Performance of Some Evapotranspiration Equations in an Arid Region

Mohammad Mehdi HEYDARI[1,*], Ali ABBASI[1] and Morteza HEYDARI[2]

[1]*Young Researchers and Elite Club, Kashan Branch, Islamic Azad University, Kashan, Iran*
[2]*Department of Computer Engineering, Ashtian Branch, Islamic Azad University, Ashtian, Iran*

([*]Corresponding author's e-mail: mehdiheydari2010@yahoo.com)

Received: 30 August 2013, Revised: 23 October 2013, Accepted: 22 November 2013

Abstract

Estimation of evapotranspiration is necessary for planning, design and irrigation design and water resources management. In order to determine the best method to estimate evapotranspiration using data of Qom synoptic meteorological stations during the years 1987 to 2007 was statistically significant. The FAO Penman Monteith (FAO-56 PM) method has been accepted by many researchers and international institutes as the reference and standard method. Accurate difference methods include Blaney-Criddle, Hargreaves-Samani, Jensen-Haise, Linacre, Rn-based method, Thornthwaite and Turc were applied and then their results were compared with the FAO-56 PM method. In this study, using statistical indicators, the best method to estimate ET_0 in Qom province was selected and found to be Blaney-Criddle (RSME = 0.690 mmd^{-1}, MAE = 0.545 mmd^{-1}, D = 0.998). The results indicate that ET_0 increases from north to south, west to east in the province. The regression relationship between the mean temperature and FAO-56 PM method and evaporation from the pan were determined. Also comparison of the pan evaporation and monthly values of FAO-56 PM method, coefficient pan (Kp = 0.583) is calculated.

Keywords: Qom province, evapotranspiration, statistical indicators, FAO Penman Monteith, Blaney-Criddle, pan evaporation

Introduction

ET_0 is one of the key processes in the hydrological cycle and it is the loss of water to the atmosphere by the combined processes of evaporation from the soil and plant surfaces and transpiration from plants [1]. Evaporation from water bodies are about 112 % of precipitation. Information about ET_0, or consumptive water use, is significant for water resources planning and for irrigation scheduling in crops [2-5]. Estimation of ET_0 is one of the major hydrological components for determining the water budget and therefore reliable and consistent estimates of ET_0 are of great importance for the efficient management of water resources. Efficient water management requires an accurate ET_0 which can be derived from the meteorological variables. ET_0 is always the important research subjects on hydrology, soil, agriculture, meteorology; ET_0 also has important applications in water resources in arid areas, regional planning and management of agricultural production [6,7]. In the semi-arid and arid zones which cover most of the Iranian platue, evaporation can be up to 96 % of annual precipitation. On average about 50 % of all precipitation is lost in evaporation in the catchments. Therefore, investigation on ET_0 processes could be very important in this country [8-10].

Empirical methods are used when all the data needed for Penman-type equations are not available. Direct measurement of ET_0 is usually not feasible in many field situations because it is expensive and time-consuming. The ET_0 computation methods can be classified into 3 types: temperature methods, radiation methods and combination methods. The Food and Agriculture Organization (FAO) recommends the use of the FAO-56 PM method for estimating ET_0 [1,11]. This method is the most widely used in the world and has been proven to accurately estimate ET_0 in different climates [1,12-16]. However, it requires several measurements of climatic variables such as air temperature, relative humidity, solar radiation and wind speed. At the planning and design stages of irrigation and water conservation schemes, historical average daily values of ET_0 for multi-day periods (e.g. weekly, ten-day and monthly) may be satisfactory for estimation of crop water use [17].

Qom province geographically is located in an arid and semi-arid region of Iran. The mountainous region is in the southern and western parts of Qom. The highest and lowest altitudes are 3209 and 792 m above sea level, respectively. This province has historically suffered from water scarcity problems. Qom province is one of the driest provinces in Iran and annual precipitation of Qom province is 135 mm. Water in this area is of great important and over 90 % of water is used in agriculture and industry. ET_0 measured using lysimeter data are scarce in central states of Iran and Qom station has complete data for use in the FAO-56 PM equation is available in this province. In this region there is no permanent river but there are some dry streams which lead to floods in the neighboring mountains to the salt lake [18]. An increase in water demand associated with rapid urban development and expansion of agricultural lands has led to overexploitation of water in this city. If water withdrawal continues, a water shortage crisis will happen in this area [19].

The objectives of this study were to (1) to evaluate, under arid conditions, the performance of empirical methods for estimating ET_0 by comparing their values to those estimated using the FAO-56 PM equation using statistical parameters, (2) to develop a relationship between Class A pan evaporation and FAO-56 PM method with mean air temperature and (3) to determine the pan coefficient by regression analysis of Class A pan evaporation and FAO-56 PM method values, based on meteorological data of Qom synoptic in Qom province, in the north and center of Iran.

Materials and method

Qom Province is one of the 31 provinces in Iran with 11,243 km², covering 0.89 % of the total area in Iran. It is located between 34° 15' and 35° 15' north latitude and 50° 30' and 51° 30' east longitude. Qom Province is bounded by Tehran Province in the north, Isfahan Province in the south, Semnan Province in the east, and Markazi Province in the west and its provincial capital is the city of Qom. In 2005, this province had a population of approximately 2,000,000. The province contains 4 synoptic stations. The location of the area of study and synoptic stations is shown in **Figure 1** and the geographic characteristics, year of establishment, climate and annual average values of temperature, rainfall of each station are presented in **Table 1**.

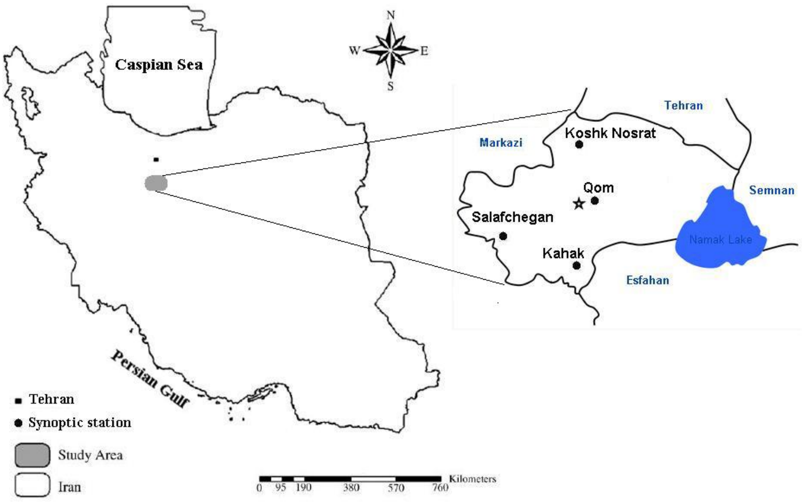
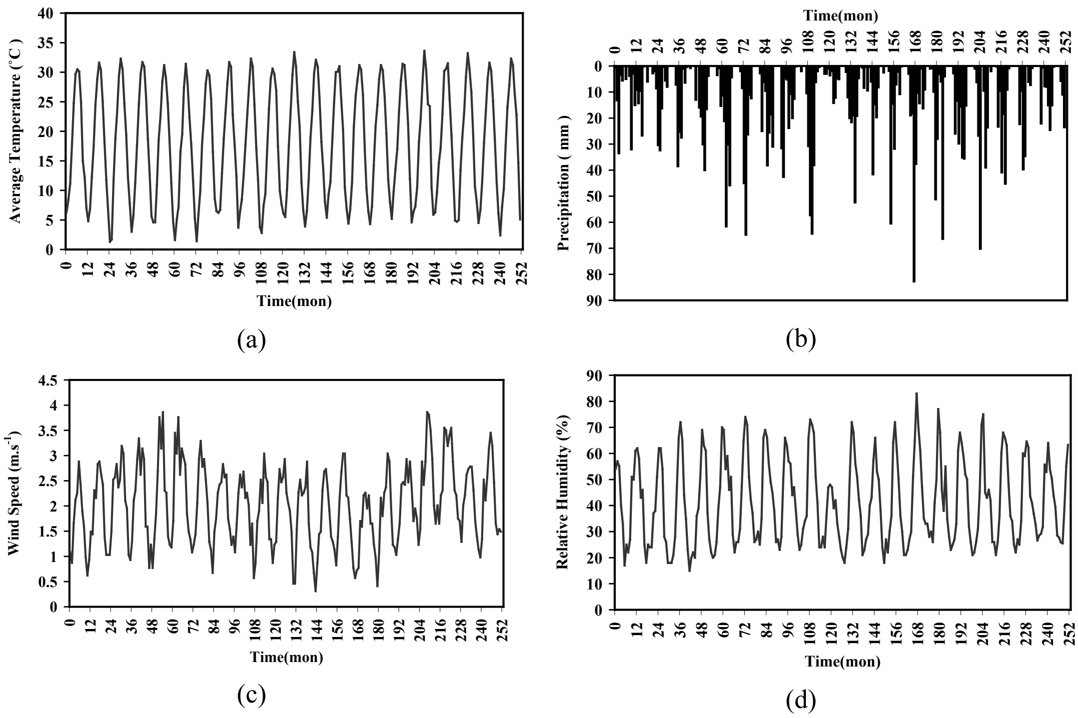


Figure 1 The area study on Iran map and the synoptic stations in the Qom province.

Table 1 Geographic Characteristics of synoptic stations of the Qom province.

Synoptic stations	Latitude (N)	Longitude (E)	Altitude (m)	Ave. temp (°C)	Ave. rain (mm)	Year of Establishment	Climate
Kahak	34˚-24'	50˚-52'	1403.20	16.30	173.60	2004	Arid
Koshk Nosrat	35˚-05'	50˚-54'	948.00	19.80	116.60	2006	Arid
Qom	34˚-42'	50˚-51'	877.40	18.00	151.10	1952	Arid
Salafchegan	34˚-29'	50˚-28'	1380.50	16.80	187.40	2003	Arid

The climate of Qom province varies between a desert and semi-desert climate, and comprises mountainous areas, foothills and plains. Due to being located near an arid region and far inland, it experiences a dry climate, with low humidity and limited rainfall. Qom station (international code: 40770) is located in the center of the province and selected for the study of the province [9]. The meteorological data of 21 years at the Qom station covering the period from January 1987 to December 2007 were analyzed for the purpose of calculating ET_0 by different methods. **Figure 2** shows the monthly precipitation, temperature, wind speed, relative humidity, dew point, sunshine hours, solar radiation and net radiation data used for ET_0 estimations.



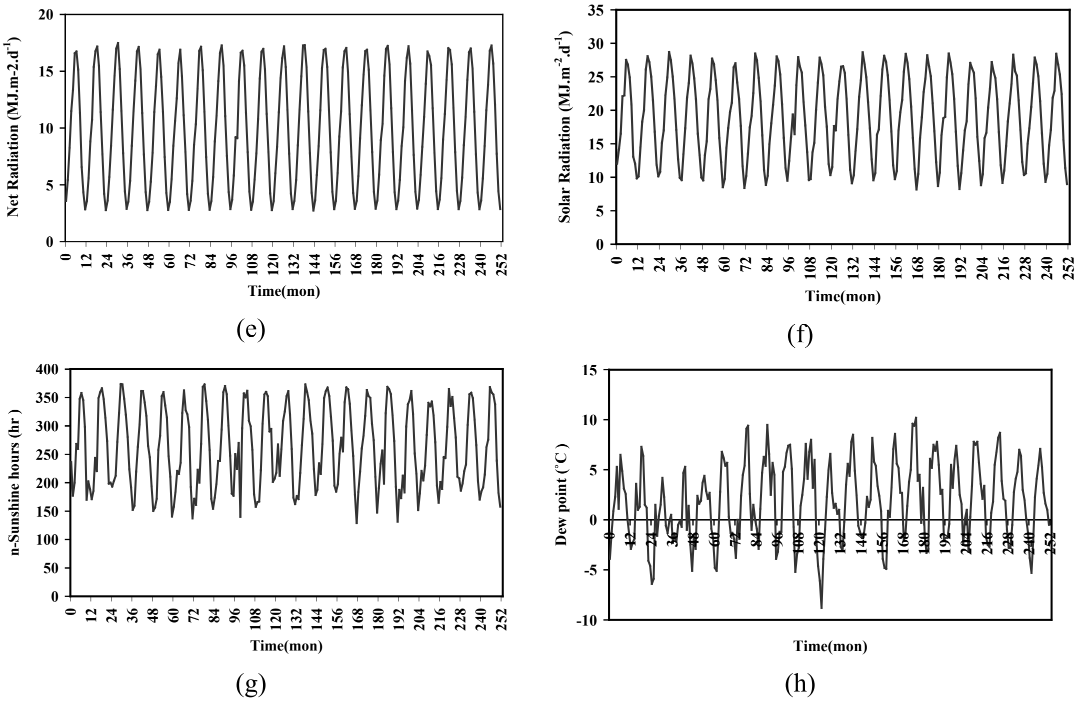


Figure 2 Monthly variations of input parameters used in the calculation of ET_0 by different methods at Qom synoptic (1987 - 2007) (a) average temperature (ºC); (b) precipitation (mm); (c) wind speed ($m.s^{-1}$); (d) relative humidity (%); (e) net radiation (MJ m^{-2} d^{-1}); (f) solar radiation (MJ m^{-2} d^{-1}); (g) sunshine hours (hr) and, (h) dew point (°C), respectively.

Monthly ET_0 was estimated using methods developed by Blaney-Criddle [20], Hargreaves-Samani [21], Jensen-Haise [22], Linacre [23,24], Rn-based method [25], Thorthwaite [26] and Turc [27], respectively (**Table 2**).

Table 2 Methods for calculation of evapotranspiration (ET_0), in mm.d^{-1}.

Method	Equation
Blaney-Criddle (1988)	$ET_0 = a + b \times [P(0.46T_{mean} + 8.13)]$
Hargreaves-Samani (1985)	$ET_0 = 0.0023 \times R_a (T_{mean} + 17.80) \times \sqrt{(T_{max} - T_{min})}$
Jensen-Haise (1963)	$PET = \frac{1}{38 - \left(2 \times Elevat/305\right) + 7.6 \times 50/\left(e_{S(T_{max})} - e_{S(T_{min})}\right)} \times \left[T_{mean} - \left(-2.5 - 0.14\left(e_{S(T_{max})} - e_{S(T_{min})}\right) - \frac{Elevat}{550}\right)\right] \times R_a$
Linacre (1983)	$ET = \frac{\frac{700 \times (T_{mean} + 0.006 \times Z)}{100 - L} + 15 \times (T_{mean} - T_d)}{80 - T_{mean}}$
Rn-based radiation (Irmak 2003)	$ET_0 = 0.489 + 0.289 \times R_n + 0.023T_{mean}$
Thornthwaite (1948)	$PET = 16N_m \left(\frac{10T_{mean}}{I}\right)^a$
Turc (1961)	$PET = 0.013\left(\frac{T_{mean}}{15 + T_{mean}}\right)(R_s + 50) \quad RH > 50\ \%$ $PET = 0.013\left(\frac{T_{mean}}{15 + T_{mean}}\right)(R_s + 50)\,(1 + \frac{50 - RH}{70}) \quad RH < 50\ \%$

In this study, the amount of reference evapotranspiration was calculated, using the FAO-56 PM method, in 15 selected synoptics. The FAO-56 PM ET_0 equation is given by Allen *et al*. [1] for predicting ET_0 where applied on 24 h calculation time steps and has the form;

$$ET_0 = \frac{0.408\Delta\ (R_n - G) + \gamma\left[\frac{900}{(T_a + 273)}\right]U_2\ \left(e_s - e_d\right)}{\Delta + \gamma\left(1.0 + 0.34U_2\right)} \tag{1}$$

where FAO-56 PM ET_0 = the grass reference evapotranspiration (mm/day); R_n = the net radiation at the crop surface (MJ/m^2.day); G = the soil heat flux density (MJ/m^2.day); T = the mean daily air temperature at 2 m height (°C); U_2 = the wind speed at 2 m height (m/sec); e_s = the saturation vapor pressure (kPa); e_a = the actual vapor pressure (kPa); e_s - e_a = the saturation vapor pressure deficit (kPa); Δ = the slope vapor pressure curve (kPa/°C); and γ = the psychometric constant (kPa/°C).

ET_0 was estimated using various empirical equations and compared with the FAO-56 PM equation. The models were compared using standard statistics and linear regression analysis [28]. Pearson's correlation (R^2), root mean squared error (RMSE), mean absolute error (MAE), maximum absolute error

(MAXE), volume error (VE), CORR, efficiency (EF) and agreement index (D) were computed using the equations described below;

$$R^2 = \left[\frac{\sum_{i=1}^{N} (ET_{EQ} - \overline{E}T_{EQ})(ET_{FAO} - \overline{E}T_{FAO})}{\sqrt{\sum_{i=1}^{N} (ET_{EQ} - \overline{E}T_{EQ})^2 \sum_{i=1}^{N} (ET_{FAO} - \overline{E}T_{FAO})^2}} \right]^2 \quad (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (ET_{EQ} - ET_{FAO})^2}{N}} \quad (3)$$

$$MAE = \frac{1}{N} \sum_{i=1}^{N} | ET_{EQ} - ET_{FAO} | \quad (4)$$

$$MAXE = MAX(| ET_{EQ} - ET_{FAO} |)_{i=1}^{n} \quad (5)$$

$$VE(\%) = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{ET_{EQ} - ET_{FAO}}{ET_{EQ}} \right| \quad (6)$$

$$CORR(\%) = \frac{COV(ET_{EQ}, ET_{FAO})}{\sigma_{ET_{EQ}} \times \sigma_{ET_{FAO}}} \quad (7)$$

$$EF = \frac{\sum_{i=1}^{n} (ET_{EQ} - \overline{ET_{EQ}})^2 - \sum_{i=1}^{n} (ET_{EQ} - ET_{FAO})^2}{\sum_{i=1}^{n} (ET_{EQ_i} - \overline{ET_{EQ}})^2} \quad (8)$$

$$D = 1 - \frac{\sum_{i=1}^{n} (ET_{EQ} - ET_{FAO})^2}{\sum_{i=1}^{n} (| ET_{FAO} - \overline{ET_{EQ}} | + | ET_{EQ} - \overline{ET_{EQ}} |)^2} \quad (9)$$

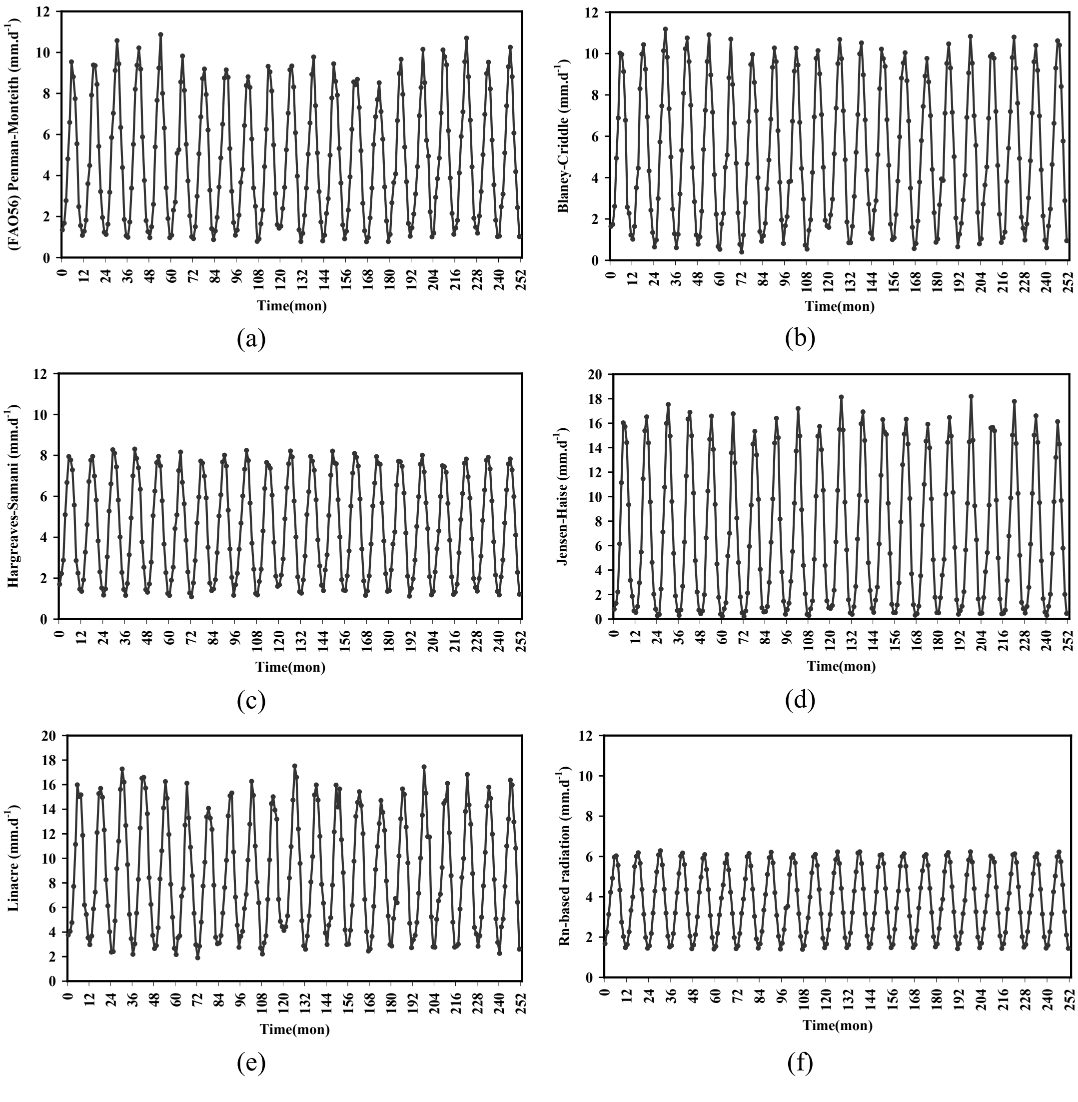
In order to have a quantitative evaluation, the calibration parameters were defined using the following equation [29];

$$ET_{EQ} = \mathbf{A} + \mathbf{B}.ET_{FAO} \quad (10)$$

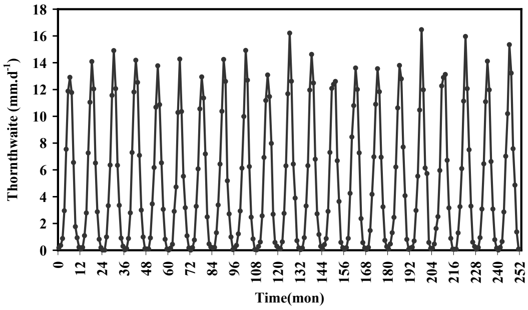
where ET_{EQ} represents the ET_0 values estimated using empirical methods. The calibration parameters A and B are determined by regression analysis using ET_{FAO} with the FAO-56 PM method as the reference. The best prediction model is the one with the smallest RMSE, MAE and VE, the highest coefficient of determination (R^2), B value closest to zero, and A value closest to unity.

Results and discussion

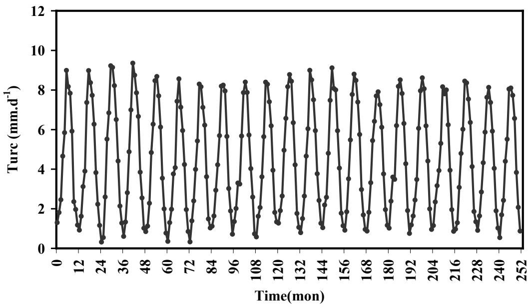
The 21 year-monthly weather data were used to validate the performances of the commonly used ET_0 estimation methods. Comparison of monthly ET_0 values specifically for the FAO-56 PM, Blaney-Criddle, Hargreaves-samani, Jensen-Haise, Linacre, Rn-based radiation, Thornthwaite and Turc equations are presented in **Figure 3**.



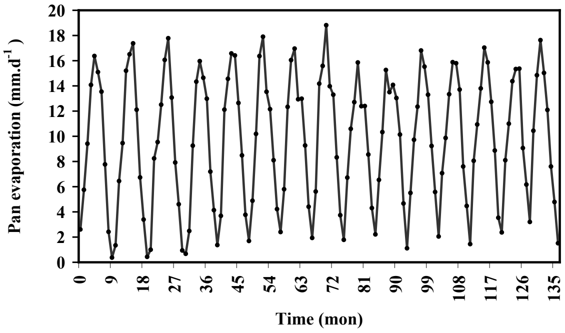
(a) (b) (c) (d) (e) (f)



(g)



(h)



(i)

Figure 3 Estimated ET_0 derived from different methods at Qom synoptic (1987 - 2007), in mm.d^{-1} (a) FAO-56 PM; (b) Blaney-Criddle; (c) Hargreaves-Samani; (d) Jensen-Haise; (e) Linacre; (f) Rn-based radiation; (g) Thornthwaite; (h) Turc and, (i) Class A Pan measurements for years of 1993 - 2007, respectively.

It can be seen that Blaney-Criddle followed the same trend as that of the FAO-56 PM method. Seasonal variations in the ET_0 estimation reflect the differences in the variables applied in each method. **Figure 4** shows a comparison of the annual ET_0 estimations.

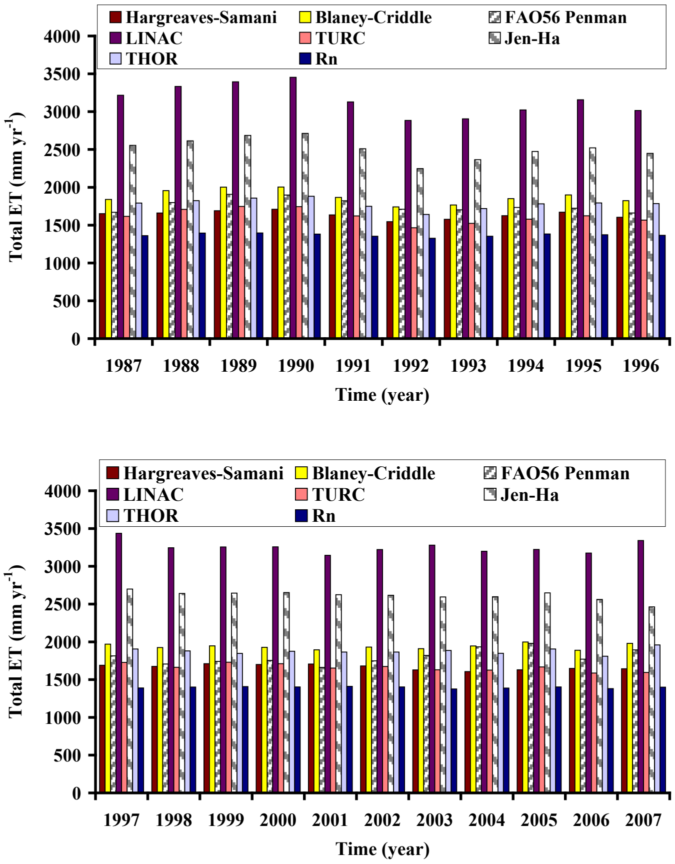


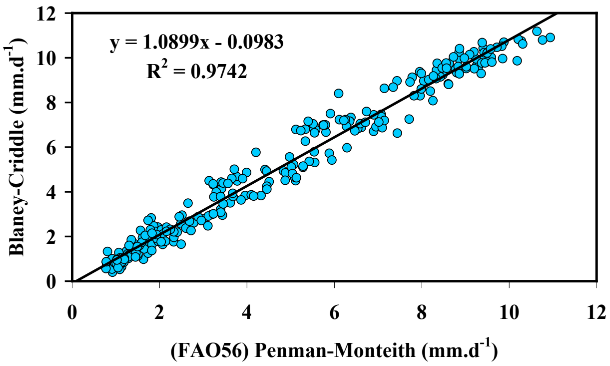
Figure 4 Total annual ET_0 estimates given by the different methods at Qom synoptic (1987 - 2007), in mm.year^{-1}.

The annual sum of ET_0 estimations by Blaney-Criddle from 1840 mm yr^{-1} in 1987 to 1980 mm yr^{-1} in 2007, while 1670 mm yr^{-1} in 1996 to 1894 mm yr^{-1} in 2007 for the FAO-56 PM method, respectively. The Rn and Linacre methods have the lowest and highest values, respectively. The maximum annual sum of ET_0 estimations by Blaney-Criddle method and FAO-56 PM method is in 2005. The details of statistical comparison are shown in **Table 3**. **Table 3** shows the performance of the models by comparison between the models' predicted ET_0 and the FAO-56 PM model. According to all the statistics, the best results are obtained by Blaney-Criddle and Turc, while weakest statistics are obtained by the Linacre and Jensen-Haise methods.

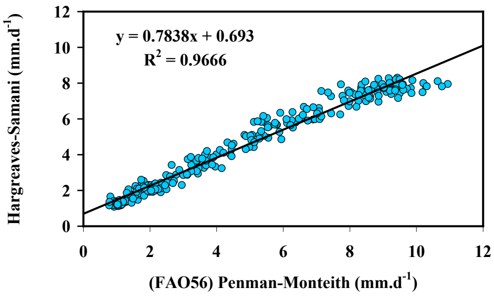
Table 3 Statistical values of the comparison between ET_0 calculated by different empirical methods with the FAO-56 PM method.

Method	R^2	RMSE mm.d^{-1}	MAE mm.d^{-1}	MAXE mm.d^{-1}	VE %	CORR %	EF	D
Blaney-Criddle	0.974	0.690	0.545	2.303	14.20	98.31	0.948	0.988
Hargreaves Samani	0.967	0.865	0.621	2.989	14.24	97.93	0.919	0.976
Jensen-Haise	0.965	3.575	2.647	8.750	47.57	97.84	-0.389	0.842
Linacre	0.926	4.317	3.894	8.243	102.70	95.85	-1.030	0.749
Rn-based radiation	0.971	1.798	1.347	4.852	26.36	98.12	0.649	0.865
Thorthwaite	0.933	2.235	1.836	6.832	49.10	95.12	0.457	0.919
Turc	0.965	0.721	0.564	2.403	14.20	97.83	0.944	0.985

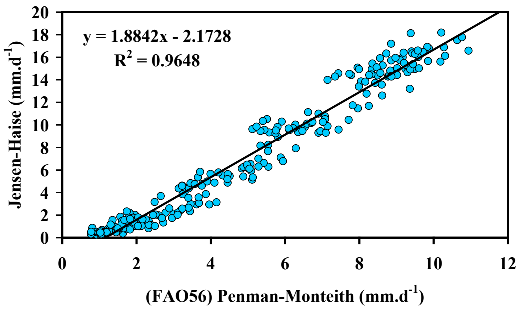
The resulting regression equations together with the cross-correlation (R^2) are presented in **Figure 5**. It displays the scatter plot between ET_0 estimates of the methods with FAO-56 PM at the Qom station.



(a)



(b)



(c)

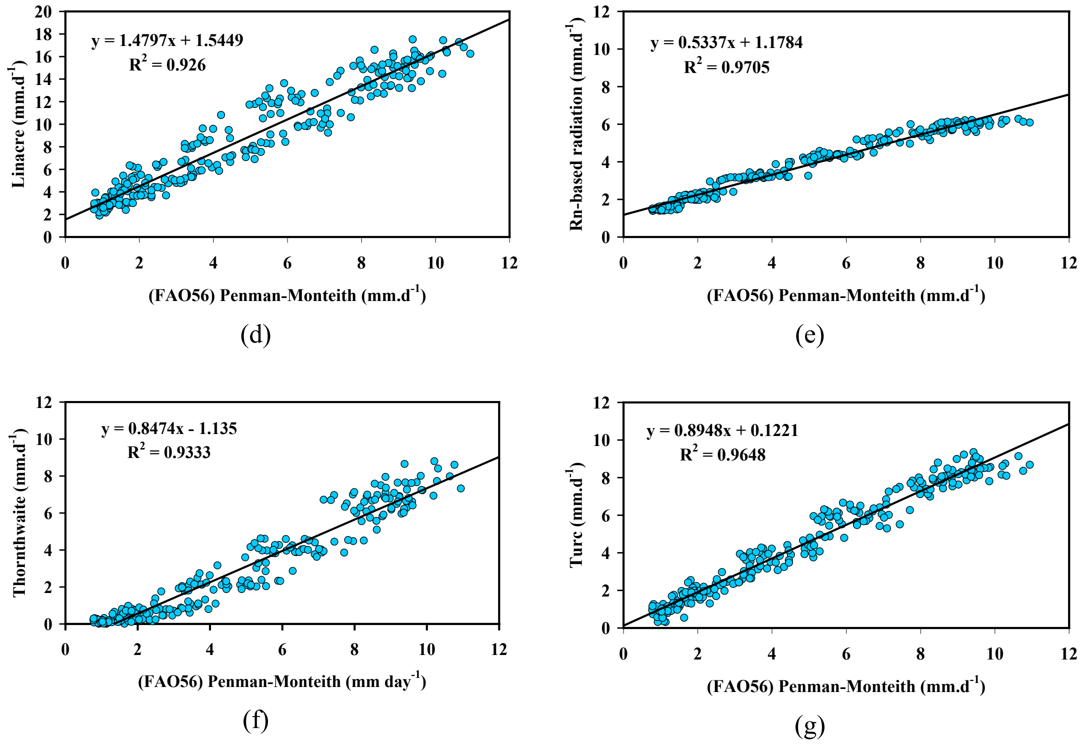


Figure 5 Regression analysis for the ET_0 estimates of different methods (a) Blaney-Criddle; (b) Hargreaves-samani; (c) Jensen-Haise; (d) Linacre; (e) Rn-based radiation; (f) Thornthwaite and (g), Turc respectively with FAO56-PM for evaluation years of 1987 - 2007 at Qom, Iran, in mm.d^{-1}

This figure reveals a very good agreement (slope = 1.08 and R^2 = 0.974) between the Blaney-Criddle and FAO-56 PM. The high correlation of ET_0 between the Blaney-Criddle with FAO56-PM methods clearly reflects the importance of the temperature and solar radiation.

Blaney-Criddle is considered a temperature method and using few weather inputs is suitable to study areas where the complete data required for ET_0 estimation is complex [30,31] and in different locations of the world with different climates [32-39]. This fact is also supported by many studies which reveal that the Blaney-Criddle method is nearly as accurate as the FAO56-PM method in estimating ET_0. For arid conditions of Iran, Mostafazadeh-Fard *et al*. [40] compared 9 different methodologies with lysimeter data and observed that the Blaney-Criddle and Turc methods showed very close agreement with the lysimeter data. Also, Blaney-Criddle is best method in Isfahan province [41], Mazandaran province [42], South Balochestan province [43] and in the center of Iran-Ardestan city.

The importance of temperature and its effect on evaporation in this region and the process parameters temperature and evaporation, which together have a lot of similarity with respect to time, a strong relationship between these 2 parameters is determined. The linear regression relationship was produced between Class A pan evaporation (1993 - 2007) and the FAO-56 PM method (1987 - 2007) with mean air temperature data (**Figure 6**).

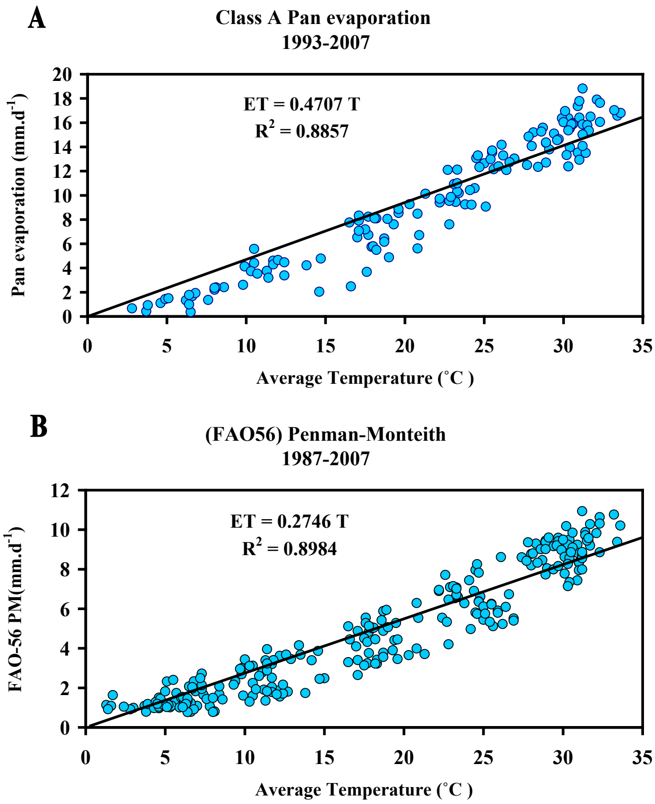


Figure 6 Relationship of between mean temperature, a) Class A pan evaporation (1993 - 2007), and b) ET_0 FAO-56 PM method (1987 - 2007).

The advantage of this method is that only climatic parameters used is temperature and in all weather stations is available. Often, the meteorological data are missing or incomplete due to instrument failure, contamination by measurement errors. For this reason, the pan Evaporation (Ep) has become a widespread method due to its simplicity, low cost, ease of data interpretation and application and suitability for locations with limited availability of meteorological data [44-46]. Commonly, ET_0 is estimated as the product of the Ep data and a pan coefficient (Kp).

$$ET_{FPM} = K_P \times E_P \tag{11}$$

Based on a literature review, the values of Kp cover a range between 0.3 and 1.1, and are proportional to relative humidity and inverse proportional to wind speed [47,48]. Linear regression analysis was performed to examine the relationship between the mean monthly values using the FAO-56 PM method and mean monthly values of Ep in Qom synoptic (1993 - 2007). **Figure 7** shows a plot of ET_0 versus Ep for this station. The value of Kp derived for the total period, was 0.583 (R^2 = 0.85).

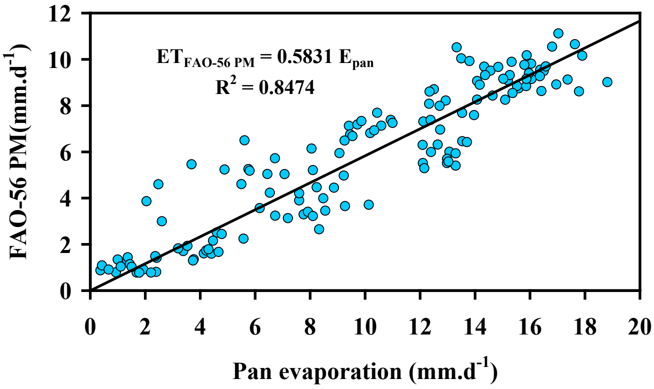


Figure 7 Relationship between class A pan evaporation and ET_0 from the FAO-56 PM method (1993 - 2007).

Conclusions

In the presented research, 21 years of meteorological data derived from the Qom station located in Qom province, in the north and center of Iran was applied as input parameters for comparing different methods to estimate ET_0 under the existing arid and warm climatic conditions in Qom. The FAO-56 PM method as recommended by FAO was taken as a standard in evaluating the different methods. By using statistical indicators, the best method to estimate ET_0 in Qom province is Blaney-Criddle. The Blaney-Criddle method underestimates FAO-56 PM in all months. Because the maximum and minimum temperature difference is very high in this station, these deviations are expected. It could be recommended to use the Blaney-Criddle method in arid and semi-arid climates. Due to the similarity of many other cities to Qom city, this study may serve as a good pattern for resolution of ET_0. The linear regression between the FAO-56 PM method and Class A Pan evaporation with mean air temperature are $ET_0 = 0.275\times T$ ($R^2 = 0.90$) and $ET_0 = 0.471\times T$ ($R^2 = 0.89$), respectively. Additionally, this study showed that, when measurements of meteorological parameters needed for estimating ET_0 (which are not always available especially in developing countries) are lacking, the mean air temperature provides an alternative and effective solution to estimate ET_0. In this area, as the evaporative demand increases (i.e., with lower humidity and lower wind speed), the difference between Ep and ET_0 increases and the Kp value decreases to nearly 0.58. However, it should be noted that this study was based on the analysis of a limited data set.

References

[1] GR Allen, LS Pereira, D Raes, M Smith. *Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56, FAO, Rome, Italy, 1998, 78-86.

[2] PJ Slabbers. Surface roughness of crops and potential evapotranspiration. *J. Hydrol*. 1977; **34**, 181-91.

[3] C Stefano and V Ferro. Estimation of evapotranspiration by Hargreaves formula and remotely Sensed data in semi-arid Mediterranean areas. *J. Agric. Eng. Res*. 1997; **68**, 189-99.

[4] IP Wu. A Simple evapotranspiration model for Hawaii: The Hargreaves model. *Engineer's Notebook* 1997; **106**, 1-2.

[5] M García, D Raes, SE Jacobsen and T Michel. Agroclimatic constraints for rainfed agriculture the Bolivian Altiplano. *J. Arid. Environ*. 2007; **71**, 109-21.

[6] J Price. Land surface temperature measurements from the split window channels of the NOAA 7 advanced very high resolution radiometer. *J. Geophys. Res.* 1984; **89**, 7231-7.

[7] WGM Bastiaanssen. SEBAL-based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey. *J. Hydrol*. 2000; **229**, 87-100.

[8] MM Heydari and M Heydari. Calibration of Hargreaves-Samani equation for estimating reference evapotranspiration in semiarid and arid regions. *Arch. Agron. Soil Sci.* 2014; **60**, 695-713.
[9] MM Heydari and M Heydari. Evaluation of pan coefficient equations for estimating reference crop evapotranspiration in the arid region. *Arch. Agron. Soil Sci.* 2014; **60**, 715-31.
[10] MM Heydari, RN Noushabadi, M Vahedi, A Abbasi and M Heydari. Comparison of evapotranspiration models for estimating reference evapotranspiration in arid environment. *Mid. East J. Sci. Res*. 2013; **15**, 1331-7.
[11] RG Allen, WO Pruitt, JL Wright, TA Howell, F Ventura, R Snyder, D Itenfisu, P Steduto, J Berengena, JB Yrisarry, M Smith, LS Pereira, D Raes, A Perrier, I Alves, I Walter and R Elliott. A recommendation on standardized surface resistance for hourly calculation of reference ET0 by the FAO56 Penmane Monteith method. *Agric. Water Manag*. 2006; **81**, 1-22.
[12] HAR de Bruin and JNM Stricker. Evaporation of grass under non-restricted soil moisture conditions. *Hydrol. Sci.* 2000; **45**, 391-406.
[13] MH Al-Ghobari. Estimation of reference evapotranspiration for southern region of Saudi Arabia. *Irrig. Sci*. 2000; **19**, 81-6.
[14] PS Kashyap and RK Panda. Evaluation of evapotranspiration estimation methods and development of crop coefficients for potato crop in a sub-humid region. *Agric. Water Manag*. 2001; **50**, 9-25.
[15] M Smith. The application of climatic data for planning and management of sustainable rainfed and irrigated crop production. *Agric. For. Meteorol*. 2000; **103**, 99-108.
[16] IA Walter, RG Allen, R Elliott, ME Jensen, D Itenfisu, B Mecham, TA Howell, S Snyder, P Brown, S Echings, T Spofford, M Hattendorf, RH Cuenca, JL Wright and D Martin. ASCE'S standardized reference evapotranspiration equation. *In*: Proceedings of the 4^{th} National Irrigation Symposium, ASAE, Phoenix, Arizona, USA, 2000, p. 14-6.
[17] KA Adeniran, MF Amodu, MO Amodu and FA Adeniji. Water requirements of some selected crops in Kampe dam irrigation project. *Aust. J. Agric. Eng*. 2010; **1**, 119-25.
[18] MM Heydari, A Abasi, SM Rohani and SMA Hosseini. Correlation study and regression analysis of drinking water quality in Kashan City, Iran. *Walailak J. Sci. & Tech*. 2013; **10**, 315-24.
[19] MM Heydari, A Abbasi and M Heydari. Estimation of Evapotranspiration in Ardestan, Center of Iran. *World Appl. Sci. J*. 2013b; **21**, 230-6.
[20] HF Blaney and WD Criddle. *Determining Consumptive Use and Irrigation Water Requirements*. Agricultural Research Service Technical Bulletin 1275, United States Department of Agriculture, 1962, p. 59.
[21] GH Hargreaves and ZA Samani. Reference crop evapotranspiration from temperature. *Appl. Eng. Agric*. 1985; **1**, 96-9.
[22] M Jensen and H Haise. Estimating evapotranspiration from solar radiation. *J. Irr. Drain. Div*. 1963; **89**, 15-41.
[23] NJ Rosenberg, BL Blad and SB Verma. *Microclimate: The Biological Environment*. 2^{nd} ed. John Wiley and Sons, NY, 1983, p. 495.
[24] R Burman and LO Pochop. *Evaportion, Evapotranspiration and Climatic Data*. Elsevier Science, 1994, p. 278.
[25] S Irmak, A Irmak, RG Allen and JW Jones. Solar and net radiation-based equations to estimate reference evapotranspiration in humid climates. *J. Irrig. Drain. Eng*. 2003; **129**, 336-47.
[26] CW Thornthwaite. An approach toward a rational classification of climate. *Geograph. Rev*. 1948; **38**, 55-94.
[27] L Turc. Estimation of irrigation water requirements, potential evapotranspiration: A simple climatic formula evolved up to date. *Ann. Agronomy*. 1961; **12**, 13-49.
[28] EM Douglas, JM Jacobs, DM Sumner and RL Ray. A comparison of models for estimating potential evapotranspiration for Florida land covers types. *J. Hydrol*. 2009; **373**, 366-76.
[29] M García, D Raes, SE Jacobsen and T Michel. Agroclimatic constraints for rain fed agriculture the Bolivian Altiplano. *J. Arid. Environ*. 2007; **71**, 109-21.
[30] DT Jensen, GH Hargreaves, B Temesgen and RG Allen. Computation of ET_0 under non ideal conditions. *J. Irrig. Drain. Eng*. 1997; **123**, 394-400.

[31] TS Lee, MMM Najim and MH Aminul. Estimating evapotranspiration of irrigated rice at the West coast of the Peninsular of Malaysia. *J. Appl. Irrig. Sci*. 2004; **39**,103-17.
[32] OSA Rizaiza and MH Al-Osaimy. A statistical approach for estimating irrigation water usage in western Saudi Arabia. *Agric. Water Manag*. 1996; **29**, 175-85.
[33] M Beyazgul, Y Kayam and F Engelsman. Estimation methods for crop water requirements in the Gediz basin of western Turkey. *J. Hydrol*. 2000; **229**, 19-26.
[34] BA George, BRS Reddy, NS Raghuwanshi and WW Wallender. Decision support system for estimating reference evapotranspiration. *J. Irrig. Drain. Eng*. 2002; **128**, 1-10.
[35] YL Li, JY Cui, TH Zhang and HL Zhao. Measurement of evapotranspiration of irrigated spring wheat and maize in a semi-arid region of north China. *Agric. Water Manag*. 2003; **61**, 1-12.
[36] RB Singandhupe and RR Sethi. Estimation of reference evapotranspiration and crop coefficient in wheat under semi-arid environment in India. *Arch. Agron. Soil Sci.* 2005; **51**, 619-31.
[37] S Chauhan and RK Shrivastava. Performance evaluation of reference evapotranspiration estimation using climate based methods and artificial neural networks. *Water Resour. Manag*. 2009; **23**, 825-37.
[38] B Benli, A Bruggeman, T Oweis and H Ustun. Performance of Penman-Monteith FAO56 in a semiarid highland environment. *J. Irrig. Drain. Eng*. 2010; **136**, 757-65.
[39] OE Mohawesh. Spatio-temporal calibration of Blaney-Criddle equation in arid and semiarid environment. *Water Resour. Manag*. 2010; **24**, 2187-201.
[40] B Mostafazadeh-Fard, M Heidarpour and SE Hashemi. Species factor and evapotranspiration for an Ash (*Fraxinus rotundifolia*) and Cypress (*Cupressus arizonica*) in an arid region. *Aust. J. Crop Sci*. 2009; **3**, 71-82.
[41] M Ehteshami, P Najafi and M Sattar. Use of minimum climate information in the estimation of the evapotranspiration reference crop in Isfahan (*in Persian*). *J. Soil Water*. 1999; **13**, 140-7.
[42] K Shahedi and M Zarei. Assessment methods to estimate the potential evapotranspiration in the province Mazandaran (*in Persian*). *J. Irrig. Water Eng*. 2011; **1**, 12-21.
[43] RA Farhoodi and AA Imamshamsi. Estimated potential evapotranspiration area of southern Baluchistan (*in Persian*). *Geog. Res*. 2000; **39**, 105-14.
[44] CJ Phene and RB Campbell. Automating pan evaporation measurements for irrigation control. *Agric. Meteor*. 1975; **15**: 181-91.
[45] G Stanhill. Is the Class A pan evaporationstill the most practical and accurate meteorological method for determining irrigation water requirements. *Agric. Meteor*. 2002; **112**, 233-6.
[46] S Trajkovic. Comparison of radial basis function networks and empirical equations for converting from pan evaporation to reference evapotranspiration. *Hydrol. Process*. 2009; **23**, 874-80.
[47] HG Gundekar, UM Khodke, S Sarkar and RK Rai. Evaluation of pan coefficient for reference crop evapotranspiration for semi-arid region. *Irrig Sci*. 2008; **26**, 169-75.
[48] A Rahimikhoob. An evaluation of common pan coefficient equations to estimate reference evapotranspi-ration in a subtropical climate (north of Iran). *Irrig Sci*. 2009; **27**, 289-96.