Comparative Study of Solar Radiation Models for Ibadan (7.23°N, 3.52°E), South West Nigeria.

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ABSTRACT

Solar radiation as a source of renewable energy is generating a lot of attention these days for the designing of many solar energy devices. This leads to the development of different models by researchers for better performance of the devices in which its accuracy is inevitable. The predictive accuracies of ten linear equations for the estimation of global solar radiation were compared with measured data obtained from International Institute of Tropical Agriculture, Ibadan **(7.23°N, 3.52°E),** Over a period of ten years. The models have varied degrees of predictive accuracies; however Models 3 and 10 have least predictive errors with Model 10 having the best performance.

(Keywords: solar radiation, sunshine hours, linear equation models, error analysis, predictive abilities)

INTRODUCTION

Energy plays an important role in determining the conditions in which living matters exist. Renewable energy is considered as the key source for the future, as it is the vital and essential ingredient to human activities of all kind. Solar radiation is one of the major sources of renewable energy. Accurate and adequate information about solar radiation is crucial in the design of solar energy utilities. Such information are best acquired by direct measurement but due to high cost of solar radiation measuring devices, efforts are made to develop various models as alternative methods for the prediction of solar radiation at any location of interest.

The prediction is done using more readily available meteorological parameters. Several researchers have used one or more meteorological parameters to estimate global solar radiation on horizontal surface (Akpabio et al., 2004; Fagbenle, 1990; Falayi and Rabiu, 2005) and of recent (Falayi et al., 2008; Falayi et al., 2011). In a recent work, we have determined these regression constants using more recently acquired data in the last twenty years (Olatona and Adeleke, 2014). However in this paper the predictive accuracies of this model together with other nine linear models found in literatures were compared with measured data collected from International Institute of Tropical Agriculture, IITA, Ibadan, Nigeria using the standard statistical error analyses i.e. mean bias error, root mean square error and mean percentage error, for their comparison.

ANGSTROM MODELING FOR SOLAR RADIATION

The Angstrom model [1924], believed to be applicable everywhere in the world, but needs some modifications to suit a particular location's weather or climatic condition is being re-modified by different researchers so that it can be applicable and simpler to use for other climates. Ahamad and Tiwari, (2010) reviewed some of this models.

Angstrom model is one of the most popular models. It is a regression equation (Angstrom, 1924), which relates global solar radiation H, to the duration of sunshine S, being the parameter mostly readily measured at most meteorological stations.

The model is thus expressed as:

$$\frac{H}{H_o} = a + b * \frac{S}{S_o}$$

H = total horizontal solar radiation, H_o = extraterrestrial solar radiation,

S = Monthly mean daily averages of sunshine hours; S_o = Maximum possible monthly mean daily averages of sunshine hours; a and b are constants which are dependent on the geographical location of the meteorological station.

The basis of modified Angstrom-type model used is to calculate the solar radiation, which relates the incident solar radiation to the extraterrestrial solar radiation and relative sunshine durations. Depending on atmospheric conditions (humidity, dust and solar declination), the Angstrom regression coefficients, 'a' and 'b', will vary. The sum of the regression coefficients (a + b) is interpreted as the transmissivity of the atmosphere for global solar radiation under perfectly clear sky conditions (FAO, Technical Papers, 1990). Similarly the intercept 'a' is interpreted as the transmissivity of an overcast atmosphere.

METHODOLOGY

Measured daily mean monthly solar radiation data R_{sm}, as well as sunshine hours data for the corresponding periods were collected from International Institute for Tropical Agriculture, IITA, Ibadan, Nigeria. Nine linear models found in literatures together with a linear model recently developed (Olatona and Adeleke) based on estimating the daily mean monthly solar radiation from daily mean sunshine hours were compared with the measured data. The model equations are given below:

Model 1: $H/H_o = 0.23 + 0.48\, S/S_o$

Page (1961) M1

Model 2: $H/H_o = 0.24 + 0.513\, S/S_o$

Jain and Jain (1988) M2

Model 3: $H/H_o = 0.23 + 0.37\, S/S_o$

Andretta et al (1982) M3

Model 4: $H/H_o = 0.29 + 0.38\, S/S_o$

Salima and Chavula (2012) M4

Model 5: $H/H_o = 0.791 - 0.635\, S/S_o$

Iqbal (1979) M5

Model 6: $H/H_o = 0.754 - 0.654\, S/S_o$

Lewis (1983) M6

Model 7: $H/H_o = 0.177 + 0.692\, S/S_o$

Jain (1986) M7

Model 8: $H/H_o = 0.206 + 0.546\, S/S_o$

Louche et al. (1991) M8

Model 9: $H/H_o = 0.34 + 0.32\, S/S_o$

Veeran and Kumar (1993) M9

Model 10: $H/H_o = 0.24 + 0.35\, S/S_o$

Olatona and Adeleke (2014) M10

These ten models were tested in order to determine their predictive accuracies in estimating the incident solar radiation using the sunshine hour duration as the available data.

The accuracy of each model used in the estimation of global solar radiation was tested by standard error analyses i,e the Mean Percentage Error (MPE), the Mean Bias Errors (MBE) and the Root Mean Square Error (RMSE). The equations are respectively given below:

$$\text{RMSE}=\left[\sum^{i}\left(R_{est}-R_{obs}\right)^2/n\right]^{1/2} \qquad \textbf{(1)}$$

$$\text{MBE}=\left[\sum^{i}\left(R_{est}-R_{obs}\right)/n\right] \quad \textbf{(2)}$$

$$\text{MPE}=\left[\sum^{i}\left(\frac{R_{obs}-R_{est}}{R_{obs}}\times 100\right)\right]/n \quad \textbf{(3)}$$

So these ten models were tested to find out the one that best correlate with the actual measured solar radiation data collected from the station.

RESULTS AND DISCUSSION

Figures 1a and 1b show respectively the plots of the measured daily mean monthly global solar radiation compared with those estimated from the first five models and the last five models. The variations follow the same trend but with various degrees of over and under estimations by the different models. However model 3 (M3) in Figure 1a and model 10 (M10) in Figure 1b, respectively, have closely matched trend with the measured data Rsm. Models M1 and M6 have the highest discrepancies from the measured data.

The root mean square error (RMSE) gives the information on the short-term performance of the correlations by allowing a term-by-term comparison of the actual deviation between the estimated and measured values. The lower the RMSE, the more accurate is the estimate the estimated values. Figure 2 depicts the root mean square error from the ten models. It could be seen that that models M3 and M10 have the least root mean square error while model M5 has the highest root mean square error.

Figure 3 shows the mean bias error (MBE) from the ten models. A positive value of mean bias error (MBE) shows an over-estimate while a negative value an under-estimate by the model. A low mean bias error is desirable while a zero mean bias error is ideal. Again models M3 and M10 have the least mean bias error except for year 2003 when model M6 has the least MBE.

The mean percentage error, MPE, gives a long term performance of the examined regression equations, a positive MPE value provides average amount of overestimation in the calculated values, while a negative value gives underestimation. A low value of MPE is desirable (Igbal, 1983).

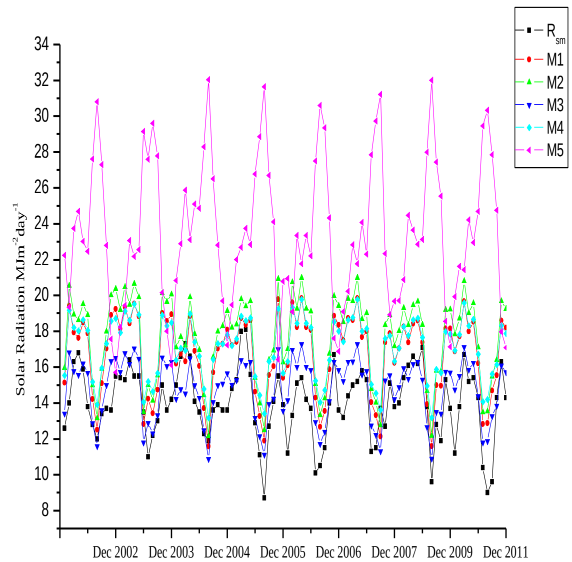

Figure 1a: Measured Solar Radiation RSM compared with the Estimated Values from the First Five Models.

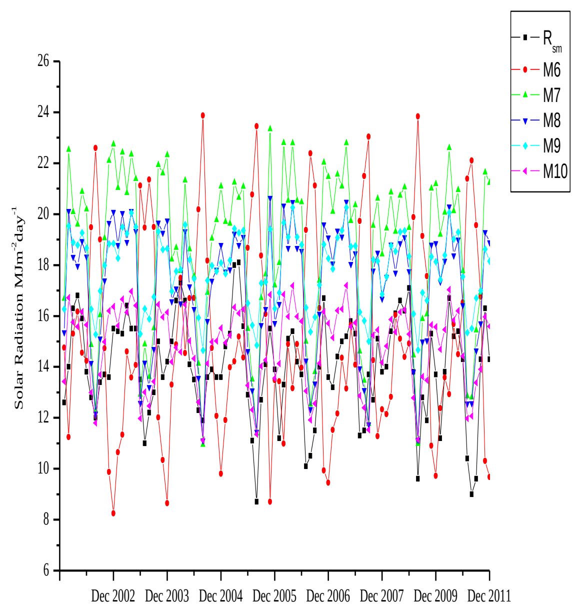

Figure 1b: Measured Solar Radiation RSM Compared with the Estimated Values from the Last Five Models.

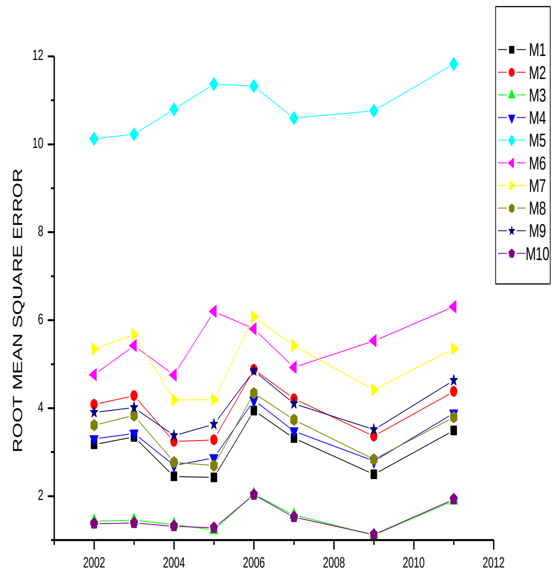

Figure 2: Annual Variation of Root Mean Square Errors for the Ten Models.

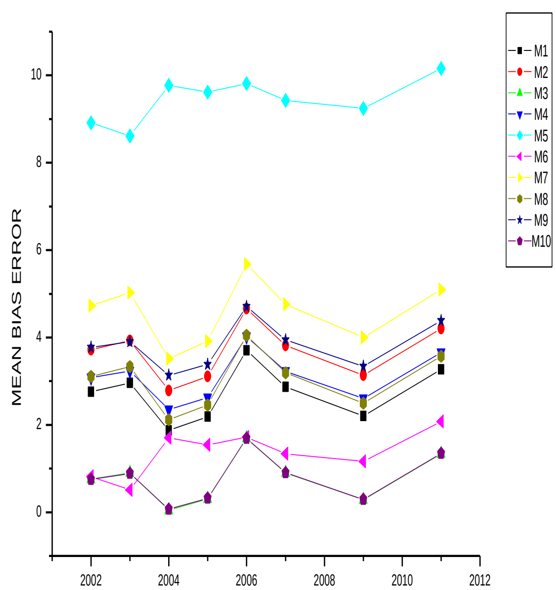

Figure 3: Annual Variation of Mean Bias Errors for the Ten Models.

Figure 4 shows the mean percentage error for the ten models. All the models showed under estimation as a result of the negative values for the MPE. However models M3 and M10 again have the least MPE.

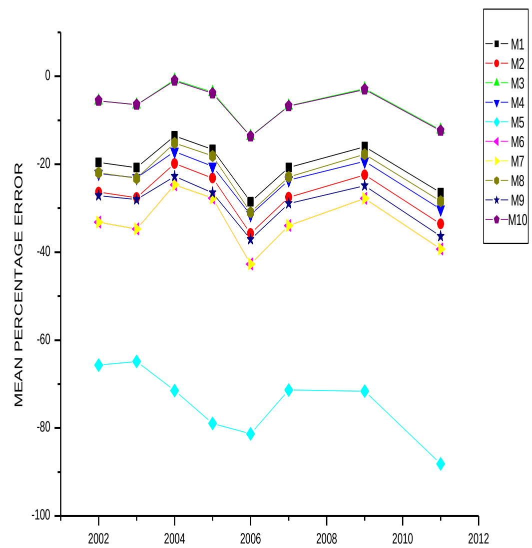

Figure 4: Annual Variation of Mean Percentage Errors for the Ten Models.

Model 10 was found to be most accurate and it is closely followed by Model 3 for the prediction of global solar radiation on a horizontal surface for Ibadan.

CONCLUSION

The predictive abilities of the models were determined using the root mean square error (RMSE), mean bias error (MBE) and mean percentage error (MPE). The results clearly showed that models M3 and M10 best predict the global solar radiation than the other eight considered in the study. It is therefore, recommended that the global solar radiation at Ibadan and areas that have similar climatic conditions with Ibadan be estimated by using either of the two models. Good agreement has been found between measured values and data estimated by the models which makes them useful in estimating global solar radiation, where there is no directly measured data, especially in the rain forest climatic zone of extreme southern Nigeria.

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