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Determining best empirical relation in order to measure evapotranspiration in arid region

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Abstract

Estimation of evapotranspiration (ET_o) 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. FAO Penman Monteith (FAO-56 PM) method has been accepted by many researchers and international institutes as the reference and Standard method. Accurate different methods include Blaney-Criddle, Hargreaves-Samani, Jensen-Haise, Linacre, Rn-based method, Thorthwaite and Turc were applied and then their results were compared with FAO-56 PM method. In this study, using statistical indicators, the best method to estimate ET_o in Qom province is selected and suggested Blaney-Criddle (RSME= 0.690 mmd^{-1}, MAE= 0.545 mmd^{-1}, D=0.998). Also the results indicate that ET_o increases from north to south, west to east of the province. The regression relationship between mean temperature and FAO-56 PM method and evaporation from the pan were determined. Also, to comparison of Pan Evaporation and monthly values of FAO-56 PM method, coefficient Pan (K_p=0.583) is calculated.

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Introduction

Evaporation from water bodies are about 112% of precipitation. Information about ET_o, or consumptive water use, is significant for water resources planning, for irrigation scheduling in crops (Slabbers, 1977; Di Stefano and Ferro, 1997; Wu, 1997; García *et al.*, 2007; Thepadia & Martinez 2012; Heydari and Heydari 2014a, 2014b). Estimation of ET_o is one of the major hydrological components for determining the water budget and it is therefore, reliable and consistent estimate of ET_o is of great importance for the management of water resources efficiently (Heydari *et al.*, 2014a). Efficient water management requires an accurate ET_o which can be derived from the meteorological variables. ET_o is always the important research subjects on hydrology, soil, agriculture, meteorology; ET_o also has important applications in water resources in arid areas, regional planning and management of agricultural production (Price, 1984; Bastiaanssen, 2000). The largest part of Iran is located in semi-arid and arid climates (Heydari *et al.*, 2014b) and ET_o of each region is generally affected by different climatic parameters as well as its geographical attributes. Therefore, investigation on ET_o process could be very important in this country (Heydari *et al.*, 2014c, 2014d).

Qom province geographically is located in an arid and semi arid region of Iran. The mountainous region is the southern and the western parts of Qom. The highest and lowest altitudes are 3209 m and 792 m above sea level, respectively. This province has historically suffered from water scarcity problem. Qom province is one of the dry provinces in Iran and Annual precipitation of Qom province is 135 mm. Water in this area is great important and over 90 percent of water used in agriculture and industry. ET_o measured data by using lysimeter are scarce in central states of Iran and Qom station with long time and complete data for using 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 the floods of the neighboring mountains to the salt lake (Heydari *et al.*, 2013a, 2013b). Increase of water demands associated with rapid urban development and expansion of agricultural lands has led to overexploitation of water in this city. Also, the region has a typical desert climate that is dry and warm in the north but more temperate in the south (Heydari and Heydari 2014c).

The objectives of this study were to (1) to evaluate, under arid conditions, the performance of empirical methods for estimating ET_o by comparing their values to those estimated using the FAO-56 PM equation using statistical parameters, (2) to develop relationship between Class A pan evaporation and FAO-56 PM method with mean air temperature and (3) to determine 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, north and center of Iran.

Materials and method

Characteristics of the study area

Qom Province is one of the 31 provinces of 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 (Heydari and Heydari 2014b; Heydari *et al.*, 2014d). The province contains four synoptic stations. The location of the area study and synoptic stations is shown in Fig. 1 and the geographic characteristics, year of establishment, climate and annual average values of temperature, rainfall of each station are presented in Table 1.

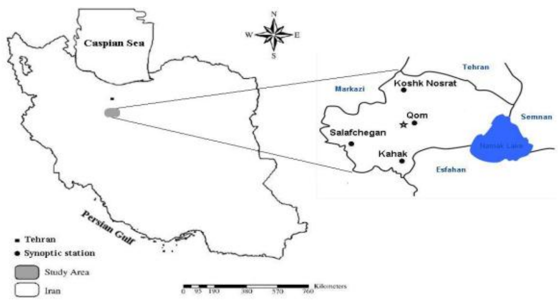

Fig. 1. The area study on Iran map and the synoptic stations in the Qom province.

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 scanty rainfall. Qom station (international code: 40770) is located in center of province and selected for study of province. The meteorological data of 21 years at the Qom station covering the period of January 1987 to December 2007 were analyzed for purposes of calculating ET_0 by the different methods. Fig. 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.

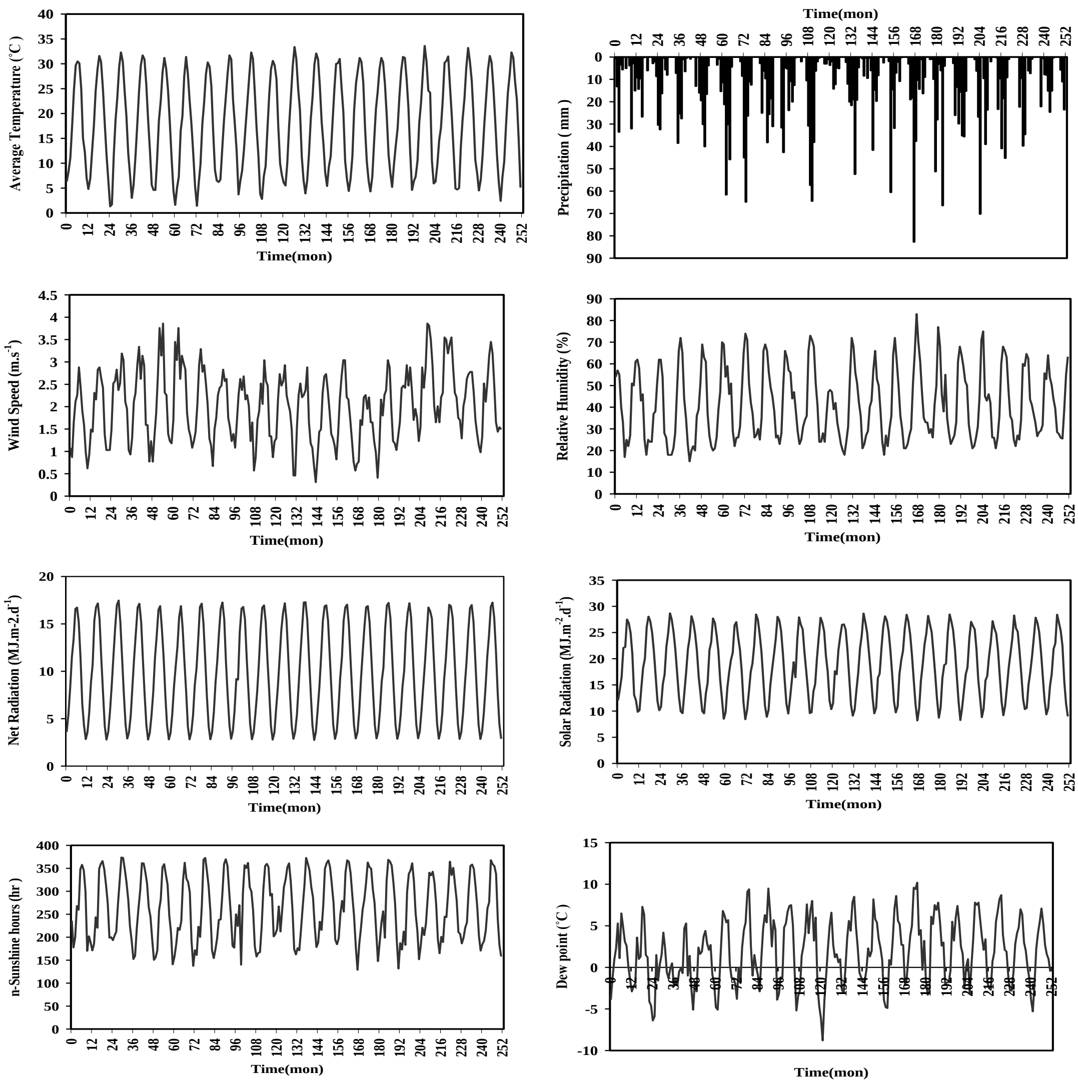

Fig. 2. Monthly variations of input parameters used in the calculation of ET_0 by different methods at Qom synoptic (1987-2007) (a) average temperature (°C);(b) precipitation (mm); (c) wind speed ($m.s^{-1}$); (d) relative humidity (%); (e) net radiation (MJ m^{-2} d^{-1}); (f) solar radiation (MJ m^{-2}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

The experimental method used

Monthly ET_o was estimated using methods developed by Blaney-Criddle (1988), Hargreaves-Samani (1985), Jensen-Haise (1963), Linacre (Rosenberg *et al.*, 1983; Burman and Pochop, 1994), Rn-based method (Irmak *et al.*, 2003), Thorthwaite (1948), and Turc (1961), respectively (see table 2).

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

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

PM equation

In this study, the amount of reference evapotranspiration was calculated, using FAO-56 PM method, in 15 selected synoptic. FAO-56 PM ET_o equation is given by Allen *et al.* (1998) for predicting ET_o where applied on 24-h calculation time steps has the form:

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

where FAO-56 PM ET_o = 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 2m height (°C); U_2 = the wind speed at 2m 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).

Statistical analysis

ET_o was estimated using various empirical equations is compared with the FAO-56 PM equation. 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:

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

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

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

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

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

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

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

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

In order to have a quantitative evaluation, the calibration parameters were defined using the following equation (García *et al.*, 2007):

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

Where ET_{EQ} represents the ET_o values estimated using the empirical methods. The calibration parameters A and B are determined by regression analysis using ET_{FAO} as reference the FAO-56 PM method. 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_o estimation methods. Comparison of monthly ET_o values specifically for the FAO-56 PM, Blaney-Criddle, Hargreaves-samani, Jensen-Haise, Linacre, Rn-based radiation, Thornthwaite and Turc equations and are presented in Fig. 3.

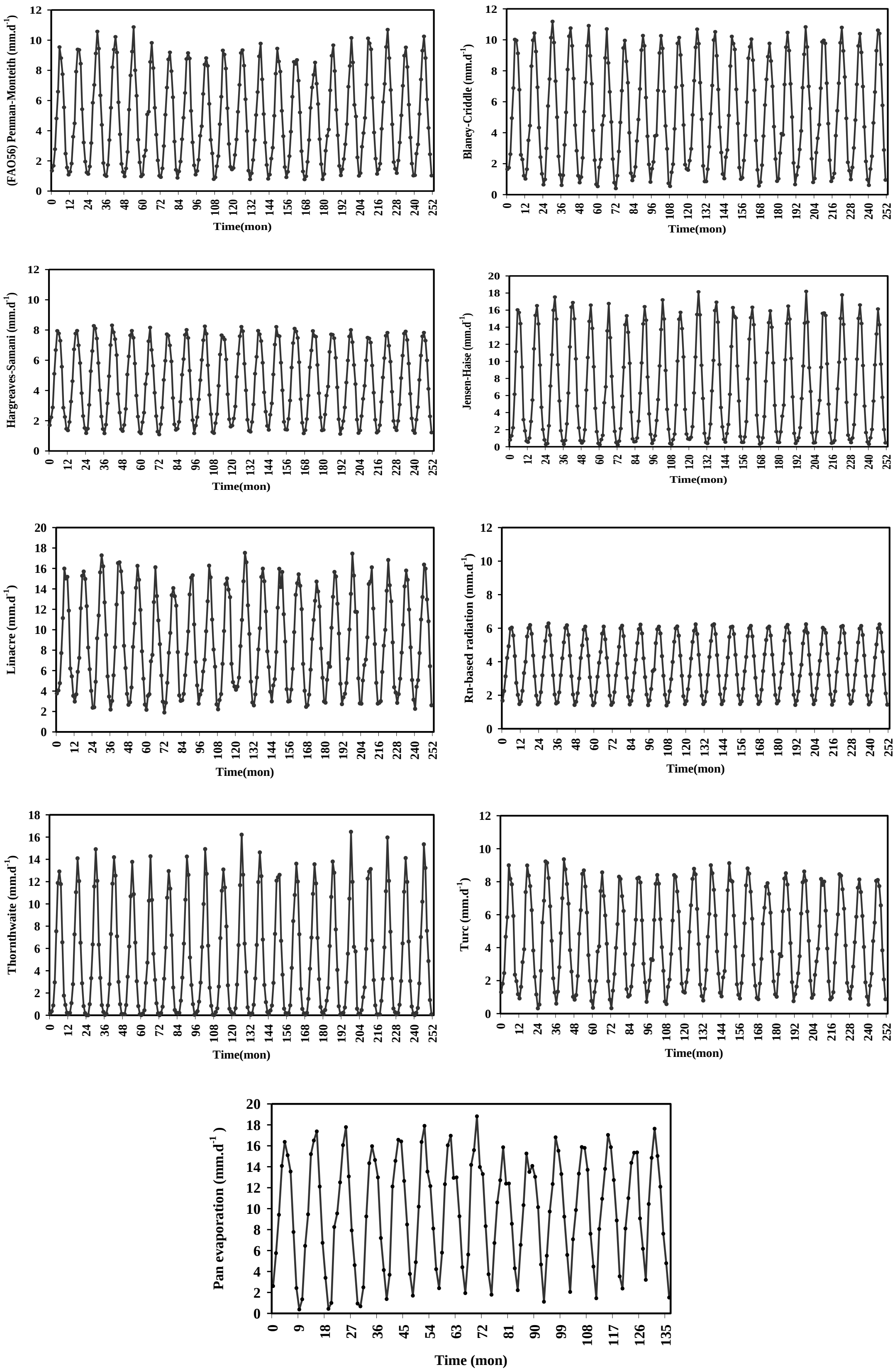

Fig. 3. Estimated ET_o derived from different methods at Qom synoptic (1987-2007), in mm.d^{-1} (a) FAO-56 PM; (b) Blaney-Criddle; (c) Hargreaves-samani; (d) Jensen-Haise; (e) Linacre; (f) Rn-based radiation; (g) Thornthwaite ; (h) Turc and, (i) Class A Pan measurements for years of 1993-2007, respectively.

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

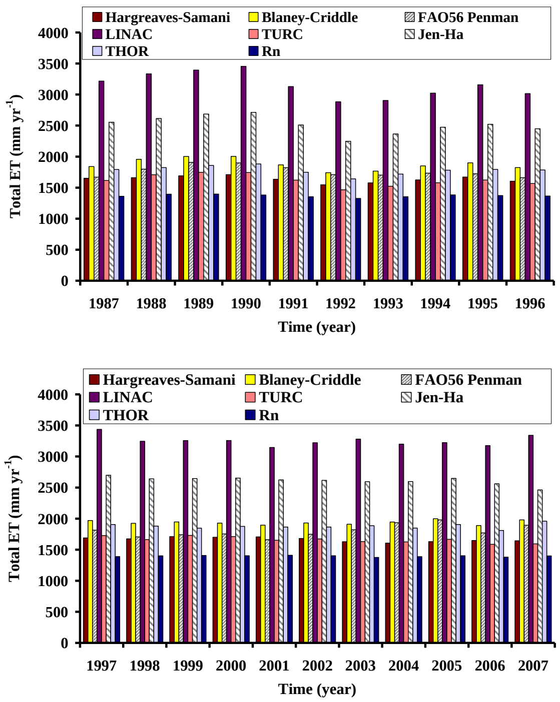

Fig. 4. Total annual ET_0 estimates given by the different methods at Qom synoptic (1987-2007), in mm.year^{-1}.

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 FAO-56 PM method, respectively. Rn method and Linacre method has 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 models predicted ET_0 and FAO-56 PM model. According to all the statistics, the best results are obtained by Blaney-Criddle and Turc, while the weakest statistics are obtained by Linacre and Jensen-Haise.

Table 3. Statistical values of the comparison between ET_0 calculated by different empirical methods with 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 resulted regression equations together with the cross-correlation (R^2) are presented in Fig. 5. It displays the scatter plot between ET_0 estimates of methods with FAO-56 PM over the Qom station.

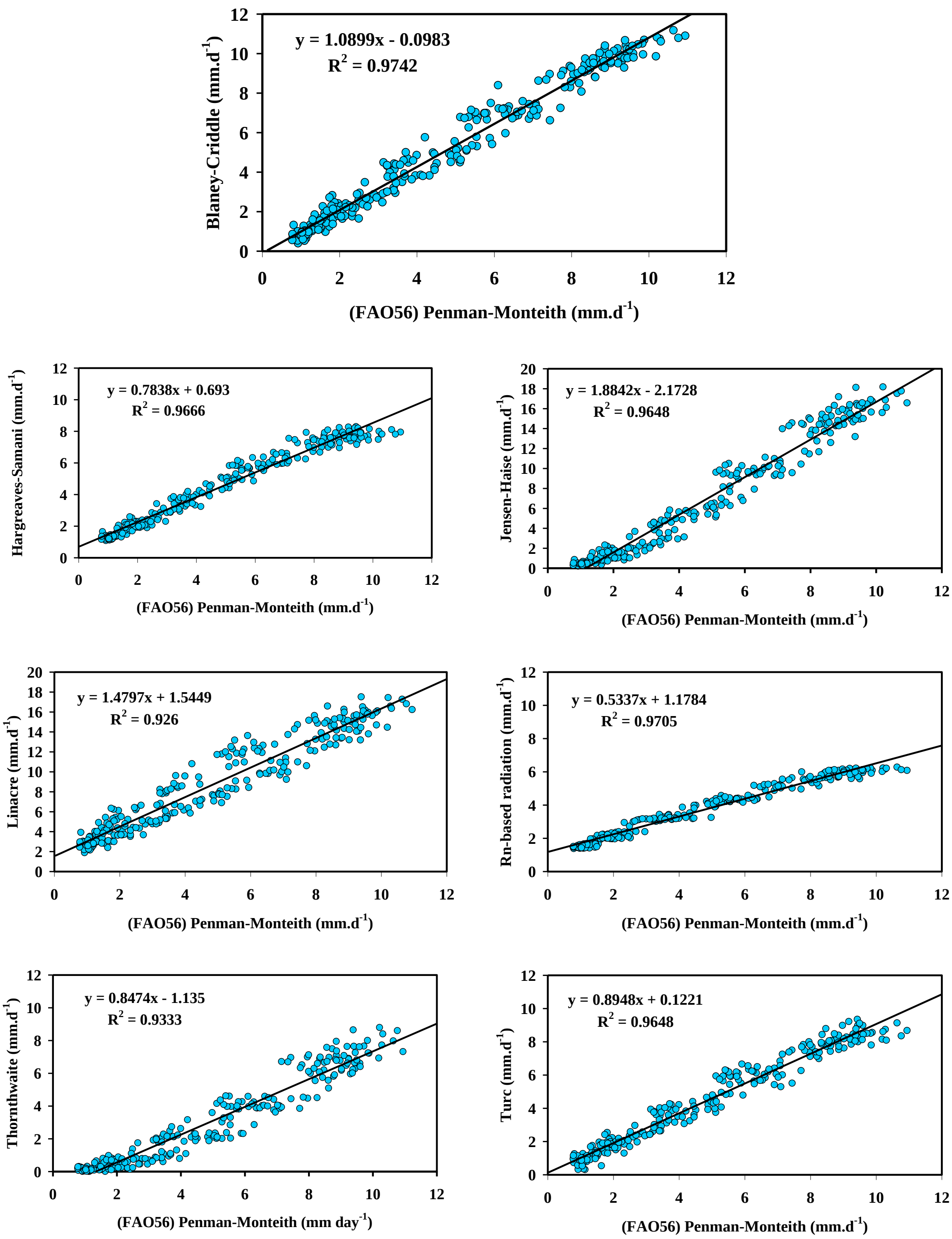

Fig. 5. Regression analysis for the ET_o estimates of different methods (a) Blaney-Criddle; (b) Hargreaves-samani; (c) Jensen-Haise; (d) Linacre; (e) Rn-based radiation; (f) Thornthwaite and, (g), respectively with FAO56-PM for evaluation years of 1987-2007 at Qom, Iran, in mm.d^{-1}.

This fig. 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_o by the Blaney-Criddle with FAO56-PM method clearly reflects the importance of the temperature and solar radiation. Blaney-Criddle considered as temperature method and using few weather input are suitable to the study area where the complete data required for ET_o estimation is complex and in different locations of the world with different climates. 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_o. Blaney-Criddle is best method in Isfahan province, Mazandaran province, South Balochestan province and Center of Iran-Ardestan city.

With According to 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, strong relationship between these two parameters is determined. The linear regression relationship was produced between Class A pan evaporation (1993-2007) and FAO-56 PM method (1987-2007) with mean air temperature data (Fig. 6).

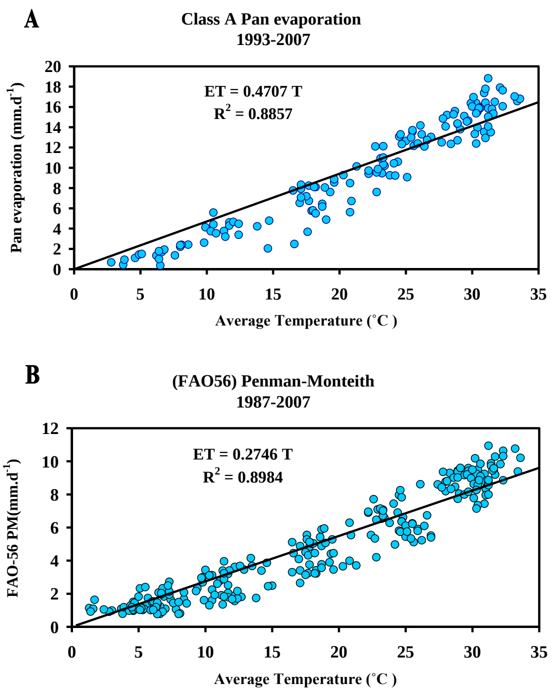

Fig. 6. Relationship of between mean temperature and: A) Class A Pan evaporation (1993-2007), B) ET_o FAO-56 PM method (1987-2007).

The advantage of this method is that only climatic parameter used in it 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 (E_p) has become widespread method due to its simplicity, low cost, ease of data interpretation and application and suitability for locations with limited availability of meteorological data. Commonly, ET_o is estimated as the product of the E_p data and a pan coefficient (K_p):

$$ET_{FPM} = K_P \times E_P \qquad (11)$$

Based on literature review, the values of K_p cover a range between 0.3 and 1.1, and are proportional to relative humidity and inverse proportional to wind speed. Linear regression analysis was performed to examine the relationship between the mean monthly values FAO-56 PM method and mean monthly values E_p in Qom synoptic (1993-2007). Fig. 7 shows a plot of ET_o versus E_p for this station. Value of K_p derived for the total period, was 0.583 (R^2 = 0.85).

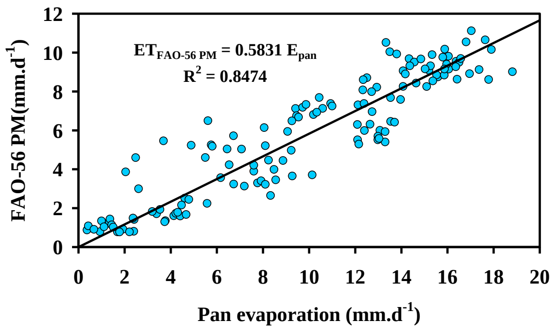

Fig. 7. Relations between class A pan evaporation and ET_o FAO-56 PM method (1993-2007).

Conclusions

In the presented research, the 21-year meteorological data derived from Qom station located in Qom province, north and center of Iran was applied as input parameters for comparing different methods to estimate ET_o under existing climatic conditions arid and warm 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_o in Qom province is selected and suggested Blaney-Criddle. The Blaney-Criddle method underestimated FAO-56 PM in the all of the months. Because 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 semiarid climate. Due to similarity of many cities to Qom city, this study may serve as a good pattern for resolution of ET_o. The linear regression are describes between FAO-56 PM method and Class A Pan evaporation with mean air temperature $ET_o = 0.275 \times T$ (R^2=0.90) and $ET_o = 0.471 \times T$ (R^2=0.89), respectively. Additionally, this study showed that, when measurements of meteorological parameters needed for estimating ET_o (which are not always available especially in developing countries) are lacking, the mean air temperature provide an alternative and effective solution to estimate ET_o. In this area, as the evaporative demand increases (i.e., with lower humidity and lower wind speed), the difference between E_p and ET_o increases and the K_p value decreases to near 0.58. However, it should be noted that this study was based on the analysis of a limited data set.

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