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Evaluation and calibration of sunshine based solar radiation models for Tabriz, Iran

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Abstract

Estimation of global solar radiation (Rs) value is essential for many applications such as architectural design, solar energy systems, crop growth models and determination of crop water requirement. In this research, twenty-four empirical global solar radiation models were evaluated using measured daily solar radiation and actual sunshine hours data for the years of 2001-2011 at Tabriz station located in the northwest of Iran. Statistical analysis showed that the most of these models presented good results in the study area. According to the relative percentage error (RPE) results, good agreement ($|RPE| \leq 10\%$) was obtained between the measured and calculated values of the solar radiation by use of nineteen numbers of the models. In contrast, the five rest models had not acceptable results. RPE values varied from 0.65% to -54.61% for the studied models. According to the ranking of the models performance, the RMSE, MBE, d and RPE values of the best model were 2.95, -0.18, 0.97 and 0.65, respectively. This model was recommended to use in the study region, where sunshine hours were measured.

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Introduction

Global solar radiation at the earth surface is an important variable used in agricultural sciences, especially in crop growth modeling and crop water requirements models. It is also important in hydrology, meteorology and soil physics sciences. Numerous models are developed to estimate global solar radiation based on different available meteorological data. They are broadly categorized as cloud-based (*Kasten* 1983), sunshine duration-based (*Angstrom* 1924, *Prescott* 1940) and air temperature-based (*Bristow and Campbell* 1984). The most commonly used parameter for estimating solar radiation is sunshine duration. In the other words, it is generally recognized that the sunshine-based models, in particular the Angstrom–Prescott and its modified models, which are based on actual to maximum possible sunshine duration ratio, have the best performance (*Almorox and Hontoria* 2004, *Trnka et al.* 2005, *Zand-Parsa et al.* 2011, *Majnooni-Heris and Bahadori* 2014). Since the establishment of the Angstrom–Prescott model, it is under constant modifications centered on improvement of its prediction accuracy and general validity. The modifications are made mainly in three forms: (1) the model coefficients are based on geographical or meteorological variables (*Glover and Mc Cullogh* 1958, *Halouani et al.* 1993). In this form, the original linear structure of the Angstrom–Prescott model remains unchanged; (2) additional terms are considered in the equation by increasing the order of measured actual sunshine (n) to maximum possible sunshine (N) durations ratio, for example to second order is used by *Akinoglu and Ecevit* (1990), *Ogelman et al.* (1984), *Bahel et al.* (1986) or to third order (*Ulgen and Hepbasli* 2004, *Zabara* 1986). In these modifications, the original structure of the Angstrom–Prescott equation is changed from linear to nonlinear form; and (3) more terms are added to the equation by introducing additional parameters such as air temperature and relative humidity (*Ododo et al.* 1995) and air vapor content *(Garg and Garg* 1982). In these modifications, the structure of the Angstrom–Prescott model is changed from single linear to multi-linear. Based on the *Menges et al.* (2006) results, the sunshine duration based methods could give more accurate results than the models that are based on the other meteorological data.

Depending on atmospheric conditions, humidity, dust and global solar declination the coefficients of Angstrom Prescott methods vary for different regions. Many researchers have calibrated and used the basic form of the Angstrom–Prescott model for different regions (*Page* 1961, *Bahel et al.* 1986, *Allen et al.* 1998, *Louche et al.* 1991, *Benson et al.* 1984). The main goal of this study was evaluation of the several sunshine hours based models for estimation of the global solar radiation and selection of the best accurate model at Tabriz meteorological station.

Materials and methods

The experimental data are obtained from the weather station of Tabriz located in east Azarbijan province, Iran. The global solar radiation and other meteorological data reported in the paper are a part of the data measured at the meteorological station during 2001 to 2011. The latitude, longitude and elevation above mean sea level of the station are 38° 04´ 47″N, 46° 17´ 30″E and 1364 m, respectively.

In this study, the investigated models coefficients were estimated by minimizing the sum of square errors between the measured and predicted values. Models performances were evaluated by statistical error tests such as correlation coefficient (r) (*Walpole et al.* 1998), index of model agreement (d) (*Willmott* 1982), and mean bias error (MBE, the difference between estimated and measured values) and relative percentage error (RPE) indexes as follows:

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

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)$$

$$d = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{1}^{n}(|P_i - \bar{O}| + |O_i - \bar{O}|)^2}$$

$$RPE = \left[\frac{(\sum O_i - \sum P_i)}{\sum O_i}\right] \times 100$$

where, n is the total number of measurements, i is the measurement number, O and P are the measured and estimated values, respectively and $\bar{O}$ is the average of measured values. When d =1, it indicates a prefect agreement between model estimations and the direct measurements of the parameters in question and d=0 indicates that the measured and estimated values are not in a good agreement. Hence, $MBE > 0$ is an indication of over-prediction and $MBE < 0$ is an indication of under-prediction. A relative percentage error between -10% and +10% is considered acceptable. The mean percentage error can be defined as the percentage deviation of the calculated and measured daily global solar radiation.

Investigated models

The *Angstrom–Prescott* (*Prescott* 1940) model is one of the most widely used sunshine based models to estimate global solar radiation, which given as follows:

$$\frac{Rs}{Ra} = a + b\frac{n}{N}$$

Where Rs and Ra are the global and extraterrestrial solar radiation (see more details in *Allen et al.* 1998), respectively, "a" and "b" are the Angstrom-Prescott model coefficients, n and N are the actual and maximum possible sunshine hours, respectively.

Page (1961) has given the coefficients of the Angstrom–Prescott model, which is believed to be applicable for any other parts of the world, as the following:

$$\frac{Rs}{Ra} = 0.23 + 0.48\frac{n}{N}$$

(Model-1)

Bahel et al. (1986) recommended the following coefficients for Angstrom–Prescott model:

$$\frac{Rs}{Ra} = 0.175 + 0.552\frac{n}{N}$$

(Model -2)

Allen et al. (1998) suggested values of 0.25 and 0.5, for "a" and "b" coefficients of Angstrom- Prescott model, respectively for the northern hemisphere.

$$\frac{Rs}{Ra} = 0.25 + 0.50\frac{n}{N}$$

(Model -3)

Louche et al. (1991) presented a model for global solar radiation prediction as follow:

$$\frac{Rs}{Ra} = 0.206 + 0.546\frac{n}{N}$$

(Model- 4)

Majnooni-Heris et al. (2008) recommended 0.31 and 0.60 for "a" and "b" coefficients of Angstrom-Prescott model, respectively for south of Iran.

$$\frac{Rs}{Ra} = 0.31 + 0.60\frac{n}{N}$$

(Model -5)

Benson et al. (1984) proposed two different formulations for two intervals of a year as follows:

$\frac{Rs}{Ra} = 0.18 + 0.60\frac{n}{N}$ January–March and October–December

$\frac{Rs}{Ra} = 0.24 + 0.53\frac{n}{N}$ April–September

(Model- 6)

Gopinathan (1988) suggested use of the Angstrom–Prescott model coefficients as follow:

$a = 0.265 + 0.07Z - 0.135\frac{n}{N}$; $b = 0.401 - 0.108Z - 0.325\frac{n}{N}$ (Model-7)

Above equations, coefficients were proposed for estimation of the global solar radiation, where Z is the station elevation.

Zabara (1986) correlated "a" and "b" values of the Angstrom–Prescott model with relative sunshine duration ($\frac{n}{N}$) as a third order function and expressed the "a" and "b" coefficients as:

$$a = 0.395 - 1.247\left(\frac{n}{N}\right) + 2.680\left(\frac{n}{N}\right)^2 - 1.674\left(\frac{n}{N}\right)^3$$

$$b = 0.395 + 1.384\left(\frac{n}{N}\right) - 3.249\left(\frac{n}{N}\right)^2 + 2.055\left(\frac{n}{N}\right)^3$$

(Model-8)

Rietveld (1978) examined several published values of the "a" and "b" coefficients and noted that "a" is related linearly and "b" hyperbolically to the appropriate mean value of $\frac{n}{N}$ such as the following:

$a = 0.10 + 0.245\frac{n}{N}$; $b = 0.38 + 0.080\frac{n}{N}$

(Model 9)

Almorox and Hontoria (2004) proposed the following exponential model to global solar radiation estimation in this form:

$\frac{R_s}{R_a} = a + b\exp\left(\frac{n}{N}\right)$

(Model-10)

Ampratwum and Dorvlo (1999) proposed the following model

$\frac{R_s}{R_a} = a + b\log\left(\frac{n}{N}\right)$

(Model-11)

Ogelman et al. (1984) correlated $\left(\frac{Rs}{Ra}\right)$ with $\left(\frac{n}{N}\right)$ in the form of a second order polynomial equation [33]:

$\frac{Rs}{Ra} = a + b\left(\frac{n}{N}\right) + c\left(\frac{n}{N}\right)^2$; $\frac{Rs}{Ra} = 0.195 + 0.676\left(\frac{n}{N}\right) - 0.142\left(\frac{n}{N}\right)^2$ (Model-12)

where a, b and c are empirical coefficients.

Akinoglu and Ecevit (1990) obtained the correlation below between $\left(\frac{Rs}{Ra}\right)$ and $\left(\frac{n}{N}\right)$ in a second order polynomial equation for Turkey:

$\frac{Rs}{Ra} = 0.145 + 0.845\left(\frac{n}{N}\right) - 0.280\left(\frac{n}{N}\right)^2$

(Model -13)

Samuel (1991) obtained the correlation between ratio of global to extraterrestrial solar radiation and the ratio of actual to maximum possible sunshine duration as follows:

$\frac{Rs}{Ra} = a + b\left(\frac{n}{N}\right) + c\left(\frac{n}{N}\right)^2 + d\left(\frac{n}{N}\right)^3$;

$\frac{Rs}{Ra} = 0.14 + 2.52\left(\frac{n}{N}\right) - 3.71\left(\frac{n}{N}\right)^2 + 2.24\left(\frac{n}{N}\right)^3$

(Model -14)

where a , b , c and d are empirical coefficients.

Bahel et al. (1987) developed a worldwide correlation based on bright sunshine hours and global radiation data of 48 stations around the world, with varied meteorological conditions and a wide distribution of geographic locations:

$\frac{Rs}{Ra} = 0.16 + 0.87\left(\frac{n}{N}\right) - 0.16\left(\frac{n}{N}\right)^2 + 0.34\left(\frac{n}{N}\right)^3$

(Model -15)

One of the most interesting solar radiation estimation models, including a logarithmic term, presented by *Newland* (1988) as follows:

$\frac{Rs}{Ra} = a + b\left(\frac{n}{N}\right) + c\log\left(\frac{n}{N}\right)$; $\frac{Rs}{Ra} = 0.34 + 0.40\left(\frac{n}{N}\right) + 0.171\log\left(\frac{n}{N}\right)$ (Model -16)

The Angstrom–Prescott–Page model has been modified by *Louche et al.* (1991) through the use of the ratio of (n/N_{nh}) instead of (n/N), where N_{nh} is the sunshine duration, so as to take into account the natural horizon of the site. It can be calculated as follows:

$\frac{Rs}{Ra} = a + b\left(\frac{n}{N_{nh}}\right)$; $\frac{1}{N_{nh}} = 0.0003 + \frac{0.8706}{N}$

(Model -17)

where a, b, c and d are empirical coefficients.

Elagib and Mansell (2000) suggested the following models:

$\frac{Rs}{Ra} = a\exp\left[b\left(\frac{n}{N}\right)\right]$

(Model -18)

$\frac{Rs}{Ra} = a + b\left(\frac{n}{N}\right)^s$

(Model -19)

Togrul et al. (2000) proposed the following correlations, where the coefficients of the Angstrom–Prescott model seem to be a function of the sunshine duration ratio:

$a = i + j\left(\frac{n}{N}\right)$ and $b = k + L\left(\frac{n}{N}\right)$

(Model -20)

$a = i\ln\left(\frac{n}{N}\right) + j$ and $b = k\ln n + m$

(Model -21)

$a = i + j\left(\frac{n}{N}\right) + k\left(\frac{n}{N}\right)^2$ and $b = l + m\left(\frac{n}{N}\right) + s\left(\frac{n}{N}\right)^2$

(Model -22)

$a = i + j\left(\frac{n}{N}\right) + k\left(\frac{n}{N}\right)^2 + l\left(\frac{n}{N}\right)^3$ and $b = m + s\left(\frac{n}{N}\right) + p\left(\frac{n}{N}\right)^2 + r\left(\frac{n}{N}\right)^3$ (Model -23)

$a = i + j\left(\frac{n}{N}\right) + k\left(\frac{n}{N}\right)^2 + l\left(\frac{n}{N}\right)^3 + m\left(\frac{n}{N}\right)^4$ and

$$b = s + p\left(\frac{n}{N}\right) + r\left(\frac{n}{N}\right)^2 + t\left(\frac{n}{N}\right)^3 + v\left(\frac{n}{N}\right)^4$$

(Model -24)

Results and Discussion

Estimation of earth received solar radiation is required in many study fields due to its vital role as a input to agronomical, ecological, hydrological and soil-plant-atmosphere transfer models. Evaluation of twenty-four radiation estimation models has been performed using the RMSE, MBE, d and RPE and the results are given in table 1. All coefficients of investigated models are presented for each equation at the end of the mentioned table columns. According to the obtained results, model -24 was found as the most accurate model for estimation of the solar radiation in Tabriz station. The RMSE, MBE, d and RPE values for this model were 2.95, -0.18, 0.97 and 0.65, respectively. The model-24 can be presented for Tabriz station as follows:

$$R_s = R_a[\left(0.24 + 0.37\frac{n}{N} - 0.62\left(\frac{n}{N}\right)^2 + 0.28\left(\frac{n}{N}\right)^3 + 0.045\left(\frac{n}{N}\right)^4\right) + \left(0.52 - 0.79\left(\frac{n}{N}\right) + 0.38\left(\frac{n}{N}\right)^2 + 3.22\left(\frac{n}{N}\right)^3 - 0.18\left(\frac{n}{N}\right)^4\right)\frac{n}{N}]$$

r=0.91

Table 1. Statistical results of investigated models.

Statistical index	Model -							
	1	2	3	4	5	6	7	8
RMSE	3.19	3.43	3.34	3.30	5.40	3.35	11.08	3.59
MBE	-0.80	-1.13	0.16	-0.32	3.78	-0.11	-7.99	0.27
d	0.93	0.94	0.94	0.94	0.88	0.94	0.45	0.92
Statistical index	Model -							
	9	10	11	12	13	14	15	16
RMSE	3.70	3.21	3.97	3.39	3.53	9.40	8.29	3.84
MBE	-0.94	-0.19	-0.34	-0.23	-0.54	7.50	5.81	-0.73
d	0.94	0.94	0.83	0.94	0.94	0.75	0.80	0.92
Local coefficients		a=-0.064	a=0.649					
		b=0.316	b=0.410					
Statistical index	Model -							
		18	19	20	21	22	23	24
RMSE	3.72	3.21	3.23	3.91	3.25	3.21	3.25	2.95
MBE	-1.47	-0.18	-0.20	1.73	-0.15	-0.18	-0.18	-0.18
d	0.91	0.94	0.94	0.93	0.94	0.94	0.94	0.97
Local coefficients	a=0.250	a=0.258	a=0.265	i=250	i=-0.05	i=0.24	i=0.24	i=0.240
	b=0.470	b=1.132	b=0.524	j=0.30	j=0.05	j=-0.23	j=0.17	j=0.370
			s=1.46	k=0.15	k=-0.13	k=-0.30	k=-0.74	k=-0.62
				l=0.18	m=1.05	m=0.04	l=0.82	l=0.280
						s=0.35	m=0.42	m=0.045
							s=-0.06	s=0.520
							p=0.34	p=-0.790
							r=-0.39	R=0.380
								t=3.220
								v=-0.180

Comparison of the measured data with the predicted values of the global solar radiation by model-24 during study years are shown in figure 1. Comparing the measured global solar radiation with the predicted values showed these values laid around the straight line. This means that the model-24 is valid for estimation of global solar radiation in Tabriz region.

Statistical results indicated that the estimated values of Rs are fairly close to the measured values as shown by the values of d=0.97 and RPE=0.65% which d and RPE are fairly close to one and zero, respectively.

Table 2. Ranking results of evaluated methods based on relative percent error.

Model-	1	2	3	4	5	6	7	8	9	10	11	12
RPE	4.88	6.89	-0.98	1.92	-22.91	0.87	48.57	-1.66	5.70	1.16	2.05	1.40
Ranking	16	18	4	12	21	2	23	11	17	8	13	10
Model-	13	14	15	16	17	18	19	20	21	22	23	24
RPE	3.31	-54.61	-35.30	4.45	8.91	1.10	1.19	-10.53	0.88	1.09	1.11	0.65
Ranking	14	24	22	15	19	6	9	20	3	5	7	1

The values of RPE, which is used to rank the models, are presented in table 2. For statistical analysis, it was assumed that the best models were those that had the lowest |RPE|. As a result, the model-14 has the lowest accuracy. The RMSE, MBE, d and RPE values for model-14 were 9.40, 7.50, 0.75 and 0.-54.61, respectively. According to the ranking results, model-24 has highest accuracy as it was depicted among the other models.

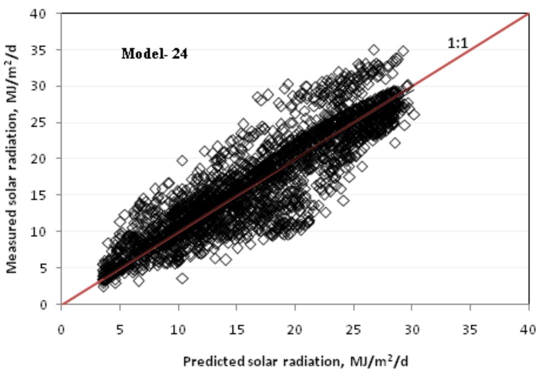

Fig. 1. Relationship between the measured and predicted values of global solar radiation by model-24.

The mean relative percentage error can be defined as the percentage deviation of the calculated and measured daily global solar radiation. Variation of RPE values for 24 investigated models are shown in figure 2. A relative percentage error between +10% and -10% is considered acceptable (Menges *et al.* 2006). According to mentioned figure RPE of five models, including model 5, 7, 14, 15 and 20, are in out of acceptable range.

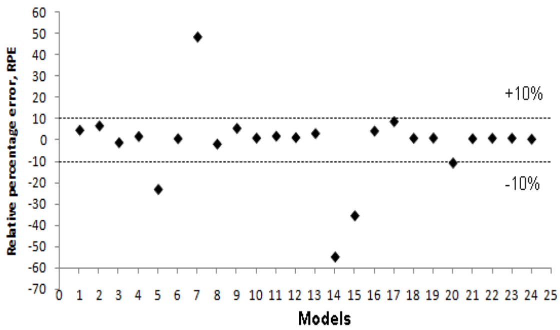

Fig. 2. Calculated relative percentage error for 24 investigated models.

Conclusions

Global solar radiation is one of primary importance for building solar energy devices, estimating crop productivity etc. However, direct measuring is not available in many areas, empirical equations become effective alternatives to estimate global radiation through observed sunshine duration data. In this study twenty-four sunshine-based radiation estimation model were evaluated for Tabriz region. According to the obtained results, the model-24 was found the most accurate for the estimation of solar radiation in study site. The RMSE, MBE, d and RPE values of above model were suitable in comparison with other studied models. This means that mentioned model is valid for estimation of global solar radiation in research site. In contrast, the model-14 had the lowest accuracy and showed poor results. As a result, good agreement (RPE ≤ ±10%) was confirmed between measured values and calculated values of solar radiation at the nineteen numbers of models.

References

Akinoglu BG, Ecevit A. 1990. A further comparison and discussion of sunshine based models to estimate global solar radiation. Solar Energy **15,** 865–872.
http://dx.doi.org/10.1016/0360-5442(90)90068-D

Allen RG, Pereria LS, Raes D, Smith M. 1998. Crop evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper **56.** 301 p.

Almorox J, Hontoria C. 2004. Global solar radiation estimation using sunshine duration in Spain. Energy Conversion and Management **45,** 1529–1535.
http://dx.doi.org/10.1016/j.enconman.2003.08.022

Ampratwum DB, Dorvlo ASS. 1999. Estimation of solar radiation from the number of sunshine hours. Appl Energy **63,** 161–7.
http://dx.doi.org/10.1016/S0306-2619(99)00025-2

Angstrom A. 1924. Solar and terrestrial radiation. Quar-terly Journal of the Royal Meteorological Society **50,** 121–5.

Bahel V, Srinivasan R, Bakhsh H. 1986. Solar radiation for Dhahran, Saudi Arabia. Energy **11,** 985–9.
http://dx.doi.org/10.1016/0360-5442(86)90029-0

Benson RB, Paris MV, Sherry JE, Justus CG. 1984. Estimation of daily and monthly direct, diffuse and global solar radiation from sunshine duration measurements. Solar Energy **32,** 523–35.
http://dx.doi.org/10.1016/0038-092X(84)90267-6

Bristow K, Campbell G. 1984. On the relationship between incoming solar radiation and daily maximum and minimum temperature. Agricultural and Forest Meteorology **31,** 159–66.
http://dx.doi.org/10.1016/0168-1923(84)90017-0

Elagib N, Mansell MG. 2000. New approaches for estimating global solar radiation across Sudan. Energy Convers Manage **41,** 419–34.
http://dx.doi.org/10.1016/S0196-8904(99)00123-5

Garg HP, Garg ST. 1982. Prediction of global solar radiation from bright sunshine hours and other meteorological parameters. In: Solar-India, Proceedings of the National Solar Energy convention. Allied Publishers, New Delhi, 1004–1007 p.

Glover J, Mc Cullogh JSG. 1958. The empirical relation between solar radiation and the hours of bright sunshine. Quart J Roy Met Soc **84,** 172–175.
http://dx.doi.org/10.1002/qj.49708436011

Gopinathan KK. 1988. A simple method for predicting global solar radiation on a horizontal surface. Solar Wind Technol **5,** 581–3.
http://dx.doi.org/10.1016/0741-983X(88)90050-1

Halouani N, Nguyen CT, Vo-Ngoc D. 1993. Calculation of monthly average global solar radiation on horizontal surfaces using daily hours of bright sunshine. Solar Energy **50,** 247–248.
http://dx.doi.org/10.1016/0038-092X(93)90018-J

Kasten F. 1983. Parametriserung der Globalstrahlung durch Bedeckungsgrad und Tru˝ bungsfaktor. Ann Meteorol **20,** 49–50.

Louche A, Notton G, Poggi P, Simonnot G. 1991. Correlations for direct normal and global horizontal irradiation on a French Mediterranean site. Solar Energy **46,** 261–6.
http://dx.doi.org/10.1016/0038-092X(91)90072-5

Majnooni-Heris A, Bahadori H. 2014. Calibration of the modified Angstrom global solar radiation models for different seasons in south of Iran. International Journal of Biosciences **3,** 53-60. http://dx.doi.org/10.12692/ijb/4.3.1-8

Majnooni-Heris A, Zand-Parsa Sh, Sepaskhah AR, Nazemosadat MJ. 2008. Development and evaluation of meteorological data based solar radiation equations. JWSS – Isfahan University of Technology, Iran. **46,** 491-499.

Menges HO, Ertekin C, Sonmete MH. 2006. Evaluation of global solar radiation models for Konya, Turkey. Energy Conversion and Management **47,** 3149–3173. http://dx.doi.org/10.1016/j.enconman.2006.02.015.

Newland FJ. 1988. A study of solar radiation models for the coastal region of South China. Solar Energy **31**:227–35.

Ododo JC, Sulaiman AT, Aidan J, Yguda MM, Ogbu FA. 1995. The importance of maximum air temperature in the parameterisation of solar radiation in Nigeria. Renew. Energy **6,** 751–763. http://dx.doi.org/10.1016/0960-1481(94)00097-P

Ogelman H, Ecevit A, Tasdemiroglu E. 1984. A new methodfor estimating solar radiation from bright sunshine data.Solar Energy **33,** 619–625.

Page JK. 1961. The estimation of monthly mean values of daily total short wave radiation on vertical and inclined surfaces from sunshinerecords for latitudes 40_N–40_S. In: Proceedings of UN conference on new sources of energy, 378–90 p.

Prescott JA. 1940. Evaporation from a water surface in relation to solar radiation. Transactions Royal Society of South Australia **64,** 114-125.

Rietveld M. 1978. A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine. Agricultural Meteorology **19,** 243–252. http://dx.doi.org/10.1016/0002-1571(78)90014-6.

Samuel TDMA. 1991. Estimation of global radiation for Sri Lanka. Solar Energy **47,** 333–7. http://dx.doi.org/10.1016/0038-092X(91)90026-S

Togrul IT, Togrul H, Evin D. 2000. Estimation of monthly global solar radiation from sunshine duration measurements in Elazig. Renew Energy **19,** 587–95. http://dx.doi.org/10.1016/S0960-1481(99)00084-1

Trnka M, Zalud Z, Eitzinger J, Dubrovsky M. 2005. Global solar radiation in Central European lowlands estimated by various empirical formulae. Agric For Meteorol **131,** 54–76. http://dx.doi.org/10.1016/j.agrformet.2005.05.002

Ulgen K, Hepbasli A. 2004. Solar radiation models. Part 2: Comparison and developing new models. Energy Sources **26,** 521–30. http://dx.doi.org/10.1080/00908310490429704

Walpole RE, Mayers RH, Mayers SL. 1998. Probability and statistics. New Jersey: Prentice Hall International. 739 p.

Willmott CJ. 1982. Some comments on the evaluation of model performance. Bull Am Meteorol Soc. **63,** 1309–1313. http://dx.doi.org/10.1175/15200477(1982)063%3C1309:SCOTEO%3E2.0.CO;2

Zabara K. 1986. Estimation of the global solar radiation in Greece. Solar Wind Technol **7,** 267–72. http://dx.doi.org/10.1016/0741-983X(86)90005-6

Zand-Parsa SH, Majnooni-Heris A, Sepaskhah AR, Nazemosadat MJ. 2011. Modification of Angstrom model for estimation of global solar radiation in an intermountain region of southern Iran. Energy and Environment **22,** 911-924.