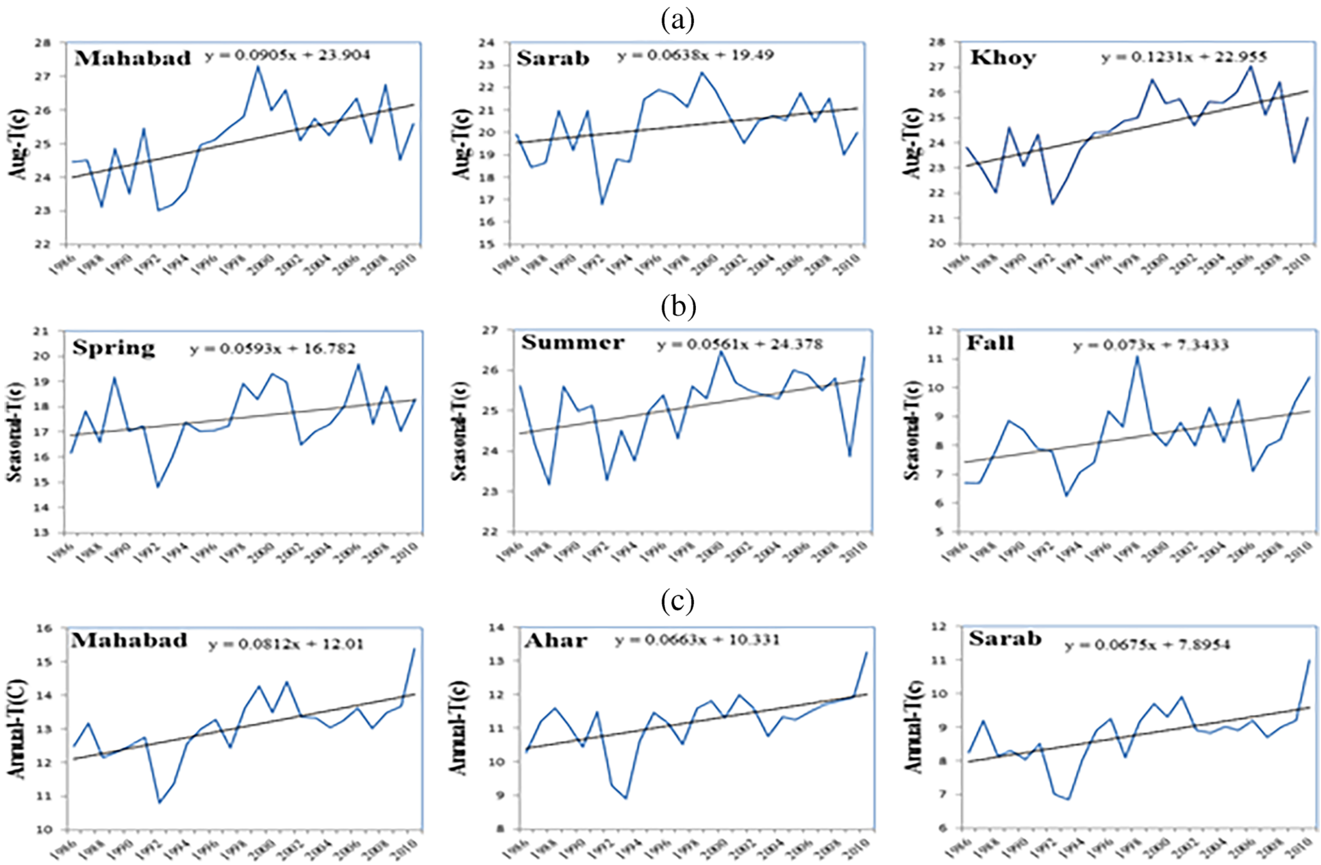

Fig. 4 The mean air temperature time series. **a** In August at the stations Mahabad, Sarab, and Khoy (from left to right at the first panel). **b** In spring, summer, and fall (from left to right at the second panel) at Tabriz. **c** Yearly mean air temperature at stations, namely Mahabad, Ahar, and Sarab (from left to right at the third panel)

64% of the seasonal ET_0 series (23 of 36 time series) had significant positive trends ($P < 0.10$). In addition, in the annual timescale, the six out of the nine stations (equal to 66.6% of the sites) had significant positive trends. For example, at the station Ahar (last column of Table 2), five out of the total 17 ET_0 time series (in the three timescales) showed significant trends ($P < 0.05$). In the monthly scale, results showed that the number of positive significant ($P < 0.10$) ET_0 trends is more than that of the opposite trends. In the seasonal scale, for example, in the station Ahar, all the Z values were positive. Even trends in autumn and winter were significant, in 0.01 and 0.05 levels, respectively. In the annual scale, the significant ($P < 0.01$) increasing trends were experienced for the annual ET_0 series.

As mentioned in the "Materials and methods" section, the magnitude of trend lines was estimated for the time series using the Sen's estimator approach. Table 4 shows the slope of trend lines in the ET_0 time series in monthly, seasonal, and annual timescales for the selected stations. As can be deduced from Table 4, that the magnitudes of trends in about 92.6% of the whole series were positive implies upward trends in them. In the monthly timescale, the steepest upward trend line slopes belonged to the station namely Marageh in August. The value of trend line slope was equal to 2.51 mm/year. It is noticed that very few cases of time series showed mild downward trends in ET_0. For example, the steepest slope of downward trend line belonged to the station namely Tekab in July (equal to − 0.53 mm/year). Other downward trend line slopes in the monthly scale were found to be very close to zero implies that the trend lines were relatively horizontal. In the seasonal timescale, results indicated that, except the station Tekab (in the spring season), all of the seasonal ET_0 time series were upward (Table 4). The highest value of positive trend line slopes is observed at the station Marageh in the summer, which was equal to 7.52 mm/year. This implies that in the last decade (in average), the summer ET_0 values increased about 75 mm in Marageh.

In the annual timescale, all the slopes of ET_0 trend lines were positive. The steepest trend line was equal to 17.34 mm/year, which belonged to the station Marageh. This means that the value of annual ET_0 in this site increased through the past decade to about 173 mm. This implies that due to increasing trends in ET_0, about 1730 (m^3 per hectare) more water needed for irrigation of the same crops in agricultural lands, comparing the previous decade, assuming the irrigation efficiency to be not change. Therefore, in the present situation, unless

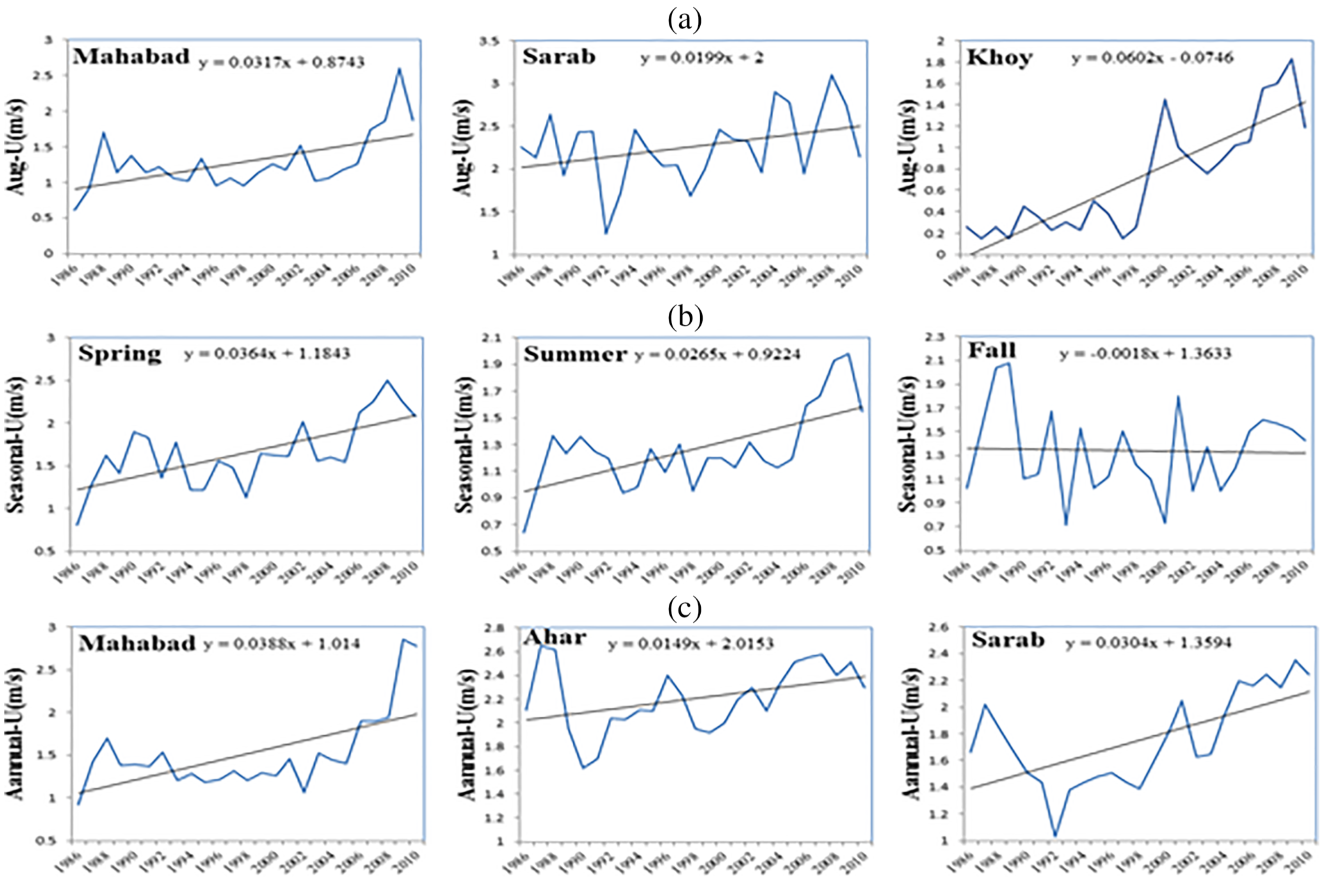

Fig. 5 Time series of mean wind speed. **a** In Mahabad, Sarab, and Khoy stations in August. **b** In three different seasons (from left to right: spring, summer, and fall) in station Tabriz. **c** In the yearly scale in Mahabad, Ahar, and Sarab

enhancing the irrigation efficiency, it is nearly impossible to meet the irrigation water demands at this basin. Figure 7 shows the time series of August ET_0 at three representative stations, namely Mahabad, Sarab, and Khoy. Increasing trends in August ET_0 time series are obvious from Fig. 7.

Figure 8 shows the seasonal ET_0 time series in some representative stations and the three seasons. The first column of Fig. 8 belongs to the spring season, whereas the second and third columns belong to the summer and autumn seasons, respectively. For each of the three seasons, only the series with high trend line slopes is shown for the sake of brevity. For example, in spring season, the stations, namely Khoy, Marageh, and Tabriz, having the large trend magnitudes, are selected to be shown (see the first column in Fig. 8). In summer, among all the sites, three stations, namely Mahabad, Sarab, and Tabriz, had large values of trend magnitudes, which are shown in the middle column of Fig. 8. Similarly, in autumn the three sites with large magnitudes of trends were found to be the Sagez, Marageh, and Tabriz, respectively. These time series are shown in the third column of Fig. 8. In winter, ET_0 values were negligible, due to being the coldest season in the study area; therefore, the winter trends in ET_0 were not analyzed here. Figure 9 shows the annual ET_0 time series at the three stations, namely Ahar, Mahabad, and Sarab. As can be seen from Fig. 9, the annual ET_0 time series exhibited increasing trends.

In the present study, an attempt was made to find the spatial trends of ET_0 over the Urmia Lake basin. In this regard some maps in which significant trends in the selected sites were shown by different markers. Figure 10 shows the mentioned maps. In the first panel (from top) of Fig. 10, the spatial monthly ET_0 trends at Urmia Lake basin in June (Fig. 10a), July (Fig. 10b), and August (Fig. 10c) were shown, respectively. The first row in Fig. 10 shows the monthly ET_0 trends in June, July, and August (from left to right) respectively. As can be seen from the mentioned maps (in Fig. 10) in these three hot months of a year, there are no negative trends experienced for ET_0 at the selected stations. In June (Fig. 10a), upward significant ($P < 0.01$) trends were observed for ET_0 in the station Mahabad. Moreover, significant trends ($P < 0.05$) were witnessed at three stations, namely Tabriz, Urmia, Marageh, and Khoy for ET_0. The trends in ET_0 series were insignificant in the stations, namely Ahar, Sarab, Tekab, and Sagez.

In the second and third panels of Fig. 10, the spatial distribution of seasonal trends in ET_0 was shown. The maps of

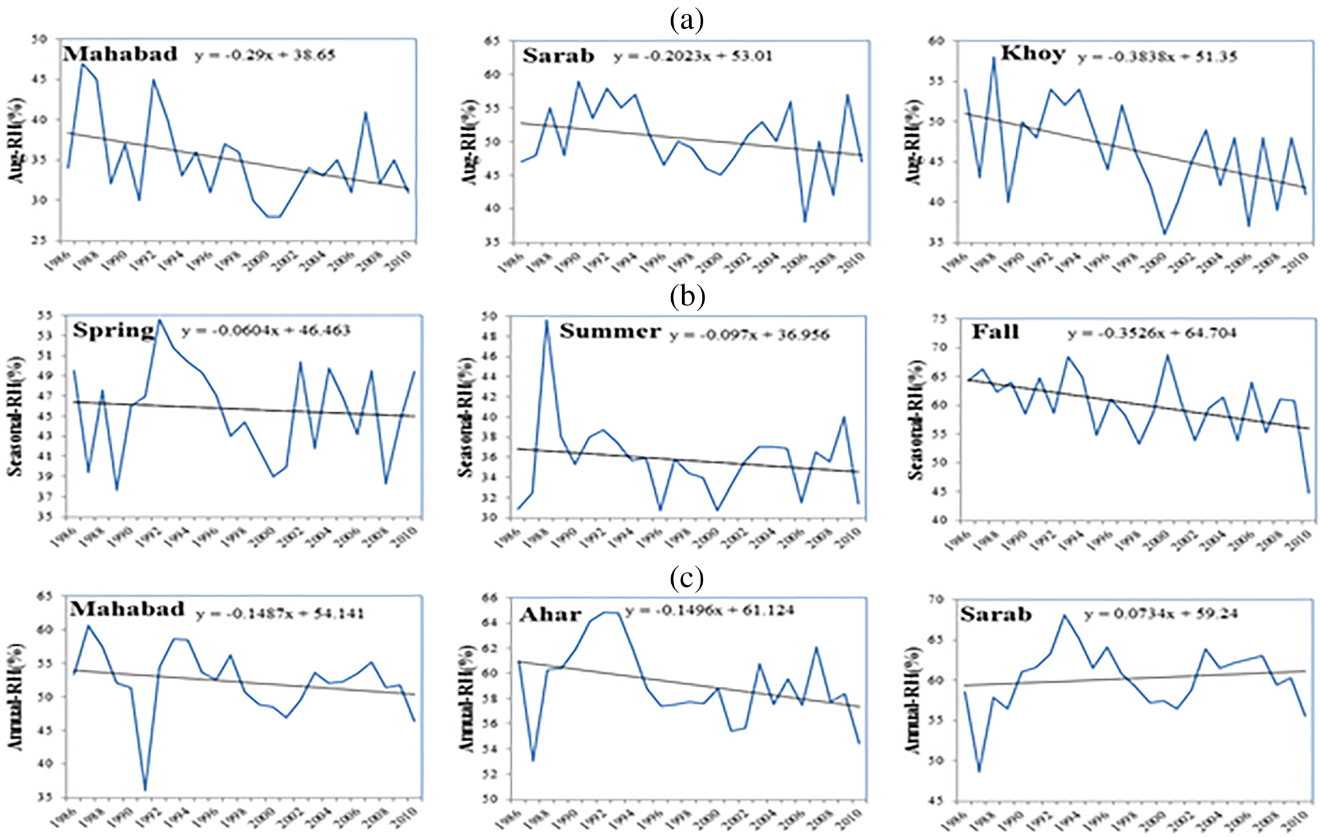

Fig. 6 The mean relative humidity (RH) time series. **a** In August at Mahabad, Sarab, and Khoy (from left to right at the upper panel). **b** In the seasonal scale at the station Tabriz (at the middle panel from left to right: spring, summer, and fall). **c** Annual RH time series in Mahabad, Ahar, and Sarab (from left to right in the third panel)

Table 4 The slope values of ET_0 trend lines in monthly (mm/month), seasonal (mm/season), and annual (mm/year) timescales in the selected stations

Station	Urmia	Tekab	Tabriz	Sarab	Sagez	Marageh	Mahabad	Khoy	Ahar
Month									
January	0.16	0.13	0.28	0.06	0.081	0.20	0.00	0.09	0.19
February	0.52	0.27	0.49	0.37	0.49	0.56	0.54	0.33	0.51
March	1.02	0.82	1.15	1.04	1.20	1.33	1.18	1.16	1.21
April	0.55	0.02	0.68	0.31	0.41	0.88	0.68	0.62	0.22
May	0.34	− 0.42	0.96	− 0.18	− 0.38	0.99	− 0.16	0.79	− 0.17
June	1.02	0.21	1.54	0.71	0.87	2.03	1.22	2.10	0.70
July	1.06	− 0.53	1.08	0.77	1.30	2.46	0.98	1.84	0.80
August	1.45	0.03	1.77	0.82	1.61	2.51	1.13	2.03	1.14
September	1.02	0.10	1.48	0.27	1.06	2.10	0.91	1.13	0.39
October	0.89	0.62	1.38	0.47	1.05	1.68	0.62	0.84	0.55
November	0.45	− 0.09	0.56	0.03	0.08	0.50	0.22	0.38	0.26
December	0.23	0.06	0.39	0.02	0.06	0.51	0.05	0.23	0.09
Season									
Winter	1.60	1.23	2.04	1.49	1.83	2.32	1.73	1.71	2.08
Spring	2.19	− 0.48	3.00	0.96	0.45	4.18	1.98	3.51	0.93
Fall	3.83	0.15	4.01	1.86	4.04	7.52	3.22	4.53	2.04
Summer	1.60	0.61	2.24	0.48	1.41	3.04	0.67	1.56	0.75
Annual	9.10	0.25	11.35	5.77	8.32	17.34	8.25	11.00	5.96

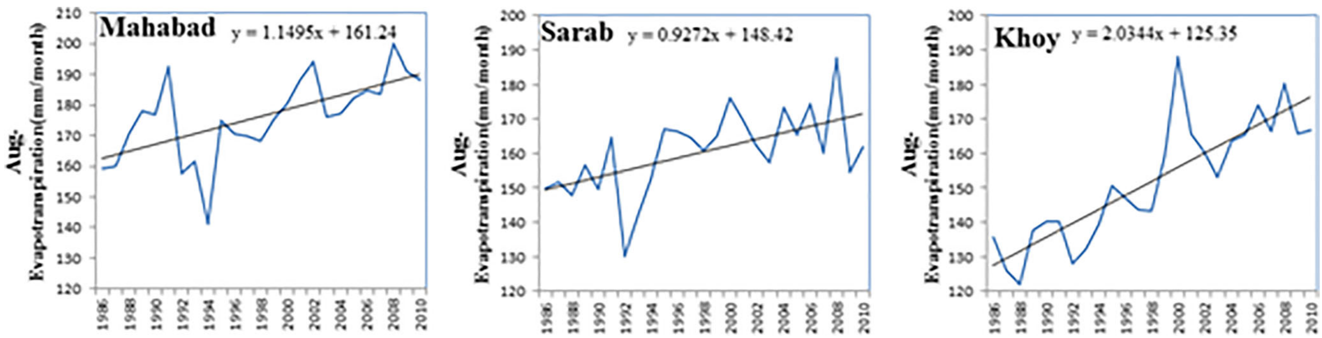

Fig. 7 The August ET_0 time series at the three representative stations (from left to right: Mahabad, Sarab, and Khoy)

trends for winter (Fig. 10a), spring (Fig. 10b), summer (Fig. 10c), and autumn (Fig. 10d) are shown in the figure. The map prepared here for annual ET_0 trends was shown in the right hand side of the third panel (Fig. 10a*). At the first view, it can be seen that in most of the stations across the basin, increasing trends were experienced in monthly, seasonal, and annual ET_0 series. Most of the trends, especially in seasonal and annual timescales, were upward and statistically significant over the basin. For example, in summer (Fig. 10c), unless the two sites located in southeast, ET_0 trends were upward over the basin. More precisely, in summer, ET_0 trends in three sites (Tabriz, Sarab, and Mahabad) were upward and statistically significant ($P < 0.01$). In the annual scale (Fig. 10a*), the two stations, namely Ahar, Sarab, located in NW of the basin and the

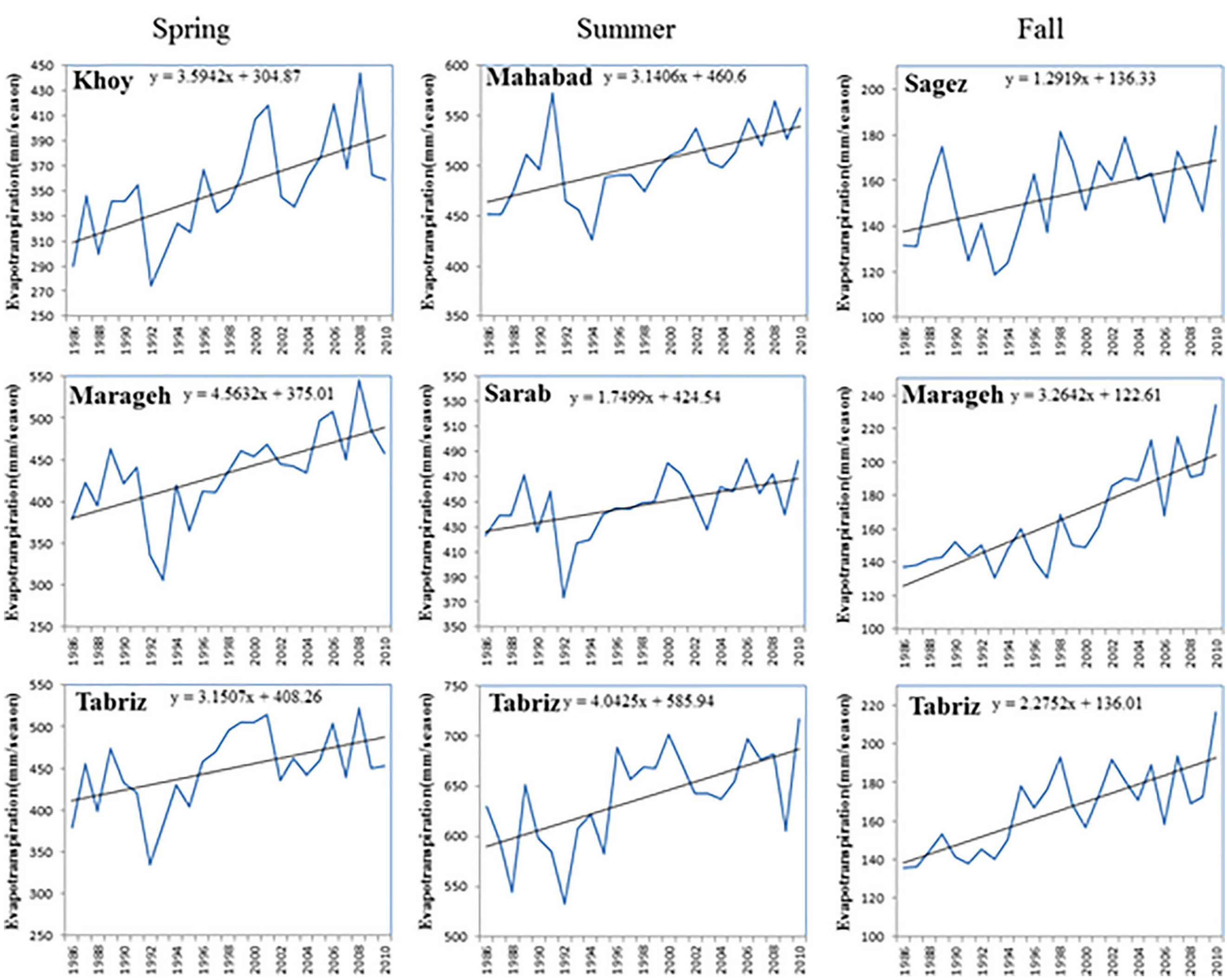

Fig. 8 The seasonal ET_0 time series in three representative stations with steep trends. Note: the columns (from left to right) belong to the spring, summer, and autumn seasons

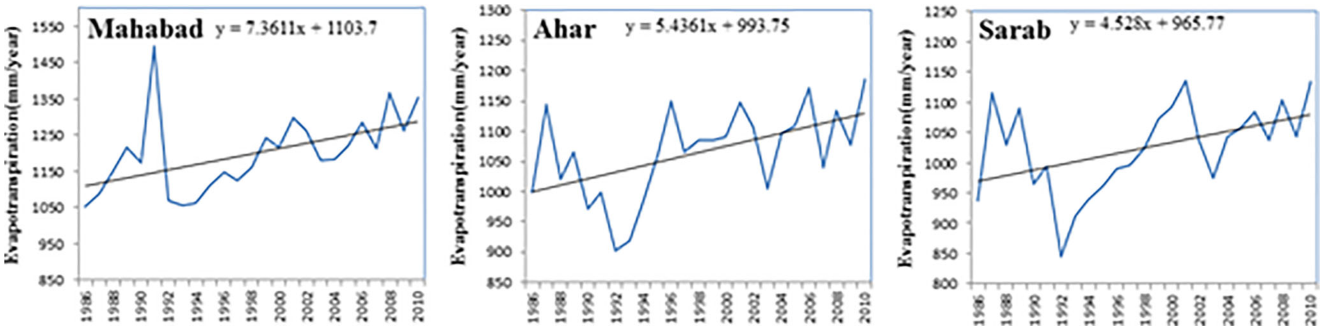

Fig. 9 The annual ET_0 time series at three representative stations (from left to right: Mahabad, Ahar, and Sarab)

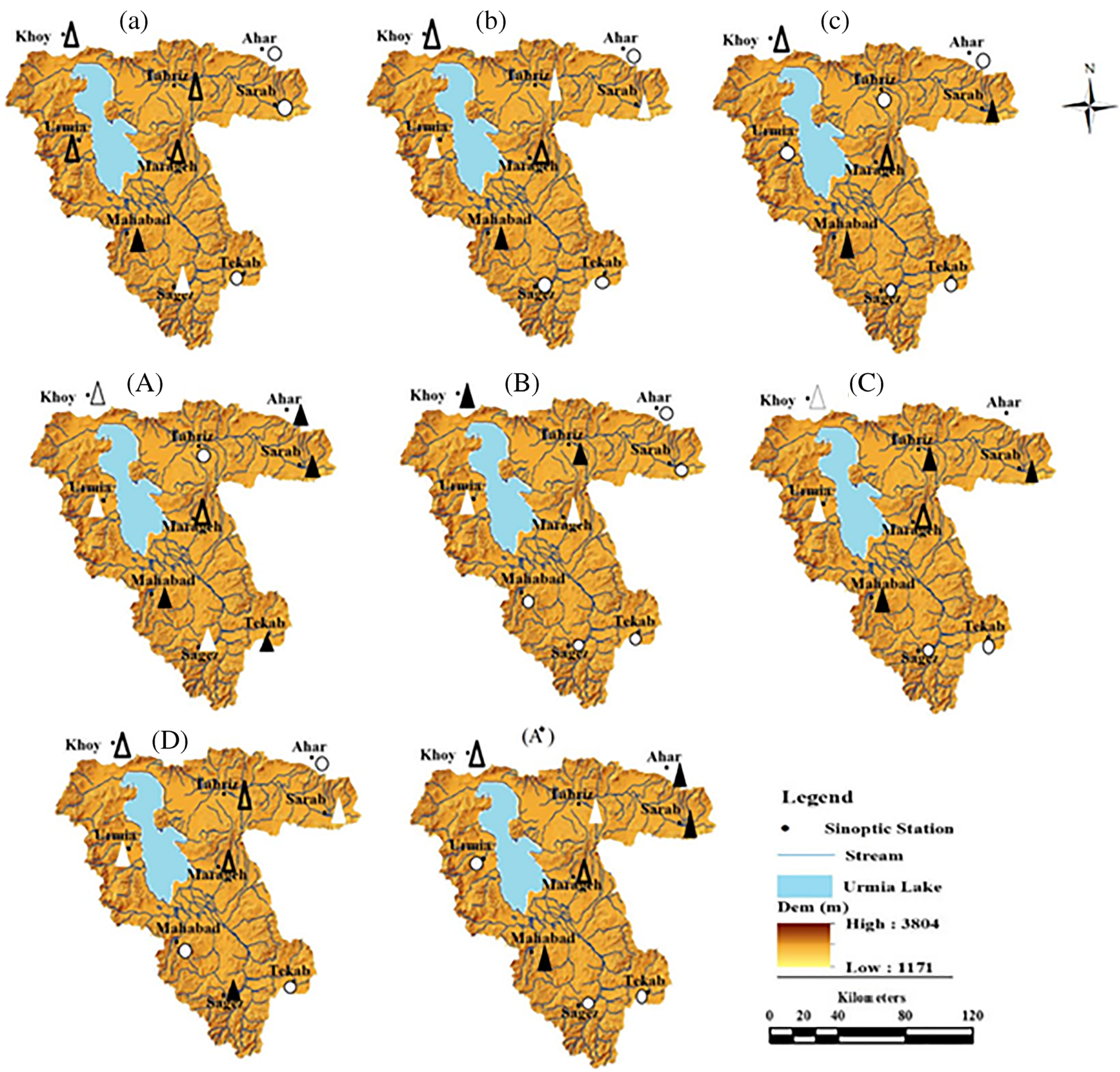

Fig. 10 The trends in monthly ET_0. **a** June. **b** July. **c** August (first panel). Seasonal ET_0: (A) winter, (B) spring, (C) summer, (D) autumn; and (A*) annual ET_0 in Urmia Lake basin (1986–2010). Note: Filled triangles indicate significant trend at 1% level; hollow triangles with bold sides indicate significant trend at 5% level; hollow triangles indicate significant trend at 10% level; and hollow circles indicate insignificant trends

station Mahabad positioned in southeast had significant ($P < 0.01$) upward ET_0 trends. In addition, two sites, namely Marageh and Khoy, showed significant (in 0.05 level) upward trends in the annual timescale. In the 0.10 significance level, the station Tabriz located in the east of the basin showed upward trends.

The relative contribution of the climatic variables on ET_0 is shown in Table 5. As can be seen from Table 5, by using the average values of the selected sites, the T_{min} and RH have 31.65 and 31.45% of contribution on ET_0. The wind speed and sunshine hours had 26.3 and 10.57% of contribution ordered in the third and fourth ranks.

Discussion

ET_0 increased in the Urmia Lake basin in the past which led to more water demand in this region. In order to relate trends in ET_0 to climatic variables, trends of some climatic parameters influencing ET_0 were examined too. One of the important climatic parameters, which may affect the ET_0 time series, is RH. Trends in RH were also analyzed at the selected sites. This parameter showed downward trends, which influenced ET_0 to increase. Moreover, trends in monthly air temperature showed increasing direction for the three sites. This result intensified the upward trends in monthly ET_0, too. In the seasonal scale, similar results were obtained which impressed the significant effect of air temperature in ET_0 trends at the seasonal scale as well. On the other hand, the 10-m wind speed in the hottest month (August) showed increasing trends. This did not coincide with the global decrease of near-surface wind speeds reported by McVicar et al. (2012). Such an increase in wind speed increases the ET_0 rate undoubtedly. In the monthly timescale, the steepest upward trend line slopes belonged to the station namely Marageh in August. The value of trend line slope was equal to 2.51 mm/year. This implies that there is an increase of August ET_0 to about 25 mm in a decade at the station Marageh. The main reason of such increase in ET_0 time series is the increasing trends in the air temperature and the wind speed as well as the decreasing trends in the relative humidity time series. It can be concluded that in the three main seasons (spring, summer, and autumn), which correspond to the growth period of many crops, the seasonal ET_0 series had upward trends. In June, July, and August (hot months), no downward significant trend observed for the stations across the Urmia Lake basin. According to the examinations of trends in meteorological parameters including T_{max}, T_{min}, T_{mean}, U, sunshine hours, and RH, it can be concluded that significant upward trends in air temperature and wind speed and/or significant downward trends in the RH time series at Urmia Lake basin led to increasing trends in ET_0. Such increasing results in ET_0 trends amplified the water needs in future certainly. This led to farmers to use more water to compensate for the additional crop water requirements.

Table 5 Relative contribution of the four climatic variables on ET_0

Station	T_{mean}	RH	Wind speed	Sunshine hours
Ahar	31.75	30.62	26.39	11.24
Khoy	34.61	31.22	26.84	7.33
Mahabad	33.45	32.51	23.38	10.66
Marageh	30.42	32.47	26.32	10.79
Urmia	32.39	33.12	25.18	9.31
Sarab	29.63	30.12	25.78	14.47
Sagez	31.28	31.94	27.13	9.65
Tekab	29.73	30.62	29.28	10.37
Tabriz	31.64	30.53	26.47	11.34
Mean of area	31.65	31.46	26.30	10.57

Previous studies in NW of Iran showed that the trends in rainfall and river discharges had decreasing trends. For example, Siahcheshm (2014) reported that the Z statistics for precipitation time series of the six stations chosen from the southern part of Aras river basin (located in the north part of the adjacent basin) were negative. In addition, the monthly precipitation trends at the station "Jolfa" for all the 12 months were decreasing. This station is located in the northern part of the adjacent basin, namely Aras. Sobhani et al. (2019) reported an increasing trend in air temperature in the Urmia Lake basin. As a result, more water shortage was experienced in this basin. On the other hand, the population of this area is continuously rising which created in turn serious water-related problems. In addition, industries continuously developing in this basin led to an increase of water demand as well. Thus, it seems that there are two approaches for decision-makers to overcome this problem: (i) wise management of available non-renewable water resources in the basin in the direction of conserving water; and (ii) transfer of water from the adjacent basins in to the Urmia Lake basin to meet the demands. It seems that the latter alternative creates in turn a variety of social, economic, and political problems. Therefore, farmers and all other water users should use available water wisely for a logical adaptation with climate change. This is accomplished by no more extension of agricultural development in the basin, reducing water losses in conveyance channels and farms. The saved water by changing traditional irrigation systems to modern should not be attributed to other sectors. As Grafton et al. (2018) stated that in order to mitigate global water scarcity, increases in irrigation efficiency must be accompanied by robust water accounting and measurements, a cap on extractions, an assessment of uncertainties, the valuation of trade-offs, and a better understanding of the incentives and behavior of irrigators. Changing the cultivation pattern from the crops that need more irrigation water (such as alfalfa, sugar beet, potato, and onion) to the crops with less water requirements (such as barley and wheat) led to cope with water shortage. It should be noted that saved water from such policies should not be attributed to other uses (such as industries and urban) as mentioned before. Finally, changing some portion of irrigated lands to the dry farming areas by supporting the farmers by the government through subsidies might change their behavior regarding water consumption which led to mitigate with climate change in the basin scale to some degree.

Conclusion

Examining the trends in ET_0 and time series in Urmia Lake basin revealed ET_0 in the most of the stations had significant upward trends in three timescales (monthly, seasonal, and annual). In this study, ET_0 was estimated using the FAO56 PM method at the sites. After calculating the Z statistics in Mann-Kendall (MK1 or MK3 depending on significance of autocorrelation coefficients) method, the magnitudes of trend lines were estimated via the Thiel-Sen approach. The results showed that there are significant upward trends in six out of the nine selected sites in the annual timescale. In addition, in the annual scale, all the trend line slopes were found to be positive. The most prominent conclusion is the fact that in a station, namely Marageh, the ET_0 increased year to year in a rate of 17.34 mm/year. This means that the value of annual ET_0 increased with a rate of 17 mm per year (i.e., 173 mm in a decade). This is equivalent to say that about 1730 (m^3 per ha) more water is needed for reference crop (grass) with respect to 10 years ago). On the seasonal scale, all the stations (except 6.5% of them) had significant positive trends. The previous studies showed that the precipitation and runoff series of this basin had decreasing trends; therefore, decision-makers are faced with water shortage to meet the demands. They had less time for taking wise decisions on available water use in this problematic basin. At the same time, increasing the air temperature and decreasing the air humidity led to the increase in evaporation from the wet soils, reservoirs, and so on. Also, such changes in climatic parameters led to increase of the evapotranspiration rate for all types of the crops, pastures, and garden trees. Wise use of water is an urgent need in this basin.

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