Impact of Metrological Parameters on Solar Radiation in Nigeria

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Abstract- The study examined the influence of metrological parameters on solar radiation in Makurdi. Correlations are developed to predict incident solar radiation at a given location developed based on meteorological parameters. However, all correlations depend on accurate measurement and availability of weather data such as sunshine duration, cloud cover, relative humidity, maximum and minimum temperature which essentially is a costly exercise in terms of equipment and labour. These data include solar radiation, sunshine hour duration, relative humidity, rainfall, cloud cover, maximum and minimum temperatures were analysed using regression techniques of the Angstrom type. The MBE values obtained from the models are positive in some cases and negative in others, which shows that these models vary between under and over estimate of global solar radiation. However, model has the lowest under estimation with a value of -1.03, which is expected and acceptable. A low value of MPE is expected, model 1 was observed to have an MPE value of (-0.074). The results obtained show a remarkable agreement between the measured and the predicted values. The study therefore recommends for designers and engineers of solar energy and other renewable energy devices in this area.

Indexed Terms- Global solar radiation, Model, Metrological Parameters Clearness Index

I. INTRODUCTION

Solar radiation data provide information on how much of the sun's energy strikes a surface at a location on earth during a particular time period. The data gives values of energy per unit of area. Readily available solar radiation data is a key to design and simulation of all solar energy applications. At present, values for the magnitude of input solar radiation at the surface of the earth are acquired in two basic ways. Radiation values are either measured with instrumentation or modeled from empirically derived relationships between solar radiation and more readily available atmospheric variables. Often, one of these methods is used to test the validity of the other [1]. The direct measurement of solar radiation is done in two basic ways as well. The values are measured either by using ground-based instrumentation known collectively as pyranometers, or remotely with satellites. These methods are often used in combination to validate one another [2]. In general, pyranometeric data from adequately maintained instruments provide an accurate description of the solar radiation values in the immediate area [2].

Solar radiation affects the earth's weather processes which determine the natural environment. Its presence at the earth's surface is necessary for the provision of food for mankind. Thus it is important to be able to understand the physics of solar radiation, and in particular to determine the amount of energy intercepted by the earth's surface at different locations [3]. The quantity of solar radiation reaching the Earth's surface varies dramatically as a function of changing atmospheric conditions as well as the changing position of the Sun through the day. Accurate data of global solar radiation are necessary at various steps of the design, simulation, and performance evaluation of any project involving solar energy [4]. The solar radiation modeling has shown significant progress in recent decades, reaching at present integration in geographic information systems that allow quantification at its spatial distribution, also provide detailed estimates or forecast climate changes which have improved significantly in recent years. Several models have been proposed for generation of global radiation [5].

Meteorological parameters such cloud cover, relative humidity, rainfall and temperature play an important role in the radiative energy budget of the Earth and in the transfer of energy between the surface and the atmosphere. [6] proposed solar radiation estimation using differences between maximum and minimum ambient temperature. Some studies were based on hourly solar radiation prediction using different meteorological parameters and the methods are claimed to perform well.

Meteorological parameters are frequently used as predictors of atmospheric parameters since acquiring detail atmospheric conditions require advance measurement. In this project, different models were used to estimate the global solar radiation using cloud cover, relative humidity, rainfall, maximum and minimum temperature difference. The purpose of using different models is to identify the most appropriate models for the estimation of global solar radiation Makurdi, Benue State. Meteorological data obtained from direct measurement provide the necessary information of radiation and weather parameters. However, in the developing countries such as Nigeria, insufficient and unreliable measuring instruments and poor maintenance culture, has led to poor data records and more often, unreliable solar radiation data. In the absence of these measurements, theoretical models have become the desired tools to predict and estimate the global solar radiation of a place using some meteorological parameters such as temperature, rainfall, and relative humidity. This study therefore intends to authenticate measured data from theoretical models. The aim and objective of this study are to Determine the influence of cloud cover, Relative Humidity, Temperature and Rainfall on Solar Radiation in Makurdi using mathematical models and meteorological data. Also, to Determine the most appropriate model for the estimation of global solar radiation for Makurdi and locations having the same geographical and climatic indices and test the performance of the models with the statistical comparison methods of mean bias error (MBE), root mean square error (RMSE), mean percentage error (MPE).

II. 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 33ºC. 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 ten years.

The first model used sunshine duration to estimate daily mean values of solar radiation on a horizontal surface can be described using Eqn. (3.1) as [7], [8], [9]:

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

H_m is daily mean values of global radiation (MJ/m2day), N the daily average value of day length, and 'a' and 'b' values are known as Angstrom constants and they are empirical. H_o is daily mean values of extraterrestrial radiation (MJ/m2day), calculated using Eq. (2) as described by [7] [9]:

$$H_o = \frac{24\times 3{,}600}{\pi} I_{sc} E_o \left[\cos(\varphi)\cos(\delta)\sin(\omega_s) + \frac{\pi\omega_s}{180}\sin(\varphi)\sin(\delta)\right] \quad (2)$$

$$I_{sc} = \frac{1{,}367\times 3{,}600}{1{,}000{,}000} MJm^{-2}day^{-1} \quad (3)$$

Is the solar constant, The units in kWh m^{-2} day^{-1} .
E_o represents the eccentricity correction, and described using Eq. (4) in Eq. (2)

$$E_o = 1 + 0.033 \cos \frac{360 n_d}{365} \quad (4)$$

n_d is the day number of the year /Julian day (1 Jan, n_d = 1 and 31st December, n_d = 365), φ is the latitude of the site, δ the solar declination and, ω, the mean sunset hour angle for the given month. The solar declination (δ) and the mean sunset hour angle (ω_s) can be calculated as suggested by [10]:

$$\delta = 23.45 \sin 360 \frac{284 + n_d}{265} \quad (5)$$

$$\omega_s = \cos^{-1}(-\tan\varphi \tan\delta) \quad (6)$$

For a given day, the maximum possible sunshine duration (monthly values of day length, (N) can be computed by using [10]:

$$N = \frac{2}{15}\omega_s \quad (7)$$

[11] developed a model containing relative humidity, rainfall, cloud cover and temperature for Sokoto, which is Model 1.

$$\frac{H_{cal}}{H_o} = -4.03308 + 0.0740\,(T_{max} - T_{min}) + 0.01075\,(RH) - 0.00065\,(RF) + 9.008\,(CC) \quad (8)$$

He also developed for Maiduguri, considered as Model 2 for this work:

$$\frac{H_{cal}}{H_o} = 0.22093 + 0.02179\,(T_{max} - T_{min}) + 0.21792\,(RH) - 0.7561\,(RF) - 0.0008\,(CC) \quad (9)$$

[12] developed a model for Kano, which is Model 3:

$$\frac{H_{cal}}{H_o} = 0.548 + 0.241\frac{n}{N} - 0.00037\,(T_{max} - T_{min}) - 0.000408\,(RF) \quad (10)$$

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. MBE provides information on the long-term performance of models. A positive and a negative value of MBE indicate the average amount of over estimation and under estimation in the calculated values, respectively. One drawback of this test is that over estimation in one observation is cancelled by under estimation in another observation. RMSE provides information on short-term performance of the models. It is always positive. The demerit of this parameter is that a single value of high error leads to a higher value of RMSE. MPE test provides information on long-term performance of the examined regression equations. A positive and a negative value of MPE indicate the average amount of over estimation and under estimation in the calculated values, respectively. It is recommended that a zero value for MBE is ideal while a low RMSE and low MPE are desirable [13], [14], [15].

Mean percentage error: The Mean percentage error is defined as:

$$MPE\ (\%) = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{(H_{i,m} - H_{i,c})}{H_{i,m}}\right) \times 100 \quad (11)$$

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.

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(H_{i,m} - H_{i,c})^2\right]^{\frac{1}{2}} \quad (12)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(H_{i,m} - H_{i,c}) \quad (13)$$

According to [9], regression coefficient *a* and *b* from the calculated monthly average global solar radiation has been obtained from the relationship given as:

$$a = -0.110 + 0.235\cos\varphi + 0.323\left(\frac{n}{N}\right) \quad (14)$$

$$b = 1.449 - 0.553\cos\varphi - 0.694\left(\frac{n}{N}\right) \quad (15)$$

To compute estimated values of the monthly average daily global radiation H_{cal}, the values of computed *a* and *b* from equations (14) and (15) were used. where a = 0.293 and b = 0.537.

RESULTS AND DISCUSSIONS

Table 1: Monthly Daily Average Meteorological data for Makurdi

Months	RH (%)	RF (mm)	T_{max} (°C)	T_{min} (°C)	$\frac{n}{N}$	H_m (MJm^{-2}da
Jan.	36.3	0.00	34.8	18.0	0.60	18.5
Feb.	30.6	0.00	38.2	21.8	0.59	20.1
Mar.	28.3	0.07	40.55	25.4	0.57	21.1
Apri.	47.5	29.5	37.4	28.0	0.55	19.8
May	65.9	78.21	33.7	26.6	0.49	18.2

Jun.	76.2	137.94	31.7	24.6	0.46	17.2
Jul	80.3	157.17	30.8	23.9	0.43	15.4
Aug.	84.3	186.0	31.1	23.6	0.36	14.2
Sept.	84.4	172.29	33.2	23.4	0.42	16.5
Oct.	76.1	53.01	36.7	23.6	0.59	18.9
Nov.	55.5	0.00	37.6	22.6	0.72	20.4
Dec.	43.2	0.00	35.6	19.6	0.62	19.0

Table 2: Monthly average daily global solar radiation for Makurdi

Months	$\frac{n}{N}$	$H_m(MJm^{-2}day^{-1})$	$H_o(MJm^{-2}day^{-1})$	$\frac{H_m}{H_o}$
Jan.	0.60	18.5	34.2	0.54
Feb.	0.59	20.1	36.4	0.55
Mar.	0.57	21.1	38.5	0.54
Apri.	0.55	19.8	39.0	0.50
May	0.49	18.2	38.2	0.47
Jun.	0.46	17.2	36.5	0.47
Jul	0.43	15.4	37.9	0.40
Aug.	0.36	14.2	34.2	0.41
Sept.	0.42	16.5	38.3	0.43
Oct.	0.59	18.9	36.0	0.52
Nov.	0.72	20.4	31.6	0.64
Dec.	0.62	19.0	30.4	0.63

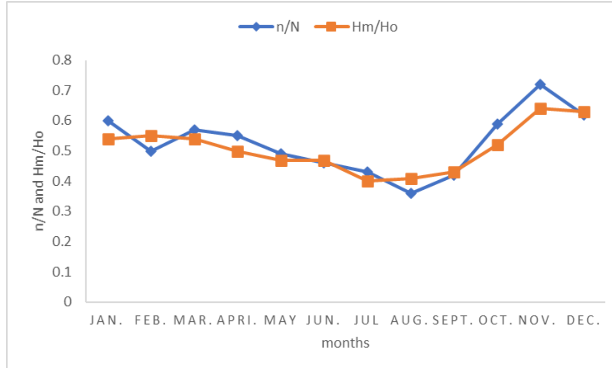

Figure 1: Relationship between the clearness index and relative sunshine duration in Makurdi.

Table 3: Monthly average daily global solar radiation for the three models

Months	$H_{measured}$	Model 1	Model 2	Model 3
Jan.	18.5	19.2	17.3	15.5
Feb.	20.1	18.6	18.7	17.8
Mar.	21.1	21.5	21.7	20.6
Apri.	19.8	20.6	23.9	22.7
May	18.2	19.1	25.5	24.1
Jun.	17.2	17.9	22.8	21.4
Jul	15.4	16.4	18.2	16.6
Aug.	14.2	15.9	17.6	16.1
Sept.	16.5	17.9	19.7	18.5
Oct.	18.9	18.2	20.3	19.3
Nov.	20.4	19.4	17.4	16.4
Dec.	19.0	19.7	15.7	15.1

All numerical values are in units of $(MJm^{-2}day^{-1})$

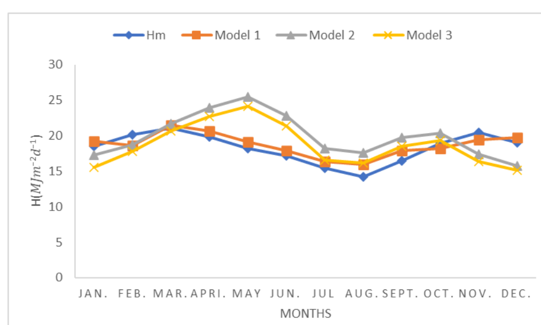

Figure 2: Estimated value of monthly average daily global solar radiation and measured value

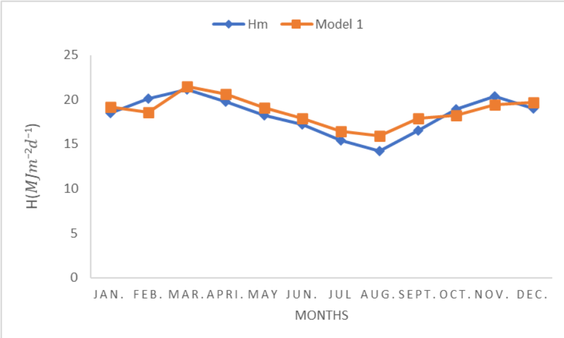

Figure 3: Estimated value of monthly average daily global solar radiation (Model 1) and measured values.

Table 4: *RMSE*, *MBE*, and *MPE* computed in the comparison between measured and estimated monthly average daily solar radiation

Models	Statistical Analysis Methods		
	RMSE	*MBE*	*MPE (%)*
Model 1	7.36	- 1.03	- 0.074
Model 2	12.86	2.39	0.195
Model 3	8.65	1.76	- 20.4

III. DISCUSSION

In Table 2 and figure 1, the value of clearness Index, K_T = 0.41 correspond to the lowest value of $\frac{n}{N}$ = 0.360 and H_m = 14.2 ($MJm^{-2}day^{-1}$) in the month of August indicate poor sky conditions. These conditions correspond to the wet or rainy season (June – September) observed in Makurdi during which is much cloud cover. The monthly average daily solar radiation estimated through model 1 and model 3 for Makurdi are given in Table 3, along with the measured values. It is very encouraging to observe a very fine agreement between model and the measured values. Figure 2 indicates that model 1 is the most suitable for the estimation of monthly average daily global solar radiation for Makurdi. Shown in table 4 are the statistical test results. The RMSE values, which are is the measure of accuracy of a particular model or correlation use. For the present analysis, it was found to be lowest for model 1 value (7.36) as shown in table 4. The MBE values obtained from the models are positive in some cases and negative in others, which shows that these models vary between under and over estimate of global solar radiation. However, model has the lowest under estimation with a value of -1.03, which is expected and acceptable. A low value of MPE is expected, model 1 was observed to have an MPE value of (-0.074).

The global solar radiation can be adequately estimated using different proposed models using daily recorded meteorological variables of maximum and minimum temperature difference, relative humidity, cloud cover and rainfall. In order to obtain some accurate solar radiation estimations, it requires accurate mathematical modelling of all the climatological parameters. From figure 1, there is high proportion of cloudy days, relative to low solar energy with low temperature in the wet season while low cloudy day with high solar energy and high temperature in dry season across the latitudes. It was observed that the equation i.e $\frac{H_{cal}}{H_o} = -4.03308 + 0.0740\,(T_{max} - T_{min}) + 0.01075\,(RH) - 0.00065\,(RF) + 9.008\,(CC)$ which gives good results when considering statistical indicators, RMSE, MBE, and MPE. It is found that the new model can be used for estimating daily values of global solar radiation with a higher accuracy and has good adaptability to highly variable weather conditions. The estimated value of global solar radiation reveals that solar radiation can be efficiently used to compensate for energy inadequacy.

CONCLUSION

In view of the worldwide concern about the economic importance of global solar radiation as an alternative renewable energy, the monthly global solar radiation using relative humidity, sunshine hour, cloud cover, rainfall, maxi maximum temperature have been employed in this study to estimate global solar radiation for Makurdi, Nigeria. The correlation coefficient used as model 1 is suitable for predicting the monthly mean daily solar radiation in Makurdi is recommended. This model will provide useful information for designers and engineers of solar energy and other renewable energy devices in Makurdi and environs. From the results when considering statistical indicators that are MBE, RMSE and MPE. This equation could be employed in the prediction of global solar radiation of location with similar latitude.

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