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GLOBAL SOLAR RADIATION ESTIMATION USING SUNSHINE DURATION IN NIGDE

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ABSTRACT
In this paper, several equations were employed to estimate global solar radiation from sunshine hours for a meteorological station in Nigde, Turkey, using only the relative duration of sunshine. These equations included the original Angstrom-Prescott linear regression and modified functions (quadratic, logarithmic and exponential functions). Estimated values were compared with measured values in terms of the coefficient of determination, root mean square error and mean absolute percentage error. All the models fitted the data adequately and can be used to estimate global solar radiation from sunshine hours. This study finds that the linear models performed better than the other models and it is preferred due to its greater simplicity and wider application.
Keywords: Angström equation, global solar radiation estimation, sunshine duration, correlation models

1. INTRODUCTION
The global solar irradiation on a horizontal surface is the minimum information generally needed as an input parameter for building a solar energy project. The accurate knowledge of the solar radiation intensity at a given location is of importance to the development of solar energy system design. This information is used in the design, cost and effectiveness estimation of a project. Further, monthly mean daily data are needed for the estimation of long-term solar systems performances. The values of the daily global irradiation measurements are not available at every location due to the cost of measuring equipment, maintenance, and calibration. In places where no measured values are available, a common application has been to determine this parameter by appropriate correlations, which are empirically, established using the measured data [1].

Several empirical models have been used to calculate solar radiation, utilizing available meteorological, climatological, and geographical parameters such as sunshine hours, air temperature, latitude, precipitation, relative humidity, and cloudiness. The most commonly used parameter for estimating global solar radiation is sunshine duration [1-7]. Sunshine duration can be easily and reliably measured, and data are widely available. Most of the models for estimating solar radiation that appear in the literature use the sunshine ratio. The most widely used method is that of Angstrom, who proposed a linear relationship between the ratio of average daily global radiation to the corresponding value on a completely clear day and the ratio of average daily sunshine duration to the maximum possible sunshine duration [2].

The objective of this study was to validate several expression models for the prediction of monthly average daily global radiation on a horizontal surface from sunshine hours and to select the most

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adequate model. The values of the monthly average daily global radiation on a horizontal surface used in the present study were taken from Turkish State Meteorological Service in the periods between 2001 and 2010. The other objective of this study is to evaluate various models for the estimation of the monthly average daily global radiation on a horizontal surface from bright sunshine hours and to select the most appropriate model for Nigde, Turkey.

2. THEORY

There are several formulae that relate global radiation to other climatological parameters such as sunshine hours, relative humidity, and outdoor temperature. The first correlation proposed for estimating the monthly average daily global radiation is based on the method of Angstrom [5]. The original Angstrom-Prescott type regression equation-related monthly average daily radiation to clear day radiation in a given location and average fraction of possible sunshine hours:

$$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) \tag{1}$$

where H is the monthly average daily global radiation, H_0 the monthly average daily extraterrestrial radiation, S the monthly average daily hours of bright sunshine, S_0 the monthly average day length, and a and b are the empirical constants.

The monthly average daily extraterrestrial radiation on a horizontal surface (H_0) can be computed from the following equation [3]:

$$H_0 = \left(\frac{24}{\pi}\right) I_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) x \left(\cos\Phi\cos\delta\sin w_s + \left(\frac{2\pi w_s}{360}\right)\sin\Phi\sin\delta\right) \tag{2}$$

where I_{sc} is the solar constant (= 1353Wm^{-2}), Φ the latitude of the site, δ the solar declination, w_s the mean sunrise hour angle for the given month ,and n the number of days of the year starting from the first of January. The solar declination (δ) and the mean sunrise hour angle (w_s) can be calculated by Eqs.(4) and(5), respectively [3]:

$$\delta = 23.45 \cdot \sin\left(360\frac{284 + n}{365}\right) \tag{3}$$

$$w_s = \cos^{-1}\left(-\tan\Phi \cdot \tan\delta\right) \tag{4}$$

For a given month, the monthly average day length can be computed by using the following equation [3]:

$$S_0 = \frac{2}{15} w_s \tag{5}$$

The regression models proposed in the literature and developed in this study are listed in Table 1. In the literature, there are numerous statistical methods available to compare solar radiation models [1-7]. In the present study, the predictive efficiencies of the models are tested using the following parameters: mean absolute percentage error (MABE), root mean square error (RMSE), and correlation coefficient (R^2).

Table 1. Regression models proposed in the literature.

Models	Mod. no.	Regression equation	Source
Linear	**1**	$H/H_0 = a + b(S/S_0)$	Angstrom [5] and Prescott [6]
Exponential	**2**	$H/H_0 = a + b\exp(S/S_0)$	Akinoglu and Ecevit [3]
Logarithmic	**3**	$H/H_0 = a + b\log(S/S_0)$	Almorox and Hontoria [4]
Quadratic	**4**	$H/H_0 = a + b(S/S_0) + c(S/S_0)^2$	Bakirci [2]

3. RESULT AND DISCUSSION

By using the data measured at the Turkish State Meteorological Service in the periods between 2001 and 2010, the regression constants a, b, and c are reported for the four models in Table 2. This supports the high determination coefficients mentioned above. For the provinces of Nigde, the following main results are obtained from the evaluation of the values in Tables 3. Considering the MAPE, RMSE, the results for all the models are generally low.

Table 2. Regression constants for provinces of Nigde, in the period of 2001-2010.

Models	R^2	a	b	c
Linear	0.9508	0.4616	0.3066	
Exponential	0.9483	0.4857	0.4694	
Logarithmic	0.9382	0.7463	0.1848	
Quadratic	0.9501	0.4799	0.2447	0.0491

Table 3. Statistic for the validation of the models.

Month	RMSE				MAPE			
	Linear	Exponential	Logarithmic	Quadratic	Linear	Exponential	Logarithmic	Quadratic
January	0.7360	0.7624	0.6353	0.7545	0.0068	0.3458	1.6573	0.2702
February	1.0370	1.0608	0.9848	1.0523	2.6929	2.4072	4.1498	2.4634
March	0.6635	0.6733	0.6154	0.6677	0.7654	0.7361	0.2182	0.6889
April	1.1849	1.1864	1.2014	1.1877	2.7152	2.5405	3.3634	2.6159
May	0.7272	0.7035	0.8364	0.7930	1.1787	0.9182	1.9742	1.5173
June	1.1732	1.1121	1.2067	1.1207	0.6799	0.9862	0.8001	1.0044
July	1.1767	1.3523	1.2706	1.1610	0.7013	3.1207	0.0278	0.8541
August	0.8395	0.8578	0.8015	0.8535	1.3470	1.5463	0.6053	1.4996
September	0.9706	0.9438	1.0732	0.9504	2.1655	2.1073	2.4767	2.1072
October	0.5076	0.5234	0.4828	0.5167	1.0066	1.2310	0.3420	1.1371
November	0.3576	0.3629	0.3567	0.3620	1.3670	1.1914	1.9787	1.2710
December	0.5640	0.6043	0.4336	0.5937	3.2076	3.6317	0.8486	3.5407

Table 4 represents the calculated values of the monthly average daily global radiation on a horizontal surface, for Nigde. As can be seen from this table, the calculated values are in good agreement with the measured data. Here, the comparison was only between the calculated global radiation with the measured global radiation data obtained from the meteorological department.

Comparing the results, we can see that all the regression equations gave very good results. The linear and quadratic models equations gave the best estimate and have the smallest errors for the monthly values. The logarithmic and exponential regression equations gave good, and very similar, accuracy. Given the small differences between the variance explained by linear regression and the most accurate equation, the quadratic and the simplicity and wider application of the linear equation, the simple linear regression, is in practice, sufficient, and the use of the logarithmic and exponential equations is not sufficiently justified.

Table 4. The comparison between measured values and estimated values monthly average daily global irradiation (MJ/m^2) for 4 Models.

Month	Measured	Models			
		Linear	Exponential	Logarithmic	Quadratic
January	9.9069	9.8287	9.9090	9.7713	9.9042
February	13.3917	12.9433	13.0647	12.9209	13.0612
March	17.7181	17.5534	17.6225	17.8183	17.6325
April	21.6891	22.2018	22.1265	22.3029	22.1427
May	26.0879	26.3725	26.3010	26.5719	25.6660
June	29.0889	29.2267	29.4056	29.3191	29.4082
July	29.0961	29.2402	29.9581	29.0309	29.3024
August	26.1947	26.5229	26.5854	26.3329	26.5725
September	22.2618	21.743	21.7426	21.6554	21.7421
October	15.8962	15.7154	15.7919	15.9324	15.8071
November	11.1291	11.2632	11.1693	11.2581	11.1780
December	8.7473	8.9737	8.9974	8.7671	8.99013

4. CONCLUSION

Several sunshine based models have been employed for estimating global solar radiation for Nigde. The differences between the results of the different models are negligible. The linear equation is the best overall, according to R^2, RMSE and MAPE, and has the best performance based on the measured data at one station in Nigde. We recommend the use of the linear equation, however, due to the small differences between the exponential regression and the quadratic regression and the greater simplicity of the linear equation. The linear equation can be used to estimate the global solar radiation in Nigde, Turkey.

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