Calibration of Angström-Prescott Solar Radiation Model for More Accurate Estimation of Reference Evapotranspiration in the Absence of Observed Solar Radiation

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***Abstract*—**The Angström-Prescott (AP) model is widely suggested for estimating global solar radiation (R_s), especially for reference crop evapotranspiration (ET_0) calculations. Many studies indicated that the coefficients of the AP model are dependent on the climatic and geographical characteristics of study sites. In the present study, calibrated AP models were developed in some Iran's climates. Different radiation scenarios from estimated and measured R_s were applied to calibrate the AP coefficients. Radiation scenarios included measured R_s (M) and estimated R_s from Daneshyar (D) and Hargreaves (H) models. Precision of the estimated daily ET_0 evaluated against field lysimeter data. Results showed that scenarios D and H can perform the minimum ET_0 deviations from lysimeter data, respectively. Results revealed that at majority of the study sites, calibration of the AP model improved the accuracy of estimated ET_0. Results also indicated the applicability of reliable R_s estimation methods for calibrating the AP model. Apart from applied R_s scenarios, the FAO56-PM model tends to under-estimate the daily ET_0.

***Keywords*—** ngström-Prescott coefficients, evapotranspiration, FAO56 Penman-Monteith, lysimeter.

I. Introduction

INACCURATE estimation of hydrologic cycle components can lead to uncertainties in water balance determination. Such discrepancies can affect the precision of water resources planning and management. Measurement of actual ET in the field is completed using Lysimeters but it is expensive and time consuming; so that, evapotranspiration is normally estimated. Numerous methods using different meteorological variables are developed for ET estimation. FAO in Irrigation and Drainage Paper No.56, proposed a standard surface covered with grass having specific properties (height = 0.12 m, surface resistance = 70 sm $^{-1}$ and surface albedo = 0.23), as a reference surface; and presented the computational procedure of evapotranspiration for mentioned surface as a reference crop evapotranspiration (ET_0). The FAO56 Penman-Monteith method (hereafter referred to as FAO56-PM) is known as the standard method for estimating ET_0 for all weather conditions [1]

As many researches addressed, these coefficients are indicators of climatic and geographical characteristics of the application site and they are not constant for all regions [2]-[4]. In Iran, some studies were carried out to improve the precision of the AP model. These studies suggest a wide range of values for the AP coefficients [e.g. 5, 6]. Considering the remarkable variability of the AP coefficients, applying FO56 proposed values without taking into account the spatial variations of coefficients, can introduce some errors in estimated R_s and ET_0.

Many researches in the world have focused on improvement of the AP coefficients. Nonetheless, the effect of employing inaccurate coefficients on the estimation of ET_0 is not widely discussed and investigated. Present study attempts to highlight the importance of using the AP model calibrated coefficients for ET_0 estimation and to assess the error introduced using the recommended form of the AP model. Hence, some radiation scenarios were defined to calibrate the AP model, including observed R_s and calculated R_s from two estimation methods.

II. Materials And Methods

A. Study area

In the present study, 6 synoptic sites were selected over Iran, covering a variety of climates, and having reliable long-term data. In the site selection, accessibility to the lysimeter evapotranspiration and observed solar radiation data are considered.

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On average the maximum and minimum amount of total annual R_s received at the surface over Iran, varies between 5600 Mj.m^{-2}.year^{-1} and 7800 Mj.m^{-2}.year^{-1}, respectively [7].

B. Data

Study sites are introduced in Table I. Climate type of the study area varies from arid to humid, based on *Köppen* climate classification.

In this study, daily weather data of Air temperature (°C), wind speed at 2 meter height (m sec^{-1}), relative humidity (%), cloudiness (okta), maximum possible and actual sunshine hours, atmospheric pressure (kPa) and global solar radiation (MJ m^{-2} day^{-1}) from the Islamic Republic of Iran Meteorological Office data center [8] were employed for ET_0 estimation.

In addition, lysimeter data were used to assess the precision of the ET_0 derived from different scenarios. These data obtained from the reports of researches were conducted under the auspices of Agricultural Research, Education and Extension Organization (AREEO).

Lysimeter data employed in this study were obtained from drainage lysimeters as introduced in Table III, filled with local soil and buried at the center of a field planted uniformly with the observed crops.

C. Data quality control

In this study adopted rules from references [9], [10] were used to check the accuracy of the daily observed R_s as follow:

1- Days with missing measured sunshine hours or R_s data were omitted from the dataset,

2- Days with the ratios of relative sunshine hours (n/N) and clearness index (R_s/R_a) greater than one, were excluded from the dataset (where R_a is the extraterrestrial radiation),

3- Assuming the clear sky transmissivity of 85%, daily R_s greater than $0.85\times R_a$ were excluded,

4- Inconsistent values of relative sunshine hours and clearness index were found plotting n/N vs. R_s/R_a and removed from the dataset.

Although the quality of other weather parameters is usually controlled by IRIMO data center, additionally, Run-test was applied on all data to remove the heterogeneous data. Moreover observed evapotranspiration data were controlled plotting them and inconsistent data were removed.

D. Estimation of reference crop evapotranspiration (ET_0)

Estimation of daily reference crop evapotranspiration was performed following the FAO56-PM method (Eq.1) [1]:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma[900/(T+273)]U_2(e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \tag{1}$$

E. Angström-Prescott model

Reference [11] modified the Angström model replacing clear-sky radiation with extra-terrestrial radiation (R_a) (Eq.2):

$$R_s = R_a(a + bn/N) \tag{2}$$

The coefficients (a) and (b) are site-dependant constants of the AP model.

F. Calibration of the Angström-Prescott (AP) coefficients

In this work, calibration of the Angström-Prescott model was accomplished through finding the best linear regression constants of relative sunshine hours (n/N) and clearness index (R_s/R_a) (Table II).

G. Global solar radiation (R_s) scenarios

Scenario M (Measured R_s)

In this scenario, the AP coefficients were derived from measured R_s data [8] without any gap filling.

Scenario D (Estimated R_s using Daneshyar method, $R_{s\text{-}D}$)

In this scenario the AP coefficients were derived from estimated R_s data based on Daneshyar method. $R_{s\text{-}D}$ (Eq. 3) is estimated as follow from reference [7]. This method is considered as scenario D in this study.

$$R_{s-D} = (1-CF)\times\int_{sunrise}^{sunset}[(81.738)[1-\exp(-0.075(90-\theta))]]\cos\theta dt + \int_{sunrise}^{sunset}[0.123+0.181(90-\theta)+10.43CF]dt \tag{3}$$

where CF is the cloud fraction, (zero for clear sky and 1 for overcast sky) and θ is the solar zenith angles (degree).

Scenario H (Estimated R_s using Hargreaves method)

In this scenario the AP coefficients were derived from estimated R_s data by Hargreaves method (Eq. 4). $R_{s\text{-}H}$ is estimated from reference [12]. This method is called in the manuscript as scenario H.

$$R_{s-H} = k_{R_s}\sqrt{(T_{\max} - T_{\min})}R_a \tag{4}$$

Where k_{Rs} is the adjustment coefficient (°C$^{-0.5}$) (0.16 for interior, and 0.19 for coastal locations) (Allen 2000). T_{max} and T_{min} are the maximum and minimum air temperatures (°C), respectively. R_a is the extraterrestrial radiation (mm/day).

Scenario F (the FAO56 recommended AP model)

Reference [1] used the following AP model (Eq. 5) for estimating the daily R_s ($R_{s\text{-}F}$) in ET_0 calculations. This method is considered as scenario F in this study.

$$R_{s-F} = R_a(0.25 + 0.5n/N) \tag{5}$$

H. Statistical analysis

Statistics of root mean square error (RMSE) (A1), mean bias error (MBE) (A2), mean percentage error (MPE) (A3) and mean absolute error (MAE) (A4) were applied to investigate and compare the functionality of the developed models (see Appendix A).

I. Crop coefficients (K_c)

Since different kinds of crops were planted in the lysimeters, suitable values of K_c were selected from the FAO56 to convert a certain crops evapotranspiration (ET_c) to ET_0 (Eq. 6).

$$ET_c = K_c .\ ET_0 \tag{6}$$

III. Conclusions

This study was an attempt toward improving the precision of estimated ET_0 calibrating the radiation model used in the FAO56-PM. Since observed R_s is not available at many sites, the possibility of employing some reliable radiation methods for calibrating the simple AP method was investigated.

Based on the results, at most of the study sites, application of the FAO56-PM using different R_s scenarios resulted in under-estimation of ET_0 in comparison with the lysimeter data (Table III). This result implies the lower estimation of the FAO56-PM model apart from applied radiation scenario.

Among the radiation scenarios, calibrated models based on Daneshyar (D) and Hargreaves (H) revealed the best AP coefficients for reliable ET_0 calculations. At most of the observed sites calibrated R_s models showed better performance in comparison with the FAO56 predefined AP model; suggesting that calibration of the AP coefficients can improve the precision of ET_0 estimates by the FAO56, even though no observed R_s is available. Hence, estimated R_s from one of the reliable methods can be applied, instead of observed R_s to calibrate the AP model. Once the AP model is calibrated, it is applicable for more extended periods by only using the sunshine hours in radiation models.

Inconsistency between the results of different lysimeters, observed at some sites (e.g. Mashhad), can be explained by differences in sample size and different periods of lysimeter observations.

APPENDIX

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{n}} \tag{A1}$$

$$MBE = 1/n \times \sum_{i=1}^{n}(P_i - O_i) \tag{A2}$$

$$MPE = 1/n \times \frac{\sum_{i=1}^{n}(P_i - O_i)}{\overline{O}} \times 100\% \tag{A3}$$

$$MAE = 1/n \times \sum_{i=1}^{n}\left|P_i - O_i\right| \tag{A4}$$

Where P_i and O_i are the i*th* predicted and observed values, respectively; $\overline{O}$ is the observed daily averaged value; and n is the total number of observations.

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TABLE I
GEOGRAPHICAL AND WEATHER CHARACTERISTICS OF THE STUDY SITES

No.	Station	Latitude (°N)	Longitude (°E)	Altitude (m)	RH (%)	$E_{(Pan\ A)}$[a] (mm)	Climate type
1	Ahwaz	31.33	48.67	22.5	43.03	2607	*BWh*[b]
2	Aark	34.10	49.77	1708	47.20	1688	*BSk*[c] (*M*[h])
3	Bushehr	28.98	50.83	19.6	64.81	1616	*BWh*
4	Kerman	30.25	56.97	1753.8	32.10	2038	*BWh*
5	Mashhad	36.27	59.63	999.2	54.68	1639	*BSh*[e]
6	Qazvin	36.25	50.05	1279.2	52.91	1397	*BSk (M)*

[a] Accumulative evaporation of class A pan (April-September) / (Sabziparvar 2008)

TABLE II
THE LOCALLY CALIBRATED ANGSTRÖM-PRESCOTT COEFFICIENTS FROM DIFFERENT RS SCENARIOS (SIGNIFICANT AT P<0.01)

Scenario	M					D					H				
Station	a	b	a+b	R^2	data	a	b	a+b	R^2	data	a	b	a+b	R^2	data
Ahwaz	0.16[a]	0.52[a]	0.68	0.76	2521	0.36	0.41	0.77	0.66	9353	0.44	0.23	0.67	0.38	9353
Arak	0.35	0.52	0.87	0.51	555	0.33	0.41	0.74	0.71	9542	0.42	0.24	0.67	0.43	9542
Bushehr	0.22[a]	0.54[a]	0.76	0.67	1290	0.35	0.43	0.78	0.59	8773	0.43	0.10	0.52	0.08	8771
Kerman	0.27[a]	0.52[a]	0.79	0.76	5145	0.36	0.40	0.76	0.71	9693	0.49	0.25	0.74	0.41	9693
Mashhad	0.27[a]	0.42[a]	0.69	0.66	4709	0.35	0.40	0.75	0.74	10067	0.40	0.28	0.68	0.53	10062
Qazvin	0.18	0.60	0.78	0.90	199	0.33	0.39	0.72	0.67	9461	0.42	0.27	0.69	0.54	9461

[a] Reference [6]

[b] NA: Measured R_s were not available or the quality of the data was not acceptable.

TABLE III
STATISTICAL DEVIATIONS OF ESTIMATED ET0 FROM FIELD LYSIMETER DATA

No.	Station	Scenario	RMSE (mm/day)	MBE (mm/day)	MPE (%)	MAE (mm/day)	No.	Station	Scenario	RMSE (mm/day)	MBE (mm/day)	MPE (%)	MAE (mm/day)
1	Ahwaz	M	1.98	-1.06	-15.89	1.47	15	Kerman	M	1.65	0.39	17.65	1.32
		D	1.75	-0.73	-9.97	1.29			D	1.66	0.39	17.88	1.32
		H	1.86	-0.90	-12.56	1.38			H	1.68	0.41	18.33	1.34
		F	1.83	-0.86	-12.55	1.36			F	1.64	0.29	15.93	1.30
2	Arak Lys. I	M	2.27	-1.56	-17.88	1.93	16	Mashhad Lys. I	M	1.17	0.41	6.04	0.98
		D	2.60	-1.99	-24.78	2.23			D	1.31	0.63	9.68	1.11
		H	2.71	-2.12	-26.74	2.34			H	1.18	0.43	6.34	0.99
		F	2.64	-2.05	-25.76	2.28			F	1.27	0.57	8.58	1.07
3	Arak Lys. II	M	2.31	-1.81	-20.98	1.98	17	Mashhad Lys. II	M	2.39	-0.83	-3.96	1.91
		D	2.71	-2.30	-27.20	2.39			D	2.32	-0.61	-0.66	1.84
		H	2.88	-2.49	-29.64	2.56			H	2.37	-0.81	-3.65	1.90
		F	2.75	-2.34	-27.78	2.43			F	2.35	-0.68	-1.69	1.87
4	Arak Lys. III	M	2.12	-1.45	-18.42	1.82	18	Mashhad Lys. III	M	2.91	-2.32	-27.81	2.42
		D	2.44	-1.86	-24.74	2.12			D	2.70	-2.09	-24.54	2.24
		H	2.56	-2.00	-26.68	2.22			H	2.88	-2.29	-27.37	2.40
		F	2.49	-1.92	-25.68	2.16			F	2.77	-2.16	-25.62	2.30
5	Bushehr	M	1.61	-0.96	-15.89	1.31	19	Qazvin	M	1.38	-0.49	0.38	1.1
		D	1.48	-0.76	-12.29	1.19			D	1.40	-0.52	0.67	1.11
		H	2.04	-1.48	-23.58	1.69			H	1.41	-0.53	1.00	1.12
		F	1.46	-0.71	-11.16	1.17			F	1.39	-0.51	0.40	1.10