Assessment of reference evapotranspiration models in cold weather conditions

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Abstract: Evapotranspiration is one of the important factors that knowing the exact amount, for determining water requirements and irrigation system design is essential. One way to determine evapotranspiration using experimental models, but to use them in every place must first be evaluated. For this purpose, the study compared the results of 18 models evapotranspiration with drainage Lysimeter and the Penman-Monteith (FAO56) was evaluated. This study was conducted in Hangar research station of the University of Mohagheghe Ardabili, Ardabil. For this purpose grass were planted in 3 Lysimeter and around the Lysimeter. Grass evapotranspiration measured by volumetric Lysimeter based on water balance equation components (input and output water volume, save moisture and evapotranspiration), was estimated. To estimate reference evapotranspiration 18 models, including models such as temperature, radiation, and the combination was chosen. The meteorological synoptic station of Ardabil was used to prepare the information needed to model. Besides the results of Lysimeter, evapotranspiration obtained by the FAO Penman-Monteith model also was used as a reference for comparing the performance model. Evapotranspiration estimation models using statistical indices, root mean square error (RMSE), mean absolute error (MAE), the estimated margin of error (PE), the ratio (MR) and spearman's rho coefficient is calculated as follows to cross they were evaluated. The results showed that for all models, high dispersion of points around the line one to one, or answer them consistent with the results of Lysimeter answer is not good. Moreover, some of these models overestimated and underestimated some of them to calculate evapotranspiration. Using statistical indicators may be compared with the results of Lysimeter, at the most proper research models, respectively Blaney Cradle, Ravazzani and the Rn and the weakest models respectively Irmak and Valiantzas. Overall fit the model results against the results of the FAO Penman-Monteith model compared to its results compared to the results of Lysimeter, was more suitable. Also according to the statistical criteria in this study, the FAO Penman-Monteith model, the most appropriate models were Turk, Berti and the Trajkovic, and the weakest models, modified Hargreaves-Samani, Irmak and Scandal were determined. In both assessments methods (Lysimeter and FAO Penman-Monteith model) were not the same in determining our study was the weakest model in place. That is, both methods together, Irmak models (2003) and models Valiantzas (2013) had the weakest results. In other words, although the sum of the two methods compares the most appropriate models cannot be identified with certainty, but the weakest model was determined.

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1. Introduction

Evapotranspiration is one of the important factors that needs to be accurately estimated for determination of the water demand and design of irrigation systems. Determination of the volumes and components of an irrigation system and estimation of its implementation costs are dependent on determination of the water demands (1, 3, 5 and 12). The plant water demand is a function of evaporation (E) and transpiration (T), which has daily fluctuations. Allen et al. (1998) introduced a new term for evapotranspiration (ET) that is known as reference evapotranspiration (ET0) (2, 4, and 7). ET is defined as is the sum of evaporation and plant transpiration from the Earth's land, but ET0 is defined as evapotranspiration from an extensive surface of green grass of uniform height, with the following specification; an assumed crop height of 8 to 15 cm, the Albedo coefficient of 0.23, Fixed Canopy Resistance of 70 seconds per meter, complete shading of the ground without water deficiency (6, 13). ET0 depends on different atmospheric factors such as solar radiation, air temperature, relative humidity, wind speed, crop conditions such as type and species, age, growth period and crop density, soil condition, soil type, salinity, fertilization and so on (8). Estimation of ET0 value based on parameters such as rainfall and irrigation is one of the most difficult parts of the water balance models (10, 11 and 13). Considering the direct and indirect measurement conditions, there are many methods for estimating the crop water demands. Direct methods consist of a variety of Lysimeters (weighting and drainage) and soil moisture balance, while indirect methods mostly include empirical models (22). Although direct methods are the most precise ET0 measurement methods, the high cost and advanced technology requirements of these methods make it impossible to provide their execution conditions in all locations. On the contrary, empirical ET measurement models are based on meteorological data and conditions, and are divided into three groups: temperature based, radiation based and hybrid models (4, 8, and 17). Despite their simplicity, these models have two major application problems: 1-, these models are not public and should be calibrated and verified for different area, in other words, they are developed under certain circumstances. 2-, some of these models require a lot of data that cannot be measured in all locations. Calibration of evapotranspiration models is usually performed using a lysimeter or a reference model, which is usually the FAO Penman-Monteith method (FAO 56) (11, 15, 20, and 21). Many studies worldwide have already verified the accuracy of the FAO Penman-Monteith model in various climatic conditions (2 to 6, 18, and 19). However, the FAO Penman-Monteith model requires a lot of information that is not completely available or measureable at some meteorological stations, on the other hand, there are no meteorological stations in many developing plains. Therefore, the use of models that require less meteorological information seems to be necessary for areas where information is lacking or defective. Attempts are made in many studies to introduce a simple model with acceptable accuracy comparable to the Penman-Monteith FAO model. These studies include: Trajkovic (2007) that was an attempt to investigate the effectiveness of the Hargreaves–Samani model in comparison with the FAO-Penman-Monteith model under wet conditions in Serbia. The researcher reported that the effectiveness of the Hargreaves–Samani model is acceptable. (21). Tabari et al. (2013) reported that the Turk method was the most suitable model in cold-humid and arid climates; and the Hargreaves–Samani model was the most accurate model in humid and semi-arid conditions (20). Liu et al. (2017) evaluated 16 models of evapotranspiration estimation using the weighting lysimeter data in Beijing, China. The results showed that compared to the lysemetric results, all the other evapotranspiration estimation methods underestimated the evapotranspiration levels. The researchers also announced that the FAO Penman-Monteith model could be accepted as a standard computational method for calculating ET0 [11]. Hezhber et al. (2015) evaluated 12 models of ETo and artificial neural network modeling in comparison with lysimetric data at the Kahriz metrological station of Urmia and found that the artificial neural network modeling results were more reliable than the results obtained from other models (7). In addition, the Turk model was recognized as the most suitable model. The high efficiency of this model despite using minimum metrological data for estimation of ETo, has given it an advantage over other models. A similar study was conducted by Mousavi Baghi et al. (2009) in Khorasan Razavi, and the results showed that the FAO Penman-Monteith model (FAO 56) outperforms the lysimeter-based model (14). In addition to the lysimeteric model, in some cases the FAO-Penman-Monteith model (FAO 56) was used as a basis for comparison. For example, Djaman et al. (2016) evaluated 16 evapotranspiration estimation models based on the results of the FAO Penman-Monteith model (FAO 56) in the Senegal River Valley. The results of their research showed that Valiantzas, Terabert, Romanenko, Schendel and Mahringer models were suitable equations for the estimation of evapotranspiration in the research site (4). Khoshhal et al (2015) evaluated several models of evapotranspiration based on the results of evaporation pan in the drainage basin of the country and found that the Hargreaves- Samani, Blaney criddle and Turk models were identified as the most suitable models in the research site (9). According to the results of the research, each reference evapotranspiration estimation model has been extracted from a particular site and the climate conditions associated with that site, therefore it is necessary to evaluate the efficiency of each model for use in other sites. To this end, 18 evapotranspiration estimation models (both simple and complex) were evaluated in comparison with the results obtained from drainage lysimeter designed for this purpose. On the other hand, considering that the FAO-56 model is a global model and has extensive application (executive and research) across the country, this model was considered as the base model in the second phase of the study and other models were evaluated against it using statistical indices.

2. Material and Methods

Case study: The present study was conducted in Ardebil with coordinates 38 ° 10'-38 ° 15'N and 48 ° 15'48 ° 20'E with an average elevation of 1,350 m (Fig. 1).) The required meteorological information was collected from Ardabil synoptic station with coordinates 38 ° 15' N and 48 ° 17' E with an elevation of 1338 meters. According to the figures obtained from 1375-1395 The average annual rainfall, the average monthly minimum temperature and the average maximum monthly temperature were equal to 28.89 mm, 2.4 and 15.1 ° C respectively.

Drainage lysimeters: The lysimeters needed to measure the water balance components, especially potential evapotranspiration at the ***Hangar*** research station of the Agricultural Faculty of Mohaghegh

Ardebili University, were constructed with the following characteristics (Fig. 2). The diameter of the lysimeters was 60 cm and their height was 90 cm. 6 sensors (gypsum block) at 5, 15, 25, 40, 60 and 80 cm depths of Surface soil, whose resistance was measured by the ELE-MC-302 were used to measure the soil moisture changes. As Fig. 2 shows, the water drained through the outlet embedded in the bottom of the lysimeters was collected and measured. Inside the lysimeters, grass was cultivated as a reference vegetation, and the required water volume was added at the three-day irrigation interval and based on the moisture content of the different soil layers inside it. for accurate measurement of the stored water, the lysimeters's soil was divided into 6 separate layers: 0-10, 10-20, 20-5 / 32, 5 / 32-50, 50-70 and 70-90 cm and a gypsum block was installed In the middle of each layer. Physical and hydraulic characteristics of the soil were determined using three Remoulded samples and three intact samples from each layer.

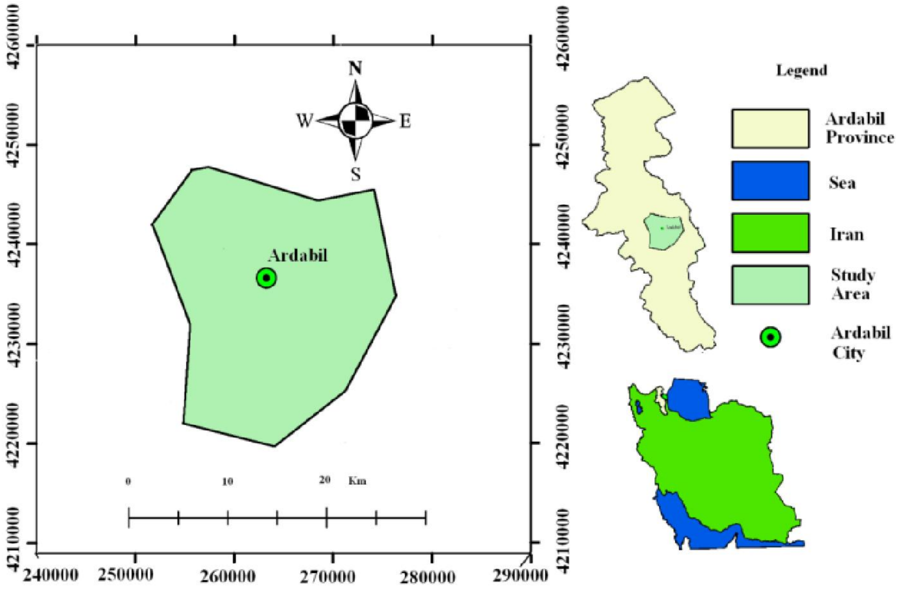

Figure1. Location of study area

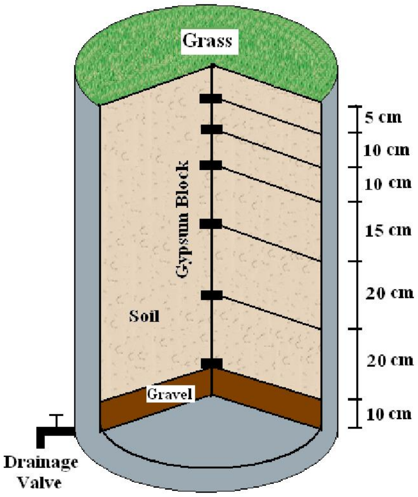

Figure 2. Sectional drawing of a Lysimeter used to ET_0 measurement

The total water stored in each layer was calculated from Equation (1).

$$S = \int_0^L \theta \, dz \simeq \sum_{i=1}^{n} \theta \, \Delta z = \theta L \tag{1}$$

Where S is the water stored in the soil (mm), θ is the water content of the soil (cm3 / cm3), L is the thickness of each layer (mm) and n is the number of layers. The changes in the soil water balance is calculated using the difference between the final and initial volume of soil at any time unit from equation (2):

$$\Delta S = S_f - S_i \tag{2}$$

Where Δ_S is the soil water storage changes (mm), and S_i nd S_f are the initial and final soil water contents (mm), respectively. The water balance equation used for lysimeters was used to measure grass evapotranspiration (ET). Equation (3) as well as the difference between input and output water and soil moisture changes were used to measure evapotranspiration of grass (ET):

$$ET = P - D \pm \Delta S \tag{3}$$

In this equation, ET is evapotranspiration (mm), P is the amount of rainfall (mm), D is the level of drainage (mm), and ΔS is the soil water storage variation (mm).

Potential Evapotranspiration estimation Models: 18 models were used to estimate potential evapotranspiration. A few points were taken into account in selection of these models: first, attempts were made to select models with fairly wide-ranging applications. Second, attempts were made to select a model that incorporates a variety of other models, including thermal, radiation, and hybrid models. Finally, a series of models ranging from the most sophisticated (FAO Penman-Monteith) to the simplest model that requires only one meteorological parameter (Blaney criddle) were used. The equation of these models is presented in Table (1).

In the equations presented in Table 1, ETo is the reference crop evapotranspiration (mm d−1), Rn is the net solar radiation at the crop surface (MJ m−2 d −1), u2 is the wind speed at 2 m height above the soil surface (m s−1), Tmean is the mean daily air temperature (◦C), G is the soil heat flux density at the soil surface (MJ m−2 d −1), es is the saturation vapour pressure (kPa), ea is the actual vapor pressure (kPa), 1 is the slope of the saturation vapour pressure–temperature curve (kPa ◦C −1), γ is the psychrometric constant (kPa ◦C −1) and Cn and Cd are constants, which vary according to the time step and the reference crop type and describe the bulk surface resistance and aerodynamic roughness. Tactual vapor pressure (kPa), ea -ea saturation vapor pressure (kPa), Tmax maximum daily temperature (0C), Tmin minimum daily temperature (0C), RH average daily relative humidity (%), Rs of short-wave radiation (MJm-2d-1), g of moisture constant (kPa C-1), Z height of the surface of the sea (m) and λ coefficient at 20 °C The 45/2 (MJm-2d-1) are the Model Evaluation Parameters: The Efficiency of Evapotranspiration Estimation models Compared to Lysymmetric Results and the FAO Penman-Monteith Equation (FAO56) In this study, is evaluated using statistical indices, root mean square error (RMSE), mean absolute error (MAE), Percentage Error of Estimation (PE), Mean Ratio (MR) that are calculated as follows (4):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2} \quad (4)$$

$$MAE = \frac{\sum_{i=1}^{n}|P_i - O_i|}{n} \quad (5)$$

$$PE = \left(\frac{|P_{av} - O_{av}|}{O_{av}}\right) \times 100 \quad (6)$$

$$MR = \frac{1}{n}\sum_{i=1}^{n}\frac{P_i}{O_i} \quad (7)$$

In these equations, Pi and Oi denote lysymmetric evapotranspiration and the models' results, and Pav and Oav show the meanly symmetric evapotranspiration and the mean of models' results. In addition to the statistical benchmarks used to check the Correlation between the models results, Spearman's correlation coefficient was also used.

Table 1. ET$_0$models equation and its applications

No	Model	Equation	Applications
1	FAO56(1998)	$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$	Rahimikhoob et al (2012)
2	Hargreaves Samani (1985)	$\mathrm{ET_0} = 0.0023\mathrm{R_a}(\mathrm{T_{mean}} + 17.8)(\mathrm{T_{max}} - \mathrm{T_{min}})^{0.5}$	Heydari et al (2013)
3	Hargreaves-Samani modified (2000)	$\mathrm{ET_0} = 0.0135\mathrm{K_T R_a}(\mathrm{T_{mean}} + 17.8)(\mathrm{T_{max}} - \mathrm{T_{min}})^{0.5}$ $K_T = 0.00185(\mathrm{T_{max}} - \mathrm{T_{min}})^2 - 0.0433(\mathrm{T_{max}} - \mathrm{T_{min}}) + 0.4023$	Hozhabr et al (2014)
4	Irmak (2003)	$ET_0 = 0.149R_s + 0.079T_{mean} - 0.611$	Hozhabr et al (2014)
5	Trajkovic (2007)	$\mathrm{ET_0} = 0.0023\mathrm{R_a}(\mathrm{T_{mean}} + 17.8)(\mathrm{T_{max}} - \mathrm{T_{min}})^{0.424}$	Djman et al (2015)
6	Ravazzani et al (2012)	$\mathrm{ET_0} = (0.817 + 0.00022\mathrm{Z})0.0023\ \mathrm{R_a}(\mathrm{T_{mean}} + 17.8)(\mathrm{T_{max}} - \mathrm{T_{min}})^{0.5}$	Djman et al (2015)
7	Berti et al (2014)	$\mathrm{ET_0} = 0.00193\mathrm{R_a}(\mathrm{T_{mean}} + 17.8)(\mathrm{T_{max}} - \mathrm{T_{min}})^{0.517}$	Djman et al (2015)
8	Schendel (1967)	$ET_0 = 16\frac{T_{mean}}{RH}$	Djman et al (2015)

No	Model	Equation	Applications
9	Blaney Criddle (1977)	$ET_0 = P(0.46T_{mean} + 8.17)$	Niaghi et al (2013)
10	Romanenko (1961)	$ET_0 = 0.0018(T_{mean} + 25)^2(100 - RH)$	Djman et al (2015)
11	Romanenko modified	$ET_0 = 4.5\left(\frac{T_{mean}}{25} + 1\right)^2\left(1 - \frac{e_a}{e_s}\right)$	Oudin et al (2005)
12	Mahringer (1970)	$ET_0 = 0.15072\sqrt{3.6u_2}(e_s - e_a)$	Djman et al (2015)
13	WMO (1960)	$ET_0 = (0.1298 + 0.0934u_2)(e_s - e_a)$	Tabari et al (2013)
14	Rn Based (2003)	$ET_0 = 0.289R_s + 0.023T_{mean} + 0.489$	Muniandy et al (2016)
15	Makkink modified	$ET_0 = 0.7\frac{\Delta}{\Delta + \gamma}\frac{R_s}{\lambda}$	Muniandy et al (2016)
16	Turk	$ET_0 = 0.013\frac{T_{mean}}{T_{mean} + 15}\frac{23.88R_s + 50}{\lambda}$	Djman et al (2015)
18	Valiantzas 1 method (2013)	$ET_0 = 0.00668R_s\left((T_{mean} + 9.5)(T_{max} - T_{min})\right)^{0.5} - 0.0696(T_{max} - T_{min})$ $-0.024(T_{mean} + 20)\left(1 - \frac{RH}{100}\right) - 0.00455R_s(T_{max} - T_{dew})^2$ $+0.0984(T_{mean} + 17)\left(1.03 + 0.00055(T_{max} - T_{min})^2 - \frac{RH}{100}\right)$ $T_{dew} = \frac{116.91 + 237.3Ln(e_a)}{16.78 - Ln(e_a)}$	Djman et al (2015)
19	Valiantzas 2 method (2013)	$ET_0 = 0.05(1 - \alpha)R_s(T_{mean} + 9.5)^{0.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 +$ $0.048(T_{mean} + 20)\left(1 - \frac{RH}{100}\right)(0.5 + 0.536u_2) + 0.00012Z \; , \alpha = 0.25$	Djman et al (2015)

3. Results and discussion

Due to the fact that moisture variation, in lysimeters, is one of the components of the water balance, and moisture variations were measured using a gypsum block, and given that the precision of the blocks was constantly monitored, the period in which the gypsum blocks showed the highest precision (lowest error) was selected as the research period (about three months of peak water demand during the growth period). In the research period, the minimum temperature variations range from 3.4 to 16.2 °C and the maximum temperature variations range from 10.4 to 40.4 °C. during the statistical period Variation in wind speed at the height of two meters above the ground level varied from 0.6 to 9.1 m / s and moderate relative humidity variations ranged from 22.6 to 97.1%. Short-wave radiation variations were in the range of 0.8 to 7.6 mm per day (Fig. 3). Comparison of the models results with the lysimetric results, according to Fig. 4, shows that the dispersion of the points around the one to one line is significant in all models and this means that there is no considerable consistency between the models' results and the lysimetric results. On the other hand, some of these models have overestimated and some of them have underestimated the evapotranspiration. According to the RMSE and MAE indices whose values are equal to 2.6 and 12 / 2 (mm.day-1) respectively, the Blaney criddle model was found to be the most appropriate model. According to table (2) and figure (4), the model proposed by Rawazani et al. (2012) with RMSE and MAE indexes of 3.02 and 2.47 (mm.day-1) is ranked second. On the contrary, the model proposed by Irmak' (2003), with RMSE and MAE indexes of 4.92 and 4.38 (mm.day-1) respectively, was ranked lowest in comparison with the lysimetry results. The Valiantzas's first and second models (2013) were ranked lowest, after the Irmak's model, with RMSE and MAE indices of 4.53 and 3.87 (mm.day-1) for the first method and 4.24 and 3.64(mm.day-1) for the Second method.

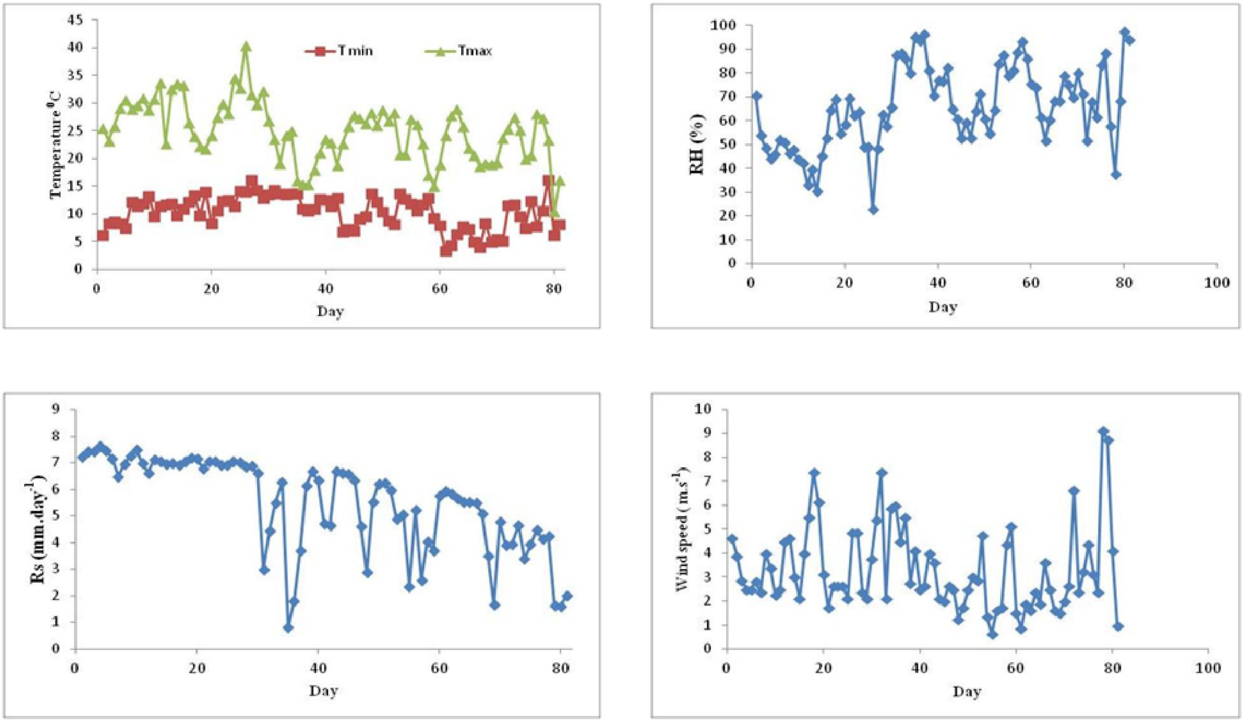

Figure 3. Climate data variable during the study at Ardabil

Using this indicator alone, the modified Hargreaves-Samani model estimates of evapotranspiration increased by 9%, but other models' estimates of evapotranspiration was lower. Similar results have also been reported by Tabari at al. (2011) and Dajaman et al (2016). The modified models presented by Schendel (2014) and Romanenko (with 4% underestimation) Rawazani et al (2012) (with 5% underestimation), and the Blaney criddle Model (with6% underestimation) were recognized as the most suitable models according to the MR index. The Valiantzas's second model (2013) (with 55% underestimation) the Valiantzas's first model (2013) (with 59% underestimation), and the model proposed by Irmak (2003) (with 69% underestimation) were ranked lowest in terms of evapotranspiration estimation compared to the lysimetric results. According to the PE index, the Valiantzas 2 (2013) model with the mean ET calculation error of 60.37%, the Valiantzas 1 (2013) model with mean ET calculation error of 64.5% and the Irmak model (2003) with the mean ET calculation error of 73.12% were ranked lowest among the ET measurement model. According to this index, however, the best results were obtained from the modified Hargreaves-Samani model with mean error of 7%, the modified Romanenko model with 16% mean error and the Blaney criddle model with a mean error of 20%. In general, and according to all statistical indices, it can be argued that in comparison with the lysimetric results, the most suitable in-site models are Blaney criddle model, the model proposed by Rawazani et al. (2012) and the Rn model respectively while the weakest models are the ones introduced by Irmak (2003) and Valiantzas (2013) models. Considering that Spearman's correlation coefficient is significant if P value is less than 0.05 (9) and According to Table 2, the results obtained from the study models, compared to the lysimeter used in the present study did not show any significant correlation. Comparison of the models results with the lysimetric results: According to Fig. 5 and The results presented in Table 3 and their comparison with Figure 4 and Table 2 it can be generally argued that the appropriateness of the models results relative to the results of FAO Penman-Monteith model is much more acceptable in comparison to their appropriateness relative to lysimetric results. This could be attributed to the fact that the information required for calculations in all models are meteorological parameters, and the computational principles of some of these models have a lot in common (11). On the other hand, the accuracy of gypsum blocks compared to the TDR machine and the total accuracy of drainage lysimeters compared to the weighting lysimeters is much lower.

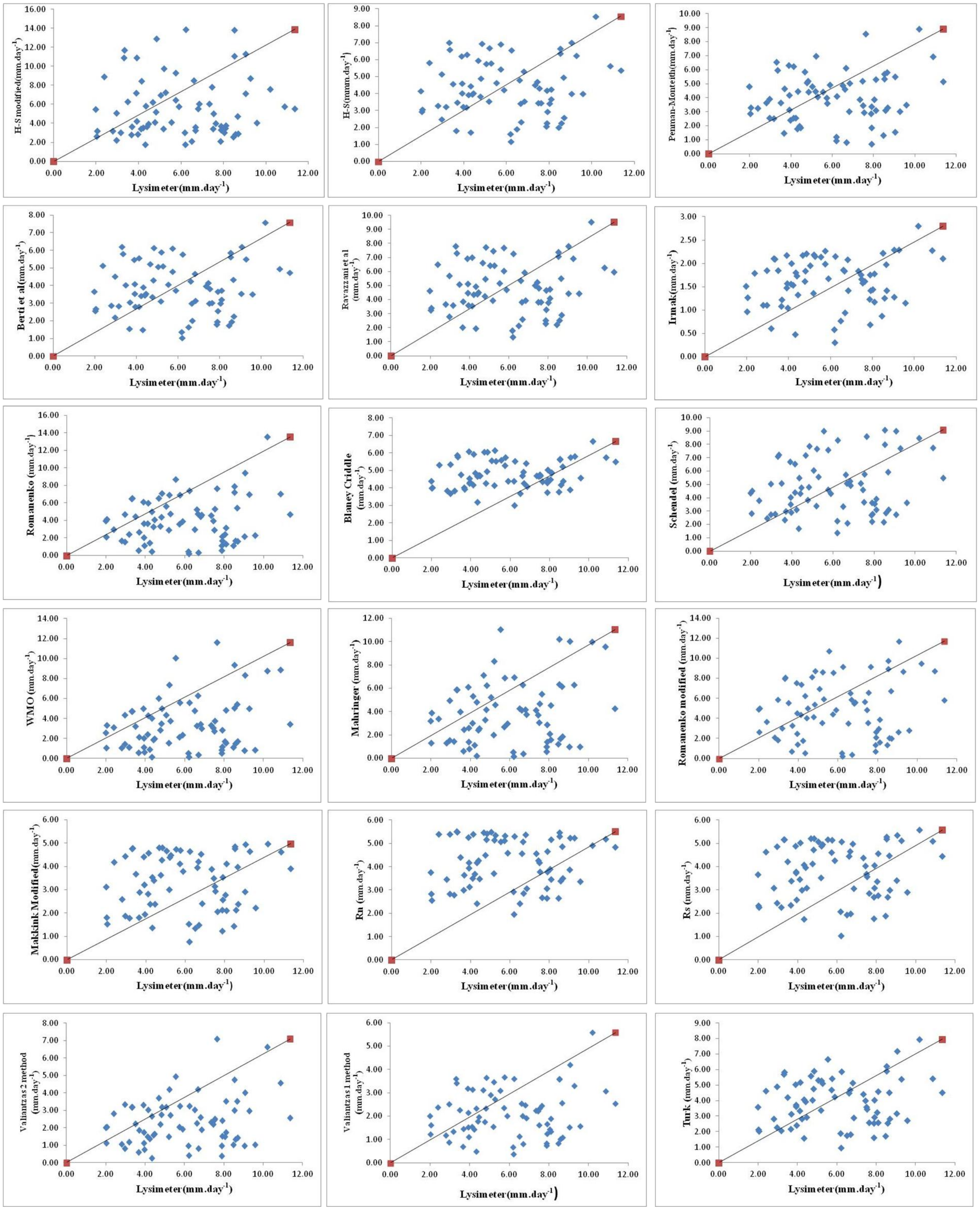

Figure 4. Relationship between the daily reference evapotranspiration (ET_0) estimates of each method versus the Lysimeter daily evapotranspiration.

Table 2. Performance evaluation of the 18 references evapotranspiration (ET_0) models versus result of Lysimeter

No	Model	PE (%)	MR (-)	MAE ($mm.day^{-1}$)	RMSE ($mm.day^{-1}$)	Spearman Coefficient R	Spearman Coefficient P-value
1	Penman-Monteith	33.52	0.78	2.69	3.35	0.04	0.70
2	Hargreaves-Samani	27.50	0.86	2.55	3.16	-0.022	0.80
3	Hargreaves-Samani modified	07.00	1.09	3.03	3.76	-0.023	0.84
4	Irmak	73.12	0.31	4.38	4.92	0.12	0.28
5	Trajkovic	41.10	0.70	2.83	3.51	-0.025	0.82
6	Ravazzani et al	19.40	0.95	2.47	3.02	-0.029	0.80
7	Berti et al	36.30	0.75	2.72	3.40	-0.029	0.79
8	Schendel	15.22	0.96	2.62	3.34	0.065	0.56
9	Blaney Criddle	20.00	0.94	2.12	2.60	0.085	0.45
10	Romanenko	32.00	0.78	2.90	3.64	0.023	0.84
11	Romanenko modified	16.00	0.96	2.97	3.66	0.025	0.82
12	Mahringer	31.00	0.75	3.25	4.02	0.074	0.51
13	WMO	43.50	0.62	3.20	3.95	0.087	0.44
14	Rn	30.30	0.82	2.37	3.04	-0.017	0.88
15	Makkink modified	45.00	0.64	2.93	3.66	0.02	0.86
16	Turk	34.70	0.76	2.57	3.28	0.041	0.71
17	Valiantzas 1 method	64.50	0.41	3.87	4.53	-0.004	0.97
18	Valiantzas 2 method	60.37	0.45	3.64	4.32	0.075	0.51

Table 3. Performance evaluation of the 18 references evapotranspiration (ET0) models versus result of Penman-Monteith model

No	Model	PE (%)	MR (-)	MAE ($mm.day^{-1}$)	RMSE ($mm.day^{-1}$)	Spearman Coefficient R	Spearman Coefficient P-value
1	Hargreaves-Samani	09.06	1.23	1.07	1.45	0.66	0.00
2	Hargreaves-Samani modified	39.90	1.58	2.21	3.17	0.56	0.00
3	Irmak	59.57	0.36	2.37	2.77	0.69	0.00
4	Trajkovic	11.38	1.01	1.07	1.40	0.65	0.00
5	Ravazzani et al	21.21	1.36	1.31	1.69	0.66	0.00
6	Berti et al	04.12	1.07	1.03	1.36	0.66	0.00
7	Schendel	27.53	1.36	1.45	2.39	0.74	0.00
8	Blaney Criddle	20.34	1.52	1.32	1.63	0.59	0.00
9	Romanenko	02.24	0.99	1.27	1.64	0.74	0.00
10	Romanenko modified	26.39	1.23	1.71	2.37	0.74	0.00
11	Mahringer	03.76	0.95	1.53	2.33	0.79	0.00
12	WMO	14.92	0.79	1.32	1.69	0.79	0.00
13	Rn	04.80	1.26	1.07	1.45	0.61	0.00
14	Makkink modified	17.12	0.92	1.10	1.49	0.68	0.00
15	Turk	01.80	1.09	1.02	1.33	0.69	0.00
16	Valiantzas 1 method	46.66	0.57	1.88	2.22	0.72	0.00
17	Valiantzas 2 method	40.38	0.61	1.63	1.88	0.80	0.00

According to the results of Table 3 versus the results of the FAO Penman-Monteith model and considering the RMSE and MAE indices, the most suitable models are the Turk model, with RMSE and MAE of 1.3 and 1.01 ($mm.day^{-1}$), the model proposed by Berti et al. (2014) with RMSE and MAE of 1.36 and 1.03 ($mm.day^{-1}$) and the Trajukovich (2007) and basic Rn models with RMSE and MAE of 45.1 and 1.07 ($mm.day^{-1}$) respectively.

Therefore, based on the RMSE and MAE indices, the modified Hargreaves-Samani model with the RMSE and MAE values of 17.3 and 21.2 ($mm.day^{-1}$), in the research site, the Irmak (2003) model with the RMSE and MAE values of 2.77 and 37.2 ($mm.day^{-1}$) and the Schendel (1967) model with the RMSE and MAE values of 39.2 and 1.45 ($mm.day^{-1}$), provided the weakest results compared to the FAO Penman-Monteith model. Moreover, taking into account the P index values in the Spearman correlation coefficient (which are less than 0.05 (Table 3)), it can be argued that the results of the models enjoy an acceptable correlation compared to the results of the FAO Penman-Monteith model. As indicated, the MR index accounts for the underestimations and overestimations of models. According to this index, the model proposed by Irmak (2003), Valiantzas 1 (2013), Valiantzas 2 (2013), WMO (1960), Makkink modified (2016) and the Mahringer (1970) have underestimated the evapotranspiration level by 54, 43%, 39, 258, and 5% respectively. In addition, the results show that the Hargreaves-Samani modified model (2000), the Blaney Criddle (1977) the Ravazani et al. (2012) and Schendel (1967) the Rn (2003). The Hargreaves-Samani models (1985) and the modified Romanenko (2005), the Turk model and the Berti et al. (2014) have overestimated the daily evapotranspiration levels by 58%, 36%, 36%, 25%, 23%, 23%, 9% and 7% respectively.

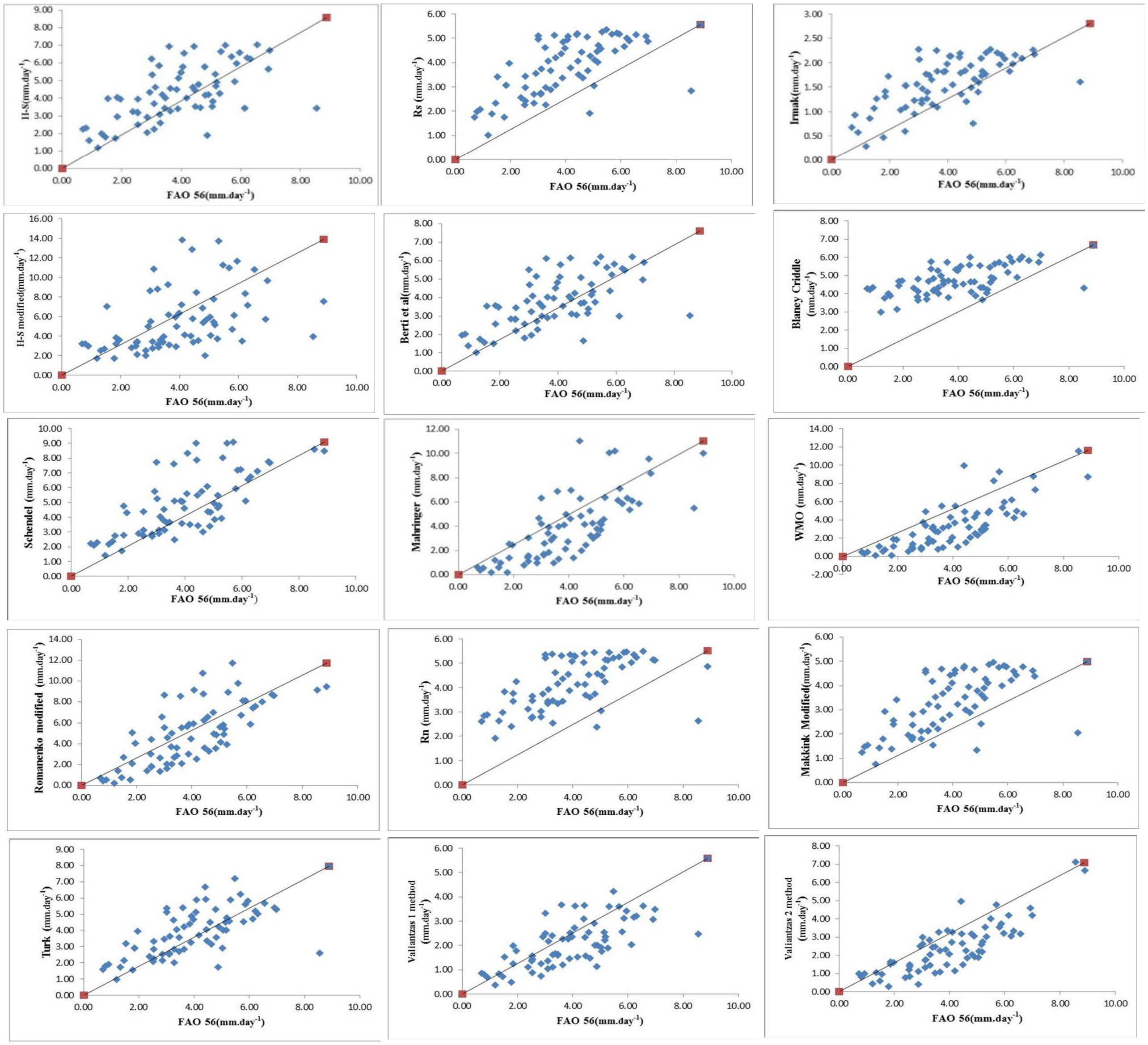

Figure5. Relationship between the daily reference evapotranspiration (ET_0) estimates of each method versus the Penman-Monteith daily Evapotranspiration.

It should be noted that according to the MR index, the Romanenko (1961) with 1% overestimation and the Trajukovich (2007) with 1%, under estimation have provided the most reasonable estimates of evapotranspiration compared to the FAO Penman-Montiot model. According to the PE index, which shows the percentage of mean error in comparison with the means calculated by the FAO Penman-Monteith model, the Turk model (1.8%,) the Mahringer (1970) (3.76%) The Berti et al. (2014) (12.4%) and the Rn (2003) (4.8%) are ranked as the most suitable models and models proposed by Irmak (2003) (59.57%), Valiantzas 1 (2013) (46%), the Valiantzas 2 (2013) (40.38%) and the Hargreaves-Samani modified model (2000) (39.9%) provided the weakest results. taking into account all statistical benchmarks in the research site, the most appropriate models are the Turk, Bertie et al. (2014), Trajukovich (2007) respectively and the weakest models are Hargreaves-Samani modified (2000), Irmak (2003) and Schendel (1967) respectively.

4. Conclusion

In this research, 18 models of potential evapotranspiration estimation were compared to the evapotranspiration estimation results obtained from drainage lysimeters in Ardebil weather conditions. In addition to comparing the models results with the lysimetric results, the models were evaluated based on the FAO56 results using some statistical benchmarks. Lysimetric results showed that the most suitable models in the research site were Blaney Criddle, Ravazani et al. (2012) and Rn model respectively and the weakest models were Irmak (2003) and the Valiantzas 1 and 2 (2013) respectively. The evaluation of evapotranspiration estimation versus the results of the FAO Penance-Monteith Global Model (FAO56) showed that the most suitable models are the Turk, Bertie et al. (2014) and the Trajukovich (2007) respectively and the weakest models are the Hargreaves-Simony modified model (2000), Irmak (2003) and Schendel (1967). Taking into account the results of Tables (2) and (3), and considering that different references and benchmarks were used in both estimation evaluations (Lysymeter and FAO Penman-Monteith model), both methods turned out to be consistent in terms of identification of the weakest models in the research sites. That is, in both methods, the Irmak (2003) and the Valiantzas (2013) models provided the weakest results. In other words, although the comparative analysis of both methods cannot help us identify the most suitable models with certainty, it can help us identify the weakest models with certainty.

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