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ESTIMATION OF SOLAR RADIATION AT MAKURDI, NIGERIA

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ABSTRACT

Solar radiation is a primary driver for many physical, chemical, and biological processes on the earth's surface. Solar energy engineers, architects, agriculturists, hydrologists, etc. often require a reasonably accurate knowledge of the availability of the solar resource for their relevant applications. In solar applications, one of the most important parameters needed is the long-term average daily global irradiation. In this paper with the help of different empirical models we have estimated the value of monthly average global solar irradiation for Makurdi, Nigeria. The performance of the models were 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. From the results, Jain model was found as the most precise model for the prediction of global solar radiation on a horizontal surface for Makurdi. The values of the correlation coefficient, determination coefficient R^2, MPE, RMSE and MBE were 0.984, 0.416, 0.0253, -0.011 $MJ^{-1}m^2$ and 0.0464 $MJ^{-1}m^2$ respectively. This model can be recommended in a different place with similar climatic conditions.

Keywords: Global solar radiation, Sunshine duration, Relationship, Models.

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 [8].

Development of a solar energy research program must always start with a study of solar radiation data at a site or region of interest [3]. Unfortunately, the measurement of these parameters is made only in a few meteorological stations, especially in developing countries, for both historical and economical reasons. 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 [19].

Solar energy is the most important energy resource to man and indeed it is essential factor for human life. Solar energy is the clean, abundant, renewable and sustainable energy resource from the sun which reaches the earth in form of light and heat. Solar energy occupies one of the most important places among the various possible alternative energy sources for both urban and rural areas. An accurate knowledge of the solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices and for estimates of their performance [6].

Solar radiation at the earth's surface is the principal and fundamental energy for many physical, chemical and biological processes. Solar radiation data at ground level are important for a wide range of applications in meteorology, engineering, agricultural sciences (particularly for soil physics, agricultural hydrology, crop modeling and estimating crop evapo-transpiration), in health sector and in research of many fields of natural sciences. A few examples showing the diversity of applications may include: architecture and building design (e. g. air conditioning and cooling systems); solar heating system design and use; solar power generation and solar powered car races; weather and climate prediction models; evaporation and irrigation; calculation of water requirements for crops; monitoring plant growth and disease control and skin cancer research [2, 7, 12, 9].

So far, a number of formulas and methods have been developed to estimate daily or monthly global radiation at different places in the world. The availability of meteorological parameters, which are used as the input of radiation models, is the important key to choose the proper radiation models at any location. Among all such meteorological parameters, cloud cover and bright sunshine hours are the most widely and commonly used ones to predict daily global solar radiation and its components at any location of interest (Sabziparvar, 2008). Most of these models estimate monthly average daily global solar radiation and are based on the modified Angstrom-type equation.

METHODOLOGY

Makurdi, having an area of about 33.16 km^2 is located at latitude 7^o.41’ N and longitude 8^o.37’E. It is the capital of Benue State, Nigeria, having a population of as about 297, 398 people. Makurdi is noted for its hotness during the dry season with an average air temperature of about 33^{o}C. This high temperature is attributed to the presence of River Benue (the second largest river in Nigeria) which cuts across the middle of the city, and serves a heat reservoir. This work will help in utilizing the solar energy potential to solve the energy problems in the state. The global solar radiation and sunshine hour data used in this research was obtained from the Gunn - Bellani radiation integrator, Air force Base Makurdi, Nigeria located at an altitude of about 106.4 m. Basically, this work have explored various models that can be used to predict global solar radiation in Makurdi. The solar radiation data comprising of monthly mean daily global solar radiation and sunshine hours for Makurdi was obtained for the period of five years.

Various climatic parameters have been used in developing empirical relations for predicting the monthly average global solar radiation [10, 13, 18, 16]. Among the existing correlations, the following relation is the generally accepted modified form of the Angstrom-type regression equation [1], relating the monthly average daily global radiation to the average daily sunshine hours [7].

$$\frac{H}{\bar{H}_o} = a + b\frac{S}{S_0} \quad (1)$$

Where H is the monthly average global solar radiation (MJm^{-2}day^{-1}), S is the monthly average daily bright sunshine hour, $S_0$is the maximum possible monthly average daily sunshine hour or the day length, a and b are coefficients of Angstrom’s formula.

S_o, is the monthly average daily extraterrestrial radiation which can be expressed as:

$$H_o = \frac{24}{\pi} I_{sc}\left[1 + 0.033\cos\frac{360n}{365}\right]\left[\cos\emptyset\cos\delta\sin\omega_s + \frac{\pi}{180}\omega_s\sin\emptyset\sin\delta\right] \quad (2)$$

Where n is the Julian day number, I_{sc} = 1367Wm^{-2} is the solar constant, $\emptyset$ is the latitude of the location, δ is the declination angle [7] given as:

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

And ω is the sunset hour angle as

$$\omega = \cos^{-1}(-\tan\emptyset\tan\delta) \quad (4)$$

The maximum possible sunshine duration $\bar{S}_0$is given by

$$S_0 = \left(\frac{2}{15}\right)\omega \quad (5)$$

The regression models proposed in the literature based on sunshine hour based models are listed below:

[5]: Model 1

$$\frac{H}{H_o} = 10.45 - 29.47\left(\frac{S}{S_o}\right) + 21.459\left(\frac{S}{S_o}\right)^2 \quad (7)$$

[14]: Model 2

$$\frac{H}{H_o} = 0.9469 - 0.809\left(\frac{S}{S_o}\right) - 0.4755\left(\frac{S}{S_o}\right)^2 \quad (8)$$

[15]: Model 3

$$\frac{H}{H_o} = 0.910 + 1.154\left(\frac{S}{S_o}\right) - 4.936\left(\frac{S}{S_o}\right)^2 + 2.848\left(\frac{S}{S_o}\right)^3 \quad (9)$$

[4]: Model 4

$$\frac{H}{H_o} = 1.0 + 0.2832\left(\frac{S}{S_o}\right) - 0.255\left(\frac{S}{S_o}\right)^2 + 0.8448\left(\frac{S}{S_o}\right)^3 \quad (10)$$

[11]: Model 5

$$\frac{H}{H_o} = -0.195 - 0.74\left(\frac{S}{S_o}\right) - 0.15\left(\frac{S}{S_o}\right)^2 + 0.324\left(\frac{S}{S_o}\right)^3 \quad (11)$$

The accuracy of the estimated values were tested by calculating the Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE) and Coefficient of Correlation (R). The expressions for the MBE ($MJm^{-2}day^{-1}$), RMSE ($MJm^{-2}day^{-1}$), and MPE (%) is stated by [17] as follows:

$$MPE = \frac{[\sum(H_{i,m} - H_{i,c})/H_{i,m}]100}{N} \quad (12)$$

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.

The root mean square error is defined as:

$$RMSE = \left(\left[\frac{\sum\{H_{i,c} - H_{i,m}\}^2}{N}\right]\right)^{1/2} \quad (13)$$

$$MBE = \frac{[\sum\{H_{i,c} - H_{i,m}\}]}{N} \quad (14)$$

$$R = \frac{\sum(\bar{H}_{estimated} - \bar{H}_e)(\bar{H}_{measured} - \bar{H}_m)}{\sqrt{(\sum(\bar{H}_{estimated} - \bar{H}_e)^2)(\sum(\bar{H}_{measured} - \bar{H}_m)^2)}}$$

(15)

Where $\bar{H}_e$ is the arithmetic mean value of the estimated value of the global solar radiation, $\bar{H}_m$ is the arithmetic mean value of the measured values of the global solar radiation. R^2

denotes the multiple coefficient of determination, which is a measure of how well the regression equation fits the sample data. A perfect fit would result in $R^2 = 1$. A very good fit results in a value near 1. A very poor fit results in a value of R^2 close to 0. The R^2 has serious flaws however; this is because, as more variables are included R^2 increases. This is not supposed to be so. Consequently, it is better to use the adjusted R^2 when comparing different model equations.

RESULTS AND DISCUSSIONS

Table 1: Meteorological data and global solar radiation for Makurdi

Month	Hm	H_o	S(hr)	S_o(hr)	S/S_o	H/H_o
JAN	19.34	32.47	7.56	10.45	0.72	0.59
FEB	20.09	33.24	6.55	10.35	0.63	0.60
MAR	21.19	34.85	6.71	11.44	0.58	0.60
APR	22.02	35.23	7.57	11.64	0.65	0.62
MAY	23.88	34.67	7.61	12.54	0.60	0.68
JUN	18.52	33.58	6.55	12.35	0.53	0.55
JUL	16.76	32.30	5.77	12.43	0.46	0.51
AUG	14.31	28.65	4.76	9.47	0.50	0.49
SEP	16.43	29.77	5.57	10.54	0.52	0.55
OCT	18.82	30.63	5.93	12.38	0.47	0.61
NOV	20.19	31.68	7.46	11.49	0.64	0.63
DEC	18.68	30.85	7.43	12.47	0.59	0.60

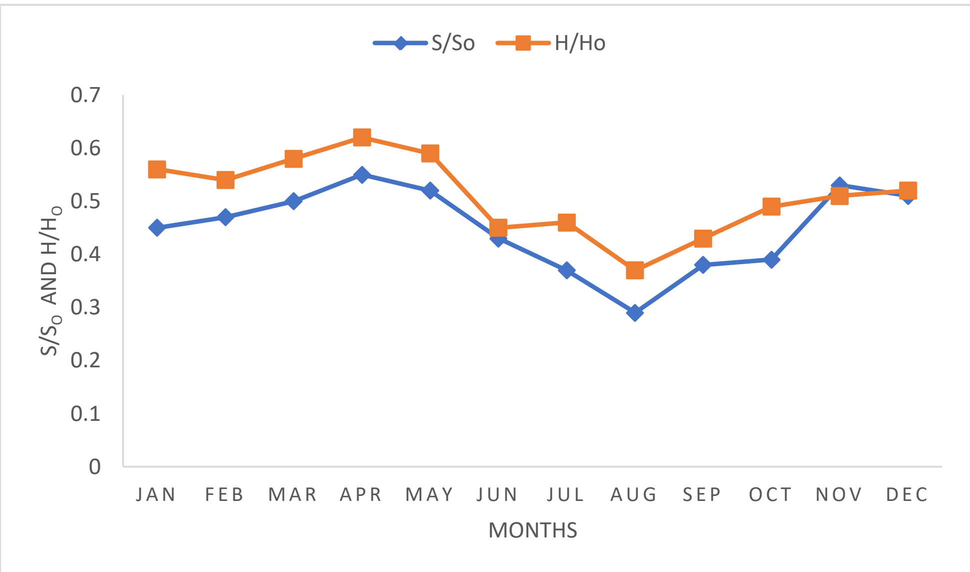

Figure 1: Variation of S/S_o and H/H_o (The clearness index) for Makurdi

Figure 1 shows the variation of S/S_o and H/H_o, the clearness index for Makurdi. The dip in the months of June-August indicates poor sky conditions where S/S_o goes as low as 0.50 and K_T values reaches minimum 0.46 (for July) and 0.47 (for October).

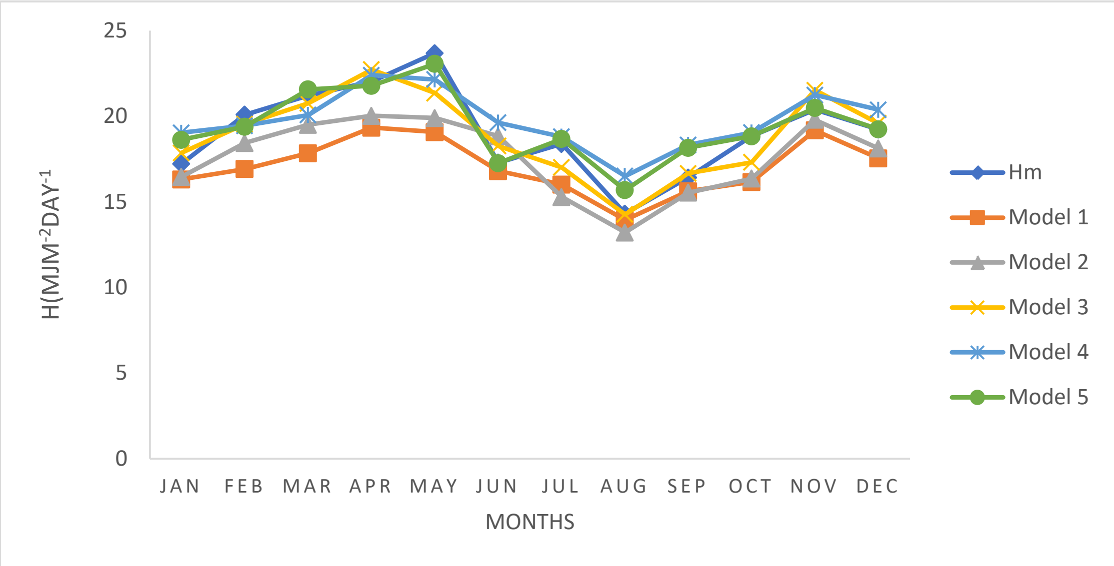

Figure 2: Comparison of monthly average daily global solar radiation models and measure values.

Table 3: Statistical indicators of models Makurdi.

Models	MPE	MBE	RMSE	R^2
Burari	0.623	-0.135	0.635	0.835
Okundamiya and Nzeako	2.312	3.928	9.524	0.653
Olopade and Sanusi	0.416	-0.011	0.0253	0.786
Bamiro	0.670	1.614	5.342	0.667
Maduekwe and Chendo	0.624	1.036	6.076	0.879

From figure 2, it is very encouraging to observe a very fine agreement between measured and estimated values obtained from model 3. The validation of these five models were performed by using MPE, MBE, RMSE, R and R^2. From Table 3, MBE values obtained from the models are positive in some cases and negative in others, which shows these models vary under and over estimate of global solar radiation. However, values of MBE from most of model 2 (2.312), model 4 (1.614) and model 5 with (1.036) indicates an over estimation, while other models indicates an under estimation. Lower MBE indicates how efficient the is the model 3 with (-0.011) has the lowest MBE. It was observed that the lower the Root Mean Square Errors (RMSE), the more precise the equation used. The RMSE values, which are a measure of the accuracy of estimation, have been found to be low for model 1 and 5, but the lowest is found to be model 3 (0.0464) which the most acceptable, while model 2 (9.524) gave the highest value. From the results, model 3 was found as the most precise model for the prediction of global solar radiation on a horizontal surface for Makurdi. The values of the correlation coefficient, determination coefficient R^2, MPE, RMSE and MBE were 0.984, 0.416, 0.0253, -0.011 MJ/m^2 and 0.0464 MJ/m^2 respectively.

CONCLUSION

Solar radiation data are essential in the design and study of solar energy conservation devices. In this regard, empirical correlations are developed to estimate the monthly average daily global radiation on a horizontal surface. Sunshine based models are employed for estimation global solar radiation for a location. The correlation equations given in this study will enable the solar energy researcher to use the estimated data with trust because of its fine agreement with the observed data. Most of solar radiation models given to estimate the monthly average daily global solar radiation are of the modified Angstrom-type equation.

It may be concluded that the models presented in this study may be used reasonably well for estimating the solar radiation at a given location and possibly in elsewhere with similar climatic conditions. Comparison of the predictive efficiency of these models showed that the Jain model performed better than all the other models. Looking at statistical analysis of the models, we also observed that despite overestimation and underestimation of the models, there are fairly good level of significance at confidence level, but model 3 by [15] was the best.

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