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Comparison of Evapotranspiration Models for Estimating Reference Evapotranspiration in Arid Environment

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Abstract: In this study, evapotranspiration (ET_0) was determined by several models for Naein city in Isfahan province (center of Iran) from 1993-2006. Outputs were obtained from IMO (Iran Meteorological Organization) weather station, located in the Naein, for all of these years. 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 were compared with FAO-56 PM method. 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.d^{-1} for BC, respectively. For all the years, ET_0 rates were low in winter and fall and highest during the summer. Also, the maximum and minimum annual ET_0 estimations by Blaney-Criddle and FAO-56 PM methods was in 2001 and 1996, respectively.

Key words: Naein % Evapotranspiration % Blaney-Criddle % Turc % Fao Penman Montieth

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 surface 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, for irrigation scheduling in crops [2-5]. Estimation of ET_0 is one of the major hydrological components for determining the water budget and it is therefore, reliable and consistent estimate of ET_0 is of great importance for the management of water resources efficiently. 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 till 96% of annual precipitation. In the average about 50% of all precipitation loose in evaporation process in the catchments. Therefore, investigation on ET_0 process could be very important in this country [8].

Empirical methods are used when all the data needed for Penman-type equations are not available. Direct measurement of evapotranspiration is usually not feasible in many field situations because it is expensive and time-consuming. The ET_0 computation methods can be classified into three 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 reference evapotranspiration (ET_0) [1, 9]. This method is the most widely used in the world and has been proven to accurately estimate ET_0 in different climates [1, 10-14].

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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 [15]. Naein city that covers an area of 35928 km^2 is located in 145 km northeast of Isfahan province, in center Iran. Due to the difference in unevenness and locating in the neighborhood of "NAMAK" desert, the north and south parts of this area are different in climate. In the north, climate is hot and dry and the south is mountainous [8]. 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 [16]. Increase of water demands associated with rapid urban development and expansion of agricultural lands has led to overexploitation of water in this city. Water withdrawal continues, water shortage crisis will happen in this area [17]. The purpose of this study was to estimate evapotranspiration of the Naein, an arid in centeral of Iran. The meteorological data necessary for the equations from 1993-2006 were obtained from synoptic station placed at Naein. In this study, 11 methodologies for estimating evapotranspiration was calculated and compared with the reference method (FAO-56 PM).The most appropriate method to estimate ET_0 using statistical indicators (RSME, MBE, RE and R^2) in Naein is selected and suggested Blaney-Criddle. Also, given the similarity of ET_0 and temperature distribution, the regression relationship with a regression coefficient of between temperature and FAO-56 PM method were determined and plotted.

MATERIALS AND METHODS

Naein city is located in central Iran and on the eastern outskirts of central mountains adjacent to Kavir desert (between the Karkas mountain slope and Iran Central Desert [18]) is between 32° 30' to 34°15' N latitude and 52°35' to 55°02' E longitude and Located in an altitude of 1,549 m above sea level (Fig. 1). It has a desert climate, with a maximum temperature of 41°C in summer and a minimum of -9°C in winter.

Naein city has a dry climate with very little precipitation. The region has a typical desert climate and the most important part of rainfall in winter and spring are unusable and most of rainfall may be in form of floods [19]. As a whole, Naein climate is dry and warm and the summer and winter temperature variation is too high because of the dry nature, stone, sandy and saline soil in the north and high evaporation in south. Climatology station in study area is Naein station. Based on years morphological statistic data, in this city, precipitation mean has reported 98.70 mm in a year and annual Temperature and humidity mean is +16.60° (centigrade) and 31%, respectively. Several hydrometeorological variables, including air temperature, wind speed, relative, solar radiation and net radiation among others, have been continuously recorded for the period of 1993 to 2006. The mean weather data for the period of study are given in Table 1 and Figure2.

In this study, the amount of reference evapotranspiration was calculated, using FAO-56 PM method, in 15 selected synoptic. 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 has the form:

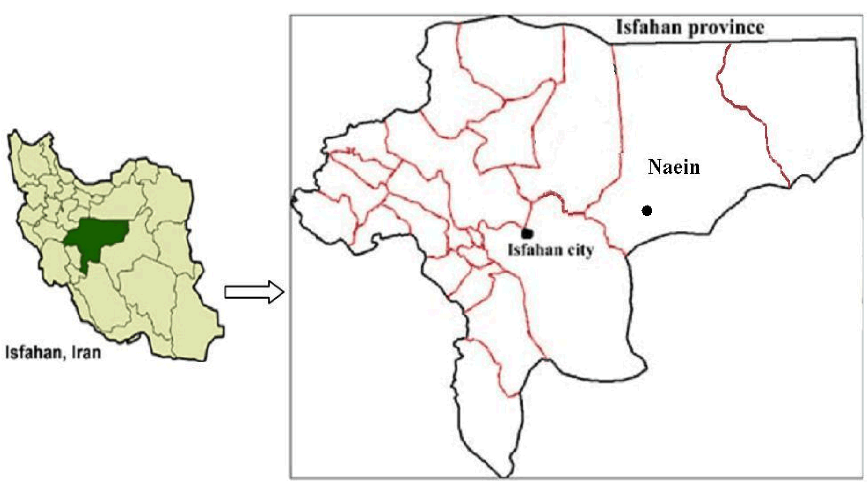

Fig. 1: The location of area study on Iran map

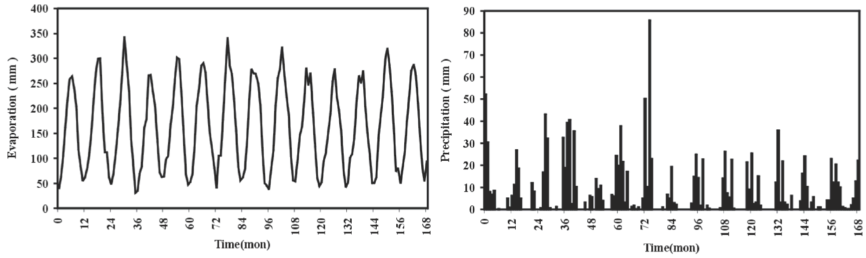

Fig. 2: Monthly variations of Evaporation and Precipitation at Naein synoptic (1993-2006)

Table 1: Mean climatology at the Naein Station used in the study

	Month											
Variables	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmin (°C)	-1.70	0.30	4.20	10.0	14.0	19.0	22.0	20.0	16.0	11.0	4.20	0.10
Tmax (°C)	9.70	13.0	17.0	24.0	28.0	34.0	37.0	36.0	32.0	25.0	17.0	12.0
Tmean (°C)	4.0	6.6	10.0	17.0	21.0	26.0	29.0	28.0	24.0	18.0	11.0	6.0
Wind speed (m.sG^{1})	2.38	3.38	3.46	3.62	3.55	3.54	3.48	3.26	3.03	2.75	2.56	2.27
RH_{mean} (%)	52.0	41.0	36.0	28.0	24.0	18.0	17.0	19.0	20.0	26.0	35.0	44.0
Ra (mm.dG^{1})	19.50	23.60	29.30	36.30	40.40	41.90	41.20	38.00	32.90	26.60	20.90	17.80

Table 2: Methods for calculation of ET_0, in mm dG^{1}

Method	Equation form	Climate parameters required
Hargreaves-Samani [20]	$ET_0 = 0.0023 \times R_a (T_{mean} + 17.80) \times (T_{\max} - T_{\min})^{0.50}$	T_{min}, T_{max}, R_a
Hargreaves-SamaniDroogers and Allen [21] (HS1)	$ET_0 = 0.0030 \times R_a (T_{mean} + 20) \times (T_{\max} - T_{\min})^{0.40}$	T_{min}, T_{max}, R_a
Hargreaves-SamaniDroogers and Allen [21] (HS2)	$ET_0 = 0.0025 \times R_a (T_{mean} + 16.8) \times (T_{\max} - T_{\min})^{0.50}$	T_{min}, T_{max}, R_a
Rn- radiation [26]	$ET_0 = 0.489 + 0.289 \times R_n + 0.023 T_{mean}$	T_{mean}, R_n
Rs- radiation [26]	$ET_0 = -0.611 + 0.149 \times R_S + 0.079 T_{mean}$	T_{mean}, R_s
TURC [25]	$PET = 0.013\left(\frac{T_{mean}}{15 + T_{mean}}\right)(R_S + 50) \quad RH > 50\ \%$ $PET = 0.013\left(\frac{T_{mean}}{15 + T_{mean}}\right)(R_S + 50)\ (1 + \frac{50 - RH}{70}) \quad RH < 50\ \%$	T_{mean}, R_s, RH_{mean}
Blancy-Criddle [24]	$ET_0 = a + b \times \left[P(0.46 T_{mean} + 8.13) \right]$	T_{mean}, U, RH_{mean}
Makkink [22]	$ET = 0.61 \frac{\Delta}{\Delta + g} \frac{R_S}{l}$	T_{min}, T_{max}, R_s
Priestley-Taylor [23]	$ET = 1.26 \frac{\Delta}{\Delta + g} \frac{R_n}{l}$	T_{min}, T_{max}, R_n

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

where FAO-56 PM ET_0 = the grass reference evapotranspiration (mm.dG^{1}); R_n = the net radiation at the crop surface (MJ/m^2.dG^{1}); G = the soil heat flux density (MJ/m^2.dG^{1}); T = the mean daily air temperature at 2m height (°C); U_2 = the wind speed at 2m height (m.sG^{1}); e_s = the saturation vapor pressure (kPa); e_a = the actual vapor pressure (kPa); e_s - e_a = the saturation vapor pressure deficit (kPa);) = the slope vapor pressure curve (kPa/°C); and (= the psychometric constant (kPa/°C).

Nine evapotranspiration models: Hargreaves-Samani original [20] (HS), Hargreaves-Samani Modified 1 (HS1) [21] and Hargreaves-Samani Modified 2 (HS 2) [21], Makkink [22] (Makk), Priestley-Taylor [23] (PT), Blaney-Criddle [24] (BC), Turc [25], (Rs) based method [26] and (Rn) based method [26] were used to estimate ET_0 (Table 2).

ET_0 was estimated using various empirical equations is compared with the FAO-56 PM equation.The models were compared using standard statistics and linear regression analysis **(Douglas *et al*., 2009).** Root Mean Squared Error (RMSE), mean biased error (MBE), Relative Error (RE) and coefficient of determination (Pearson type goodness of fit index, R^2) were computed using the equations described below:

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

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(ET_{EQ} - ET_{FAO}\right) \quad (3)$$

$$MAXE = MAX\,(|\,ET_{EQ} - ET_{FAO}\,|)_{i=1}^{n} \quad (4)$$

$$RE(\%) = \frac{ET_{EQ} - ET_{FAO}}{ET_{EQ}} \times 100 \quad (5)$$

$$R^2 = \left[\frac{\sum_{i=1}^{N}(ET_{EQ} - \bar{E}T_{EQ})(ET_{FAO} - \bar{E}T_{FAO})}{\sqrt{\sum_{i=1}^{N}(ET_{EQ} - \bar{E}T_{EQ})^2\sum_{i=1}^{N}(ET_{FAO} - \bar{E}T_{FAO})^2}}\right]^2 \quad (6)$$

In order to have a quantitative evaluation, the calibration parameters were defined using the following equation [5]:

$$ET_{EQ} = \mathrm{A} + \mathrm{B}.ET_{FAO} \quad (7)$$

Where ET_{EQ} and ET_{FAO} as reference the method represents the ET_0 values estimated using the empirical methods and FAO-56 PM. The best prediction model is the one with the smallest RMSE, MBE and RE, the highest coefficient of determination (R^2), B value closest to zero and A value closest to unity.

RESULTS AND DISCUSSION

The 14 year-monthly weather data were used to validate the performances of the commonly used ET_0 estimation methods. Monthly ET_0 values computed from ten empirical methods were first compared with the FAO-56 PM values (Fig. 3). A visual comparison shows that the values Blaney-Criddle and Turc empirical equations worked quite well.

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, while the weakest statistics are obtained by R_n- radiation [26] and Makkink.

This results reveals a very good agreement (slope=1.05 and R^2=0.985) between the Blaney-Criddle and FAO-56 PM. This results were in agreement with the obtained results by Fooladmand and Ahmadi [28]. They found correlation coefficients up to 0.96 in the linear regression analysis between the Blaney-Criddle and the FAO-56 PM methods applied in the south of Iran. For arid conditions of Iran, Mostafazadeh-Fard *et al*. [29] compared nine different methodologies with lysimeter data and observed that the the Blaney-Criddle and Turc methods showed very close agreement with the lysimeter data. Also, Blaney-Criddle is best method in North of Isfahan province [8], Mazandaran province and South

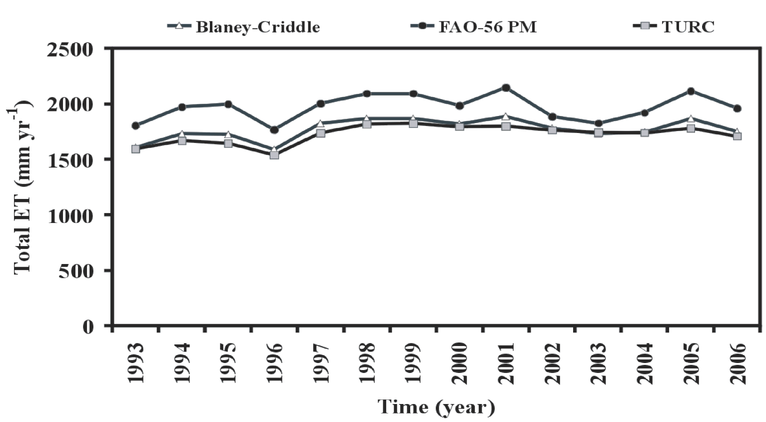

Fig. 3: Total annual ET_0 estimates given by the 2 methods and FAO-56 PM at Naein synoptic (1987-2007), in mm.year^{-1}

Table 3: Summary of the comparison results obtained from the models, error analysis and linear regression analysis and FAO-56 PM

Method	RMSE	MBE	MAXE	RE %	R^2	A	B
	----------------------	mm.d^{-1}	------------------------				
Hargreaves Samani(HS)	1.774	-1.496	4.283	-25.80	0.968	0.695	0.169
Hargreaves Samani(HS1)	1.558	-1.257	4.012	-20.20	0.967	0.711	0.326
Hargreaves Samani(HS2)	1.518	-1.248	3.833	-21.00	0.968	0.744	0.134
Blaney-Criddle	0.690	-0.555	1.429	-14.83	0.985	1.050	-0.830
Priestley-Taylor	1.957	-1.761	4.318	-34.65	0.963	0.743	-0.354
Makkink	2.599	-2.112	5.997	-33.00	0.965	0.484	0.712
TURC	0.833	-0.679	2.478	-16.65	0.973	0.943	-0.368
Rs- radiation (Irmak 2003)	2.338	-1.840	5.648	-27.70	0.964	0.511	0.835
Rn- radiation (Irmak 2003)	2.775	-2.176	7.268	-31.97	0.900	0.422	0.988

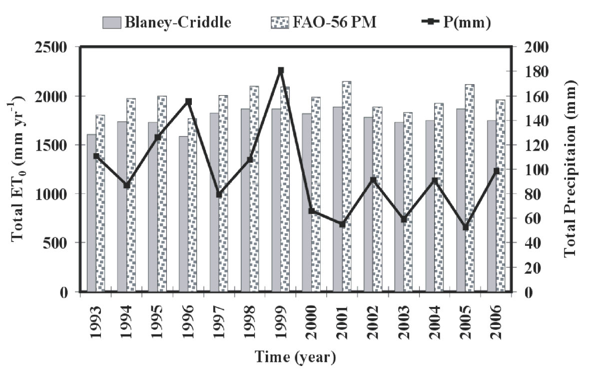

Fig. 4: Total annual ET_0 estimates given by Blaney-Criddle and the FAO-56 PM methods, in mm.year^{-1} and total annual precipitation (1993-2006)

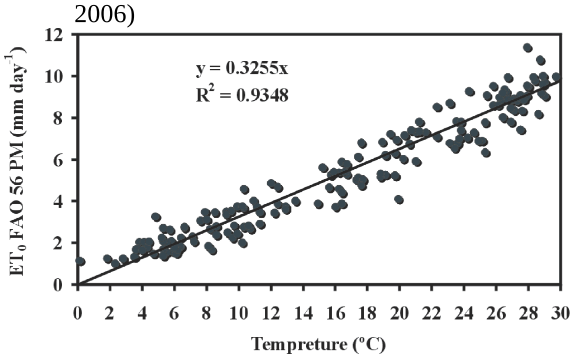

Fig. 5: Regression analysis and relationship of between mean temperature and FAO-56 PM method (1993-2006)

Balochestan province. Figure 4 shows the comparisons of annual ET_0 estimations between the Blaney-Criddle and the FAO-56 PM methods and annual precipitation.

The maximum annual sum of ET_0 estimations by BC and FAO-56 PM method is 1885 and 2146 in 2001, respectively. While in this year annual sum of precipitation is the lowest values (55 mm). The high correlation of ET_0 by the BC with FAO-56 PM method clearly reflects the importance of the temperature and solar radiation. 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 FAO-56 PM method and mean air temperature data (Fig. 5).

Linear regression of air temperature and ET_0 as FAO-56 PM method explains 90% of the variance. The advantage of this method is that only climatic parameter used in it is temperature and in all weather stations is available. Thus, ET_0 models can help to choose an appropriate deficit irrigation approach by combining ET_0 information with the crop performance and soil water content [30, 31].

CONCLUSION

In arid regions, ET_0 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. The 14-year meteorological data derived from Naein station located in Isfahan Iran was applied as input parameters for comparing different methods to estimate ET_0 under existing climatic conditions arid and warm in Naein, Iran. Nine empirical methods for calculating ET_0 were evaluated using meteorological data from Naein Station in Iran. The FAO-56 PM method as recommended by FAO was taken as a standard in evaluating the nine methods. In this study, using statistical indicators, the best method to estimate ET_0 in Naein station is selected and suggested Blaney-Criddle. The Blaney-Criddle method underestimated FAO-56 PM in the all of the months. The linear regression are describes between FAO-56 PM method with mean air temperature $ET_0 = 0.325×T$ (R^2=0.93). Additionally, the comparisons made for all the methods signifies that all these methods can be successfully used to estimate the ET_0 specifically in areas having the same climatic conditions as the one presented in this study.

REFERENCES

1. Allen, G.R., L.S. Pereira, D. Raes and M. Smith, 1998. ‘‘Crop Evapotranspiration-Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. FAO, Rome, Italy, pp: 78-86.
2. Slabbers, P.J., 1977. Surface roughness of crops and potencial Evapotranspiración. J. Hydrol., 34: 181-191.
3. Stefano, C. and V. Ferro, 1997. Estimation of evapotranspiration by Hargreaves formula and remotely Sensed data in semi-arid Mediterranean Areas. J. Agric. Eng. Res., 68: 189-199.
4. Wu I-Pai., 1997. A Simple evapotranspiration model for Hawaii: The Hargreaves model. Engineer’s Notebook, 106: 1-2.
5. García, M., D. Raes, S.E. Jacobsen and T. Michel, 2007. Agroclimatic constraints for rainfed agriculture the Bolivian Altiplano. J. Arid Environ., 71: 109-121.
6. Price, J., 1984. Land surface temperature measurements from the split window channels of the NOAA 7 Advanced Very High Resolution Radiometer [J]. J. Geophys. Res., 89(D5): 7231-7237.
7. Bastiaanssen, W., XXXX. SEBAL-based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey [J]. J. Hydrol., 229(1-2): 87-100.
8. Heydari, M.M. and M. Heydari, 2013. Calibration of Hargreaves-Samani equation for estimating reference evapotranspiration in semiarid and arid regions. Arch Agron Soil Sci. http:// dx.doi.org/ 10.1080/ 03650340.2013.808740.
9. Allen, R.G., W.O. Pruitt, J.L. Wright, T.A. Howell, F. Ventura, R. Snyder, D. Itenfisu, P. Steduto, J. Berengena, J.B. Yrisarry, M. Smith, L.S. Pereira, D. Raes, A. Perrier, I. Alves, I. Walter and R. Elliott, 2006. A recommendation on standardized surface resistance for hourly calculation of reference ET0 by the FAO56 Penmane Monteith method. Agric. Water Manage, 81: 1-22.
10. De Bruin, H.A.R. and J.N.M. Stricker, 2000. Evaporation of grass under non-restricted soil moisture conditions. Hydrol. Sci., 45(3): 391-406.
11. Hussein, M., Al-Ghobari, 2000. Estimation of reference evapotranspiration for southern region of Saudi Arabia. Irrig. Sci., 19(2): 81-86.
12. Kashyap, P.S. and R.K. Panda, 2001. Evaluation of evapotranspiration estimation methods and development of crop coefficients for potato crop in a sub-humid region. Agric. Water Manage., 50(1): 9-25.
13. Smith, M., 2000. The application of climatic data for planning and management of sustainable rainfed and irrigated crop production. Agric. For. Meteorol., 103: 99-108.
14. Walter, I.A., R.G. Allen, R. Elliott, M.E. Jensen, D. Itenfisu, B. Mecham, T.A. Howell, S. Snyder, P. Brown, S. Echings, T. Spofford, M. Hattendorf, R.H. Cuenca, J.L. Wright and D. Martin, 2000. ASCE’S standardized reference evapotranspiration equation. In: Proceedings of 4th National Irrigation Symposium, ASAE, Phoenix (Arizona, USA), pp: 14-16.
15. Adeniran, K.A., M.F. Amodu, M.O. Amodu and F.A. Adeniji, 2010. Water requirements of some selected crops in Kampe dam irrigation project. Australian Journal of Agricultural Engineering, 1(4): 119-125.
16. Heydari, M.M., A. Abasi, S.M. Rohani and S.M.A. Hosseini, 2013a. Correlation Study and Regression Analysis of Drinking Water Quality in Kashan City, Iran, Walailak Journal of Science and Technology, pp: 10.
17. Heydari, M.M., A. Abbasi and M. Heydari, 2013b. Estimation of Evapotranspiration in Ardestan, Center of Iran, World Applied Sciences Journal, 21(2): 230-236.
18. Heydari, M.M. and H. Noori Bidgoli, 2012. Chemical Analysis of Drinking Water of Kashan District, World Applied Sciences Journal, 16(6): 799-805.
19. Heydari, M.M. and R. Mousavi, 2011. Reconstruction of Sheikhbahaie dam of Kashan-Iran (Determination of sediments filled in dam reservoir), World Applied Sciences Journal, 14(5): 760-766.
20. Hargreaves, G.H. and Z.A. Samani, 1985. Reference Crop Evapotranspiration from Temperature. Applied Engrg. In Agric., 1(2): 96-99.
21. Droogers, P. and R.G. Allen, 2002. Estimating reference evapotran-spiration under inaccurate data conditions. Irrigation and Drainage Systems, 16: 33–45.
22. Makkink, G.F., 1957. Testing the Penman formula by means of lysimeters, J. Instit. Water Engineers, 11: 277-288.
23. Priestley, C.H.B. and R.J. Taylor, 1972. On the assessment of surface heat flux and evaporation using large scale parameters. Monthly Weather Reviews, 80: 81-92.

24. Blaney, H.F. and W.D. Criddle, 1962. Determining consumptive use and irrigation water requirements. U. S. Dept. Agr. Agricultural Research Service Tech. Bull, 1275: 59.
25. Turc, L., 1961. 'Estimation of IrrigationWater Requirements, Potential Evapotranspiration: A Simple Climatic Formula Evolved Up to Date', Ann. Agronomy, 12: 13-49.
26. Irmak, S., A. Irmak R.G. Allen and J.W. Jones, 2003. Solar and net radiation-based equations to estimate reference evapotranspiration in humid climates.Journal of Irrigation and Drainage Engineering. ASCE, 129(5): 336-347.
27. Douglas, E.M., J.M. Jacobs, D.M. Sumner and R.L. Ray, 2009. A comparison of models for estimating potential evapotranspiration for Florida land cover types, Journal of Hydrology, 373(3-4): 366-376.
28. Fooladmand, H.R. and S.H. Ahmadi, 2009. Monthly spatial calibration of BlaneyeCriddle equation for calculating monthly ET_0 in south of Iran. Irrigation and Drainage, 58(2): 234-245.
29. Mostafazadeh-Fard, B., M. Heidarpour and S.E. Hashemi, 2009. Species factor and evapotranspiration for an Ash (Fraxinus rotundifolia) and Cypress (Cupressus arizonica) in an arid region, Australian Journal of Crop Science, 3(2): 71-82.
30. Fernandez, J.E., M.J. Palomo, A. Diaz-Espejo, B.E. Clothier, S.R. Green, I.F. Giron and F. Moreno, 2001. Heat-pulse measurements of sap flow in olives for automating irrigation: tests, root flow and diagnostics of water stress. Agricultural Water Management, 51: 99-123.
31. Fernandez, J.E., S.R. Green, H.W. Caspari, A. Diaz-Espejo and M.V. Cuevas, 2008. The use of sap flow measurements for scheduling irrigation in oloive, apple and Asian pear trees and in grapevines. Plant and Soil, 305: 91-104.