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EMPIRICAL MODELS FOR THE CORRELATION OF GLOBAL SOLAR RADIATION WITH SUNSHINE DURATION ON A HORIZONTAL SURFACE IN SERBIA

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ABSTRACT
This paper presents an analysis of the relationship between global solar radiation and the sunshine duration at different locations in Serbia. Several regression methods, which were previously used by researchers, were used to analyze. The global solar radiations estimated from the ten models were compared with the measured values. The estimated values are compared with the measured values in terms of mean bias error (MBE), root mean square error (RMSE), and mean percent error (MPE). Results show that the second and the third regression models performed better than the other used in the paper. The proposed models show a good agreement with measured values of solar global radiation and could be used to other locations in Serbia where solar data are not available.
Keywords: Solar radiation, Empirical models, Sunshine duration

1. INTRODUCTION
The measured data of the solar radiation are the best form of this knowledge, but there are few meteorological stations that measured solar radiation, especially in developing countries. In Serbia, global solar radiation data on a horizontal surface is recorded at only 4 stations. For stations where no measured data are available the practice is to estimate global solar radiation from other measured meteorological parameters [1]. Several empirical models have been used to calculate solar radiation using variables such as extraterrestrial irradiance and measured and theoretical sunshine duration [2-8], air temperature, relative humidity, and wind speed and moisture.
In this an analysis of the relationship between global solar radiation and the sunshine duration at three different locations in Serbia are presented. The first purpose of the present paper is to validate those models for the prediction of monthly average daily global radiation on a horizontal surface from sunshine duration. The second objective is to test the performance of the presented models against the measured global radiation for selected locations.

2. MODELS AND DATA
For this analysis the measured data of monthly average daily solar radiation, sunshine duration and temperature are used from the Study of Energy Potential of Serbia, published by National Ministry of Science. The study was based on data collected over 34 years. Measurements of global solar radiation were performed with Moll-Gorczynsky pyranometers, while for the recording of sunshine duration Campbell-Stokes heliographs were used.
Ten different regression models proposed in the literature were applied in this study and presented in Table 1. Coefficient values for models were calculated from regression analysis between H/H_0 and S/S_0, where H is daily solar global radiation on a horizontal surface, H_0 is the monthly average daily extraterrestrial radiation, S is the monthly average daily hours of bright sunshine (h), S_0 is the monthly average day length (h), a and b are empirical coefficients, ϕ *is* latitude and Z is altitude (km). The regression coefficients of the models 1, 6 and 8 for analyzing locations are given in Table 2.

Table 1. The empirical models for the correlation of global solar radiation data.

Model No.	Author / Source		Correlation
1	Angstrom-Prescott	[1]	$H/H_0 = a + b(S/S_0)$
2	Rietveld	[2]	$H/H_0 = 0.18 + 0.62(S/S_0)$
3	Glover and McCulloch's	[3]	$H/H_0 = 0.29cos\ \phi + 0.52(S/S_0)$, $\phi < 60^{o}$
4	Dogniaux and Lemoine	[4]	$a = 0.3702 - 0.00313\phi$ $b = 0.32029 + 0.00506\phi$
5	Gopinathan	[2]	$H/H_0 = [-0.309 + 0.539cos\phi - 0.0693Z + 0.290(S/S_0)] + [1.527 - 1.027cos\phi + 0.0926 - 0.359(S/S_0)](S/S_0)$
6	Akinoglu and Ecevit	[5]	$H/H_0 = a + b(S/S_0) + c(S/S_0)^2$
7	Ogelman	[6]	$H/H_0 = 0.195 + 0.676(S/S_0) - 0.142(S/S_0)^2$
8	Ertekin and Yaldiz	[7]	$H/H_0 = a + b(S/S_0) + c(S/S_0)^2 + d(S/S_0)^3$
9	Zabara	[4]	$a = 0.395 - 1.274(S/S_0) + 2.680(S/S_0)^2 - 1.674(S/S_0)^3$ $b = 0.395 + 1.384(S/S_0) - 3.249(S/S_0)^2 + 2.055(S/S_0)^3$
10	Bahel	[8]	$H/H_0 = 0.16 + 0.87(S/S_0) - 0.61(S/S_0)^2 + 0.34(S/S_0)^3$

Table 2. The regression coefficients of models.

Location	Model No.	a	b	c	d
Belgrade ($44^{o}47'^{o}$N, $20^{o}32'^{o}$E)	1	0.259	0.502	-	-
	6	0.174	0.929	-0.494	-
	8	0.096	1.559	-2.068	1.239
Negotin ($44^{o}14'^{o}$N, $20^{o}33'^{o}$E)	1	0.254	0.598	-	-
	6	0.202	0.870	-0.315	-
	8	0.660	-2.682	8.232	-6.475
Zlatibor ($43^{o}44'^{o}$N, $19^{o}43'^{o}$E)	1	0.339	0.334	-	-
	6	0.358	0.230	0.132	-
	8	0.017	3.062	-7.302	6.251

The performance of the models was evaluated on the basis of the statistical indicators: the mean bias error (MBE), the root mean square error (RMSE), and the mean percentage error (MPE). These tests are the most commonly applied in comparing the models of solar radiation estimations [9].

3. RESULTS AND DISCUSSION

The accuracy of different models was determined using the measured data. The values of monthly mean daily global solar radiation intensity were estimated using the above ten models and were compared with the corresponding measured values. The statistical tests of MBE, RMSE and MPE were determined using measures of sunshine hours and monthly average daily solar radiation at given location for the entire period, and the results are summarized in Table 3.

Table 3. Model validations under different statistical tests.

Model No.	Belgrade			Negotin			Zlatibor		
	MBE	RMSE	MPE	MBE	RMSE	MPE	MBE	RMSE	MPE
1	0.007	0.069	-2.89	0.015	0.121	-2.00	-0.004	0.078	18.89
2	0.156	0.192	5.45	0.485	0.531	12.84	0.242	0.273	9.26
3	0.337	0.369	9.33	0.643	0.723	15.58	0.349	0.359	11.47
4	0.058	0.102	1.88	0.375	0.435	8.86	0.101	0.154	4.72
5	-0.061	0.242	1.52	0.257	0.301	9.19	0.245	0.363	11.5
6	0.012	0.046	0.10	0.007	0.102	-0.07	-0.003	0.073	0.21
7	0.113	0.138	3.49	0.441	0.498	10.72	0.159	0.194	6.54
8	0.011	0.046	0.60	0.000	0.098	-0.15	-0.013	0.060	-0.04
9	0.084	0.118	2.48	0.403	0.466	9.41	0.132	0.173	5.63
10	0.205	0.228	5.94	0.532	0.598	13.02	0.247	0.262	8.92

According to the results from the Table 3 it can be seen that the MBE values of all models are close to zero as desired. Models 1, 6 and 8 has the lowest MBE values, while the maximal MBE values for all the stations are obtained from model 3. The other statistical parameter RMSE shows that the lowest RMSE values for all the stations are obtained using the model 8, while the highest RMSE values are obtained with models 3 and 5. According to the MPE values, the lowest errors are obtained with model 6 and 8, and the highest with models 1 and 3. According to the all statistical indicators it has been concluded that the models 6 and 8 achieve the best results for the studied sites. This means that these models give a precise estimation of monthly mean daily global solar radiation for the analyzing stations. The measured and calculated values of the monthly average daily global radiation using models 6 and 8 for the Belgrade, Negotin and Zlatibor are illustrated in Figure 2. As can be seen from Figure 2 agreement between the values obtained from these models and the measured data are good for all the months of the year.

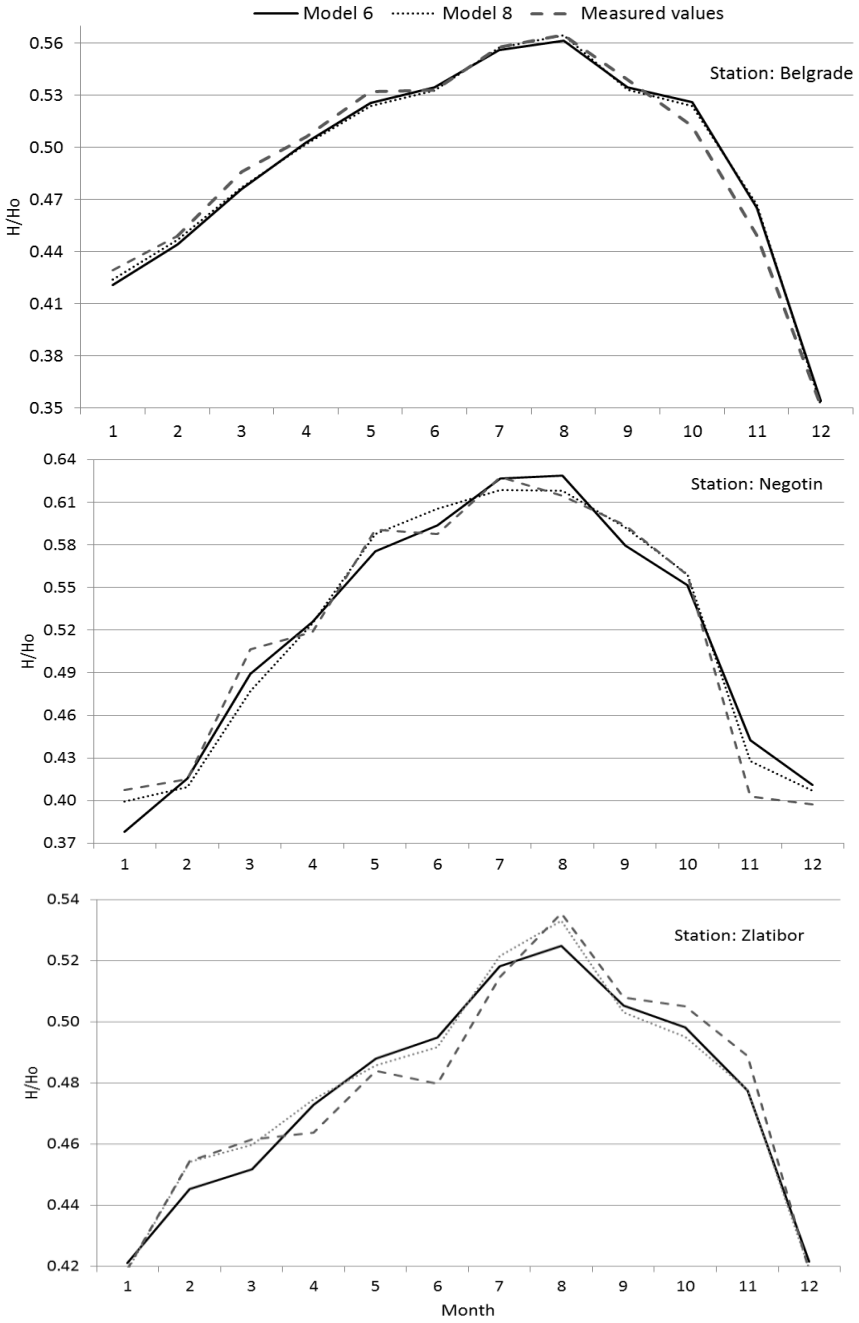

Figure 1. Comparison of the measured and calculated total monthly global solar radiation from model 6 and 8 for three different locations in Serbia.

Utilizing a combination of used stations in Serbia, it has been shown that the global solar radiation across the country can be related to the relative sunshine duration. The values of the regression coefficients obtained for all the stations were found to be different. These differences suggest that the regression coefficients associated with meteorological data changes with latitude and atmospheric conditions.
According to the results, the model 6, second regression model, is recommended for the estimation of monthly average daily global solar radiation.

4. CONCLUSION

This paper analyses the relationship between global solar radiation and sunshine duration with different estimation models for three locations in Serbia. The objective was to evaluate various models for the estimation of the monthly average daily global radiation on a horizontal surface from bright sunshine hours and to propose a new and appropriate model for Serbia. The collected models were compared on the basis of the statistical error tests such as MBE, RMSE and MPE. According to the results new model given by the second regression equation is recommended. Future work is being carried out with a view to enlarge the scope by increasing the number of the meteorological data.

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