Estimation of Global Solar Radiation over Makurdi, Nigeria

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ABSTRACT— ***Solar radiation studies have been carried out using meteorological parameters to assess the feasibility of solar energy utilization in Makurdi (7.74°N, 8.51°E and 104m above sea level). Measured solar radiation, relative sunshine hours, air temperature and relative humidity data for Makurdi covering a period of 10 years (2000 - 2010) were used to establish Angstrom type correlation equations to estimate global solar radiation. Among the models formulated, the model equation with R^2 of 84.3%, MBE of 1.079×10^{-1} and RMSE of 2.466×10^{-2}, which can best be used to estimate the global solar radiation, was obtained.***
From this formulated equation, the highest global solar radiation of 15.702 $MJm^{-2}day^{-1}$ was estimated in the dry season against the measured value of 15.690 $MJm^{-2}day^{-1}$ for the same period, while the lowest radiation of 11.805 $MJm^{-2}day^{-1}$ was obtained for rainy season as against 11.354 $MJm^{-2}day^{-1}$ of measured value. The observed performance of this formulated model implies that it can be used to predict global solar radiation for Makurdi and its environs.

Keywords— solar radiation, relative sunshine hour, temperature, Makurdi.

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1. INTRODUCTION

With the rapid depletion of fossil fuel reserves, it is feared that the world especially Nigeria will soon run out of its energy resources. Under these circumstances, it is highly desirable that alternative energy resources should be utilized with maximum conversion efficiency to cope with the ever increasing energy demand. Among the renewable resources, only the solar energy has the greatest potentiality, availability and is free from environmental hazards.

The comprehensive design and assessment of solar energy systems depend largely on adequate information of the solar radiation characteristics of the region where the systems are to be located. Obviously, the best radiation information is that obtained from experimental measurements of the global solar radiation at the location in question.

Makurdi is the capital of Benue State located in the north-central region of Nigeria. Makurdi, having an area of about 33.16 km^2, is located at latitude 7.74°N and longitude 8.51°E. It is noted for its hotness during the dry season with an average air temperature of about 33°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 as heat reservoir.

Benue State is regarded as the food basket of the nation since agriculture is the main occupation in the state and about 90% of its population is engaged in it. However, each year large quantities of agricultural produce especially vegetables and fruits are allowed to waste due to lack of adequate preservation and storage facilities.

This research work hopes to give detail information about the availability of solar energy in the state which can be used by solar energy technology to design and fabricate solar dryers and appropriate solar refrigeration units.

There are many empirical and theoretical relations developed for the estimation of global solar radiation using meteorological parameters such as relative sunshine hour, relative humidity, maximum and minimum air temperature and total solar radiation on the horizontal surface. Among the existing correlation for determining the global radiation, the simplest is [4] regression equation which relates the monthly average daily global irradiation, H to the number of hours of bright sunshine, n. The equation is of the form:

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

where H_0 is the monthly average daily extraterrestrial solar radiation ($MJm^{-2}day^{-1}$), measured on a horizontal surface, N is the monthly average daily maximum number of hours of possible sunshine (or day length) and, a and b are the regression coefficients.

[21] developed a model of Angstrom type regression equation for humid tropical countries as:

$$\frac{H}{H_o} = 0.30 + 0.40\left(\frac{n}{N}\right) \quad (2)$$

[18] used measured data collected from 42 stations in different countries has proposed a unified correlation to compute the horizontal global solar radiation. This model is believed to be applicable in most locations and is given as:

$$\frac{H}{H_o} = 0.18 + 0.62\left(\frac{n}{N}\right) \quad (3)$$

[5] developed a model for the correlation of global solar radiation with meteorological parameters as:

$$\frac{H}{H_o} = 0.136\left(\frac{n}{N}\right)^{0.374} (T_a)^{0.00584} (R)^{0.000451} \quad (4)$$

where T_a is the air temperature and R is the relative humidity

[19] used various meteorological parameters from Northern Nigeria to predict the global solar radiation for the region as follows:

$$\frac{H}{H_o} = 0.621 - 0.294\left(\frac{n}{N}\right) + 0.178\left(\frac{n}{N} - R - \theta\right) + 0.1491\left(\frac{n}{N}.\theta\right) \quad (5)$$

Where θ is the temperature ratio.

[6] used various meteorological parameters to predict the global solar radiation for Bauchi, Nigeria as follows:

$$\frac{H}{H_O} = 0.449 - 0.139\left(\frac{n}{N}\right) + 0.185\left(\frac{n}{N}.\Theta\right) - 0.00022(\Theta.R) \quad (6)$$

[14] developed an empirical model using relative sunshine duration and measured global solar radiation data for Makurdi as:

$$\frac{H}{H_o} = 0.138 + 0.488\left(\frac{n}{N}\right) \quad (7)$$

In this present work, apart from developing solar models as in the case of previous researches in this area, a step is taken further to predict the values of solar radiation available in Makurdi. Besides, it investigates if the model with single or combination of meteorological data gives better prediction of solar radiation.

2. METHODOLOGY AND DATA SET

In this work, a total of three different formulations also involving other meteorological parameters are employed to determine a suitable correlation equation with the least RMSE and MBE for predicting solar radiation for Makurdi, Nigeria. These are:

$$\frac{H_{est}}{H_o} \; a_o + a_1 \frac{n}{N} \quad (8)$$

$$\frac{H_{est}}{H_o} = b_o + b_1 \frac{n}{N} - b_2\left(\frac{n}{N} - R - T\right) - b_3\left(\frac{n}{N}\right)T \quad (9)$$

$$\frac{H_{est}}{H_o} = c_o + c_1 \frac{n}{N} - c_2\left(\frac{n}{N}\right)T + c_3 TR \quad (10)$$

H or H_{est} is the predicted monthly average daily global solar radiation ($MJm^{-2}day^{-1}$), T depicts the ratio of average total minimum to average maximum temperature, R is the relative humidity, and n/N is the relative sunshine duration. n is the monthly average daily number of bright sunshine, N is the monthly average daily maximum number of hours of possible sunshine (or day length). Values of N are computed using [13]:

$$N = \frac{2}{15} W_s \quad (11)$$

W_s is the sunrise sunset hour angle given by [11] as:

$$W_s = \cos^{-1}(-\tan \emptyset \tan \delta) \quad (12)$$

$\emptyset$ and δ are the latitude and declination angles respectively. The value of declination can be found from the equation of [8] as:

$$\delta = 23.45 \sin\left[360\left(\frac{J+284}{365}\right)\right] \quad (13)$$

J is the day number of the year. Usually, the solar declination is calculated on the 15th of each month. I_{sc} is the solar constant having the value $4.921 MJm^{-2}day^{-1}$ and $\emptyset$ is the latitude of the location under investigation. H_0 is the monthly average daily extraterrestrial solar radiation ($MJm^{-2}day^{-1}$), measured on a horizontal surface and is given by the expression [10]:

$$H_o = \frac{24}{\pi} I_{sc} E_o \left(\frac{\pi}{180} W_s \sin\emptyset \sin\delta + \cos\emptyset \cos\delta \cos W_s\right) \tag{14}$$

E_o is the eccentricity correlation factor of the Earth's orbit. The value of E_o is given by [15]:

$$Eo = 1 + 0.0033 \left(\frac{360\, J}{365}\right) \tag{15}$$

Equation (8) expresses global solar radiation in terms of relative sunshine duration only while equations (9) and (10) are in terms of relative sunshine duration and other atmospheric parameters such as relative humidity and air temperature.

The monthly mean daily global solar radiation, relative sunshine hour, relative humidity, and air temperatures data used in this work were obtained from daily measurements covering a period of ten (10) years (2000-2010) from the Air Force Base Makurdi, Nigeria located at an altitude of about 106.4 m. Maximum day length and Extraterrestrial radiation where computed for each month using equations (11) and (14) respectively.

The relative sunshine duration, measured solar radiation and other atmospheric parameters were used in equations (8) – (10) to obtain the regression coefficients. Subsequently, those coefficients were used to estimate the global solar radiation for Makurdi based on the models of equations (8) – (10). The Mean Bias Error (MBE) and the Root Mean Square Error (RMSE) were also obtained to assess the validity of estimation made through the developed correlation equations.

3. RESULTS

The input parameters used in this analysis are given in Table 1, while the results of the statistical analyses of equations (8) – (10) are presented in Table 2. A comparison between the measured and predicted solar radiation using relative sunshine duration only is presented in Figure 1, while Figure 2 gives the relationship between measured and predicted solar radiation using combination of other parameters. The predicted forms of equations (8) – (10) respectively become:

$$\frac{H_{est}}{H_O} = 0.138 + 0.488\frac{n}{N} \tag{16}$$

$$\frac{H_{est}}{H_O} = 0.165 + 0.557\frac{n}{N} - 0.00128\left(\frac{n}{N} - R - T\right) - 0.823\left(\frac{n}{N}\right)T \tag{17}$$

$$\frac{H_{est}}{H_O} = 0.168 + 0.583\frac{n}{N} - 1.04\left(\frac{n}{N}\right)T + 0.0088\,TR \tag{18}$$

Table 1: Input Parameters for Estimation of Monthly Average Daily Global Solar Radiation for Makurdi, Nigeria.

Months	n (hours)	N (hours)	n/N	H_O ($MJm^{-2}day^{-1}$)	H_{mea} ($MJm^{-2}day^{-1}$)	T (T_{min}/T_{max})°C	R (%)
Jan	6.64	11.993	0.620	33.254	14.054	0.1685	21.4545
Feb	6.93	11.995	0.562	35.572	15.618	0.1900	22.1818
Mar	6.75	11.999	0.578	37.446	15.554	0.2053	17.3636
Apr	7.35	12.002	0.603	38.084	14.791	0.2114	13.5909
May	6.68	12.006	0.558	37.270	14.354	0.2002	11.4090
June	6.00	12.007	0.494	36.462	13.654	0.1912	10.3180
July	5.03	12.007	0.402	37.348	12.009	0.1944	8.7727
Aug	4.30	12.004	0.348	37.489	11.354	0.1912	7.8181
Sept	4.65	12.000	0.399	37.565	13.063	0.1888	8.9090
Oct	6.04	11.996	0.516	36.014	14.863	0.1901	10.9594
Nov	7.22	12.000	0.592	33.665	15.690	0.1823	14.9090
Dec	7.61	11.992	0.647	32.379	15.263	0.1443	22.8181

Table 2: Statistical Results of Model Equations

Predictor	**Coef**	**St Dev**	**MBE**	**RMSE**	**R^2 (%)**
Model equation (16): $\frac{H_{est}}{H_O} = 0.138 + 0.488\frac{n}{N}$					
Constant	0.138	0.025	0.000424	0.002524	79.5
n/N	0.488				
Model equation(17): $\frac{H_{est}}{H_O} = 0.165 + 0.557\frac{n}{N} - 0.00128\left(\frac{n}{N} - R - T\right) - 0.823\left(\frac{n}{N}\right)T$					
Constant	0.165	0.04632	0.10236	0.02494	83.9
n/N	0.5574	0.2298			
n/N - R – T	-0.001278	0.002691			
(n/N)T	-0.8234	0.8379			
Model equation (18): $\frac{H_{est}}{H_O} = 0.168 + 0.583\frac{n}{N} - 1.04\left(\frac{n}{N}\right)T + 0.0088\,TR$					
Constant	0.16763	0.04632	0.107962	0.02466	84.3
n/N	0.5830	0.1657			
(n/N)T	-1.0378	0.17142			
TR	0.00881	0.01375			

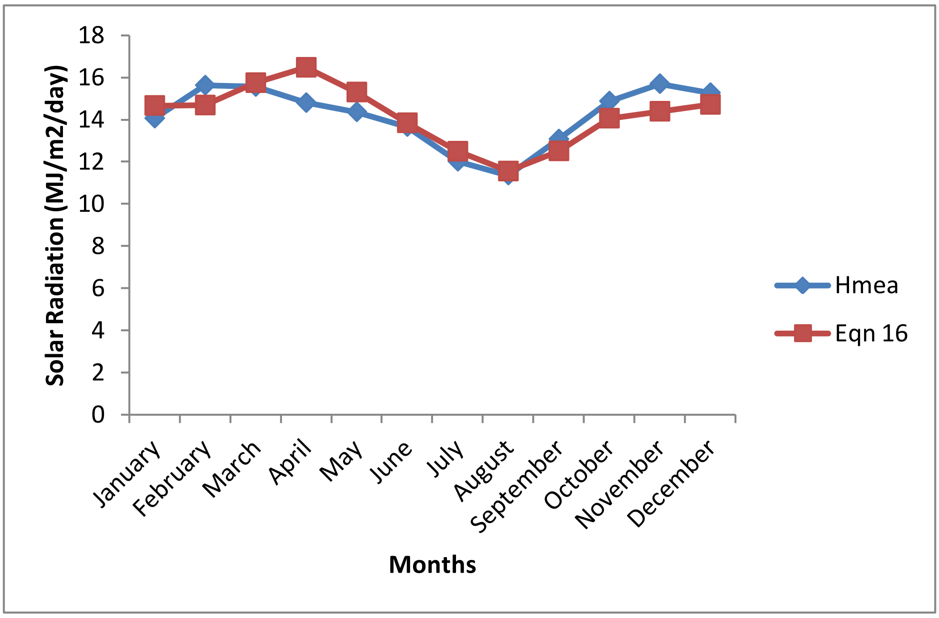

Figure 1: Comparison between measured and estimated solar radiation using relative sunshine duration hour

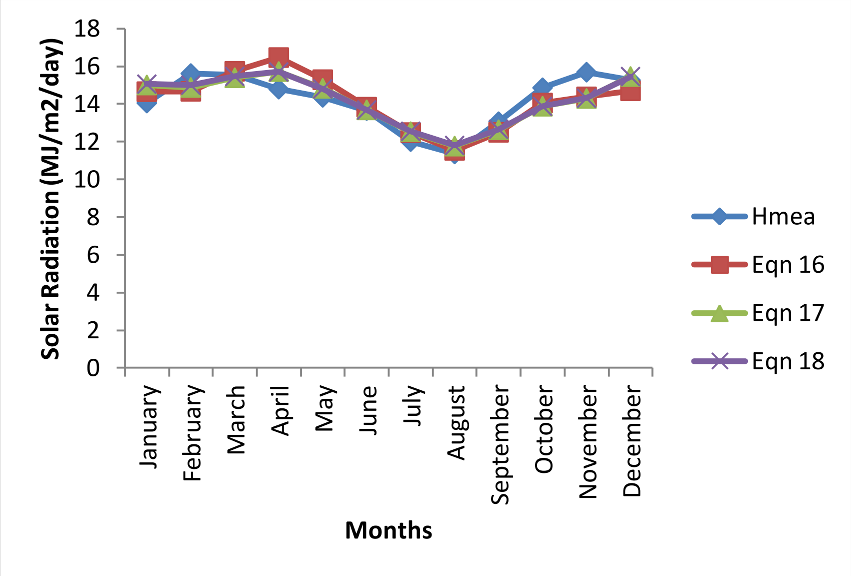

Figure 2: Comparison between measured and estimated solar radiation using meteorological parameters

4. DISCUSSION

The variation of the predicted solar radiation using eqn. 16 with the measured exhibit the same trend except that the predicted values are both underestimated and overestimation in some months. This was also noted by [15]. Similarly, it could be observed that the estimated values due to equations 16, 17 and 18 with the measured values exhibit the same behaviour (Fig.2).

The model equation (16) which contains only relative sunshine duration has RMSE, MBE, and R^2 of 2.524 x 10^{-3}, 4.24 x 10^{-4} and 79.5% respectively, while model equations (17) and (18) which contain combination of meteorological parameters has RMSE, MBE, and R^2 of 2.494 x 10^{-2}, 1.024 x 10^{-1}, and 83.9% respectively and RMSE, MBE and R^2 of 2.466 x 10^{-2}, 1.079 x 10^{-1}, and 84.3% respectively (Table 2).

From these statistical results, it could be observed that the models having combination of meteorological parameters particuarly equation (18) gives better prediction. This agrees with the work of [20], [17], [6] and [1], that many meteorological parameters should be use in the prediction of solar radiation. Hence, the higest values of global solar radiation estimated from this model equation (18) during the period of dry season was 15.702 MJm^{-2}day^{-1} while the lowest values of global solar radiation of 11.805 MJm^{-2}day^{-1} was obtained during the period of rainy season.

[12] and [9] have recommended that a zero value for MBE is ideal and a low RMSE is desirable. Also, [2] noted that the model with the highest R^2 give better prediction. A low value of MPE is desirable according to [3]. [12] noted that the MBE and RMSE test provide information on long and short terms performance of solar model and the model equation with the smallest RMSE and MBE are more appropriate for long and short terms performance of solar model. Among the predictive models enumerated, equation (18) can best be used to estimate global solar radiation since it satisfied most of the above mention criteria. It can predict solar radiation both on short-term and long-term basis. Hence, it is recommended for predicting solar radiation for Makurdi and its environs.

The highest global solar radiation estimated (15.702 MJm^{-2}day^{-1}) occurs in dry season in the month of April while the lowest radiation (11.805 MJm^{-2}day^{-1}) occurs during rainy season in the month of August. This is within the range of annual average solar radiation of 3.5 KWhm^{-2}day^{-1} (12.5 MJm^{-2}day^{-1}) in the coastal latitude and about 7.0 KWhm^{-2}day^{-1} (25.5 MJm^{-2}day^{-1}) in the far north of Nigeria [7].

Although, the high coefficient of determination, R^2 with small RMSE and MBE exhibited by the correlation equations (16) and (17) show how well the model equations fit the data.

5. CONCLUSION

- New model for estimating monthly mean daily global solar radiation on a horizontal surface in Makurdi metropolis has been developed.

- The main conclusion of this work is that monthly mean daily global solar radiation can best be estimated from the Angstrom type correlation equation using many meteorological parameters.

- The Angstrom type correlation equation developed for estimating global solar radiation on a horizontal surface in Makurdi metropolis is:

$$\frac{H_{est}}{H_O} = 0.168 + 0.583\,\frac{n}{N} - 1.04\left(\frac{n}{N}\right)T + 0.0088\,TR$$

- The estimated global solar radiations available in Makurdi from this research work are 15.702 $MJm^{-2}day^{-1}$ and 11.805 $MJm^{-2}day^{-1}$ during dry and rainy season respectively.

- The observed performance of the formulated models implies that practitioners of solar energy technology can use the models to conduct design calculations for appliances to be located at the localities that do not have solar radiation data but have similar meteorological parameters.

6. RECOMMENDATIONS

It is hereby recommended that:

- Modern technology should be directed towards the design and construction of modern facilities such as solar cookers, solar dryers, solar heaters, solar refrigerators and solar cars.

- More researches should be carried out on how to utilize solar radiation since among the renewable resources; only solar energy has the greatest potentiality, availability and is free from environmental hazard.

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