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Estimation of Global Solar Radiation from Sunshine Duration for Mostar, Bosnia and Herzegovina

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Abstract As it is well known, the most important parameter for estimating global solar radiation is sunshine duration combined with a knowledge of local atmospheric conditions. Knowing the monthly mean daily sunshine duration it is possible to obtain the hourly global solar radiation incident on a horizontal surface. There are a number of available models to apply for studies on solar radiation, such as linear Angstrom-Prescott model and non-linear polynomial relations correlating sunshine hours and sun radiation, but for particular geographical location is of vital importance to find out and apply an adequate model for the development of solar energy devices and for estimates of their performances.

In this paper are given the results of testing the applicability of several models according to the data obtained from meteorological station located in Mostar City (Bosnia and Herzegovina). Estimated values of global solar radiation were compared with the measured values in terms of the coefficient of determination, coefficient of regression, mean percentage error and root mean square error, and the most applicable model for this location is determined on the base of agreement between the measured and estimated data.

Keywords Sunshine based models, insolation, model equations, correlation, Mostar

1. Introduction

Solar radiation plays an important role as a renewable energy source, as solar radiation measurements could be used to estimate potential power levels that can be generated from photovoltaic cells and also necessary for determining cooling loads for buildings [1]. For the development and the use of solar energy systems, it is essential to understand the solar radiation data. In all examples of systems and applications using Solar Energy, the most important parameters required for their operation and understanding are the parameters related to the total Sun's radiation and its components. Measuring these parameters, despite the development of numerous meteorological instruments, is inaccessible to most meteorological stations not only in Bosnia and Herzegovina, but also in the world. Therefore, it is necessary to examine the possibilities of its estimation from other parameters whose measurements are available and less complicated. The parameter used in this paper to estimate Solar radiation is the duration of sunshine (insolation). The sunshine duration is readily available and measured in most meteorological stations in Bosnia and Herzegovina, and most of the available literature models use the duration of sunshine to estimate radiation. The models that base their estimation on the Sun duration are known as "sunshine" models.

2. Renewable Energy

Adequate supply of energy always has been one of the important factors of economic growth and development. The growing demand in urban and rural areas for energy has necessitated the finding of alternative sources of energy [2]. During the past 25 years, there has a significant growth of the renewable energy technology, and today it considered by many countries as an important technology for the future. Many countries have already established or are in the process of establishing support programs to encourage the adoption of this new technology. To overcome the dependency on conventional fuels, researchers and many organizations are working on alternative fuels, which should be commercially viable, easy to use, less pollutant, and must be abundant in nature. In this direction, renewable energies, like solar energy, tidal energy, wind energy, biofuels, and so forth, are suitable than conventional sources of energy. Germany is one of the leading countries in regard with development and deployment of renewable energy technologies and the competition triggered by Germany as well as other developed countries has led to a significant drop in prices of solar energy generation equipment [3]. These nonconventional forms are not only renewable but also maintain ecology and environment as they are eco-friendly and do not contribute in global warming and production of green house gases, and so forth [2].

Solar energy is the most important energy resource to man and indeed it is essential factor for human life [4]. Solar energy is incident on the earth at a rate of $2.0 \cdot 10^{15}$ kWh/day and is estimated to last for 704 billion years [4]. Although the supply of solar energy received by the earth is substantial, it has three peculiar characteristics that cause problem in its collection and practical application as an economic substitute for conventional energy source [5].

Today, the use of solar energy has become a global trend and as a result an increasing number of companies are becoming engaged in production of solar panels [6].

3. Study Area of the City Mostar

The historic town of Mostar, spanning a deep valley of the Neretva River between Hum Hill and the foot of the Velež Mountain, in the southern part of Bosnia and Herzegovina. The town was developed in the 15th and 16th centuries, as an Otoman frontier town and during the Austro-Hungarian period in the 19th and 20th centuries. Mostar area has humid subtropical climate Cfa with lighter, but cold winters with little or no snow, and hot summer. The town lies on northern latitude 43°19′41″ and eastern longitude 17°48′46″ (60-80) m above sea level. The mean annual rainfull usually ranges from 50 mm to 200 mm. The driest month is July, with 49 mm rainfall, while most of the precipitation here falls in December, averaging 201 mm. The warmest month of the year is July, with an average temperature of 25,1°C, while the maximum temperature can reach up to 40°C. January is the coldest month, with temperatures averaging 5,3°C, while the minimum temperature can be as low as -10°C. Figure 1 shows the mean annual temperature for the city of Mostar. The Mostar region has about 230 sunny days annually and 2 285 sunny hours.The date used in this paper cover the period from 1998 till 2017.

Meteorological station: Bijeli Brijeg - Mostar, Bosnia and Herzegovina.

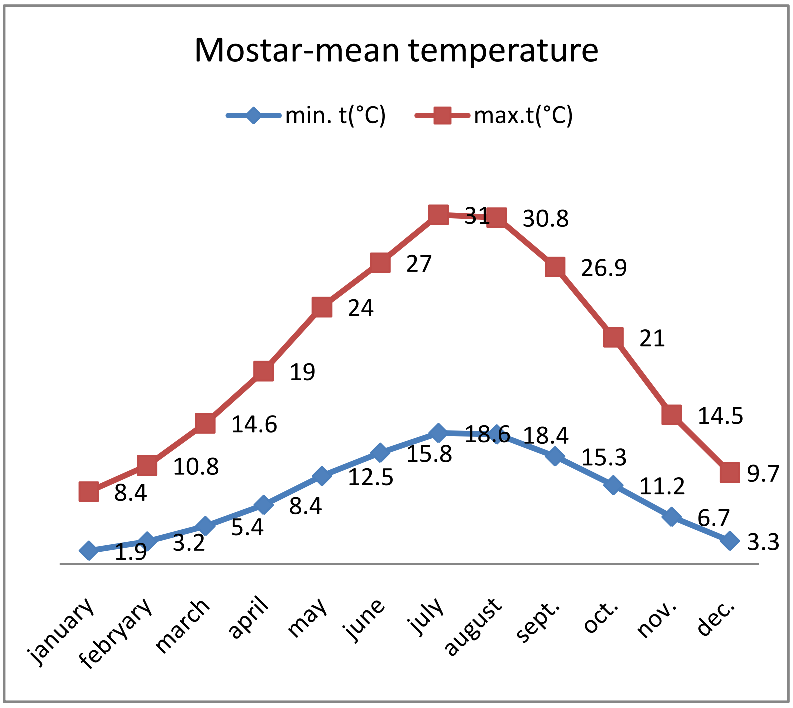

Figure 1: Mean min. and. max. temperature during the year

4. Sunshine based Models

Development of a solar energy research program must always start with a study of solar radiation data at a site or region of interest. For places where it is not directly measured, solar radiation can be estimated by using models and empirical correlations [7]. Information of local solar radiation is essential for analysis and assessment of solar radiation potential of the given region, architectural design, solar energy systems and design. For many developing countries, solar radiation measurements are not easily available due to the cost and maintenance and calibration requirements of the measuring equipment. Therefore, it is important to elaborate methods to estimate the solar radiation based on readily available meteorological data. Sunshine based models are employed for estimation global solar radiation for a location. The correlation equations given in this work will enable the solar energy researcher to use the estimated data with trust because of its fine agreement with the observed data.

Ǎngström [8] proposed the first theoretical model for estimating global solar radiation based on sunshine duration [9].

Page [10] and Prescott [11] reconsidered this model in order to make it possible to calculate monthly average of the daily global radiation (MJ/m^2 day) on a horizontal surface from monthly average daily total insolation on an extraterrestrial horizontal surface as per the following relation. The monthly average daily global radiation on horizontal surface:

$$\frac{\bar{H}}{\bar{H}_0} = a + b\frac{\bar{S}}{\bar{S}_0} \tag{1}$$

$\bar{H}_0$ - the monthly average daily extraterrestrial radiation on horizontal surface can be computed from the model of Duffies and Beckman [12], which is cast as [13]:

$$H_0 = \frac{24 \cdot 3600 \cdot G_{sc}}{\pi}\left[1 + 0{,}003cos\left(\frac{360°}{365}n\right)\right] \cdot \left(cos\varphi cos\delta cos\omega_s + \frac{\pi\omega_s}{180°}sin\varphi sin\delta\right) \tag{2}$$

$\bar{S}$ - monthly average of daily sunshine duration.

$\bar{S}_0$ - the monthly average of the maximum possible daily solar radiation (day lenght) [12]:

$$\bar{S}_0 = \frac{2}{15}arccos(-tan\varphi tan\delta) = \frac{2}{15}\omega_s \tag{3}$$

Parameters a and b are the regression coefficients.

Gsc- the solar constant

$$G_{sc} = 1367\frac{W}{m^2} = 4{,}9212\frac{MJ}{m^2 h} \tag{4}$$

δ - solar declination [12]:

$$\delta = 23{,}45° sin\left(\frac{n + 284}{365} \cdot 360°\right) \tag{5}$$

n - the day of year starting from first January.

Mean sunshine hour angle:

$$cos\omega_s = -tan\varphi tan\delta \tag{6}$$

φ - the latitude of location.

4.1. Prediction of global solar radiation using five models

Most empirical models used to predict global solar radiation are based on the Angstrom-Prescott model. In this study we evaluated five models and chose the best models for the city of Mostar.

Model 1. Dogniaux and Lemoine linear monthly dependent model [14]. The model is based on data from 116 meteorological stations northern latitude (4°52´ - 60°8´) for January-December:

January
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00301\varphi + 0{,}34507) + (0{,}00495\varphi + 0{,}34572)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (7)$$

February
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00255\varphi + 0{,}33459) + (0{,}00495\varphi + 0{,}34572)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (8)$$

March
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00303\varphi + 0{,}36690) + (0{,}00466\varphi + 0{,}36377)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (9)$$

April
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00334\varphi + 0{,}38557) + (0{,}00456\varphi + 0{,}35802)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (10)$$

May
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00245\varphi + 0{,}35057) + (0{,}00485\varphi + 0{,}33550)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (11)$$

June
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00327\varphi + 0{,}39890) + (0{,}00578\varphi + 0{,}27292)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (12)$$

July
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00369\varphi + 0{,}41234) + (0{,}00568\varphi + 0{,}27004)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (13)$$

August
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00269\varphi + 0{,}36243) + (0{,}00412\varphi + 0{,}33162)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (14)$$

September
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00338\varphi + 0{,}39467) + (0{,}00564\varphi + 0{,}27125)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (15)$$

October
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00317\varphi + 0{,}36213) + (0{,}00504\varphi + 0{,}31790)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (16)$$

November
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00350\varphi + 0{,}36680) + (0{,}00523\varphi + 0{,}31467)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (17)$$

December
$$\bar{H} = \bar{H}_0 \left\{(-0{,}00350\varphi + 0{,}36262) + (0{,}00559\varphi + 0{,}30675)\frac{\bar{S}}{\bar{S}_0}\right\} \quad (18)$$

Model 2: Rietveld linear monthly dependent model. Measurement based on 100 European meteorological stations for January-December [15]:

January
$$\bar{H} = \bar{H}_0 \left(0{,}18 + 0{,}66\frac{\bar{S}}{\bar{S}_0}\right) \quad (19)$$

February
$$\bar{H} = \bar{H}_0 \left(0{,}20 + 0{,}60\frac{\bar{S}}{\bar{S}_0}\right) \quad (20)$$

March
$$\bar{H} = \bar{H}_0 \left(0{,}22 + 0{,}58\frac{\bar{S}}{\bar{S}_0}\right) \quad (21)$$

April
$$\bar{H} = \bar{H}_0 \left(0{,}20 + 0{,}62\frac{\bar{S}}{\bar{S}_0}\right) \quad (22)$$

May
$$\bar{H} = \bar{H}_0 \left(0{,}24 + 0{,}52\frac{\bar{S}}{\bar{S}_0}\right) \quad (23)$$

June
$$\bar{H} = \bar{H}_0 \left(0{,}24 + 0{,}53\frac{\bar{S}}{\bar{S}_0}\right) \quad (24)$$

July
$$\bar{H} = \bar{H}_0 \left(0{,}23 + 0{,}53\frac{\bar{S}}{\bar{S}_0}\right) \quad (25)$$

August
$$\bar{H} = \bar{H}_0\left(0{,}22 + 0{,}55\frac{\bar{S}}{\bar{S}_0}\right) \quad (26)$$

September
$$\bar{H} = \bar{H}_0\left(0{,}20 + 0{,}59\frac{\bar{S}}{\bar{S}_0}\right) \quad (27)$$

October
$$\bar{H} = \bar{H}_0\left(0{,}19 + 0{,}60\frac{\bar{S}}{\bar{S}_0}\right) \quad (28)$$

November
$$\bar{H} = \bar{H}_0\left(0{,}17 + 0{,}66\frac{\bar{S}}{\bar{S}_0}\right) \quad (29)$$

December
$$\bar{H} = \bar{H}_0\left(0{,}18 + 0{,}65\frac{\bar{S}}{\bar{S}_0}\right) \quad (30)$$

Model 3: Dogniaux and Lemoine linear monthly independent model. Accuracy is greater if used for northern latitude 4° to 61° [14]:

$$\bar{H} = \bar{H}_0\left\{0{,}37022 + \left(0{,}00506\frac{\bar{S}}{\bar{S}_0} - 0{,}00313\right)\varphi + 0{,}32029\frac{\bar{S}}{\bar{S}_0}\right\} \quad (31)$$

Model 4: Rietveld linear monthly independent model. Measurement based on 100 European meteorological stations [15]. Rietveld examined several published values of *a* and *b* and noted that *a* is related linearly and *b* hyperbolically to the mean value of S such that this equation is believed to be applicable anywhere in the world and yields superior results for cloudy conditions, for $S < 0.4$:

$$\bar{H} = \bar{H}_0\left(0{,}18 + 0{,}62\frac{\bar{S}}{\bar{S}_0}\right) \quad (32)$$

Model 5: Gopinathan quadratic model. Gopinathan proposed *a* and *b* are related to three parameters: the latitude, the elevation and the sunshine hours [1]:

$$\bar{H} = \bar{H}_0\left\{\begin{matrix}\left(\left(-0{,}309 + 0{,}539cos\varphi - 0{,}0693h + 0{,}290\frac{\bar{S}}{\bar{S}_0}\right) + \right.\\ \left.\left(1{,}527 - 1{,}027cos\varphi + 0{,}0926h - 0{,}359\frac{\bar{S}}{\bar{S}_0}\right)\frac{\bar{S}}{\bar{S}_0}\right)\end{matrix}\right\} \quad (33)$$

4.2 Compare solar radiation estimation equations

To compare solar radiation estimation equations, the most widely used statistical indicators are the root mean square error (RMSE), mean percentage error (MPE) and the mean bias error (MBE).

- The root mean square error (RMSE) [12]:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{12}\left(\bar{H}_{i,estim} - \bar{H}_{i,measur}\right)^2}{12}} \quad (34)$$

- Mean bias error (MBE):

$$MBE = \frac{\sum_{i=1}^{12}\left(\bar{H}_{i,estim} - \bar{H}_{i,measur}\right)}{12} \quad (35)$$

- The calculated values were compared to the measured values in each regression relation through correlation coefficients [16]:

$$r = \frac{\sum_{i=1}^{12}\left(\bar{H}_{i,estim} - \bar{H}_{estim}\right)\cdot\left(\bar{H}_{i,measur} - \bar{H}_{measur}\right)}{\sqrt{\sum_{i=1}^{12}\left(\bar{H}_{i,estim} - \bar{H}_{estim}\right)^2\cdot\sum_{i=1}^{12}\left(\bar{H}_{i,measur} - \bar{H}_{measur}\right)^2}} \quad (36)$$

- Mean percentage error (MPE) [17]:

$$PE = \frac{\bar{H}_{i,estim} - \bar{H}_{i,measur}}{\bar{H}_{i,measur}} \cdot 100\% \quad (37)$$

$\bar{H}_{i,measur}$ - the measured values of global solar radiation on the day *i*,

$\bar{H}_{i,estim}$ - the calculated values of global solar radiation calculation on the day *i*.

5. Result and Discussion

Table 1 shows the monthly average daily extraterrestrial radiation on horizontal surface, monthly average of daily sunshine duration, monthly average of the maximum possible daily solar radiation (day lenght) which are needed for estimating global solar radiation. Measured values and based on five models estimated values of the monthly average daily global radiation are shown in Table 2.

Table 1: Extraterrestrial solar radiation, sunshine duration, maximum possible solar radiation

Months	$\bar{H}_0/MJm^{-2}$	$\bar{S}/h$	$\bar{S}_0/h$
Jan.	13.17	3.87	9.18
Feb.	18.62	4.40	10.33
Mar.	26.19	5.61	11.75
Apr.	33.79	6.3	13.22
May.	39.36	8.14	14.49
Jun.	41.77	9.64	15.15
Jul.	40.63	10.85	14.88
Aug.	36.19	10.24	13.81
Sep.	29.15	7.45	12.36
Oct.	21.40	5.76	10.90
Nov.	14.83	3.86	9.57
Dec.	11.77	3.96	8.86

Table 2: Comparison of the estimated value of daily global solar radiation from various models with the measured data

Months	$\bar{H}_{measur}$	$\bar{H}_{estim}$ Model 1	$\bar{H}_{estim}$ Model 2	$\bar{H}_{estim}$ Model 3	$\bar{H}_{estim}$ Model 4	$\bar{H}_{estim}$ Model 5
Jan	5.51	6.46	6.03	6.65	5.81	6.15
Feb	8.24	8.97	8.48	9.43	8.27	8.76
Mar	13.39	14.16	13.01	13.70	12.46	13.34
Apr	17.14	18.79	16.74	17.66	16.06	17.19
May	21.53	21.22	20.95	21.65	20.80	22.40
Jun	24.80	23.91	24.11	23.98	24.00	25.79
Jul	25.81	24.75	25.05	24.53	25.68	27.31
Aug	22.75	22.02	22.73	22.00	23.16	24.58
Sep	16.42	16.27	16.20	16.42	16.14	17.38
Oct	11.20	11.34	10.85	11.54	10.86	11.68
Nov	6.19	7.32	6.47	7.41	6.38	6.72
Dec	4.68	5.89	5.54	6.05	5.39	5.74

The measured and calculated values of the daily global solar radiation, using the five models are illustrated in Figure 3. As can be seen from this figure, agreement between the values obtained from Model 4 (Rietveld linear monthly independent model) and the measured data are good for all the months of the years. Model 5 overestimated measured data.

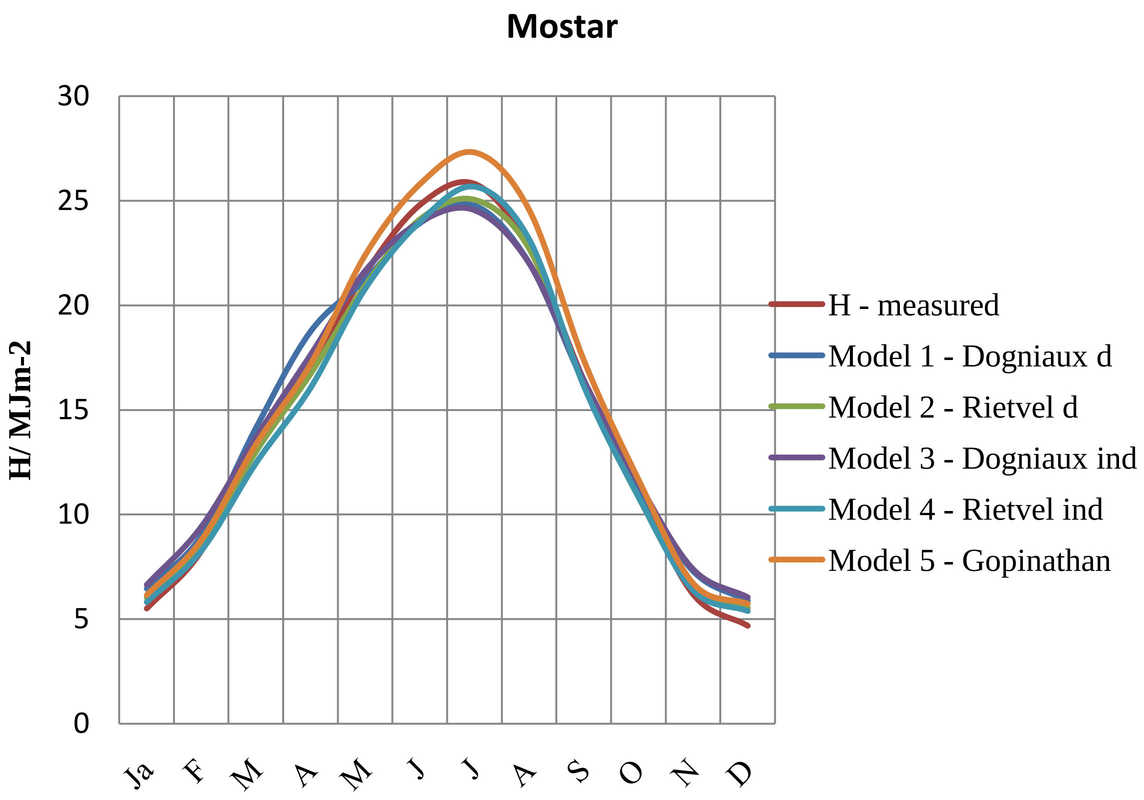

Figure 3: Comparison of the estimated value of daily global solar radiation from various models with the measured data

The above mentioned statistical indicators are used to examine the performance of the model of solar radiation estimation (Table 3). In general, low values of RMSE, MBE and MPE are desirable. The MBE provides a clue to whether a given model has a tendency to under- or over-predict. MBE values closest to zero being desirable. The positive MBE points out shows the overestimation and negative MBE shows the underestimation of the radiation. Ideally coefficient of correlation (r) and coefficient of determinant (R^2) should be 1. for the best performance, a very good fit results in a value near 1. and a very poor fit results in a value of R^2 close to zero [18]. Mean percentage error (MPE) for every month is given in Table 4. In winter months MPE values are higher than summer months. Best monthly MPE results are seen in model 4. The MPE indicates the percentage deviation of the predicted and measured monthly average daily global solar radiation data. The RMSE on the other hand indicates the level of scatter that a model produces, thus providing a term-by-term comparison of the actual deviation between the predicted and observed values, with a lower RMSE value reflecting a better model in terms of its absolute deviation. The equations with the highest values of and r and R^2 least values of MBE, RMSE, and MPE are suitable for predicting global solar radiation [17, 19].

Table 3: Values of MBE (MJ/m^2), RMSE (MJ/m^2), r, R^2 and MPE (%)

		Model				
		1	2	3	4	5
Mostar	MBE	0.283	-0.126	0.276	-0.222	0.783
	RMSE	0.904	0.503	0.878	0.592	0.939
	r	0.9971	0.9993	0.9977	0.9982	0.9992
	R^2	0.9942	0.9986	0.9983	0.9955	0.9965
	MPE	-6.063	-1.428	-6.718	-0.050	-6.762

Table 4: Values of MPE (%)

	PE (%) for Mostar				
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Jan	-17.197	-9.547	-20.637	-5.517	-11.711
Feb	-8.732	-2.873	-14.240	-0.280	-6.293
Mar	-5.585	2.848	-2.190	6.938	0.378
Apr	-9.483	2.320	-2.979	6.264	-0.334
May	1.409	2.708	-0.543	3.404	-4.064
Jun	3.534	2.798	3.328	3.258	-3.985
Jul	4.041	2.962	4.892	0.504	-5.815
Aug	3.179	0.105	3.246	-1.794	-8.037
Sep	0.874	1.330	-0.019	1.670	-5.882
Oct	-1.233	3.112	-3.028	3.004	-4.366
Nov	-17.991	-4.450	-19.408	-2.983	-8.478
Dec	-25.571	-18.449	-29.033	-15.072	-22.556

The results showed that in five model evaluation methods, Model 2: Rietveld linear monthly dependent model, compared to the other models, displayed the smallest MBE and RMSE while Model 4: Rietveld linear monthly independent model displayed the smallest MPE. The results showed that Model 2 was able to predict the variability of the monthly mean daily global solar radiation with a very high coefficient of determination of 0.9986 (Table 3). Rietveld linear independent model has relative error in absolute value of 0,050 % (MPE), indicating a very good agreement between measured data and those calculated. This error is acceptable in terms of technic. This makes Rietveld linear independent model most suitable for estimating global solar radiation for the town Mostar.

To reach the final conclusion that the model is more acceptable for Mostar we have calculated the coefficient of residual mass (CRM):

$$CRM = \frac{\sum\left(H_{i,meas} - H_{i,estim}\right)}{n\overline{H}_{meas}}. \qquad (38)$$

Model 2 gives a value of 0.008 and Model 4 a value of 0.015. CRM equals zero gives a perfect estimation. A positive value of CRM indicates underestimation of the measured values while a negative indicates overestimation of the measured values [20].

Solar energy technologies offer a clean, renewable and domestic energy source and are essential components of a sustainable energy future. The amount of global solar radiation and its temporal distribution are the primary variable for the use of solar energy. Development of a solar energy research program must always start with a study of solar radiation data at a site or region of interest [21]. Unfortunately, the measurement of these parameters is made only in a few meteorological stations, especially in developing countries, for both historical and economic reasons [22]. For places where it is not directly measured, solar radiation can be estimated by using models and empirical correlations. Therefore, there have been numerous investigations on the examination of the relationship between global radiation and sunshine duration for which data are available in a greater number of meteorological stations [22].

6. Conclusion

Empirical models can be used to estimate the monthly average daily global solar radiation in areas where there are no appropriate measurement devices available. The amount of global solar radiation and its temporal distribution are the primary variable for the use of solar energy. Development of a solar energy research program must always start with a study of solar radiation data at a site or region of interest. For places where it is not directly measured, solar radiation can be estimated by using models and empirical correlations. After confronting the measured values and those estimated by models, we noted that Model 4 and Model 2: Rietveld linear monthly independent and dependent model give the best results. The values of mean bias error, root mean square error and also the mean percentage error are in acceptable ranges. Rietveld linear monthly dependent model given in this work will enable the solar energy researches to use the estimated data due to fine agreement with the observed dana, especially because CRM is approximately zero.

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