Comparison of Several Methods to Estimate Reference Evapotranspiration

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Abstract

Evapotranspiration is one of the major components of the hydrologic cycle is highly important in studies relevant to design and management of irrigation systems. The knowledge of the evapotranspiration of natural ecosystems and plant populations is of fundamental importance in several branches of science, research and practical uses. Nevertheless, the harmonization of the large number of methods and user needs often causes problems. The aim of these analyses was to explore the output range and sensitivity of models of different physical approaches under local conditions. In this study, evapotranspiration (ET0) was determined by several models include: Penman-Monteith-FAO-56, Blaney-Criddle, Hargreaves-Samani modified 2, Pan Evaporation, Jensen-Haise and Thornthwait in the Garebayegan research station at Fars province. Penman-Monteith-FAO-56 was reference model. Results of this research show that Pan Evaporation method, Hargreaves-Samani modified 2 and Blaney-Criddle have not significant difference by Penman-Monteith-FAO-56 in (P value< 0.05 level). Pan Evaporation method has most similarity to Penman-Monteith-FAO-56. Jensen-Haise and Thornthwait models have significant difference by Penman-Monteith-FAO-56 in (P value< 0.01 level). Thornthwait model has most difference by Penman-Monteith-FAO-56.

Introduction

Research of evapotranspiration plays an important role in the field of agro- and hydrometeorology. Due to the complexity of evapotranspiration as a biophysical phenomenon, several approaches and variants were developed.

Water being a major ingredient of life is becoming scarce in many parts of the world and also in Iran. Over the years, it is widely believed that any change in climate will have a significant impact on the availability of water. A lot of water is needed for agricultural practices and also for domestic purposes. The rate at which water returns from the earth (also from vegetations) back to the atmosphere in the form of vapor is referred to as ‘evapotranspiration’. Its knowledge helps in estimating irrigation requirements and carrying out its scheduling, estimate moisture loss from reservoirs and river basins. In physical sense, evapotranspiration (ET) is the sum of the evaporation (E) from the water and soil surfaces and the amount of water transpired by plants (transpiration, T). It is often limited by the currently available

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evaporable water, as well as by characteristics of the plant cover and the soil. Based on these factors, two values can be distinguished, namely potential (ETP) and actual evapotranspiration (AET). Reference evapotranspiration (ET0) represents theoretical evapotranspiration from an extensive surface of green grass of uniform height, actively growing, completely shading the ground, and not short of water (Allen *et al.,* 1998). This concept is suitable for deriving ET values for any crop, although significant differences between values of diverse model equations may be confusing for practical users.

For each of the wide range of applications, such as hydrological and ecosystem models, aridity assessments, or irrigation planning etc. (FAO 1996, Lieth, 1975), it is crucial to find the most appropriate method to estimate ET0. Differences among methods often reach hundreds of millimeters per growing season (Federer *et al.,* 1996), and accuracy of a given method depends heavily on the climatic conditions of the study site. For humid climate the Penman- Monteith-FAO-56 method is generally recommended (Jensen *et al.* 1990, Sumner – Jacobs 2005, Yoder *et al.* 2005, McMahon *et al.,* 2012), and its extensions e.g. the Shuttleworth– Wallace equation also proved to be effective (Zhou, 2011) because of its robust physical basis.

Several studies preferring Priestley-Taylor's approach (Lu *et al.,* 2005, Adeboye *et al.,* 2009), point out that under such climatic conditions it performs better than any other radiation and temperature based methods. Most of the authors confirmed that temperature and radiation based methods tend to give the highest, while pan-coefficient based ones result in the lowest ET0 values (Yates – Strzepek 1994, Tabari *et al.,* 2011). Under arid and semi-arid climates radiation based models may perform poorly (Er-Raki *et al.,* 2010), however, use of locally calibrated equations can make them more accurate than temperature based and even combination type ones (Bois *et al.,* 2005, Schneider *et al.,* 2007). Since the accuracy of estimated values of ETo is important for water resources planning and management, irrigation scheduling, control and agricultural productivity; it has given rise to numerous researches that were carried out in different parts of the world to ascertain the best model which is suitable for application in such parts. Similar researches have been carried out in Japan (Alexandris *et al.,* 2008), Bulgaria (Popova *et al.,* 2006), Central Serbia (Alkaheed *et al.,* 2006), a region of Florida in the United States of America (Hargreaves and Samani, 1982) and a region in south western Nigeria (Adebayo *et al.,* 2009). In general, Penman-Monteith- FAO-56 and radiation based methods estimate ET0 higher than pan-coefficient methods do (Rao – Rajput 1992) in arid environment.

The necessity of comparison, sensitivity testing and calibration of methods in a local context is emphasized by a large number of studies. Additionally, in continental climate of Eastern Hungary, there is a considerable variability of humid and arid characteristics, thus, to find the most suitable models, a local test appeared to be indispensable. For our assessment we selected two methods of each the four basic ET0 approaches. Since it is also highly recommended by literature (Federer *et al.* 1996, McMahon *et al.,* 2012) to consider locally measured data, we decided to involve pan evaporation data series as a reference value.

The main objective of this study was the statistical evaluation of the outputs of several approaches to reference evapotranspiration and comparison the accuracy of these methods to determination of reference evapotranspiration.

Material and methods

Study area

The study area is kowsar research station (Garebayegan). This station located in the south east of fars province, Iran. This station locate in 28° 25′ N and 53° 53′ E. The elevation of this area is 1120.3 meter from sea level. Climate condition of this station based on the de marten index is semi arid with average precipitation of 211.2 mm per year. The main period of precipitation is during winter (60% of total rainfall is in the winter and about 20% in the autumn and about 20% in the spring and summer). The average temperature stands at +2°C in January and +29°C in July, but annual of average temperature in this region is 19.3 centigrade (Fig. 1).

Methodology

In this study, 5 methodologies for estimating evapotranspiration was calculated and compared with the reference method (FAO-56 PM). These methods include:

Penman-Monteith-FAO-56 method

The Penman-Monteith-FAO-56 method is a new standard for reference evapotranspiration and advised on procedures for calculation of the various parameters. By defining the reference crop as a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s m-1 and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered, the Penman-Monteith-FAO-56 method was developed. The method overcomes shortcomings of the previous FAO Penman method and provides values more consistent with actual crop water use data worldwide.

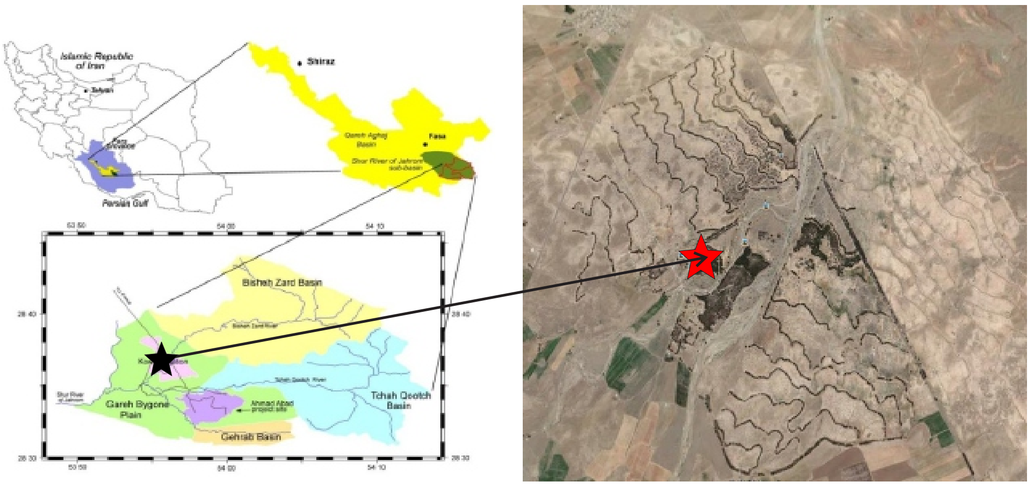

Fig. 1. Study area

This method based on the equation 1:

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

where as: Et_0 : Reference evapotran-spiration (mm day^{-1}), R_n : Net radiation at the crop surface (MJ m^{-2} day^{-1}), G : Soil heat flux density (MJ m^{-2} day^{-1}), T: Mean daily air temperature at 2 m height (°C), u_2 :Wind speed at 2 m height (m s^{-1}), e_s: Saturation vapor pressure (k Pa),e_a : Actual vapor pressure (k Pa), $e_s - e_a$: Saturation vapor pressure deficit (k Pa), Ä: slope vapor pressure curve (k Pa °C^{-1}) and ã: psychometric constant (k Pa °C^{-1}).

Hargreaves- Samani modified 2 method

The FAO-56 PM is a physically based approach which requires measurements of air temperature, relative humidity, solar radiation, and wind speed. The number of stations where there are reliable data for these parameters is limited. This lack of data provoked Hargreaves et al. (1985) to develop a simpler approach where only air temperatures are required. Samani(2000) modified this model. The modified Hargreaves equation was based on the equation 2:

$$Et_o = 0.0023 \times (T_{max} - T_{min})^b \left(\frac{T_{max} + T_{min}}{2} + 17.8\right) \times R_a \quad (2)$$

where as: ET_0: Estimated Reference evapotranspiration by the Hargreaves equation (mm day^{-1}), Ra: Extraterrestrial radiation (MJ m^{-2} day^{-1}), T_{max}: Maximum air temperature (°C), : Minimum air temperature (°C) and the value of the exponent 'b' was found to be 0.653.

Jensen-Haise method

Under situation of limited data, Jensen-Haise model is used in computing reference evapotranspiration as reported by James, (1988). The Jensen-Haise method was based on the equation 3:

$$ET_0 = C_\Upsilon\,(T - T_x).\ K_\Upsilon.\ Ra.\ T.\ D^{0.5} \quad (3)$$

where as: ET0: Estimated Reference evapotranspiration by the Jensen-Haise equation (mm day^{-1}), Ra: Extraterrestrial radiation (MJ m^{-2} day^{-1}), T: Average of daily temperature (°C), D : Different between maximum and minimum daily temperature (°C) and C_T, T_x, K_T are standard coefficient.

Pan Evaporation method

The evaporation rate from pans filled with water is easily obtained. In the absence of rain, the amount of water evaporated during a period (mm/day) corresponds with the decrease in water depth in that period. Pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. Although the pan responds in a similar fashion to the same climatic factors affecting crop transpiration, several factors produce significant differences in loss of water from a water surface and from a cropped surface. Reflection of solar radiation from water in the shallow pan might be different from the assumed 23% for the grass reference surface. Storage of heat within the pan can be appreciable and may cause significant evaporation during the night while most crops transpire only during the daytime. There are also differences in turbulence, temperature and humidity of the air immediately above the respective surfaces. Heat transfer through the sides of the pan occurs and affects the energy balance.

This method based on the equation 4:

$$ET_o = E_{pan} \times K_p \quad (4)$$

where as: Et_o : Reference evapotranspiration (mm/day), K_P: pan coefficient that in the A class pan (Colorado pan) is 0.65 and E_{pan}: Is pan evaporation (mm/day).

Blaney-Criddle method

The Blaney-Criddle method is simple, using measured data on temperature only (see also Fig. 11). It should be noted, however, that this method is not very accurate; it provides a rough estimate or "order of magnitude" only. Especially under "extreme" climatic conditions the Blaney-Criddle method is inaccurate: in windy, dry, sunny areas, the ETo is underestimated (up to some 60 percent), while in calm, humid, clouded areas, the ETo is overestimated (up to some 40 percent). This method was based on the equation 5:

$$ET_o = a + b\,[p(0.46\,T + 8.13) \qquad (5)$$

where as: ET0: Estimated Reference evapotranspiration by the Blaney-Criddle equation (mm day^{-1}), T : Average of monthly temperature (°C) and *a, b* are climatic coefficient.

Thornthwait method

In this method Reference evapotranspiration will be calculated for each month, this method was based on the equation 6:

$$ET_o = 16\,N_m\,\frac{(10T_m)}{1}\,a \qquad (6)$$

where as: ET0: Estimated Reference evapotranspiration by the Thornthwait equation (mm per month), N_m : correction coefficient for light hours in the each day, T_m: Average of monthly temperature (°C) and is coefficient that calculate with equation 7:

$$a = (6.75 \times 10^{-7}).\,1^{3} - (7.72 \times 10^{-5}).\,1^{2} + (1.792 \times 10^{-2}).\,1 + 0.49 \qquad (7)$$

where as: I is annual temperature index.

Result and discussion

The 24 years weather data were used to validate the performances of the commonly used ET0 estimation methods. ET0 values computed from five empirical methods were first compared with the FAO-56 PM values (Fig. 2).

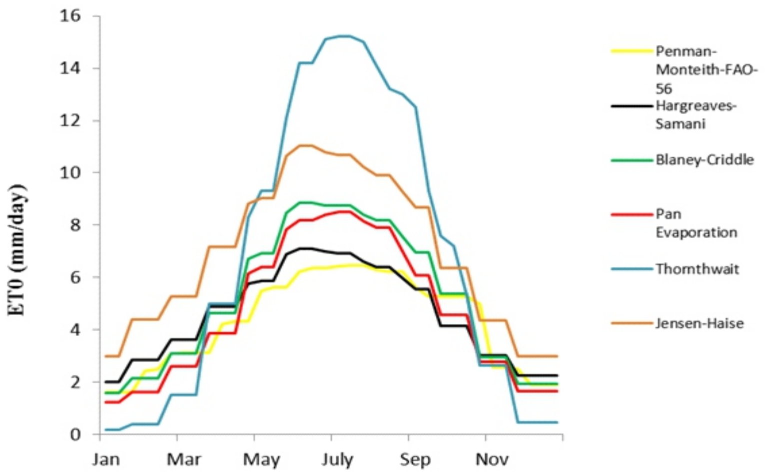

Fig. 2. Average monthly ETo estimated by the standard Penman Monteith FAO and five empirical equations at the study area

According to statistical analysis of all methods by ANOVA test for compare average of estimated ET0 by each models, results are not similar at *P* valve < 0.05 (Table 1). The details of statistical comparison are shown in Table 2. Table 2 shows the performance of the models by comparison between models ET0 and FAO-56 PM model. According to all the statistics, the best results are obtained by Pan Evaporation method**,** while the weakest statistics are obtained by Thornthwait model.

According Table 2 Pan Evaporation method, Hargreaves-Samani modified 2 and Blaney-Criddle have not significant difference by Penman-Monteith-FAO-56 in (*P* value < 0.05 level). Pan Evaporation method has most similarity to Penman-Monteith-FAO-56. Jensen-Haise and Thornthwait models have significant difference by Penman-Monteith-FAO-56 in (*P* value < 0.01 level). Thornthwait model has most difference by Penman-Monteith-FAO-56.

The maximum annual sum of ET0 estimated by Jensen-Haise about 2490.1 mm per year and minimum annual sum of ET0 estimated by Penman-Monteith-FAO-56 about 1540 mm per year. Correlation between estimated ET0 by Penman-Monteith-FAO-56 and other methods showed in Fig. 3. According to result of Fig. 3 ET0 estimated by Penman-Monteith-FAO-56 has highest R^2 by Blaney-Criddle model.

Conclusion

In arid regions, ET0 is a large component of the hydrologic cycle and a key component of any applied catchment model. An improved irrigation schedule, results in enhanced water use efficiency and hence irrigation water saving. Oluwaseun et al.

TABLE 1
Compare of average of estimated ET0 by ANOVA test

Source of variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	3377.74	5	675.54	12.64	0.00
Within Groups	11215.62	210	53.40		
Total	14593.36	215			

TABLE 2
Comparison between models predicted ET0 and FAO-56 PM model

	Compare with	*F*	*P-value*
Penman-Monteith-FAO-56	Hargreaves- Samani modified	0.579	0.449^{ns}
	Pan Evaporation	0.503	0.480^{ns}
	Blaney-Criddle	2.480	0.119^{ns}
	Thornthwait	12.11	0.000**
	Jensen-Haise	10.22	0.0002**

ns :Difference is not significant. **: Difference is significant at 0.01 level.

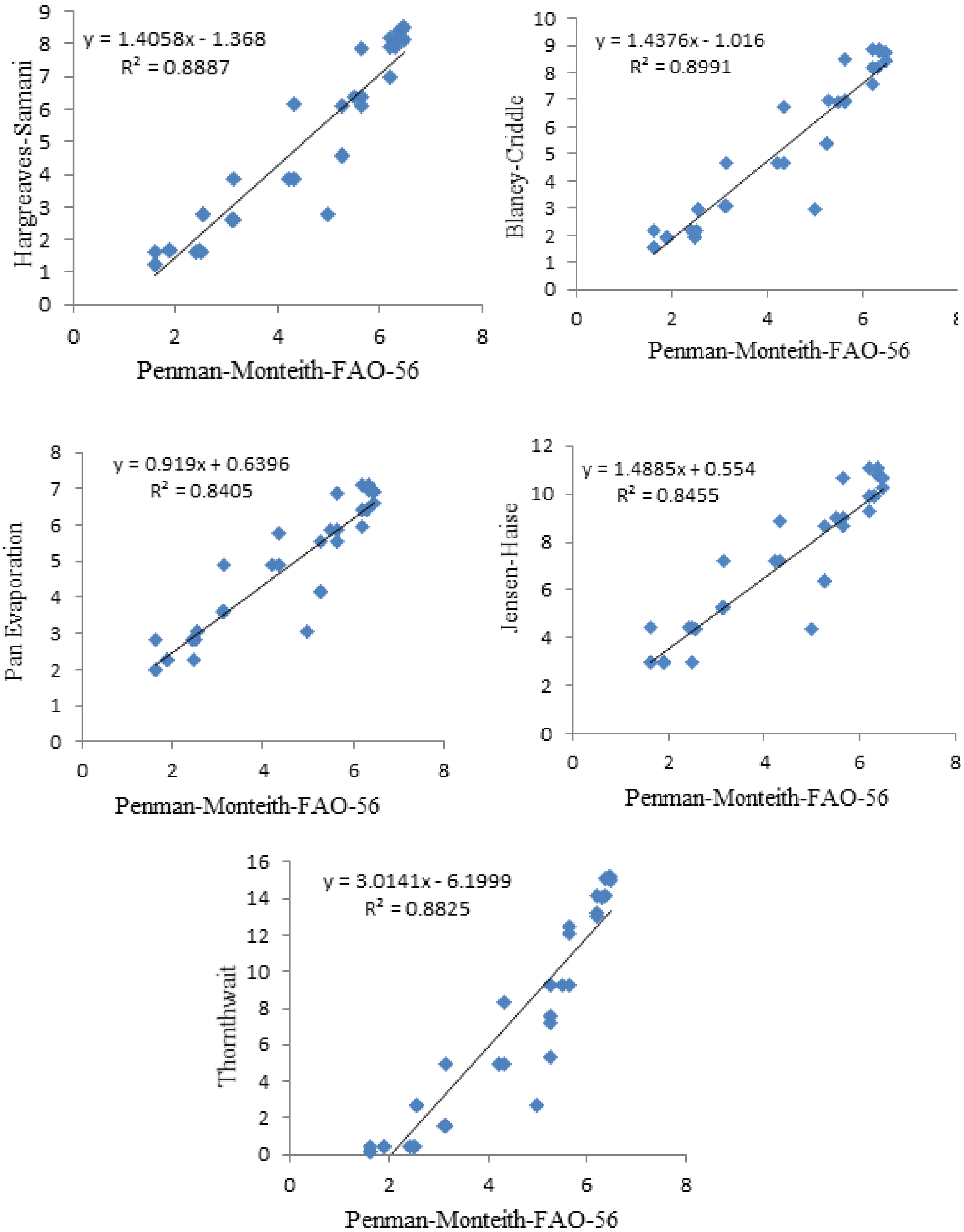

Fig. 3. Correlation between estimated ET0 by Penman-Monteith-FAO-56 and other methods

2014 evaluated the Four ETo Models (Blaney-Morin-Nigeria (BMN), Hargreaves-Samani, Priestly-Taylor and Jensen-Haise models) with reference to FAO 56. According to result o this study: The BMN model was found out to be the best model that can be applied to estimate ET in each of these stations because it has a high correlation value with the values obtained from FAO56-PM model along with favorable statistic values and it requires a considerably less number of variables for its estimation with correlation (r) values of 0.7, 0.77 and 0.75 respectively for Ibadan, Onne and Kano. Mohammadi, 2014 evaluated the two ETo Models (Blaney-Criddle and Turc) with reference to FAO 56. Results show that Blaney-Criddle (BC) model were the best in light of mean biased error (MBE), root mean square error (RMSE) and maximum absolute error (MAXE).The mean values MBE, RMSE and MAXE computed -0.554, 0.690 and 1.429 mm per day for BC, respectively. For all the years, ET0 rates were low in winter and fall and highest during the summer. Also, the maximum and minimum annual ET0 estimations by Blaney- Criddle and FAO-56 PM methods was in 2001 and 1996, respectively. The 24 years meteorological data derived from Garebayegan station located in Fars, Iran was applied as input parameters for comparing different methods to estimate ET0 under existing climatic conditions arid and warm in study area. Five empirical methods for calculating ET0 were evaluated using meteorological data from Garebayegan Station in Iran. The FAO-56 PM method as recommended by FAO was taken as a standard in evaluating the five methods. In this study, using statistical indicators, the best method to estimate ET0 in Garebayegan station is selected and suggested Pan Evaporation.

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