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Determining the Appropriate Method for Estimating Potential Evapotranspiration: A Case Study of Meshkinshahr Synoptic Station, Ardabil Province, Northwestern Iran

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Abstract

Evaporation as a basic data has a special importance in agricultural, hydrological, meteorological, and water and soil conservation research; however, measurement of actual evapotranspiration (via lysimeter as an exact measurement instrument) is so difficult and impractical. During the past 50 years, several empirical methods were developed by different scientists and technicians for measuring evapotranspiration based on various climatic variables. In the present study, monthly potential evaporation was estimated using the data obtained from Meshkinshahr synoptic via 5 empirical and theoretical methods of Turc, Linacre, Thornthwaite, Blaney-Criddle and Ivanov. Then, in order to select the best empirical model for Meshkinshahr Synoptic Station, SPSS and Excel softwares were used for statistical analysis. In addition, different correlation models were developed between class-A pan data and empirical models. In order to select the best model, correlation among the three models (i.e. linear, logarithmic, and inverse) was determined and the model with the highest correlation coefficient was chosen. The obtained results were compared with class-A pan data. The results showed that among the tested methods, Turc method had the highest consistency with class-A pan evaporation data.

Keywords: Class-A Pan, Empirical Methods, Meshkinshahr, Potential Evapotranspiration

1. Introduction

Fifty five percent of rainfall on lands is directly evaporated. In dry and semi-dry climates, much of annual rainfall returns to the atmosphere through evaporation and transpiration. Evapotranspiration may be defined as the sum of evaporation rate from soil surface and the amount of water absorbed by plant roots and transpired from the surface of branches and leaves. There are almost fifty methods for estimating evapotranspiration; however, the methods present different results due to their various hypotheses and input data requirements in different climatic regions (Grismer, 2002). Having knowledge about evaporation rate is very important hydrological variable in agricultural research and water and soil conservation plans as well as modeling for such conservation. Iran benefits from 251 mm of the overall global rainfall, 71 percent of which (i.e. 179 mm) is lost through evaporation (Saadatkhah et al., 2001; Shaban et al., 2007).

Salih and Sendil (1984) stated that temperature and sunlight play principle roles in evaporation and transpiration in arid and semi-arid regions of Saudi Arabia. Furthermore, Shih (1984) claimed that the mentioned parameters result in the same numerical results as other parameters in daily and monthly estimations of evaporation and transpiration. In Iran, there are only a few climatology stations and they don't have a proper spatial distribution (Daneshkar Arasteh et al., 2007). In the meanwhile, the data collected from a few stations are not applicable due to the lack of sufficient statistics and sometimes low-quality information. Climatology pans are among the tools used directly for estimating the evaporation rate with low cost. The results obtained from the pans are generalizable to the evaporation in lakes, ponds, and agriculture (Irmak et al., 2002).

In the present study, five methods (Turc (1961), Linacre (1977), Thornthwaite (1948) and Blaney-Criddle (1950)) were used for estimating the potential evaporation and transpiration in synoptic station of Meshkinshahr-Iran. The present study was aimed to compare annual and monthly potential evapotranspiration rates estimated through various methods with class-A pan in synoptic station of Meshkinshahr-Iran.

2. Materials and Methods

The synoptic station is placed in Meshkinshahr in Ardebil Province (longitude: 47° 40'; latitude: 38° 233'; altitude: 1568.5 m). The annual mean precipitation rate and average monthly temperature between 1995 and 2005 were 383.9 mm and 107°C, respectively.

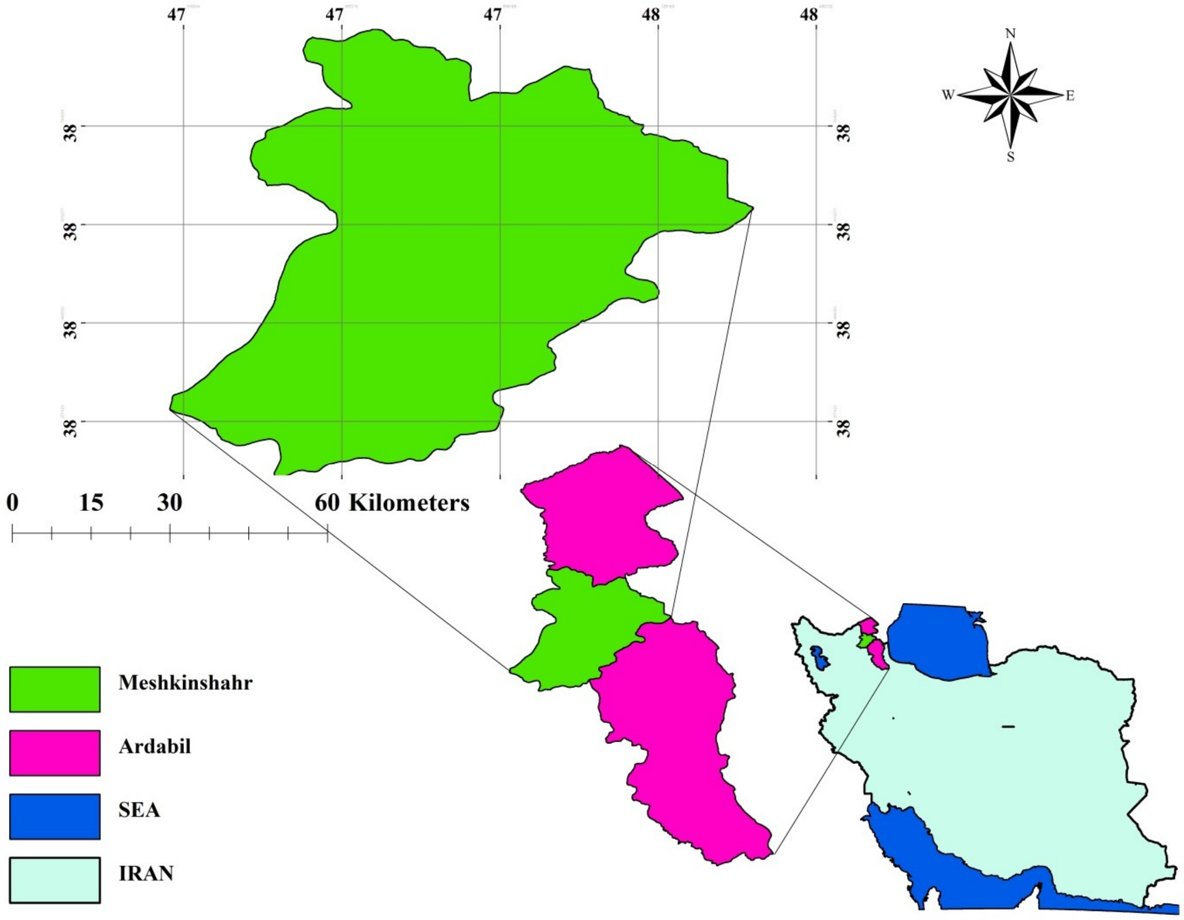

Fig. 1. Location of Meshkinshahr synoptic station in Ardebil Province– Iran.

Table 1. The mean monthly evaporation rates in Meshkinshahr synoptic station.

Month	Dec.	Nov.	Oct.	Sep.	Aug.	Jul.	Jun.	May.	Apr.	Mar.	Feb.	Jan.
Evaporation from class-A pan (mm)	5.7	34.5	88.9	131.4	193.3	191.4	172.4	122.8	69.8	1.7	0	0

In order to estimate the potential evapotranspiration rate in the synoptic station, the reflection models, Turc and Linacre, were used in addition to the temperature models, Thornthwaite, Blaney-Criddle, and Ivanov. Brief descriptions of the methods are as follows:

2.1. Ivanov Method

With regard to the relationship between evaporation rate, temperature and relative humidity, monthly evapotranspiration rate (mm) is obtained as follows:

(1) $$E=0.0018(25+T^2)(100-R)$$

where E, R and T stand for monthly evapotranspiration rate (mm), relative humidity, and monthly temperature average (°C), respectively.

2.2. Turc Method

Here, two different formulae are presented for areas with relative humidity of lower and higher than 50 percent:

(2) $$ET=0.13(R+50)\left(\frac{t_m}{t_{m+15}}\right)$$

(3) $$R=R_a\left(0.35+0.68\left(\frac{n}{D}\right)\right)$$

where ET, R, Rα, and n/D denote evapotranspiration rate (mm) within a 10-day period, the average sunlight (cal/cm^2/d), intensity of sunlight (derived in terms of latitude in a given month) and cloudiness ratio, respectively.

2.3. Thornthwaite Method

This method is suitable for temperate regions, for it only considers temperature for estimating the potential evapotranspiration rate. It is estimated as follows:

(4) $$EPT=1.6\left(\frac{10T}{I}\right)^{a}$$

(5) $$I=\sum_{n=1}^{12} i$$

(6) $$a=0.000000675I^3-0.0000771I^2+0.01792I+0.49239$$

where ETP, T, and I denote monthly potential evapotranspiration (mm), monthly average temperature (°C), and annual temperature index (sum of monthly temperature indices), respectively. Moreover, α coefficient was derived through annual temperature index.

Thornthwaite method is adopted for the monthly average temperatures 0-26.5 and evapotranspiration is considered to be zero for the temperature 0°C and minus 0°C; on the other hand, for the temperatures over 26.5°C, it is independent from I and is obtained according to the monthly average temperature.

Furthermore, the rate estimated by this method is for the months with 30 days and 12 hours light; in case one of the mentioned criteria changes, the estimated rate should be corrected as follows:

(7) $$ETPc=EPT\left(\frac{D.N}{360}\right)$$

where ETPc and ETP are corrected and estimated potential evapotranspiration (mm), respectively.

2.4. Blaney-Criddle Method

This method estimates evapotranspiration power as follows:

(8) $$EPT=p(0.46T+8.13)$$

where ETP, p, and T stand for evapotranspiration power (mm/d and mm/month), average daily light percentage in a given month and monthly average temperature (°C), respectively.

After estimating the evapotranspiration, the obtained rate is corrected with regard to the related graphs, the average relative humidity and the ratio of measured sunny hours to light duration and wind speed.

2.5. Linacre Method

The following formula is utilized in this method:

(9) $$ET=\frac{\frac{700Tm}{100-L}+15(T\alpha-Td)}{80-T\alpha}$$

(10) $$Tm=T\alpha+0.006Z$$

where ET, Tα, Td, and Z denote evapotranspiration (mm), air temperature (°C), dew point temperature (°C), and altitude (m), respectively.

Since the present paper aimed to determine the relationships between evaporation estimations, the measured evaporation was compared with the rates estimated by each method. The following statistical tests were used to evaluate evaporate estimation accuracy.

(11) $$ME=Max\left|E_i-\hat{E}_i\right|_{i=1}^{n}$$

(12) $$MAE=\frac{1}{n}\sum_{i=1}^{n}\left|\hat{E}_i-E_i\right|$$

(13) $$MBE=\frac{1}{n}\sum_{i=1}^{n}(\hat{E}_i-E_i)$$

(14) $$RRMSE=\frac{1}{\bar{E}}\left[\frac{1}{n}\sum_{i=1}^{n}(E_i-\hat{E}_i)^2\right]^{0.5}$$

(15) $$EF=\frac{\sum_{i=1}^{n}(E_i-\bar{E})^2-\sum_{i=1}^{n}(E_i-\acute{E}_i)^2}{\sum_{i=1}^{n}(E_i-\bar{E})^2}$$

(16) $$CRM=\frac{\sum_{i=1}^{n}E_i-\sum_{i=1}^{n}\acute{E}_i}{\sum_{i=1}^{n}E_i}$$

The parameters ME, MAE, MBE, RRMSE, EF, CRM, Ei, Ē, and n stand for Maximum error, Mean absolute error, Mean bias error, Relative root mean square error, Model efficiency, Coefficient of residual mass, estimated evaporation rate (mm/month), measured average evaporation (mm/month), and overall number of data, respectively (Noshadi et al., 2003).

RRMSE shows error rates with regard to the favorable amount (zero) and depicts the error in the region. CRM parameter shows underestimation or overestimation of the model. If CRM is negative, the suggested model overestimated evaporation and vice versa (Zare' Abyaneh et al., 2010). The closer EF to 1, the more correct and efficient the method is; if it is zero, model estimation is not more suitable than using data average. Of course, EF may be negative. In this case, that it shows ambiguity and lack of proper result (Kouchakzadeh and Nikbakht, 2004).

The mentioned statistical parameters state information on efficiency of the suggested model for estimation. The lower ME, MAE, and MBE, the higher the efficiency of the model (Tanny et al., 2008). The positive and negative scores show overestimation and underestimation of the real rate, respectively (Wackernagel, 2003).

The data were statistically analyzed by SPSS and Excel software.

3. Results and Discussion

The results obtained for the required parameters are shown in Table 2.

Table 2. Required climatological parameters in Meshkinshahr synoptic station for calculation of potential evapotranspiration.

	Dec.	Nov.	Oct.	Sep.	Aug.	Jul.	Jun.	May.	Apr.	Mar.	Feb.	Jan.
Monthly Average Temperature (°C)	2.4	6.6	12.8	17	21.3	20.7	18.2	13.9	10	4.2	0.8	0.1
Monthly Temperature Index (I)	0.33	1.52	4.15	6.37	8.97	8.59	7.07	4.7	2.85	0.67	0.062	0.002
Average Light Hours (D)	9.5	10.2	11.25	12.45	13.6	14.5	15.3	14.2	13.2	11.9	10.2	9.9
Dew Point Temperature (Td)	-6.2	-2.4	3.4	8.8	11.5	10.7	9	6	1.1	-4.1	-8.1	-8.2
Relative Humidity (R)	59	60	61	65	58	56	59	64	60	61	58	59
Average Wind Speed (m/s)	2.72	2.26	1.8	0.87	0.77	0.87	1.03	1.59	2.83	2.93	3.55	2.47
Cloudiness Ratio (n/N)	0.48	0.52	0.58	0.58	0.65	0.65	0.64	0.59	0.46	0.48	0.56	0.49
Average Sun Light (R)	4.08	5.27	7.41	9.55	12.2	13.3	13.7	12.4	9.61	7.89	6.48	4.65

The results of evapotranspiration estimation are provided in Table 3.

Table 3. The measured potential evapotranspiration by the mentioned methods.

	Average Precipitation	Class-A Pan	Turc	Ivanov	Thornthwaite	Blaney-Criddle	Linacre
Jan.	24.6	0	1.4	46.5	0.44	12.4	78.2
Feb.	28.9	0	11.4	50.3	1.63	20.3	79.2
Mar.	41.5	1.7	50.7	59.9	15.1	40.3	96
Apr.	57	69.8	95.4	88.2	46.3	123	124.6
May	73.4	122.8	120	98	76.7	102.3	144.2
Jun.	25.1	172.4	139.6	137.7	110.9	126	175.6
Jul.	22.5	191.4	146.8	165.4	122.8	129	199.4
Aug.	11.8	193.3	146	162	123.2	127	209.1
Sep.	24.8	131.4	126.56	111.1	83	93	160.5
Oct.	24.21	88.9	105.7	100.3	55	71.3	148.1
Nov.	33.2	34.5	67.6	71.9	21.6	36	108.2
Dec.	17	5.7	29.9	55.4	6.1	24.8	89.8

The results obtained from the statistical tests of the models are provided in Table 4.

Table 4. Statistical indices for estimation of the efficiency of the models.

	MBE	MAE	ME	RRMSE	EF	CRM
Ivanov	7.36	30.2	58.2	0.39	0.15	-0.13
Turc	2.43	24.48	49	0.34	0.66	-0.028
Thornthwaite	-29.09	31.74	70.1	0.74	0.19	0.35
Blaney-Criddle	-8.88	33.05	66.3	0.51	0.25	0.03
Linacre	50.08	50.08	94.3	0.44	-0.82	-0.72

Moreover, the correlation between the measured evaporation from class-A pan and evaporation models was determined. In order to study regression relations of the models, three correlation models (i.e. linear, logarithmic, and reverse) were evaluated. The results are shown in Table 5. Afterwards, the model with the highest correlational coefficient was chosen as the most suitable correlational model.

Table 5. Regression results of experimental models with class-A pan.

	Correlation	Confidence level	R^2	α	b
Ivanov	Linear	99%	0.96	-87.164	1.795
	Logarithmic	99%	0.963	-672.38	169.27
	Reverse	99%	0.902	253.1	-13499
Turc	Linear	99%	0.908	-35.324	1.379
	Logarithmic	99%	0.52	-75.288	39.848
	Reverse	99%	0.168	96.37	-155.93
Linacre	Linear	99%	0.959	-312.04	1.654
	Logarithmic	99%	0.964	-958.62	215.20
	Reverse	99%	0904	295.09	-25382.3
Thornthwaite	Linear	99%	0.994	-4.938	1.616
	Logarithmic	99%	0.706	-27.495	35.129
	Reverse	99%	0224	99.375	-55.523
Blaney-Criddle	Linear	99%	0.832	-29.264	1.505
	Logarithmic	99%	0.766	-244.74	80.92
	Reverse	99%	0.564	145.59	-2543.5

The different models of estimation were evaluated through seven criteria (i.e. ME, MAE, MBE, RRMSE, CRM, EF, and R^2). The most and least suitable methods received lower and higher scores, respectively. The final result for each model was obtained by summing up the criteria scores (Table 6); the model with the lowest score can be considered the most suitable one for estimating the potential evapotranspiration in the region.

Table 6. The final results of scoring different methods for estimating the potential evapotranspiration in Meshakinshahr synoptic station.

	R^2	EF	CRM	RRMSE	MBE	MAE	MA	Total
Ivanov	3	3	3	2	2	2	1	16
Turc	4	1	1	1	1	1	4	13
Linacre	2	5	5	3	5	5	2	27
Thornthwaite	1	4	4	5	4	3	3	24
Blaney-Criddle	5	2	2	4	3	4	5	25

All relations used for estimating the potential evapotranspiration do not make use of similar climatic parameters; that's why there is a lack of uniformity in the results estimated by various methods. Therefore, it may be asked which relation can present a better estimation of potential evapotranspiration in every region and necessity of evaluation of each region in order to determine the most suitable method for that region is more pronounced (Rahimzadegan, 1991).

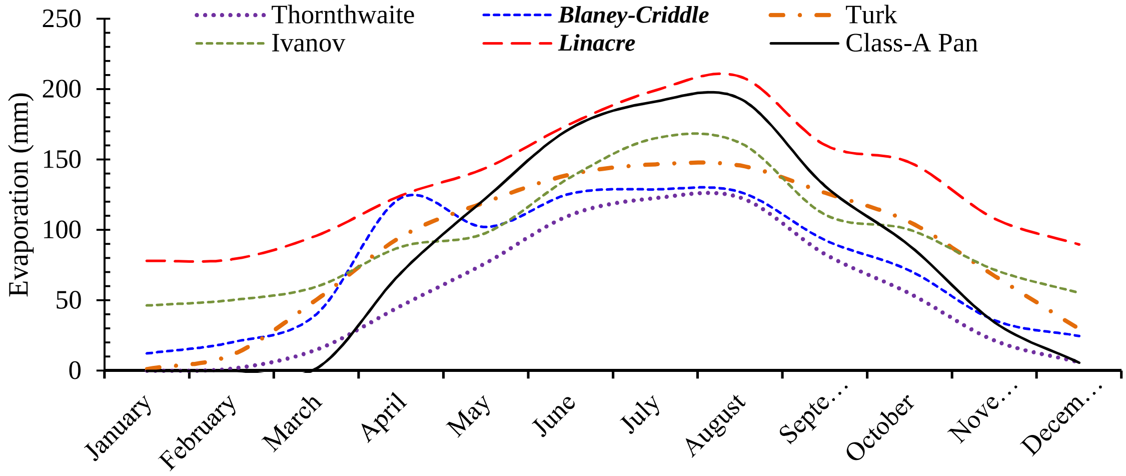

Fig. 2. Comparison of different methods for estimating potential evapotranspiration through the measured evaporation in class-A pan.

Table 7. Comparison of estimated annual potential evapotranspiration in class-A pan.

Method	**Turc**	**Blaney-Criddle**	**Thornthwaite**	**Linacre**	**Evaporation**	**Precipitation**
Annual average	1041.12	905.5	662.6	1316.2	1011.9	383.9

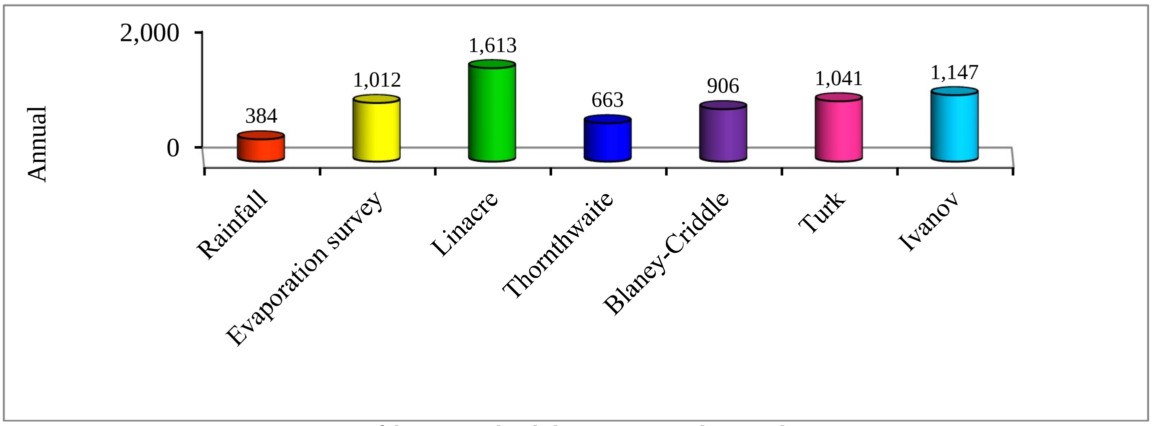

Fig. 3. Comparison of the estimated and class-A pan annual potential evapotranspiration.

As it is shown in Table 7 and Fig. 2, the estimated evapotranspiration by Turc and Ivanov methods is closer to the one measured by class-A pan; however, because Turc method was more consistent with the data obtained from the pan, Turc reflection model seems to present better estimation of the potential evapotranspiration compared to the other models due to taking more environmental parameters (temperature, humidity, sunlight, and intensity of sunlight) into consideration. Therefore, Turc method is recommended for Meshkinshahr region.

4. Conclusion

With regard to the amounts of precipitation and evaporation in Table 3 and Fig. 1, it can be concluded that the potential evapotranspiration is higher than precipitation except for January, February, March and December. This ratio decreases in cold seasons and increases in warm seasons so that the highest evapotranspiration occurs in June, July, and August due to aridity and intense sunlight. Furthermore, potential evaporation plummeted in February and January. Moreover, the highest evapotranspiration in all models took place in summer, notably in August with the lowest precipitation rate.

Selecting a suitable method is based upon acquiring the lowest scores of statistical parameters and highest correlational coefficient for each method compared to the amounts of measured evaporation from evaporation pan. Additionally, with regard to Table 6, it can be seen that the logarithmic model is the best correlational model for Ivanov and Linacre methods; however, the linear model can be regarded as the most suitable model for Turc, Thornthwaite, and Blaney-Criddle methods. Finally, the estimated amount of the models was compared with the one obtained from class-A pan by via seven criteria (i.e. ME, MAE, MBE, RRMSE, CRM, EF, and R^2) and it was found that the best experimental models are Turc, Ivanov, Thornthwaite, Blaney-Criddle, and Linacre, respectively.

With regard to the fact that in order to estimate potential evapotranspiration, class-A pan is used in many stations in Iran and it is difficult to measure its real amount by lysimeter, Turc method can be used in other areas of Ardebil Province such as Ardebil, Sarein, and Namin because of high accuracy of this method in estimating the potential evapotranspiration in Meshkinshahr. Furthermore, as experimental relations have more parameters for their estimations, their calculations are more accurate and realistic. Therefore, Turc method is strongly recommended. Future studies are directed toward determining the methods' performance in different regions with varying climatic situations.

References

Blaney, H. F. & Criddle, W. D. (1950) *Determining Water Requirements in Irrigated Areas from Climatological Irrigation Data*. Technical Paper No. 96, US Department of Agriclture, Soil Conservation Service, Washington, D. C.

Daneshkar Arasteh, P., Tajrishi, M. & Mirlatifi, S. M. (2007) Determination of the Effect of Wind Speed on Evaporation from Nimeh Sistan Well Surface by Use of Dalton Method; *Sharif Journal*, 37(2), 13-20.

Grismer, M. E., Orang, M., Snyder, R. & Matyac, R. (2002) Pan Evaporation to Reference Evapotranspiration Conversion Methods. *Journal of Irrigation and Drainage Engineering*, 128(3), 180-184.

Irmak, S., Haman, D., Jones & J. W. (2002) Evaluation of Class A Pan Coefficients for Estimating Reference Evapotranspiration in a Humid Location. *Journal of Irrigation and Drainage Engineering*, 128(3), 153–159.

Kouchakzadeh, M. & Nikbakht, J. (2004) Comparison of Different Methods for Estimation of Reference Evapotranspiration in Various Climates of Iran by Use of Standard FAO Penman-Monteith Method. *Journal of Agricultural Sciences*, 10(3), 43-57.

Linacre, E. T. (1977) A Simple Formula for Estimating Evaporation Rates in Various Climates, Using Temperature Data. *Alone Agricultural and Forest Meteorology*, 18(6), 409-424.

Noshadi, M., Amin, S. & Maleki, N. (2003) Determination of Variations in Concentration of Atrazine in a Silt-Clay Soil and Calibration of PRZM-2 Model. *Journal of Agricultural and Natural Sciences and Skills*, 7(1), 47-59.

Rahimzadegan, R. (1991) Finding a Suitable Method for Estimation of Evapotranspiration in Esfahan Region. *Journal of Iranian Agricultural Sciences*, 22(1-2), 1-10.

Saadatkhah, N., Sarang, S. A., Tajrishi, M. & Abrishamchi, A. (2001) Estimation of Evaporation from Wells. *Journal of Water and Wastewater*, 40(5), 12-32.

Salih, A. M. A. & Sendil, U. (1984) Evapotranspiration Under Extremely Arid Climates. *Journal of Irrigation and Drainage Engineering (ASCE)*, 110(3), 289-303.

Shaban, M., Khajeddin, S. J. & Karimzadeh, H. R. (2007) Determination of Drought Tolerance in a Number of Tree Species in Order to Reform Arid and Semiarid Regions. *Iranian Journal of Watershedding Sciences and Engineering*, 1(2), 58-63.

Shih, S. F. (1984) Data Requirement for Evapotranspiration Estimation. *Journal of Irrigation and Drainage Engineering (ASCE)*, 110(3), 263-274.

Tanny, J., Cohen, S., Assouline, S., Lange, F., Grava, A., Berger, D., Teltch, B. & Parlange, M. B. (2008) Evaporation from a Small Water Reservoir: Direct Measurements and Estimates. *Journal of Hydrology*, 351(1-2), 218– 229.

Thornthwaite, C. W. (1948) An Approach Toward a Rational Classification of Climate. *Geographical Review*, 38(1), 55-94.

Turc, L. (1961) Estimation of Irrigation Water Requirements, Potentioal Evapotranspiration: A Simple Climatic Formula Evolved up to Date. *Annales Agronomiques*, 12(1), 13-49, (in French).

Wackernagel, H. (2003) *Multivariate Geostatistics: An Introduction With Applications*. Berlin Heidelberg and New York, Springer.

Zare' Abyaneh, H., Moghaddamnia, A. R., Bayat Varkeshi, M., Ghasemi, A. & Shadmani, M., (2010) Spatial Variations of Evaporation from Pan and Comparison with the Models of Evaporation Estimation in Iran, *Journal of Soil and Water Knowledge*, 1(4), 113-130.