

Performance of the Penman-Monteith reference Crop Evapotranspiration in Iran

Babak Mohammadi

Department of Water Engineering, University of Tabriz, Tabriz, Iran
babakmsh@yahoo.com

Abstract: Sensitivity analysis of reference crop evapotranspiration (ET₀) in Iran is an important necessity due to better management of water in such an arid and semi-arid country. It is important to analyze the sensitivity of ET₀ to weather parameters as climate seems to be changed to some degree everywhere. In this study, sensitivity of ET₀ to climatic variables at the eight selected stations of Iran was investigated. To estimate the ET₀, the most recommended form of the FAO-56 Penman-Monteith method was used. Sensitivity of ET₀ was analyzed in terms of change in mean air temperature (T_{mean}), actual vapor pressure (ea), wind speed (u₂) and net solar radiation (R_n) within a range of ±20 %, in 5 % steps, from their corresponding normal long-term values (1965–2005). Results showed that ET₀ was most sensitive to T_{mean} at the six of the stations in annual time scale. Increase in T_{mean} by +20 %, caused the most increase in ET₀ at Chabahar. In contrast ET₀ was least sensitive to ea in most selected stations. In this study, we investigated the interaction parameters in different scenarios on ET₀ at all stations in monthly and annual time scale. Results showed in annual time scale increasing T_{mean} and WS by 20% and decreasing ea by 20 % yielded ET₀ increasing 36.4 % at Chabahar. But, in monthly time scale 10 % increase in T_{mean} and WS as well as 10 % decrease in R_n yielded ET₀ to be increase to about 30.5 % in December at Bandar Anzali.

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1. Introduction

Crop reference evapotranspiration (ET₀) is an important element for estimating crop water requirement and an important variable in the agro hydrological system. Accurate and consistent estimate of ET₀ in irrigated agriculture is needed for agricultural water management and for using water resources efficiently. Actual crop evapotranspiration can be derived from ET₀ by means of proper crop and water stress coefficients (Rana and Katerji 2000; Kite and Droogers 2000). Direct measurement of ET₀ is not easy and needs more time and cost. Therefore, in most situations, ET₀ is estimated from meteorological parameters. Numerous methods exist to estimate ET₀ (e.g. Penman 1948; Blaney and Criddle 1950; Hargreaves and Samani 1985; FAO-56 Penman-Monteith 1998). Among this method FAO-56 PM is considered to be the most appropriate model to predict ET₀. The American Society and Civil Engineers (ASCE) recommended the use of the ASCE- Penman- Monteith method, as simplified by FAO Paper No. 56 (Allen et al. 1998), to estimate ET₀. Itenfisu et al. (2003) concluded this method provides a consistent basis for objectively assessing the relative performance of ET₀ equations over a variety of climates. Sensitivity analysis is an essential task to determine the expected change in ET₀ in response to a known change in meteorological variables. McCuen (1973) was one of the pioneer

researchers, who investigated the sensitivity of various evaporation models to change in weather parameters on evaporation rates and the effect of meteorological measurements errors. Several studies have carried out on sensitivity of ET₀ to weather parameters (Saxton 1975; Ley et al. 1994; Rana and Katerji 1998; Goyal 2004). But the most of them conducted in a single station and fewer studies on regional and seasonal behavior of the sensitivity of ET₀ have been done. Beven (1979) investigated the sensitivity of estimates of actual crop evapotranspiration (ET_a) to errors in input data of the three stations across England and Wales. Beven found that in humid temperate region, the sensitivity of Penman-Monteith estimates of ET_a to different input data and parameters is more sensitive to the values of the aerodynamic and canopy resistance parameters that introduce the influence of vegetation type into the predictions. Singh and Xu (1997) investigated the influence of data errors on evaporation computed by mass transfer-based equation in the State of Vaud in Switzerland. They added 5, 10 and 20 % of systematic and random errors to original data and evaluated the change in evaporation. They found that evaporation is sensitive to vapor pressure gradient, less sensitive to wind speed and most insensitive to air temperature data. Systematic errors in vapor pressure data influenced evaporation inversely to the same magnitude for both monthly and daily time scales.

They found that evaporation estimates are more sensitive to random data errors in the monthly time scale. Systematic errors in wind speed and temperature data affect evaporation inversely to the magnitude of about a half and a quarter of the magnitude of the influence of vapor pressure errors, respectively. Systematic errors in vapor pressure data influenced evaporation estimates inversely to more or less the same magnitude. Goyal (2004) studied the sensitivity of ET₀ to change in four climatic parameters (i.e. T_{mean}, R_n, u₂ and e_a) within a range of ±20 % in Rajasthan (India). Goyal found that increase in mean air temperature by 20 % (maximum 8 °C) cause ET₀ to be increased by 14.8 % in the study area. ET₀ found to be less sensitive (11 %) to increase in R_n. Increase in e_a (20 %) had a small negative effect (say about -4.3 %) on ET₀. Gong et al. (2006) studied the sensitivity of ET₀ calculated from the FAO-56 PM to change in climatic variables in the Changjiang (Yangtze River) basin. They found that relative humidity was the most sensitive variable followed by radiation, air temperature and wind speed. Irmak et al. (2006) conducted a sensitivity analysis in the different climatic regions of USA. They used daily time scales and found that ET₀ was most sensitive to vapor pressure deficit (VPD) at all regions. In semi-arid regions ET₀ was most sensitive following VPD in summer months. Estevez et al. (2009) conducted the sensitivity analysis to assess the impact of climatic parameters on reference crop evapotranspiration calculated by Penman-Monteith equation in Spain. They selected four climatic variables namely mean air temperature, relative humidity, solar radiation and wind speed from 1996 to 2006. They added random and systematic errors to meteorological data to obtain ET₀ deviations. Results indicated that the effect of introduced random errors was larger than that of the systematic errors. They found that using positive errors in RH resulted in ET₀ underestimations, but positive errors in the three mentioned variables resulted in ET₀ overestimations. Liu et al. (2010) analyzed the sensitivity of ET₀ calculated by Penman-Monteith method to meteorological variables in Yellow River basin, China. They used air temperature, solar radiation, relative humidity and wind speed as key climatic parameters for this purpose. They reported that ET₀ is sensitive to different variables in different locations of the Yellow River Basin. They also found that in general R_s (Solar Radiation) was the most sensitive variable for ET₀ followed by RH, T_{mean} and wind speed in the basin scale. Zhang et al. (2010) studied the sensitivity of ET₀ obtained from the FAO-56 PM method to change in climatic variables in Shiyang river basin of northwest China. They found that actual vapor pressure, e_a, is the most sensitive variable in

cool months and in mountainous area, but minimum air temperature, T_{min}, is the least sensitive parameter during the year. Dinpashoh (2006) has estimated ET₀ for Iran and applied appropriate method for three distinct areas of Iran according to the ratio of precipitation to ET₀. Although ET₀ values were computed by him based on corrected T_{mean} for non-ideal condition, but, he did not analyze the sensitivity of ET₀ for weather parameters. Bakhtiari and Liaghat (2011) investigated seasonal sensitivity for climatic variables of ASCE Penman-Monteith model in Kerman. Eslamian et al. (2011) studied effects of variation in climatic parameters on evapotranspiration in five area of Iran (including Tehran, Mashhad, Isfahan, Tabriz and Shiraz). Their results showed temperature and relative humidity is the most sensitive parameters in Penman-Monteith method respectively. They did not investigate the effect of R_n (net radiation at crop surface) on ET₀. There is no detailed study on sensitivity of ET₀ to key climatic parameters in different scenarios at the selected station of Iran. However, very little information is available on the sensitivity of ET₀ in some part of Iran (Eslamian et al. 2011). Also, global warming cause major changes in various meteorological variables. On the other hand, meteorological variables have interaction effect on each other. Therefore, sensitivity analysis of ET₀ is essential to better manage the available water resources. These resources in Iran have reduced due to drought in recent years. Therefore, the three main objectives of this study are: (i) to estimate ET₀ at the selected station using FAO-56 PM method, (ii) to analyze the sensitivity of ET₀ to some key meteorological variables in different scenarios at all stations and (iii) to compare findings of the present study with those of others.

2. Material and Methods

The study area encompasses the whole Iran country. The area of Iran is about 1,650,000 Km² located approximately between 25°00' N and 38°39' N in latitudes and between 44°00' E and 63°25' E in longitudes. Due to vast area of Iran, different types of climates can be found. Generally, Iran is categorized as having arid and semi-arid climates based on Köppen climatic classification (Allen et al. 1998). The mean annual precipitation of Iran is about 224 mm. For this study, eight stations namely Abadan, Anzali, Chabahar, Isfahan, Sabzevar, Sanandaj, Tabriz and Zahedan were selected from different types of climates. Figure 1 shows the location of the selected stations in Iran and the details of the selected stations were presented in Table 1. The stations have their own meteorological station.

Monthly meteorological data of the selected stations were collected from Islamic Republic of Iran

Meteorological Organization (IRIMO) in the period of 1965 to 2005. Quality of data was checked prior to the analyzed and missing data was reconstructed. In this study, mean, maximum and minimum air temperature, relative humidity, wind speed at 10 m height above the ground surface and number of sunshine hours in monthly time scale were used. These data were converted to the standard form of the input parameters of FAO-56 PM ET₀ model. 2.2 Calculation of the Reference Crop Evapotranspiration (ET₀) The FAO-56 PM model for estimating ET₀ (Allen et al. 1998) where ET₀ is reference crop evapotranspiration (mm.day⁻¹), Δ is the slope of vapor pressure versus temperature curve at temperature T_{mean} (KPa.°C⁻¹), γ is the psychrometric constant (KPa.°C⁻¹), u₂ is the wind speed at a 2 m height (m.s⁻¹), R_n is the net radiation at crop surface (MJ.m⁻².d⁻¹), G is the soil heat flux density (MJ.m⁻².d⁻¹), T is the mean daily air temperature at 2 m height (°C), and (e_s-e_a) is the saturation vapor pressure deficit (KPa).



Fig. 1 Study area and location of stations

3. Results

Lat., long., alt., m amsl and N denote latitude, longitude, altitude, meter above mean sea level and north, respectively

Table 1. Details of the selected stations of Iran

No.	Name of site	Köppen's climatic class	Lat. (N)	Long. (E)	Alt., m amsl
1	Abadan	Bw	30° 22'	48° 15'	7
2	Anzali	C	37° 28'	49° 28'	-26
3	Chabahar	Bw	25° 17'	60° 37'	8
4	Esfahan	Bs	32° 37'	51° 40'	1550
5	Sabzevar	Bs	36° 12'	57° 43'	978
6	Sanandaj	D	35° 20'	47° 00'	1373
7	Tabriz	C	38° 05'	46° 17'	1361
8	Zahedan	Bs	29° 28'	60° 53'	1663

The sensitivity of ET₀ in each month to the four key climatic variables including T_{mean}, actual vapor pressure (e_a), u₂ and R_n were investigated in all selected stations. For this purpose, the parameters were changed within a range of -20 to +20 % at an interval of ± 5 % (eight scenarios) and then the percent change of ET₀ was calculated (Goyal 2014). Finally, the percent changes of the mentioned climatic parameters against percent changes of the output ET₀ were plotted as a sensitivity curve. Sensitivity curves were plotted for all stations in annual and monthly time scales. 3 Results and Discussion Figure 2 shows temporal pattern of T_{max}, T_{mean}, T_{min}, u₂, sunshine hours in a month (n), percent of mean relative humidity (RH) and ET₀ (mm/month) at five stations namely Abadan, Bandar Anzali, Chabahar, Esfahan and Sabzevar, in monthly time scale. The same plots for three other stations are shown in Fig. 3. According to Figs. 2 and 3, the air temperature pattern is almost the same for all the sites. It usually reaches to the maximum (minimum) value in July (January). The difference between T_{max} and T_{min} remain approximately constant for most of the stations (except Bandar Anzali and Chabahar). Bandar Anzali station experiences the largest value of T_{max}-T_{min} in July, which is the hottest month of Iran. This parameter declines to a minimum values at January, which is the coldest month of Iran. This station is known as a humid station located in the shore of Caspian Sea having the largest amount of annual precipitation across the country (Dinpashoh et al. 2004). The temporal pattern of u₂ is not the same for all the selected stations (Figs. 2 and 3). The maximum value of wind speed in all stations is about 3.6 (m/s) in Abadan in June and in contrast, the minimum value of u₂ belonged to Esfahan (~0.78 m/s) in December. The largest difference between the highest and lowest value of u₂ in a year belonged to the Tabriz (~2.1 m/s) following Abadan (~1.9 m/s) and Sabzevar (~1.8 m/s). Figures 2 and 3 show the pattern of n, RH and ET₀ (mm/month).

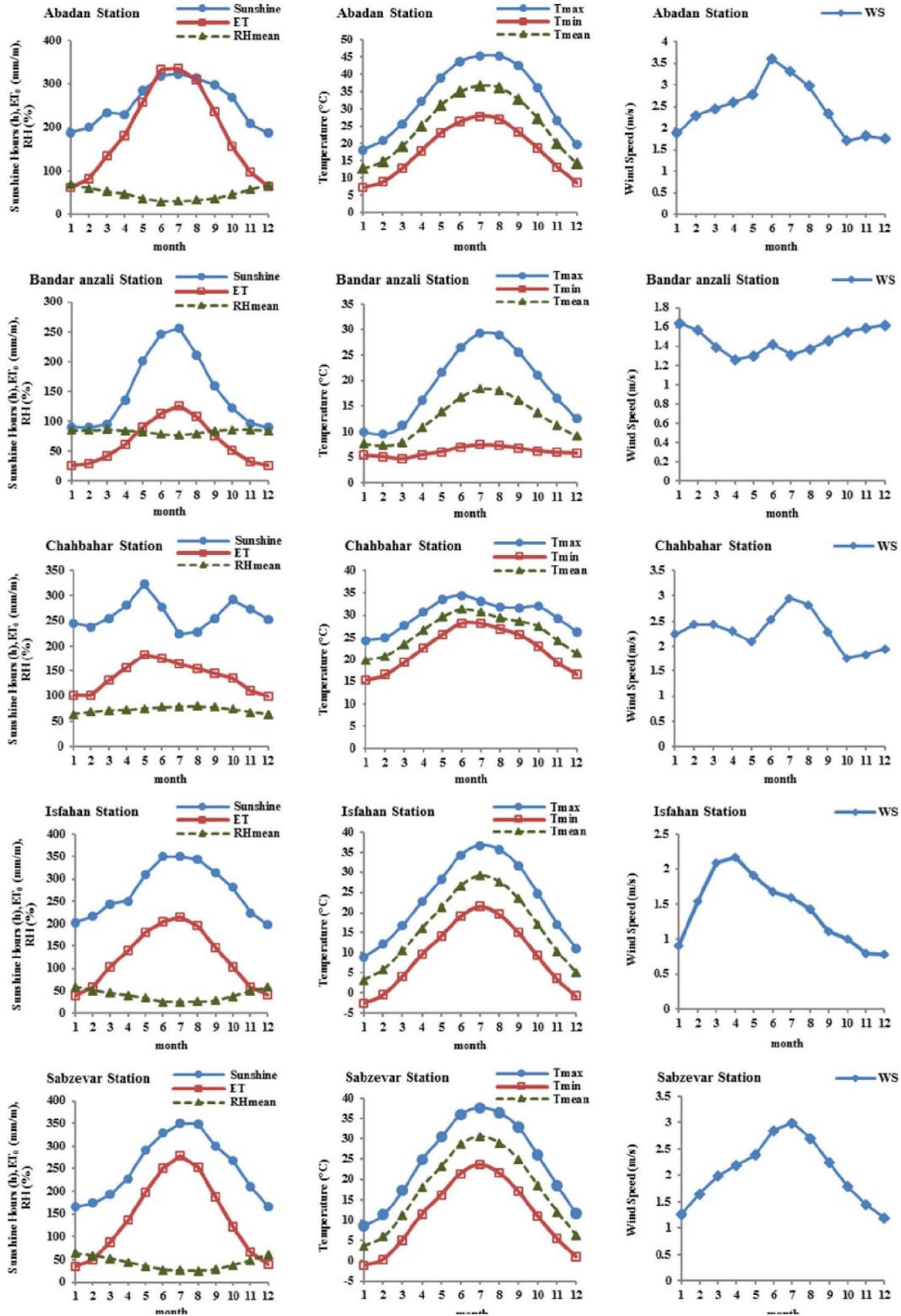


Fig. 2 Temporal pattern of meteorological parameters in the case of five stations. Note: the left column indicate ET0, Sunshine hours and RHmean. Middle column indicate Tmax, Tmean and Tmin. Right column shows WS (u2) Panels 1–5 are for Abadan Bandar Anzali, Chahbahar, Isfahan and Sabzevar stations, respectively

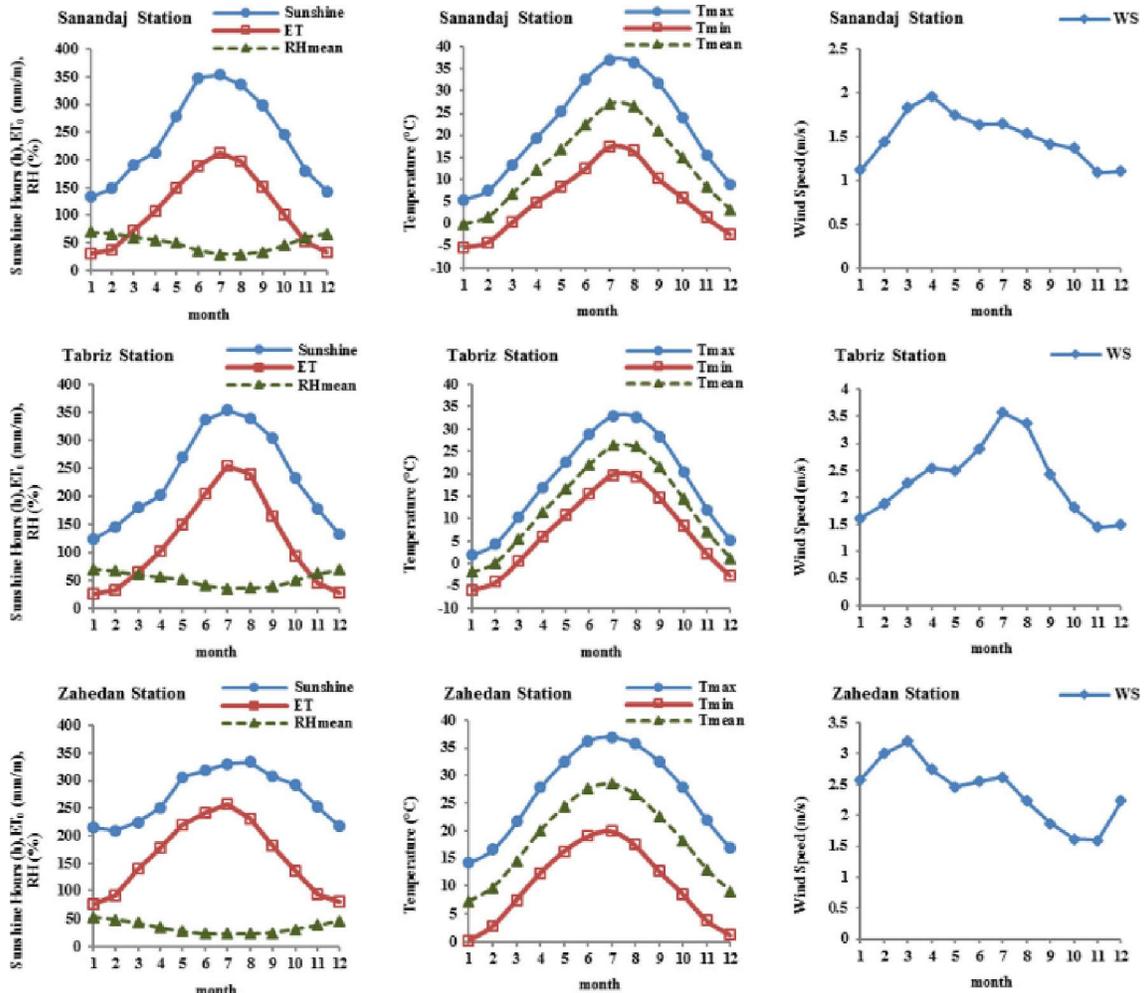


Fig. 3 Temporal pattern of meteorological parameters. Note: explanation is same as in Fig. 2. The first, 2nd and 3rd panel are for Sanandaj, Tabriz, and Zahedan, respectively

The pattern of n is nearly similar to the air temperature. All stations (except Chabahar) experienced the maximum (minimum) amount of n at summer (winter). On the other hand, most of the stations experienced the lowest (highest) value of mean RH in summer (winter). The pattern of ET_0 is nearly similar to the air temperature and sunshine hours. The lowest value of ET_0 mainly occurs in the coldest month of winter (i.e. January), while the highest value occurs in the hottest month of summer (i.e. July). Generally, ET_0 values gradually increases from January and reaches to the maximum amount in July. It declines and reaches to the lowest value in December. The pattern of ET_0 is same for all stations except Chabahar. This coastal station which is located at the south east of Iran, is mainly affected by monsoon system comes from the Bay of Bengal and Pakistan to Iran from June to October. Such variation in the meteorological parameters of Chabahar in

monsoon season causes ET_0 to be starting to decrease about 2 months early. 3.1 Results of the Sensitivity Analysis Figure 4 shows the curves of the sensitivity analysis of ET_0 obtained by FAO-56 PM model for each of the weather parameters in the selected stations in annual time scale. Sensitivity curves of ET_0 to climatic variables are generally linear. Also, the slope of lines for sensitivity of ET_0 to e_a is negative for all stations. According to Fig. 4, at six stations including Abadan.

Chabahar, Sabzevar, Sanandaj, Tabriz and Zahedan the most sensitive variable on ET_0 is T_{mean} . At Bandar Anzali and Isfahan, e_a and R_n are the most sensitive variable, respectively. On the other hand, e_a is the less sensitive variable on ET_0 at Abadan, Isfahan, Sabzevar, Sanandaj, Tabriz and Zahedan. At Bandar Anzali and Chabahar, WS is the less sensitive variable. In response to the increase T_{mean} by +20 %, the larger and less value of percent change

in ET₀ are about 16.7 % and 10.3 % at Chabahar and Isfahan, respectively. Change in actual vapor pressure had a large effect on ET₀ at Bandar Anzali as a representative of humid climatic station of Iran. But, ET₀ was found to be less sensitive to change in ea in Isfahan as a representative of arid climate station. WS had a less effect on ET₀ in all stations as, 20 % increase in WS cause to ET₀ increase just about 8.8 % in Abadan. Unlike WS, Rn approxi- mately had a

more effect on ET₀ at all stations. Table 2 shows the value of percent change in ET₀ in monthly time scale for all climatic stations. In this Table, the four months namely January, April, July and October are selected to represent winter, spring, summer and autumn, respectively. As can be seen in Table 2, each parameter in annual time scale had the greatest impact on ET₀, has the greatest impact in monthly time scale.

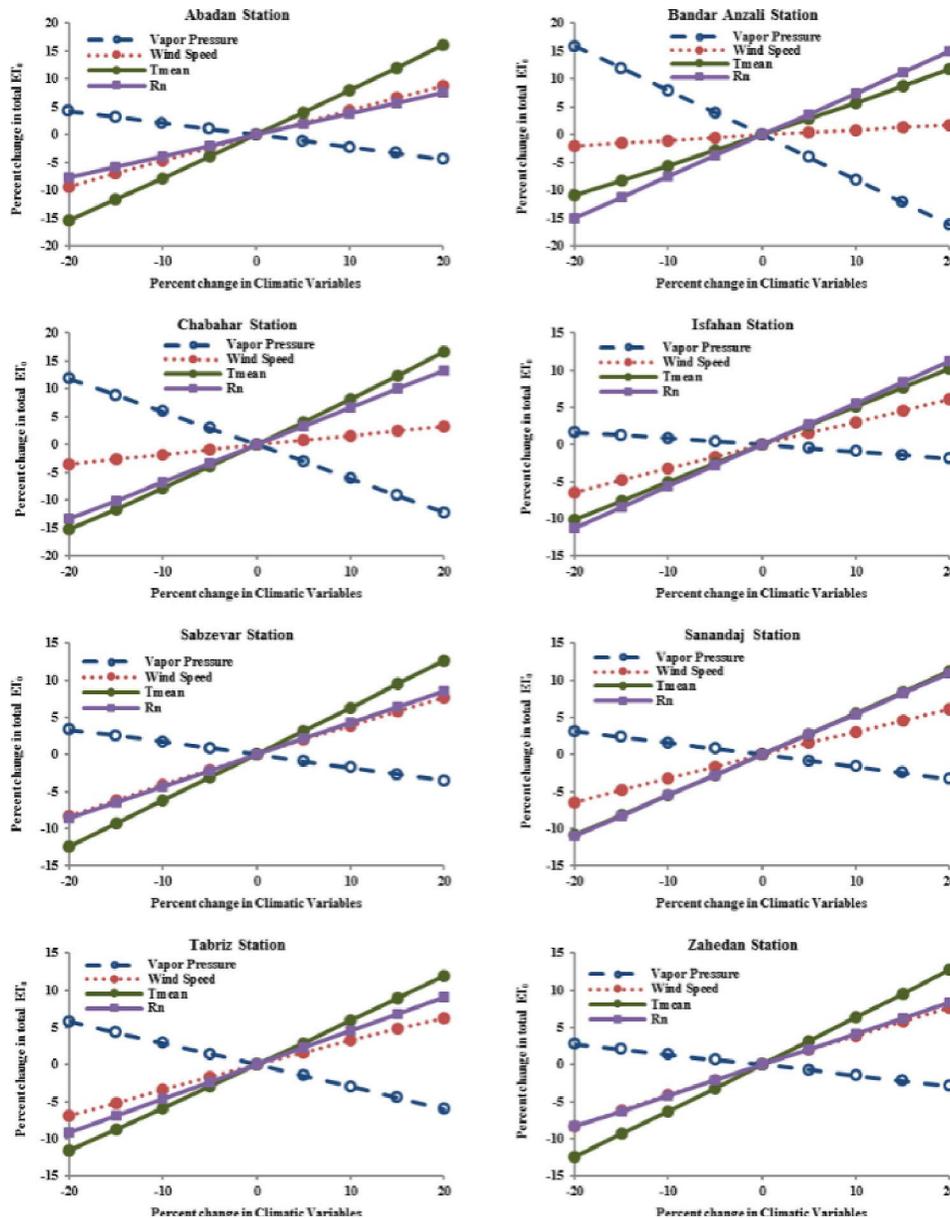


Fig 4 Percent changes in ET₀ with respect to changes in climatic variables in annual time scale

According to Table 2, Tmean has larger effect on ET₀ during autumn months in all selected stations. On the other hand, ET₀ in the summer months is more sensitive to Tmean compared to winter months at all

of the eight selected stations. In winter, the air temperature is too low for growing crops and pasture. Therefore, winter's ET₀ is not important from the view of crop production in Iran. Sensitivity of ET₀ to

change in e_a is more pronounced in summer comparing winter (except Chabahar). Although actual vapor pressure (e_a) in FAO-PM model is an exponential function of air temperature, a large increase in ET_0 is expected for an increase in T_{mean} at all station (except Chabahar) during summer months. Sensitivity of ET_0 in winter months to WS is less than that in summer months at all stations except Bandar Anzali and Chabahar. At two stations, sensitivity of ET_0 to WS in winter months is more than summer months. During spring months, sensitivity of ET_0 to change in R_n is pronounced at most of stations. In this study, we investigated the interaction parameters in different scenarios on ET_0 at all stations in monthly and annual time scale. Because in fact all meteorological parameter are independent, have effect to each other and change at the same time. Table 3 and 4 presents the percentage change in ET_0 for a scenario of 10 % and 20 % increase in T_{mean} and WS and 10 % and 20 % decrease in e_a respectively. According to Table 3, in annual time scale increasing T_{mean} and WS by 10 % and decreasing e_a by 10 % yielded ET_0 increasing 16.9 % at Chabahar. But, if the change is 20 % causes ET_0 increasing about 36.4 %. Also, in monthly time scale 10 % increase in T_{mean} and WS as well as 10 % decrease in R_n yielded ET_0 to be increase to about 30.5 % in December at Bandar Anzali. The results of this study showed change in ET_0 with respect to change in climatic variables varied by month and station. Irmak et al. (2006) found increase in ET_0 with respect to increase in climatic variable changed by month. Also Eslamian et al. (2011) reported the effective climatic variables on evapotranspiration are changing, though in each region the variables have significant long-term trends and persistence. According to Irmak et al. (2006) in summer months ET_0 was most sensitive to T_{max} at Bushland, Scottsbluff and Twitchell, located in USA whereas it was equally sensitive to both T_{max} and solar radiation, R_s , at Clay Center of USA. Zhang et al. (2010) found that T_{mean} is the least sensitive variable to ET_0 variation in Shiyang river basin of northwest China. The change of T_{mean} has slightly less effect on ET_0 computed by FAO-56 PM in winter season in Rajasthan, India as compared to summer season (Goyal 2004). This is consistent with our findings to all selected stations. Dinpashoh et al. (2011) reported an increasing wind speed trends at eastern Iran. Therefore, it can be concluded that increasing trends of ET_0 at the east part of Iran is mainly due to the increasing trends of u_2 . Zhang et al. (2010) found that wind speed plays an important role in ET_0 changes at northern parts of the Shiyang river basin of China. Goyal (2004) in Rajasthan, India reported increasing trend for ET_0 with increase in R_n .

4. Discussions

Although there is a few studies about evapotranspiration conducted in different region of Iran, however, none of them were analyzed the sensitivity of ET_0 to weather parameters in different scenarios. In this study, 40 years climatic data was used and the sensitivity of ET_0 to four key weather parameters namely T_{mean} , e_a , u_2 and R_n was analyzed at eight selected stations of Iran. The results showed that most portion of annual ET_0 belongs to the summer months (June, July and August). On the other hand, in most part of Iran, the most of agricultural activities are done in summer months. Therefore, sensitivity analysis of ET_0 would be more important in summer months comparing the winter months. Using the fixed values for the mentioned weather parameters and changing a certain climatic parameter by $\pm 5\%$, $\pm 10\%$, $\pm 15\%$ and $\pm 20\%$, the percent change in ET_0 computed for all months and years for selected stations. Results showed that ET_0 is more sensitive to T_{mean} for most of the stations of Iran. ET_0 is more sensitive to T_{mean} in summer months comparing winter months at all stations. It was found that nearly all parts of Iran exhibited increasing trends for T_{mean} (Dinpashoh et al. 2011). It is very important for decision makers to search ways for optimum water use techniques to face this problem. In contrast, ET_0 is less sensitive to WS especially in summer months comparing winter months at six stations. Most parts of Iran will be face to lack of sufficient water for water related activities especially agriculture comparing past years. That is due to drought, high demand and global warming. These factors will cause changes in climatic parameters. On the other hand, changes in climatic parameters cause to change in ET_0 . Increasing the value of ET_0 causes to increase demand for agricultural water. However, other factors such as available water, crop type, irrigation type and etc. also have effect on the agricultural water management. Furthermore, the population of Iran and standards of people sanitation will increase in future. Therefore, management and efficient use of water should be a priority in Iran.

Corresponding Author:

Babak Mohammadi
 Department of Water Engineering
 University of Tabriz, Tabriz, Iran
 Telephone: +989364108282
 E-mail: babakmsh@yahoo.com

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