Evaluation of Some Existing Empirical and Semi-Empirical Net Radiation Models for Estimation of Daily ET0

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***Abstarct*—Net radiation (R_n) is one of the effective parameters in predicting reference evapotranspiration (ET_0) rate. In this research, the accuracy of some empirical and semi-empirical R_n models is compared against FAO 56 recommended net radiation model (hereafter referred as FAO 56) in different climates of Iran. Daily reference evapotranspiration was calculated by Penman-Monteith-FAO 56 standard model during a 28-year period (1980-2007). For estimating daily net radiation, various net radiation models (FAO 56, Wright, Basic Regression, Linacre, Berlind, Irmak and Monteith) were applied. The model evaluations were implemented for four climate types. For warm-arid and cold-arid climates, Basic Regression Model (BRM) performed the best estimates in comparison with the FAO 56. In cold semi-arid and warm semi-arid regions, Wright model presented the nearest results to the reference model (FAO 56), but for warm humid, using Irmak net radiation model was the best choice. In regional averages (all climates), linear BRM net radiation model performed the superior performance in estimating the daily ET_0. Results showed that for 75 percent of the study sites, the linear R_n models can be reliable candidates instead of non-linear R_n models such as net radiation as used in FAO 56 model. For some sites with low altitude and high relative humidity (e.g. coastal sites) Irmak model showed the minimum deviations from the reference FAO 56 model. These results can be useful for the sites where all weather parameters are not available.**

***Index Terms*—net radiation, Reference crop evapotranspiration, penman monteith FAO 56 model, different climates, Iran.**

I. Introduction

Rate of evapotranspiration for a reference crop, which does not face water shortages, is called reference crop evapotranspiration (ET_0). The reference surface is a hypothetical grass reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23. The reference surface closely resembles an extensive surface of green, Well-watered grass of uniform height, actively growing and completely shading the ground. Net radiation (R_n) and global solar radiation (R_s) are two determinant components controlling the rate of evapotranspiration and many other processes involved in surface energy balance [1]. For locations facing the shortage of observed radiation data, estimation and calibration of R_n and R_s can provide more accurate prediction for ET0. Sabziparvar *et al*. [2] noted that local calibration of Angstrom-Prescott Rs model can improve the ET0 estimates (at daily scale) by up to 72.7%. Net radiation (R_n) at the Earth's surface is a result of four radiation components (1). In 1, $R_{sw\text{-}in}$ and $R_{sw\text{-}out}$ are downward and upward shortwave fluxes. Also, $R_{Lw\text{-}in}$ and $R_{Lw\text{-}out}$ refer to incoming and outgoing longwave radiation, respectively.

$$Rn= (R_{sw\text{-}in}-R_{sw\text{-}out}) - (R_{Lw\text{-}in}-R_{Lw\text{-}out}) \quad (1)$$

Due to the high costs of establishment and maintenance of net radiation sites, many empirical or semi-empirical R_n models have been developed in the literatures for estimating this parameter.

In Report No. 56 released by FAO, the Penman Monteith FAO 56 (PMF-56) method is introduced as a standard method to estimate ET_0 [3]. It should be noted that this method is also addressed by Jensen *et al.* [4], Hargreaves [5] and Irmak *et al.* [6] as a reliable replacement of Lysimeter data.

Most of the ET_0 models, which require net radiation, use the FAO56 recommended model to estimate R_n, which is a non-linear sophisticated model and requires many weather data. The main goal of this study is to evaluate some simple existing R_n models with the R_n as used in FAO 56. In this work, the final results are compared in terms of daily ET_0.

Irmak *et al*. developed two R_n models with minimum number of input data. Their models in comparison with FAO 56 R_n model showed reasonable result in wet, arid, coastal and inland sites over the United States.

Kjaersgaard *et al*. [7] examined six R_n models using the measured R_n in the sub-humid temperate climate of East of Denmark. Their model results were improved

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after calibrating the coefficients. They suggested better results in summer than winter due to the reduction of sun elevation angle in the winter. In another study conducted in sub-humid and semi-arid climates of Denmark. In another work Kjaersgaard *et al*. [8] compared the estimated R_n values from three net long wavelength radiation models versus the measured R_n. Their study showed that application of locally calibrated coefficients improved the R_n estimations. By contrast, application of non-calibrated R_n coefficients led to significant errors.

Monteith and Szeicz [9] demonstrated that R_n is linearly dependent to the incoming shortwave radiation (R_s). They introduced their baseline regression model (BRM) with different coefficients for three different climate regimes in Germany (sub-humid and humid climates). Their models showed more reasonable results in plain sites.

Linacre [10] proposed a BRM model on a grass-covered surface with average of *a* and *b* coefficients obtained from 23 empirical BRM models [Shaw [11] for Iowa; Clothier [12] for New Zealand; Hu and Lim [13] for Malaysia and Monteith and Szeicz for the England and 19 other stations].

Badescu [14] proposed clearness index regression model (CIRM) for calculating daily R_n values based on the ratio of global solar radiation (R_s) to extraterrestrial solar radiation (R_a).

Iziomon *et al*. [15] examined four linear models of Basic Regression R_n (BRM), modified regression model (MRM), clearness index regression model (CIRM) and Extended Regression Model (ERM) against measured R_n data in Germany. They indicated that in mountainous regions the MRM model is more appropriate than BRM model.

So far in Iran, some studies have been conducted to estimate the daily ET_0 in local and regional scales by itself [e.g. 16]; but no relevant study has addressed the role of net radiation using different R_n models on the accuracy of ET_0 estimates.

Net radiation which is estimated by FAO 56 requires many input parameters (e.g. vapor pressure, maximum temperature, minimum temperature, surface albedo, etc.) which are not always available in many agricultural regions.

We used measured daily weather data during 1980-2007 [17]. Meteorological data include: wind speed, temperature, sunshine hours, relative humidity, dew point temperature, air pressure, pan evaporation, precipitation and global solar radiation at 8 meteorological sites The quality of the observed Rs data was controlled by the Run-test method and other approaches [18]. In this regard, those data which contained significant statistical deviations from the climatic averages were removed from the dataset.

Figure 1. Geographical location of the study sites

Climate types of the study sites was classified by Köppen [19] and UNESCO classification [20] that are more appropriate for agricultural purposes. For the UNESCO some abbreviations are defined where A, S-A, S-H and P-H indicate arid, semi-arid, sub-humid and perhumid climate regimes, respectively; M and C represent mild and cold winter; and VW and W represent very warm and warm summer (Table I). Fig. 1 shows geographical location of the study sites.

TABLE I. GEOGRAPHICAL INFORMATION AND CLIMATE TYPE OF THE STUDY SITES

No.	Station	Longitude (°E)	Latitude (°N)	Altitude (m)	Rainfall (mm/year)	E_{pan}^{*} (mm)	Average Wind speed (m/s)	Average RH (%)	Climate type	
									Köppen	UNESCO
1	Ahwaz	48.67	31.33	22.5	239	2603	9.1	43.2	BWh[a]	A, M, VW
2	Arak	49.77	34.10	1708	325	1679	3.1	45.1	BSk[c] (M[f])	S-A, C, W
3	Bushehr	50.83	28.98	19.6	267	1616	5.6	64.5	BWh	A, M, VW
4	Gorgan	54.27	36.85	13.3	557.7	987	2.2	73.2	BSk (M)	S-H, C, W
5	Hamedan (Airport)	48.53	34.87	1741.5	312	1401	2.8	52.4	BSk (M)	S-A, C, W
6	Iranshahr	60.70	27.20	1195	107.8	3397	4.7	29.5	BWh[b]	A, M, VW
7	Isfahan	51.67	32.62	1550.4	130	1765	2.2	36.4	BWK	A, C, W
8	Ghazvin	50.05	36.25	1279.2	330	1365	3.2	52.9	BSk (M)	S-A, C, W

[*] Total evaporation from U.S. Class A pan from April to September in the studied sites
[a] Dry/arid (warm), low-latitude *desert* / [b] *Dry/arid (cold), mid-latitude desert* / [c] Semi-arid, steppe (cold), mid-latitude steppe
[d] Humid subtropical / [e] Sub-humid subtropical-Mediterranean / [f] Marginal climate

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A. Calculation of ET0 Values

1) Reference ET_0 model (PMF-56)

In this work, daily reference evapotranspiration was estimated from(2).

$$ET_o = \left[0.408\Delta(R_n - G) + \gamma(900/T_a + 273)u_2(e_s - e_a)\right] / \left[\Delta + \gamma(1 + 0.34u_2)\right] \quad (2)$$

where the unit of R_n and G are $Mjm^{-2}day^{-1}$; T_a is in $^{\circ}C$; e_s and e_a are in KPa; and Δ and γ are in KPa/^{o}C.

B. Emperical and Semi Emperical Net Radiation Models

For estimating daily net radiation, various net radiation models including: FAO 56, Wright 1982 [21], Basic Regression, Linacre 1992, Berlind 1970 [22], Irmak 2003 and Monteith 1973 [23] were applied.

TABLE II. The Best Performance R_N Models (BPR) in Each Site, in Comparison with the FAO 56 R Model

Station		Wright	BRM (Br)	BRM (Ge)	BRM (Fe)	BRM (mean)	Berlind	Irmak	Linacre	Monteith	BPR
Ahwaz	RMSE	0.41	0.37	0.35	0.41	0.34	0.37	0.55	0.54	1.69	$BRM_{(mean)}$
	MPE	0.87	3.77	0.90	-6.20	-0.79	-3.91	10.96	7.82	-14.81	
Bushehr	RMSE	0.29	0.51	0.58	0.84	0.64	0.65	0.26	0.34	1.91	Irmak
	MPE	3.23	-4.82	-7.73	-13.81	-8.83	-10.98	2.81	-3.44	-22.19	
Iranshahr	RMSE	0.39	0.42	0.40	0.42	0.38	0.41	0.65	0.61	0.72	$BRM_{(mean)}$
	MPE	-1.68	3.10	0.84	-5.64	-0.84	-3.20	9.45	7.03	13.31	
Arak	RMSE	0.18	0.35	0.33	0.38	0.32	0.35	0.42	0.50	0.56	Wright
	MPE	-0.14	5.01	-0. 12	-8.63	-1.31	-6.15	9.35	9.96	-2.97	
Hamedan	RMSE	0.27	0.28	0.29	0.41	0.30	0.33	0.24	0.38	0.61	Wright
	MPE	-4.71	5.26	-4.09	-11.88	-4.30	-9.38	4.86	7.33	-4.75	
Ghazvin	RMSE	0.16	0.31	0.32	0.43	0.33	0.36	0.34	0.40	0.65	Wright
	MPE	-2.15	4.89	-2.67	-9.19	-3.70	-7.33	11.11	9.39	-2.82	
Gorgan	RMSE	0.76	0.44	0.51	0.67	0.53	0.59	0.37	0.39	0.80	Irmak
	MPE	-28.20	18.88	-19.01	-18.79	-19.95	-19.70	18.94	20.49	-19.24	
Isfahan	RMSE	0.39	0.38	0.33	0.33	0.31	0.32	0.50	0.56	0.65	$BRM_{(mean)}$
	MPE	-4.34	8.99	4.65	-3.42	3.36	-5.31	12.50	14.28	-5.77	

TABLE III. Statistics for ET_0 Values as Obtained from the Differences Between the Selected R_N Models and FAO 56 R_N Model

No.	Station	*RMSE* (mm day^{-1})	*MPE* (%)	*R*	Mean of Difference (mm day^{-1})	Maximum Difference (mm day^{-1})	*t*
1	Ahwaz	0.34	-0.79	0.995	-0.023	2.320	6.95**
2	Arak	0.32	-1.31	0.990	-0.024	1.910	7.57**
3	Bushehr	0.26	2.81	0.995	0.037	5.750	15.15**
4	Ghazvin	0.16	-2.15	0.998	-0.082	0.740	58.76**
5	Gorgan	0.37	18.94	0.988	0.260	3.000	96.83**
6	Hamedan	0.24	4.71	0.995	0.130	1.330	65.19**
7	Iranshahr	0.38	-0.84	0.993	0.016	2.350	4.34**
8	Isfahan	0.31	3.36	0.991	0.065	1.980	21.55**

**Significant at 99% (p < 0.1) confidence level

II. Conclusions

The study was conducted with to evaluating different R_n models and the possibility of replacing them instead of the pre-defined R_n model as used in the FAO 56 model. Results showed that the differences in the altitude, the relative humidity and wind speed of the sites have significant effect on selection of the best net radiation model in each climate. In general, for sites with low altitude, near to sea level and high relative humidity, Irmak model presented the highest performance than other R_n model.

This study highlighted that in warm arid and cold arid climates basic regression R_n model (BRM_{mean}) performs the best results. In cold semi-arid and warm semi-arid climates, the Wright and the Irmak models presented the highest performance, respectively.

As shown in Table II and Table III, in warm humid climate, Irmak R_n model showed the least differences compare to the FAO 56 results. Elevation and humidity of the study sites were two dominant factors in determining the appropriate R_n model in each climate.

For more than 50 percent of the study sites, linear (BRM) R_n models performed the best ET_0 results. In addition, linear models of Irmak and Wright suggested the most accurate ET_0 values for about 25 percent of the study sites. This shows that in 75 percent of the cases, the linear R_n models can be good candidates instead of

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sophisticated non-linear R_n models for the places where all required weather data are not available. The maximum relative errors were observed for humid sites such as Rasht and Gorgan. By contrast, the lowest differences were occurred for cold arid and cold semi-arid climates.

In general, cold arid climates experienced the lowest range of errors for estimating daily R_n than warm climates. To achieve more reliable results, using lysimeter observations is highly recommended. This work can be completed by installation of net radiation logging system in the study fields.

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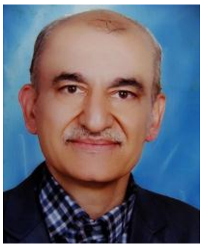

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