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Reference Evapotranspiration Estimation Using Locally Adjusted Coefficient of Angstrom's Radiation Model in an Arid-Cold Region

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ABSTRACT

Acceptable estimation of reference Evapotranspiration (ET_0) values by the Penman-Monteith FAO (PM FAO) equation requires accurate solar radiation (R_s) data. R_s values could be estimated using the Angstrom's radiation model. The aim of this study was to determine the a_s and b_s coefficient (as Angstrom's parameters) for the Ardabil plain as an arid and cold region. Angstrom's radiation model and PM FAO equation were calibrated for the study area, by optimizing the a_s and b_s parameter using Generalized Reduced Gradient (GRG) method. Measured $R_s$data were collected from the Ardabil Synoptic Station and measured ET_0 data were determined using three lysimeters that were installed at the Hangar Research Station. Calibrated results showed that optimized a_s and b_s values were 0.117 and 0.384, respectively. Compared to the original models, errors including RMSE, AE and RE values were decreased and fitted parameters including R^2 and regression line slope (m) were improved in the calibrated models. The GMER values for the original models showed that Angstrom's radiation model overestimated the R_s values and PM FAO equation underestimated the ET_0 values. Locally calibrated models estimated R_s and ET_0 values better than the original one. Nash-Sutcliffe efficiency coefficient (NSE) values proved that R_s and ET_0 estimation by the original models were not satisfactory, but were acceptable in the case of the calibrated models. However, calibration of Angstrom's radiation model and PM FAO equation is necessary for each region.

Keywords: Penman-Monteith, Model calibration, Validation, Lysimeter, Ardabil

INTRODUCTION

Accurate estimates of actual evapotranspiration are a prerequisite for real-time irrigation forecasting (Doorenbos and Kassam, 1979). Lysimeters have been used to analyze precipitation (P), drainage water, root water uptake, and to determine actual evapotranspiration (ET_a) (Young *et al*., 1996; Bakhtiari *et al*., 2011). Specific devices and lysimeters are required to determine evapotranspiration, various physical parameters, and soil water balance (Allen *et al*., 2006). The estimation of crop evapotranspiration (ET_c) often involves calculating the reference evapotranspiration (ET_0) (Xu *et al*., 2012). Reference evapotranspiration (grass) is defined as the evapotranspiration rate from a hypothetical crop with an assumed height of 0.12 m, a fixed surface resistance of 70 $s.m^{-1}$, and an albedo of 0.23. The only factors affecting ET_0 are climatic parameters. Therefore, ET_0 is a climatic parameter that can be computed from weather data (Allen *et al*., 1998). The FAO Penman–Monteith combination equation (FAO-56 PM Equation) was proposed as a standard method for estimating reference evapotranspiration, and for evaluating other equations. It is accepted worldwide as the optimum method and the standard for evaluating other methods (e.g., Jacovides and Kontonyiannis, 1995; Antonio, 2004; Hossein *et al*., 2004; Xu and Chen, 2005; López- Urrea *et al*., 2006; Trajkovic, 2007; Meshram *et al*., 2010; da Silva *et al*., 2011; Mohawesh, 2011).

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From the original equations of Penman-Monteith and the aerodynamic and surface resistance, the FAO Penman-Monteith method to estimate ET_0 can be derived as follows (Temesgen *et al*., 2005):

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)} \quad (1)$$

Where, ET_0 is the reference evapotranspiration [mm day $^{-1}$], R_n is the net radiation at the crop surface [MJ m^{-2} day^{-1}], G is the soil heat flux density [MJ m^{-2} day^{-1}], T is the mean daily air temperature at 2 m height [°C], u_2 is the wind speed at 2 m height [m s^{-1}], e_s is the saturation vapor pressure [kPa], e_a is the actual vapor pressure [kPa], $(e_s - e_a)$ is the saturation vapor pressure deficit [kPa],Δ is the slope vapor pressure curve [kPa °C^{-1}], and γ is the psychometric constant [kPa °C^{-1}].

The FAO-56 PM is a physically based approach which requires measurements of air temperature, relative humidity, solar radiation, and wind speed. Net radiation, R_n, is the most important parameter in the calculation of ET_0 by FAO-56 PM (Xu, *et al*., 2009). Solar radiation, R_s, can be calculated with the Angstrom formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration as:

$$R_s = \left(a_s + b_s\frac{n}{N}\right)R_a \quad (2)$$

Where, R_s is the solar or shortwave radiation [MJ m^{-2} day^{-1}], n is the actual duration of sunshine [hour], N is the maximum possible duration of sunshine or daylight hours [hour], $\frac{n}{N}$ is the relative sunshine duration [-], R_a is the extraterrestrial radiation [MJ m^{-2} day^{-1}], a_s is the regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0), a_s+b_s is the fraction of extraterrestrial radiation reaching the earth on clear days (n = N). Depending on atmospheric conditions (humidity, dust) and solar declination (latitude and month), the Angstrom's values a_s and b_s will vary. Where no actual solar radiation data are available and no calibration has been carried out for improving a_s and b_s parameters, the values a_s= 0.25 and b_s= 0.50 are recommended (Allen *et al*., 2006). Values for R_a and N for different latitudes are listed in FAO Irrigation and Drainage Paper No. 56, or could be calculated from related equations. The actual duration of sunshine, n, is recorded with a Campbell Stokes sunshine recorder. Net radiation is measured in some meteorological stations such as Ardabil station. Estimation of various R_s using equation (2), can affect ET_0 values change, because the hypothetical surface with uniform albedo of 0.23 can't be realized in the measurement of net radiation in all climate stations. Based on solar radiation determined with different regimes of a_s and b_s, influence on calculation of ET_0 have been investigated (Xu *et al*., 2006). Xu *et al*. (2009) concluded that errors in ET_0 caused by different values of a_s and b_s are not neglectable. In stations with solar radiation measurement, it is possible and necessary to evaluate and estimate the Angstrom's coefficients, to calculate solar radiation and hence ET_0. Many studies have been done on the estimation of reference plant evapotranspiration by various methods. Gocic´ *et al*. (2015) indicated that SVM–W (support vector machine–wavelet) is the best methodology for prediction of ET_0, whereas SVM–Wavelet and SVM-FFA (support vector machine-firefly algorithm) models have higher correlation coefficient as compared to ANN (artificial neural network) and GP (genetic programming) computational methods. Petkovic´ *et al*. (2015) used the neuro-fuzzy inference system (ANFIS) for selection of the most influential reference evapotranspiration (ET_0) parameters. They concluded that, among the input variables, sunshine hours, actual vapor pressure, and minimum air temperature are the most influential for ET_0 estimation. In another research, Petkovic´ *et al*. (2016) showed that the radial basis function network with particle swarm optimization (RBFN-PSO) had better

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statistical characteristics than radial basis function network with back propagation (RBFN-BP) and could be helpful for the ET_0 estimation. Shamshirband *et al*. (2016) indicated that combination of adaptive neuro fuzzy interference system (ANFIS) and cuckoo search algorithm (CSA) could be used for ET_0 estimation with high reliability. Gocic´ *et al*. (2016) used the extreme learning machine (ELM) for estimating monthly reference evapotranspiration (ET_0) in two weather stations including Nis and Belgrade, Serbia. Results showed that adjusted Hargreaves model was found to be superior in modeling monthly ET_0 than the Priestley-Taylor and Turc models.

The main aim of this study was to investigate the effect of different values of Angstrom's coefficients for estimation of solar radiation and ET_0 in Ardabil plain as an arid and cold region, using lysimeter data.

MATERIALS AND METHODS

Site Description

This study was conducted in Ardabil plain (38°, 10' to 38°, 15' N, 48°, 15' to 48°, 20' E and 1350 m elevation above the sea). The Ardabil climate station (38°, 15' N, 48°, 17' E) was selected as a typical climate station in an arid and cold region in northeast of Iran (Figure 1). Experimental site was located at Hangar Farm of Mohaghegh Ardabili University. The annual mean precipitation rate, average minimum monthly temperature, and average maximum monthly temperature through 1995 to 2015 were obtained as 280.9 mm, 2.4 °C, and 15.07 °C, respectively.

For the following two reasons, the length of the study period was considered 81 days.

1. The growth period of the grass is 45 days and then the cutting period. Thus, the earliest 45 days were the growth period, and the end 36 days were the cutting period.
2. Snow in early November (Aban) led to the completion of the study period.

At the study period, the averages of minimum (Tmin) and maximum air temperature (Tmax), daily sunshine hour (n), actual relative humidity (RH_a), solar radiation (R_s), and wind speed (v) were 10.43 °C, 25.04 °C, 8.85 hr, 65.31%, 5.25 mm/day and 3.33 m/s, respectively. Statistical parameters of the observed meteorological data from 22 July, 2014, to 10 October, 2014, (calibration and validation periods) are listed in Table 1.

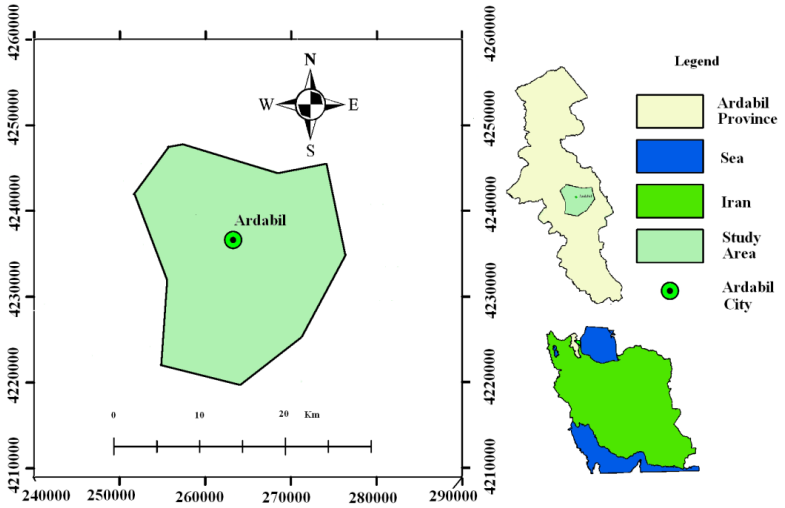

Figure 1. Location of study area.

Table 1. Statistics of observed meteorological data.

Statistic parameters		T_{max} ($°c$)	T_{min} ($°c$)	T_{avg} ($°c$)	RH_a (%)	R_s ($MJ/m^2.day$)	n (hr)	u_2 (m/s)
Calibration period (22 July 2014 to 13 September 2014)	Maximum	40.4	16.2	29.9	96	7.63	13	7.37
	Minimum	15.4	6.2	12.6	22.6	0.81	0.2	1.25
	Average	26.43	11.4	19.1	61.58	6.17	9.89	3.46
	Cv (%)	19.53	20.43	16.61	27.51	23.64	34.48	42.2
Validation period (14 September 2014 to 10 October 2014)	Maximum	29	16.2	20.2	97.12	5.93	11.2	9.12
	Minimum	10.4	3.4	8.5	37.62	1.59	0.2	0.62
	Average	22.26	8.5	14.83	72.76	4.09	6.75	3.06
	Cv (%)	37.16	20.56	18.72	19.27	33.17	46.05	70.2

Lysimeters Characteristics

Three lysimeters were installed to determine the water balance equation, estimate reference evapotranspiration, and calibrate Angstrom's Radiation Model (determining the a_s and b_s coefficients) in Hangar Farm site. Sectional drawing of a lysimeter is illustrated in Figure 2. Dimensions of each lysimeter were 60 cm diameter and 90 cm height. To measure the water content changes in each lysimeter, 6 sensors (gypsum block) were installed at depth of 5, 15, 25, 40, 60 and 80 cm, from the soil surface. To measure soil moisture, it is necessary that the resistance of the gypsum blocks is measured, then, the values of the block resistance are converted to soil moisture using a calibration curve. Blocks resistance data was measured at 10:00 AM and 18:00 PM every day using an ELE-MC-302 soil moisture instrument. Drained water was collected in a drainage tank located under the lysimeters and was measured two times every day, the same as blocks resistance.

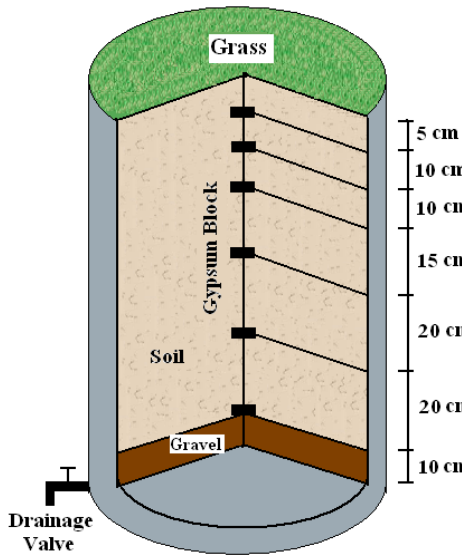

Figure 2. Sectional drawing of a lysimeter used for ET_0 measurement.

In the lysimeters, grass was planted, as reference crop, on 22 July, 2015, and irrigated every 3 days, according to the lysimeters soil type. Given that the purpose of this study was to measure potential evapotranspiration, the irrigation interval was chosen to avoid plant stress. For irrigation intervals of 3 days, soil type did not create restrictions. Figure 2 illustrates schematic of lysimeters and its devices. To calculate soil water storage, lysimeters soil was divided into 6 layers, including the depth of 0-10, 10-20, 20-32.5, 32.5-50, 50-70, and 70-90 cm, according to the depth of installation of gypsum blocks (at depths of 5, 15, 25, 40, 60 and 80 cm). The value of the soil water content was obtained for each of the layers using the gypsum blocks data. To determine some soil physical and hydraulic properties, three disturbed and three undisturbed soil sample were taken. The total soil water storage was determined by the sum of storage in each of the considered layers (Equation 3) (Feltrin *et al*., 2011):

$$S = \int_0^L \theta \, dz \simeq \sum_{i=1}^{n} \theta \, \Delta z = \theta L \qquad (3)$$

Where, S is the soil water storage (mm), θ is the volumetric soil water content (cm^3/cm^3), L

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is the total soil depth (mm), and n is the number of layer. Thus, the change in soil water storage was determined by the difference between the values of the soil water content obtained in the final and initial time of each period (daily period), using equation 4:

$$\Delta S = S_f - S_i \quad (4)$$

Where, ΔS is the change in soil water storage (mm), S_i and S_f are the initial and final soil water storage (mm), respectively. The water balance equation of the lysimeters was used to calculate the grass evapotranspiration (ET_0). The evapotranspiration was obtained by the difference between the soil water inputs and outputs (Equation 5):

$$ET = P - D \pm \Delta S \quad (5)$$

Where, ET is the evapotranspiration (mm), P is the rainfall (mm), D is the drainage (mm), and ΔS is the change in soil water storage (mm).

PM FAO Equation: Calibration and Validation

The coefficients a_s and b_s, with the original values of 0.25 and 0.5, respectively, should be determined according to the local calibration. Based on observed evapotranspiration data from 22 July to 13 September, 2014, local calibration was performed to determine the values of coefficients a_s and b_s through nonlinear multiple regression for the ET_0 calculated using the FAO-56 PM equation and measured ET_0. The nonlinear multiple regressions were realized using the Solver extension of Excel software with Generalized Reduced Gradient method (GRG). The locally calibrated PM FAO equation was validated for the data from 14 September to 10 October 2014, by comparing the results with the measured data. For evaluation of the ET_0 calculated by PM FAO equation relative to the measured data, firstly, the calculated and measured data were plotted around the 1:1 line. Linear regressions with zero interception were made, and slopes and determination coefficients (R^2) were calculated.

Statistical Analysis

In the present study, root mean square error (RMSE), average absolute errors (AE), Nash-Sutcliffe efficiency coefficient (NSE) and relative error (RE), were used to evaluate the Angstrom's radiation model (in estimation of R_s) and PM FAO equation (in estimation of ET_0), derived from different values of a_s and b_s coefficient. Statistical parameters were calculated using the following expressions:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2} \quad (6)$$

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

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \quad (8)$$

$$RE = \frac{\sum_{i=1}^{n}|O_i - P_i|}{\sum_{i=1}^{n} O_i} \times 100 \quad (9)$$

Results were categorized into four groups by analysis of the relative error using the following criteria (Xu *et al*., 2009):

RE <10% indicates very good, 15%>RE>10% indicates good, 20%>RE>15% indicates acceptable, and RE>20% indicates poor result.

To evaluate the overestimation or underestimation of Angstrom's radiation model and PM FAO equation, geometric mean error ratio (GMER) were also used as follows:

$$GMER = \exp\left(\frac{1}{n}\sum_{i=1}^{n}\ln\left(\frac{O_i}{P_i}\right)\right) \quad (10)$$

If predicted values were equal to observed values, GMER reach unity. A GMER>1 indicates overestimation and GMER<1 shows underestimation of the mentioned values (Wagner *et al*., 2001). In all evaluation equations (Equations 6 to 10), O_i and P_i represent the observed and predicted data, respectively.

RESULTS AND DISCUSION

Soil Properties and Water Balance

Results from the granulometric analysis of the samples collected at the site of the lysimeters installation are shown in Table 2. The amount of sand percentage, which was over 60% of the total in all lysimeters, caused soil available water to decrease and drained

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water to increase. Some soil hydraulic properties that determine the soil available water are illustrated in Table 3. Total soil available water was 140 mm/m, as calculated from the field capacity and permanent wilting point water content. Volumetric soil water content changes in depth of 5, 15, 25, 40, 60 and 80 cm and water storage in the period are shown in Figure 3. In this figure, increase in water content indicates irrigation (wetting trend) and decrease in the water content indicates soil water extraction (drying trend). Because evaporation is more intense in the surface layer, for the depth of 5 and 15 cm, water content changes more rapidly than other depths. The positive and negative values of water storage represent the frequent addition and depletion of water in the lysimeters.

Evaluation of Estimated R_s and ET_0 during the Entire Period

Daily radiation values estimated by the Angstrom's radiation model and daily ET_0 values estimated by the PM FAO equation compared with the measured data are illustrated in Figures 4 and 5, respectively, in which R_s and ET_0 values are also shown around the 1:1 (one to one) line. Regression equation has been derived between the measured and estimated R_s and ET_0 with zero interception. The radiation values in warm

Table 2. Some soil physical properties of the study site.

Parameter	Particle Density (gr/m^3)	Bulk density (gr/m^3)	Total Porosity (%)	Granulometry			Texture Class
				Clay (%)	Silt (%)	Sand (%)	
Mean	2.4235	1.225	49.45	6.67	31.47	61.87	Sandy Loam
Standard Deviation	0.0456	0.0925	3.203	0.9428	2.494	2.944	
CV	0.02	0.07	0.06	0.14	0.08	0.04	

Table 3. Some soil hydraulic properties of the study site.

θ_r (cm3/cm3)	θ_{FC} (cm3/cm3)	θ_s(cm3/cm3)	K_s(cm/day)	α (-)	n (-)
0.1226	0.2626	0.4945	281.6	0.01556	1.76466

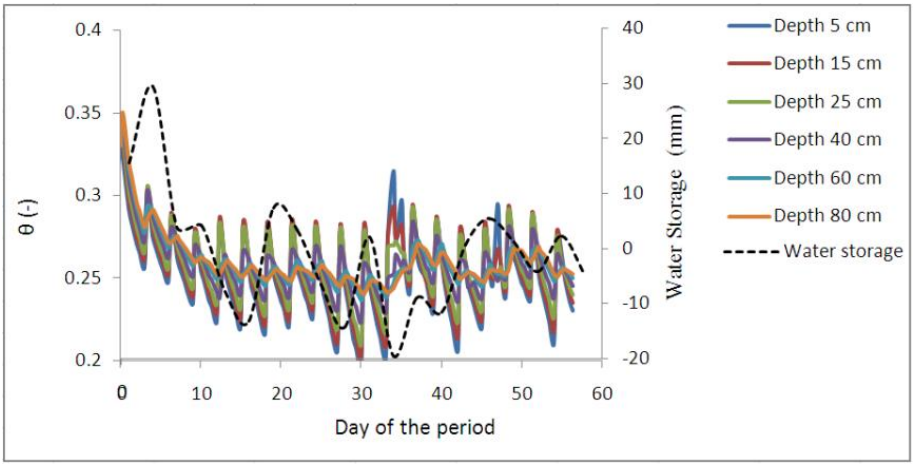

Figure3. Volumetric soil water content changes in depth of 5, 15, 25, 40, 60 and 80 cm and daily water storage.

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days are greater than cold days. According to Figures 4 and 5, measured daily radiation values fluctuated between 0.81 and 7.63 mm/day and measured evapotranspiration (ET_0) values fluctuated between 0.54 and 12.42 mm/day. Before local calibration and validation (with a_s=0.25 and b_s=0.75, recommended by FAO), the PM FAO model had a high error and therefore the model must be calibrated and validated locally. Statistical parameters of Angstrom's radiation model and PM FAO equation estimation are showed in Table 4. In both R_s and ET_0 estimation with a_s and b_s coefficient recommended by FAO, results are not satisfactory. The RMSE, AE, and RE, which explain the error between the measured and estimated parameters, have high values, indicating that Angstrom's radiation model and PM FAO equation require calibration in each region.

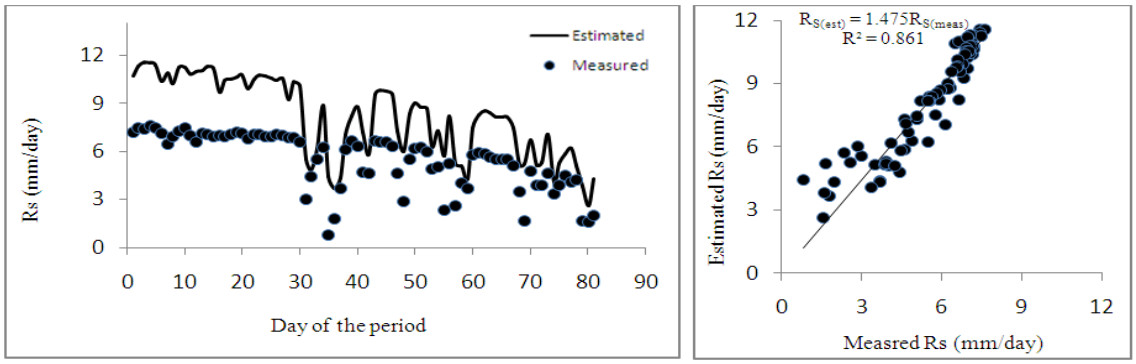

Figure 4. Daily radiation values (R_s) estimated by the Angstrom's radiation model compared with the measured data, before local calibration (during the entire period and around the 1:1 line)

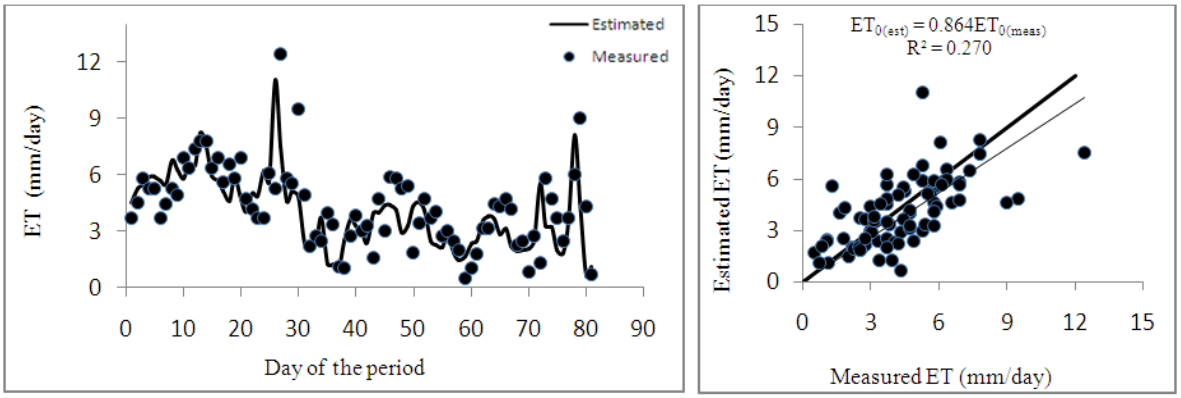

Figure 5. Daily ET_0 values estimated by the PM FAO equation compared with the measured data, before local calibration (during the entire period and around the 1:1 line)

Table 4. Statistical parameters of Angstrom's radiation model and PM FAO equation before local calibration.

Angstrom's radiation model			PM FAO equation		
Parameter	Value	Explanation	Parameter	Value	Explanation
R^2 (-)	0.861	Acceptable	R^2 (-)	0.27	Non acceptable
M (line slope) (-)	1.475	Non acceptable	M (line slope) (-)	0.864	Non acceptable
RMSE (mm/day)	2.882	High	RMSE (mm/day)	1.778	High
AE (mm/day)	2.688	High	AE (mm/day)	1.342	High
NSE (-)	-0.114	Non satisfied	NSE (-)	0.291	Non satisfied
RE (%)	49.061	Poor	RE (%)	30.96	Poor
GMER (-)	0.656	Overestimated	GMER (-)	1.054	Underestimated

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Value of R^2 is acceptable for radiation model, but it is small for PM FAO equation. For ET_0 values, points are very far from 1:1 line. In Table 4, M values represent the slope of the fitted line between the measured and estimated data with zero interception. The value of M close to one indicates high accuracy of the model. For both models, Nash-Sutcliffe efficiency coefficient (NSE) values are not acceptable, because NSE of both models is less than 0.36. This parameter is better for ET_0 estimation than for R_s estimation. The GMER values showed that the Angstrom's radiation model overestimated the R_s values, but PM FAO equation underestimated the ET_0 values. R_s overestimation and ET_0 underestimation related to parameters of those equations. In the study period, the average of overestimation of R_s is 2.69 mm/day, corresponding to a relative difference of approximately 49.06 % with respect to measured R_s data. The average of underestimation of ET_0 is 0.29 mm/day, corresponding to a relative difference of approximately 6.66% with respect to measured ET_0 data. These overestimation and underestimation could not be ignored.

Local Calibration and Validation

Local calibration of Angstrom's radiation model and then PM FAO equation was carried out using two third of the entire data, including 54 days. Calibration was performed by optimization of Angstrom's a_s and b_s coefficients using the Solver extension of Excel software with Generalized Reduced Gradient (GRG) method. Local a_s and b_s coefficients were obtained equal to 0.117 and 0.384, respectively. To validate the models, values of R_s and ET_0, were estimated using calibrated radiation and ET_0 equation for one third of the entire data, including 27 days. Coefficients a_s and b_s in the current study are much smaller than the original value suggested by Allen *et al*. (2006) and Xu *et al*. (2009).

Evaluation of Estimated R_s and ET_0 during the Calibration and Validation Periods

Coefficients a_s and b_s were estimated in Ardabil plain as an arid-cold region to improve results of Angstrom's radiation model and PM FAO equation for estimation of R_s and ET_0. In the calibration step, the values of a_s and b_s were determined as 0.117 and 0.384 for the study region. The R_s and ET_0 values were re-calculated with these new values of a_s and b_s. For calibration step, estimated daily radiation values compared with those measured one are illustrated in Figure 6. Estimated daily ET_0 values compared with the measured data, also, are illustrated in Figure 7. The statistical parameters of the Angstrom's radiation model and PM FAO equation, related to the calibration step, are given in Table 5.

Validation of the model was carried out with 27 data. The values obtained from the calibration step, were used in the validation step. The values of ET_0 and R_s obtained in the validation step are shown in Figures 8 and 9, respectively. The statistical parameters of the Angstrom's radiation model and PM FAO equation, related to the validation step, are also given in Table 6. Comparing the results of the original Angstrom's radiation model and original PM FAO equation with those locally calibrated showed that the errors (RMSE, AE and RE) were decreased and the fitted parameters (M, R^2 and NSE) were improved. In estimation of R_s, the RMSE, AE and RE decreased 2.427 mm/day, 2.381 mm/day and 42.041%, respectively. In estimation of ET_0, the RMSE, AE and RE also decreased 1.01mm/day, 0.895 mm/day and 16.246%, respectively.

The R^2 values in validation step were increased compared to before calibration from 0.861 to 0935 for R_s model and from 0.27 to 0.877 for ET_0 equation, indicating that the ET_0 estimation improved highly. The GMER values in different stages proved that underestimation or overestimation of R_s and ET_0 decreased in locally calibrated models

[DOR: 20.1001.1.16807073.2019.21.2.5.6]

and caused the line slopes (M) reach near unity and the points were perched in around the 1:1 line in Figures 6 to 9. If NSE values reach values more than 0.36, the efficiency of the model will be satisfactory. In locally calibrated models, compared to the original models, the NSE values were increased from -0.114 to 0.887 in R_s model and from 0.291 to 0.809 in ET_0 model. The RE value and its criteria showed that the original Angstrom's radiation model and the original PM FAO equation have poor accuracy, whereas the locally calibrated ones have very good and good accuracy, respectively.

CONCLUSION

For an arid-cold region, the Angstrom's radiation model and the PM FAO equation

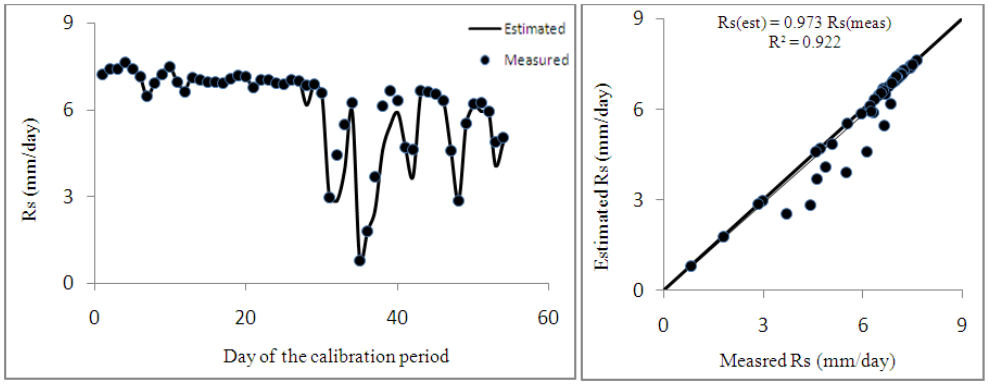

Figure 6. Daily R_s values estimated by the locally calibrated Angstrom's radiation model compared with the measured data (during the calibration period and around the 1:1 line)

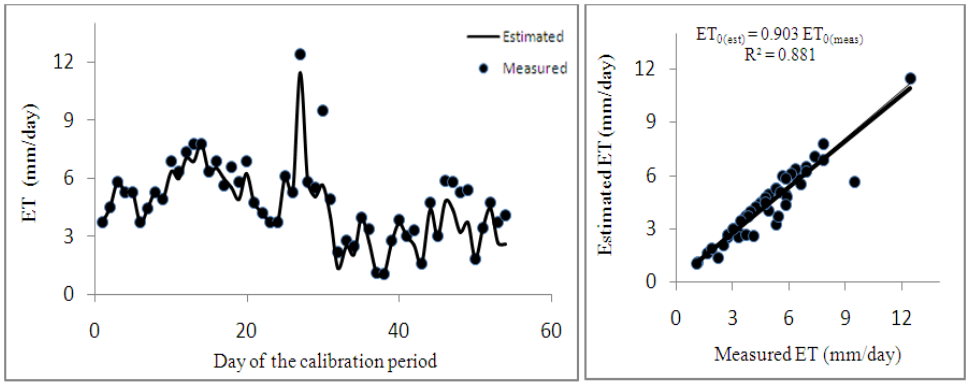

Figure 7. Daily ET_0 values estimated by the locally calibrated PM FAO equation compared with the measured data (during the calibration period and around the 1:1 line)

Table 5. Statistical parameters of locally calibrated Angstrom's radiation model and PM FAO equation in the calibration stage.

Angstrom's radiation model			PM FAO equation		
Parameter	Value	Explanation	Parameter	Value	Explanation
R^2 (-)	0.922	Acceptable	R^2 (-)	0.881	Acceptable
M (line slope) (-)	0.973	Acceptable	M (line slope) (-)	0.903	Acceptable
RMSE (mm/day)	0.483	Low	RMSE (mm/day)	0.818	Low
AE (mm/day)	0.215	Low	AE (mm/day)	0.447	Low
NSE (-)	0.891	Satisfied	NSE (-)	0.838	Satisfied
RE (%)	3.483	Very good	RE (%)	9.183	Very good
GMER (-)	1.045	Underestimated	GMER (-)	1.101	Underestimated

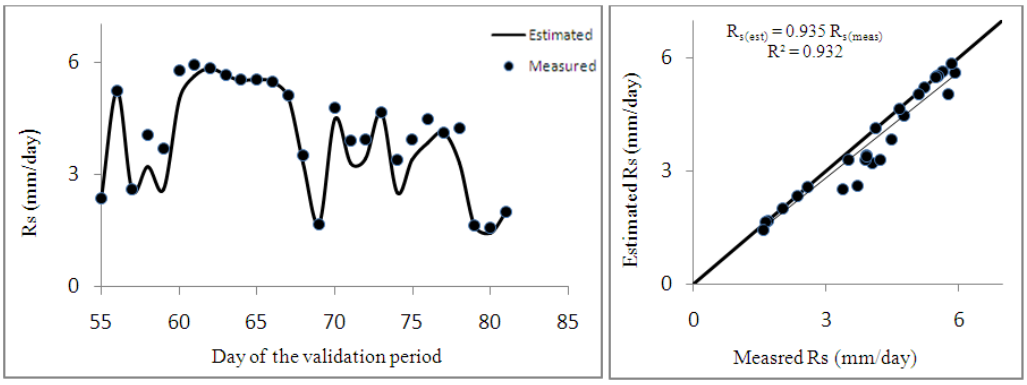

Figure 8. Comparing the estimated R_s values with the measured data in validating the locally calibrated Angstrom's radiation model

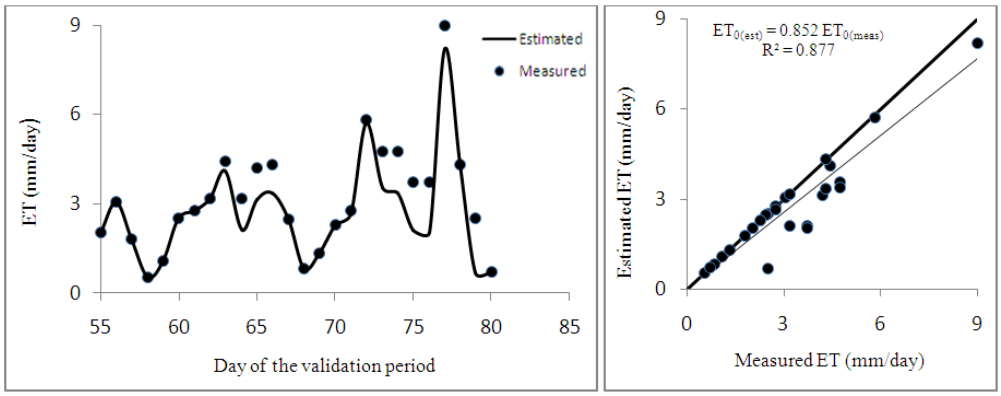

Figure 9. Comparing the estimated ET_0 values with the measured data in validating the locally calibrated PM FAO equation

Table 6. Statistical parameters of locally calibrated Angstrom's radiation model and PM FAO equation in the validation stage.

Angstrom's radiation model			PM FAO equation		
Parameter	Value	Explanation	Parameter	Value	Explanation
R^2 (-)	0.935	Acceptable	R^2 (-)	0.877	Acceptable
M (line slope) (-)	0.932	Acceptable	M (line slope) (-)	0.852	Acceptable
RMSE (mm/day)	0.455	Low	RMSE (mm/day)	0.768	Low
AE (mm/day)	0.287	Low	AE (mm/day)	0.447	Low
NSE (-)	0.887	Satisfied	NSE (-)	0.809	Satisfied
RE (%)	7.02	Very good	RE (%)	14.714	Good
GMER (-)	1.083	Underestimated	GMER (-)	1.171	Underestimated

with original recommended angstrom's coefficients were evaluated. The capabilities to estimate R_s and ET_0 values were examined using some statistical parameters. Both original models had low accuracy in estimation of R_s and ET_0 values. Originals Angstrom's radiation model overestimated and original PM FAO equation underestimated the values of daily R_s and ET_0, respectively. Therefore, local calibration of both models was performed in Ardabil plain using the measured R_s and ET_0 values. Three lysimeters were installed at the study site to measure ET_0 values. To optimize the a_s and b_s parameters, the GRG optimization method from the Solver extension of Excel

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software was used. To calibrate the Angstrom's radiation model and PM FAO equation, a_s and b_s coefficients were determined by using the Solver extension of Excel software. The values of a_s and b_s were determined as 0.117 and 0.384 for the study region (compared to 0.25 and 0.5 as original values). The errors of Angstrom's radiation model and PM FAO equation were decreased and the fitted parameters were increased by local calibration of the models. By using the new values of a_s and b_s (using calibrated models), the estimates for R_s and ET_0 improved and the accuracy of the models increased. Therefore, the calibration of R_s and PM FAO models is essential for each region.

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تخمین تبخیرتعرق مرجع با استفاده از ضرایب تعدیل شده محلی معادله تابش آنگستروم در یک منطقه سرد و خشک

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چکیده

تخمین قابل قبول تبخیرتعرق مرجع (ET_0) بوسیله رابطه پنمن مونتیث فائو نیازمند داده‌های صحیح تابش خورشیدی (R_s) می‌باشد. مقادیر R_s می‌تواند با استفاده از معادله تابش آنگستروم تخمین زده شود. هدف اصلی این مطالعه تعیین ضرایب a_s و b_s (به عنوان پارامترهای آنگستروم) برای دشت اردبیل به عنوان یک منطقه سرد و خشک می‌باشد. مدل تابش آنگستروم و معادله پنمن مونتیث فائو (PM FAO) با بهینه کردن مقادیر a_s و b_s، با استفاده از روش گرادیان کاهشی تعمیم یافته (GRG)، برای منطقه مورد مطالعه واسنجی گردید. مقادیر اندازه‌گیری شده R_s از ایستگاه سینوپتیک اردبیل به دست آمد و مقادیر اندازه‌گیری شده

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ET_0 با استفاده از سه عدد لایسیمتر که در ایستگاه تحقیقاتی هانگار نصب شده بود، تعیین شد. نتایج واسنجی مدل‌ها نشان داد که مقادیر بهینه شده a_s و b_s به ترتیب برابر با ۰/۱۱۷ و ۰/۳۸۴ بود. در مدل‌های واسنجی شده برای منطقه نسبت به مدل‌های پیشنهادی اصلی، مقادیر خطا شامل RMSE، AE و RE کاهش یافت و مقادیر پارامترهای برازش مدل شامل R^2 و شیب خط رگرسیون (m) بهبود یافت. مقادیر GMER برای مدل‌های اصلی نشان داد که مدل تابش آنگستروم مقادیر R_s را بیش برآورد و مدل پنمن مونتیث مقادیر ET_0 را کم برآورد می نمایند. مدل‌های واسنجی شده محلی مقادیر R_s و ET_0 را بهتر از مدل‌های اصلی برآورد می‌نمایند. مقادیر ضریب کارآیی نش-ساتکلیف ثابت نمود که تخمین R_s و ET_0 با استفاده از مدل‌های اصلی رضایت بخش نبوده اما با استفاده از مدل‌های واسنجی شده محلی رضایت بخش می باشد. واسنجی مدل تابش آنگستروم و معادله پنمن مونتیث فائو برای هر منطقه‌ای ضروری می‌باشد.

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