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Empirical Model for Estimation of Global Solar Radiation in Mubi, Adamawa State

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Abstract

An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices. In this study, empirical model with logarithmic equation was used to estimate the global solar radiation based on the average monthly mean sunshine hour for Mubi town, Adamawa State. The daily sunshine hour were measured for five years (2010 to 2014) from which the monthly mean values were determined. Maximum solar were observed in January, February, March and April with the values18.03 $MJm^{-2}day^{-1}$, 19.07 $MJm^{-2}day^{-1}$, 20.399 $MJm^{-2}day^{-1}$ and 22.14 $MJm^{-2}day^{-1}$respectively. But on the other hand, in the months of June, July, August and September recorded the minimum amount of solar radiation of 17.62 $MJm^{-2}day^{-1}$, 17.80 $MJm^{-2}day^{-1}$, 16.50 $MJm^{-2}day^{-1}$ and 17.32 $MJm^{-2}day^{-1}$ respectively. This is as a result of the peak period of the cloud cover in Mubi region. The MPE, MBE and RMSE values were found to be -0.511, 1.236 and 4.274 for Almorox and Hontoria model, while – 0.0128, - 0.0436 and - 0.0780 for Ampratwum and Dorvlo model were low compare to Almorox and Hontoria model. A low value of MBE and RMSE is expected and acceptable. Ampratwum and Dorvlo model can be used with confidence for other locations with similar climate conditions, the results can be utilized in the design and performance estimation of solar energy systems.

Keywords: Estimation; Solar Radiation; Empirical Model; Sunshine Hour; Performance

Introduction

Solar radiation is the most important parameter in the design and evaluation of solar energy devices. An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for surveys in agronomy, hydrology, ecology and sizing of the photovoltaic or thermal solar systems and estimates of their performances (Jakhrani et al, 2010). Unfortunately, many developing nations' solar radiation measurements data are not easily available; therefore it is rather important to elaborate methods to estimate the solar radiation on the basis of more readily meteorological data. Over the years, many models have been proposed to predict the amount of solar radiation using various parameters (Okundamiya and Nzeako, 2010).

Solar energy occupies one of the most important places among the various possible alternative energy sources. It is the energy provided by the sun. Nigeria receives abundant solar energy that can be usefully harnessed with an annual average daily solar radiation of about 5250 Whm^{-2} day^{-1}. This varies between 3500 Whm^{-2} day^{-1} at the coastal areas and 7000 Whm^{-2} day^{-1} at the northern boundary. The average amount of sunshine hours all over the country is about 6.5 hours (Chineke and Igwiro, 2008; Yakubu and Medugu, 2012).

Accurate quantitative data of the variation of solar radiation reaching the earth surface, together with relevant meteorological parameters are essential requirements for conducting a wide range of scientific studies. Typical examples are found in hydrological studies when calculating soil moisture deficits (Mills, 2000), investigation of biological process, climatology (Dissing and Wendler, 1998), thermal design of environmental control of buildings (Agboola, 2011) and quantitative evaluation of eco-physiological system for the determination of irrigation water needs and the potential yield of crops (Tardieu, 2013). The design and estimation of performance of solar heating, cooling and distillation systems also requires detailed knowledge of solar radiation data (Tarawneh, 2007). Hence this work is aimed at estimating solar radiation for Mubi region using empirical model.

Materials and Methods

The monthly mean daily data for sunshine hours were obtained from Department of Geography metrological unit situated in Adamawa State University, Mubi Nigeria. The data obtained covered a period of five years (2010 – 2014) for Mubi Town, Nigeria located on latitude 10.2667° N and longitude 13.2667° E. The performance of the models was evaluated on the basis of the following statistical error tests: the mean percentage error (MPE), root mean square error (RMSE) and mean bias error (MBE). These tests are the ones that are applied most commonly in comparing the models of solar radiation estimations.

Empirical Model Based on Sunshine Hour

Angstrom (1924) and Prescott (1940) developed a correlation model for estimating monthly mean daily global solar radiation on a horizontal surface given as:

$$\frac{H_m}{H_o}\ a + b\left(\frac{n}{N}\right) \quad (1)$$

'a' and 'b' are climatologically determined regression constants.
Ampratwum and Dorvlo model (1999) suggested the following logarithmic equation:

$$\frac{R_s}{R_o}\ 0.6376 + 0.2490 log\left(\frac{n}{N}\right) \quad (2)$$

R_s is the monthly mean daily global solar radiation in $MJm^{-2}day^{-1}$ on a horizontal surface, while R_o is the monthly mean daily extraterrestrial solar radiation ($MJm^{-2}day^{-1}$), expressed as:

$$R_o = \frac{24(60)}{\pi} G_{sc} dr[W_s \sin\emptyset \sin\delta + \cos\delta \cos\emptyset W_s] \quad (3)$$

G_{sc} is solar constant = 0.0820 $MJm^{-2}min^{-1}$. The inverse relative Earth - Sun distance, dr [rad] is given by;

$$dr = 1\ + 0.33 \cos\left[\frac{2\pi}{365} - J\right] \quad (4)$$

where J is the number of the day in the year between 1 (1 January) and 365 (December). N is the daylight hour given as;

$$N = \frac{24W_s}{\pi} \quad (5)$$

where W_s, which is thee hour angle, is expressed as:

$$W_s = arc\cos[-\tan\emptyset \tan\delta] \quad (6)$$

$\emptyset\ and\ \delta$ are the latitude and declination angles respectively. The declination measured in degree is given as:

$$\delta = 23.45\ \sin\left(\frac{360}{365}\right)\ [284 + d] \quad (7)$$

where d is the day of the year. R_s is the monthly mean daily global solar radiation ($MJm^{-2}day^{-1}$).

The empirical model by Ampratwum and Dorvlo (1999) logarithmic equation used is:

$$\frac{R_s}{R_o}\ 0.6376 + 0.2490 log\left(\frac{n}{N}\right) \quad (8)$$

Almorox and Hontoria (2002) proposed the following exponential equation:

$$\frac{R_s}{R_o}\ 0.0271 + 0.3096\ exp\left(\frac{n}{N}\right) \quad (9)$$

Model Evaluation Schemes

In this work, the performance of the models was evaluated on the basis of the following statistical error tests: the Mean Percentage Error (MPE), Root Mean Square Error (RMSE), Mean Bias Error (MBE) and Percentage Error. These tests are applied most commonly in comparing the models of solar radiation estimations.

where $MPE = \frac{[\sum(H_{i,m} - H_{i,c})/H_{i,m}]100}{N}$ (10)

where $H_{i,m}$ is the ith measured value, $H_{i,c}$ is the ith calculated value of solar radiation and N is the total number of observations. Root Mean Square Error: The root mean square error is defined as:

$$RMSE = \left(\left[\frac{\sum\{H_{i,c} - H_{i,m}\}^2}{N}\right]\right)^{1/2} \quad (11)$$

Mean Bias Error: The mean bias error is defined as:

$$MBE = \frac{[\sum\{H_{i,c} - H_{i,m}\}]}{N} \quad (12)$$

Results and Discussion

The two models (Ampratwum and Dorvlo model; Almorox; Hontoria models) were computed. The estimation of monthly average daily solar radiation from the two models for Mubi for the period of five years were presented in Table 1. The relevant meteorological and solar radiation data were computed using equation 1 – 9.

From table 1, it observed that the estimated values of solar radiation vary correspondingly throughout the study for the models used. Maximum solar radiation were observed in January, February, March, April, May and June with the corresponding values of 18.03 $MJm^{-2}day^{-1}$, 19.07 $MJm^{-2}day^{-1}$, 20.399 $MJm^{-2}day^{-1}$ and 22.14 $MJm^{-2}day^{-1}$, 19.14 $MJm^{-2}day^{-1}$ respectively. But on the other hand, the months of August and September recorded the minimum amount of solar radiation with 16.50 $MJm^{-2}day^{-1}$ and 18.32 $MJm^{-2}day^{-1}$ for Ampratwum and Dorvlo respectively. January, February, March and April maximum value of solar radiation with the corresponding values of 19.00 $MJm^{-2}day^{-1}$, 20.55 $MJm^{-2}day^{-1}$, 20.50 $MJm^{-2}day^{-1}$, and 21.39 $MJm^{-2}day^{-1}$, while minimum values were obtained in the months of August, September and October with 17.66, 18.10 $MJm^{-2}day^{-1}$ and 18.76 $MJm^{-2}day^{-1}$ respectively. The minimum value of solar was a result of the peak period of the cloud cover in Mubi region.

Table 1 presents the estimation of monthly average daily global solar radiation from the models for the period of five years. Table 2 presents the Error values for the estimated monthly average daily global solar radiation from different models. Figure 1 displays the variation of monthly average daily global solar radiation of the two models and measured values. It was observed that the performance of Almorox and Hontoria model was very poor. However, the performance of Ampratwum and Dorvlo model is better. It is very encouraging to observe a very fine agreement between measured and estimated values obtained from the model.

Table 1: Estimation of monthly average daily global solar radiation from two models for Mubi for the period of years (2010 – 2014).

Month	H_m ($MJm^{-2}day^{-1}$)	Ampratwum and Dorvlo Model ($MJm^{-2}day^{-1}$)	Almorox and Hontoria Model ($MJm^{-2}day^{-1}$)
JAN	18.35	18.03	19.00
FEB	19.29	18.44	20.55
MAR	18.11	19.07	20.50
APR	21.02	20.39	21.39
MAY	22.68	22.14	23.26
JUN	18.29	19.62	19.17
JUL	19.38	18.80	18.61
AUG	15.31	16.50	17.66
SEP	17.42	18.32	18.10
OCT	18.84	19.04	18.76
NOV	20.38	20.24	21.32
DEC	18.22	18.38	19.61

Table 2: Error values for the estimated monthly average daily global solar radiation from different models.

Error terms	Almorox and Hontoria Model	Ampratwum and Dorvlo Model
MPE	- 0.511	- 0.0128
MBE	1.236	- 0.0436
RMSE	4.274	- 0.0780

In the present work, the validation of these models has been performed by using MPE, MBE, and RMSE. From the results in table 1 and figure 2, Ampratwum and Dorvlo Model were found to more accurate model for the prediction of global solar radiation on a horizontal surface for Mubi. In table 2, with respect to MPE, Ampratwum and Dorvlo Model gives the best correlation, while

Almorox and Hontoria Model present the worst. On the whole, low MPE, MBE and RMSE value is desirable. However, an over estimation of MPE may be cancelled by an under estimation. The MBE and RMSE values were given as - 0.0128 $MJm^{-2}day^{-1}$ and - 0.0780 $MJm^{-2}day^{-1}$ respectively which is low in Ampratwum and Dorvlo Model, compare to what is obtained from Almorox and Hontoria Model.

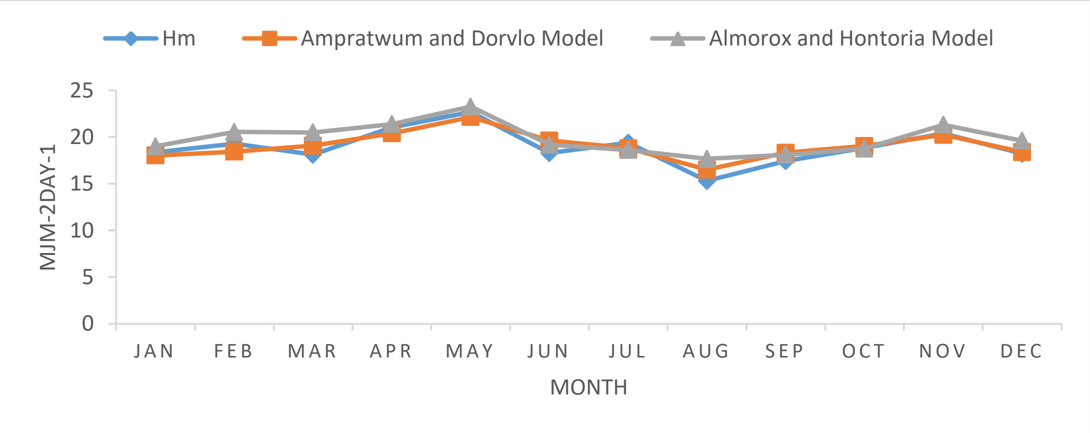

Figure 1: Variation of monthly average daily global solar radiation of Ampratwum and Dorvlo Model; Almorox and Hontoria Model.

Almorox and Hontoria Model were found to be adequately fit the radiation data present. This Model can also be used in estimating global solar radiation in any part of Nigeria with similar climatic conditions. This could be due to variability in atmospheric parameters during the measurement. In general, higher value of solar radiation is obtained in dry season than wet season. In the absence and scarcity of trust worthy solar radiation data, the need for empirical model to predict and estimate solar radiation seems inevitable. From this study, the results clearly indicates the significance of using empirical model for estimating global radiation on horizontal surfaces reaching the earth for a particular geographical location.

Conclusion

Solar radiation data are essential in the design and study of solar energy conservation devices. Sunshine based models are employed for estimation global solar radiation for a location. The Ampratwum and Dorvlo Model used in this study can also be applied to other locations to estimate global solar radiation. The global solar radiation intensity predicted in this study can also be utilized in design, analysis and performance estimation of solar energy systems, which is gaining significant attention in Nigeria and Mubi North in particular and the world at large.

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