Predicted and Measured Global Solar Radiation in Maiduguri, Nigeria.

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Abstract- A model for estimating sunshine hours from some meteorological parameters was developed. Ten years (2001 – 2010) period of Sunshine hour and Solar radiation at Maiduguri, Nigeria (11.85º N, longitude is 13.08°E) was analyzed. A correlation equation of the Angstrom type was developed to predict the monthly mean daily global solar radiation incident on a horizontal surface in Maiduguri, Nigeria: $\frac{\bar{H}_m}{\bar{H}_o} = 0.34 + 0.42\frac{\bar{S}}{\bar{S}_o}$***. The statistical error estimations such as RMSE, MPE and MBE used to test the correlation between the measured global solar radiation and the calculated global solar radiation. The RMSE was found to be 0.05 as low as expected, the MBE was also found to be 0.015 and MPE to be 0.062 values are low. The developed model can be used in estimating global solar radiation for Maiduguri and other locations with similar climatic conditions.***

Indexed Terms- Measured, Global Solar Radiation, Sunshine Hour, Clearness Index, Model.

I. INTRODUCTION

Energy which is the ability or capacity to do work is accepted as a phenomenon that has great link with environmental, social and economic dimensions of sustainable development. The demand of energy, the consumption of fossil fuels and pollution level are increasing with an alarming rate worldwide. With the high demand for this commodity, various stakeholders have now become aware of the urgent need for management of resources and energy conversion activities. The energy consumed in the household sector is perhaps the single largest consumer of energy in the nation's economy in developing countries of the world and Nigeria in particular. With the rapid depletion of fossil fuel reserves around the world due to high demand, it is feared that the world will soon run out of its nonrenewable energy resources which present the huge amount of energy use in the world. This is a matter of concern for the developing countries like Nigeria and others whose economy heavily depends on imported petroleum products. Under these circumstances it is highly desirable that alternate energy resources should be utilized with maximum conversion efficiency to cope with the increasing energy demand. Among the non-conventional energy resources, solar energy, wind energy and biomass has emerged as most prospective option for the future [1].

This aggressive consumption rate of fossil fuels has created unacceptable environmental problems such as greenhouse effects, which may lead to disastrous climatic consequences. Thus, renewable and clean energy such as that obtained by using solar cells is required to maintain the quality of human life as well as the environment [2]. The utilization of solar energy, like any other natural resources, requires detailed information on availability of the amount of total solar radiation striking the earth surface. This total amount of solar radiation incidents on the earth surface is called global solar radiation. Global solar radiation data are necessary at various steps of the design, engineering, simulation and performance evaluation of any project involving solar energy. Solar radiation provides the energy for photosynthesis and transpiration of crops and is one of the meteorological factors determining potential yields. Crop growth models, which have been developed since the 1960s, have been regarded as important tools of interdisciplinary research and have since been used in a number of areas such as the assessment of agriculture potential of a given region in the field of crop yield forecasting or as a climate change impact assessment tool [3]. Actually, the mapping of the solar radiant energy on the earth's surface is a requirement not only in the studies of climate change, environmental pollution but also in agriculture, hydrology, food industry and non-conventional energy development programs [4].

Several models have been proposed to estimate global solar radiation. [5] presents a linear regression model used in correlating the global solar radiation data with relative sunshine duration, which is a modified Angstrom type model [6]. [7] studied the correlation between the measurements of global solar radiation and the meteorological parameters using solar radiation, mean daily maximum temperature, mean daily relative humidity, mean daily sea level pressure, mean daily vapour pressure, and hours of bright sunshine data obtained from different parts of Egypt. [8] has demonstrated the predictive ability of the Angstrom type model, correlating the global solar radiation to relative sunshine duration in a simple linear regression form. [9] observed that the meteorological stations measuring solar radiation data in the developing countries are few. This situation can be solved by using empirical models, which estimate global solar radiation based on the relationships with frequently measured climatic variables. Solar energy occupies one of the most important places among the various possible alternative energy sources. An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices. Unfortunately, for many developing countries solar radiation measurements are not easily available due to the shortage of measurement equipment's [10]. It is therefore important to consider methods of estimating the solar radiation based on the readily available meteorological parameters.

II. MATERIALS AND METHOD

Maiduguri is the capital city of Borno state and one of the largest cities of Nigeria, situated in north eastern part of the country. The latitude of Maiduguri is 11.85^o N, longitude is 13.08°E with altitude of 354m. The following parameters were collected from the Archives of Nigerian meteorological Agency, National Weather Forecasting and Climate Research Centre Abuja for the period of ten years, from two thousand and one to two thousand and ten (2001-2010). Mainly daily global solar radiation and Sunshine hour.

The Angstrom- Prescott regression equation which has been used to estimate the monthly average daily solar radiation on a horizontal surface in Nigeria or other places is given as [7, 15]:

$$\frac{\bar{H}_m}{\bar{H}_o} = \left[a + b\frac{\bar{S}}{\bar{S}_o}\right] \quad (1)$$

$\bar{H}_m$ is daily mean values of global radiation (MJm^{-2}day^{-1}), $\bar{S}_o$ the daily average value of day length, and 'a' and 'b' values are known as Angstrom constants and they are empirical. $\bar{H}_o$ is daily mean values of extraterrestrial radiation (MJm^{-2}day^{-1}), calculated using equation (2) as described by [11, 14].

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

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

I_s the solar constant, The units in kWhm^{-2}day^{-1}

E_o represents the eccentricity correction, and described using Eq. (3.4) in Eq. 3.2

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

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_s, the mean sunset hour angle for the given month. The solar declination (δ) and the mean sunset hour angle (ω_s) can be calculated:

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

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

For a given day, the maximum possible values of day length can be computed by using Cooper's formula [12]:

$$\bar{S}_o = \frac{2}{15}\cos^{-1}(-\tan\varphi\tan\delta) \quad (7)$$

According to [13], regression coefficient *a* and *b* from the calculated monthly average global solar radiation has been obtained from the relationship given as:

$$a = -0.110 + 0.235\cos\varphi + 0.323\left(\frac{n}{N}\right) \quad (8)$$

$$b = 1.449 - 0.553\cos\varphi - 0.694\left(\frac{n}{N}\right) \quad (9)$$

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. 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. It is recommended that a zero value for MBE is ideal while a low RMSE and low MPE are desirable [16].

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

$$MPE\ (\%) = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{(H_{i,m}-H_{i,c})}{H_{i,m}}\right) \times 100 \qquad (10)$$

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.

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(H_{i,m}-H_{i,c}\right)^2\right]^{\frac{1}{2}} \qquad (11)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(H_{i,m}-H_{i,c}\right) \qquad (12)$$

III. RESULTS AND DISCUSSION

Table 1 shows the values of measured monthly mean daily sunshine hours $\bar{S}$, day length $\bar{S}_o$, global solar radiation on a horizontal surface $\bar{H}_m$, extraterrestrial solar radiation on a horizontal surface $\bar{H}_o$, as well as the clearness index K_T. A fitting scrutiny of Table 1, as well as Figures 1 and 2, shows that the maximum values of the monthly mean daily sunshine hours and monthly mean daily global solar radiation on a horizontal surface are 10.3 hours in December and 38.41MJm^{-2} day^{-1} in the month of March.

Table 1: Meteorological parameters for Maiduguri for the period of ten years (2001-2010)

Months	$\bar{S}$ (hr)	$\bar{S}_o$ (hr)	$\bar{S}/\bar{S}_o$	$\bar{H}_m$	$\bar{H}_o$	K_T ($\bar{H}_m/\bar{H}_o$)
Jan.	9.0	11.51	0.78	20.30	32.32	0.54
Feb.	9.7	11.76	0.83	24.50	34.71	0.62
Mar.	8.1	12.09	0.66	28.40	36.99	0.77
Apr.	8.3	12.40	0.67	26.80	37.91	0.71
May	8.9	12.63	0.71	29.10	37.46	0.75
Jun.	8.4	12.67	0.66	25.30	36.74	0.69
Jul.	6.6	12.51	0.53	24.20	36.89	0.66
Aug.	6.3	12.23	0.52	21.50	37.46	0.57
Sep.	7.5	11.89	0.63	23.40	37.16	0.63
Oct.	8.7	11.59	0.75	28.30	35.35	0.80
Nov.	10.0	11.40	0.88	24.80	32.79	0.76
Dec.	10.3	11.37	0.91	20.00	31.42	0.64

Table 2: Measured and Estimated values of solar radiation for the period of ten years (2001-2010).

Months	$\bar{S}$	$\bar{S}_o$	$\bar{H}_m$	$\bar{H}_o$	$\bar{H}_e$	Error (%)
Jan.	9.0	11.51	20.30	32.32	22.32	9.95
Feb.	9.7	11.76	24.50	34.71	26.81	9.42
Mar.	8.1	12.09	28.40	36.99	27.58	- 2.88
Apr.	8.3	12.40	26.80	37.91	24.96	- 6.86
May	8.9	12.63	29.10	37.37	27.54	- 5.36
Jun.	8.4	12.67	25.30	36.74	24.43	- 3.43
Jul.	6.6	12.51	24.20	36.89	23.54	2.80
Aug.	6.3	12.23	21.50	37.46	21.62	- 5.55
Sep.	7.5	11.89	23.40	37.16	22.23	- 5.0
Oct.	8.7	11.59	28.30	35.35	26.75	- 5.47
Nov.	10.0	11.40	24.80	32.79	24.87	0.28
Dec.	10.3	11.37	20.00	31.42	22.40	11.70

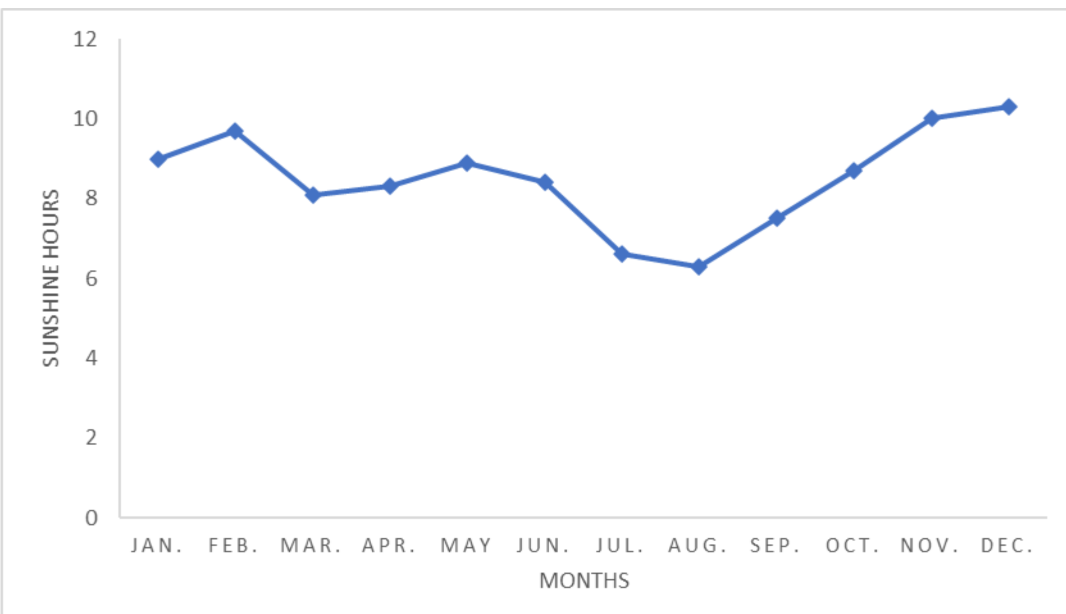

Fig. 1: Monthly mean daily sunshine hours on a horizontal surface

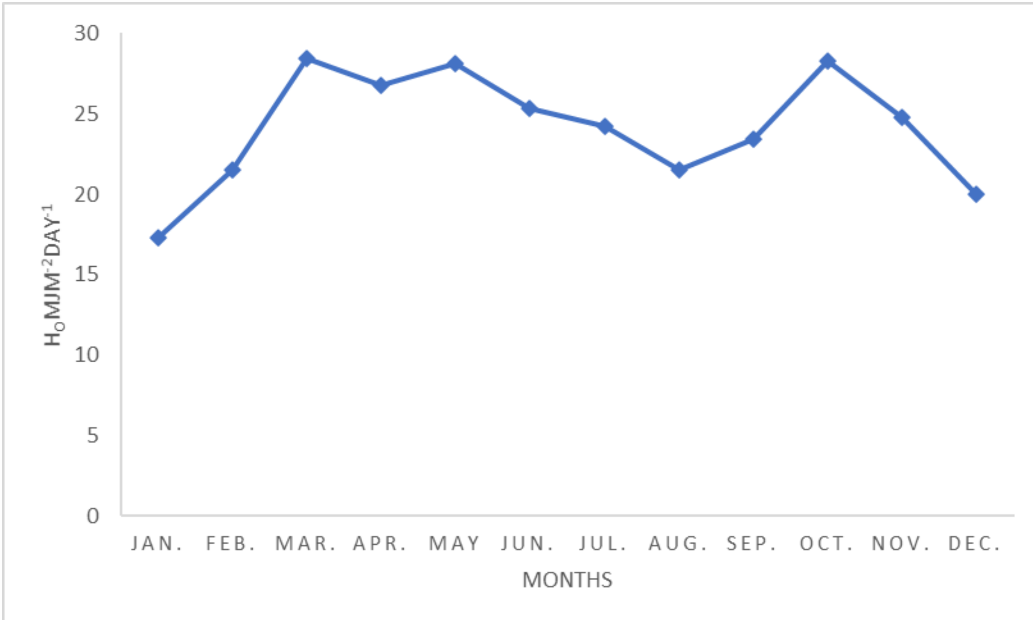

Fig. 2: Monthly mean daily global solar radiation on a horizontal surface.

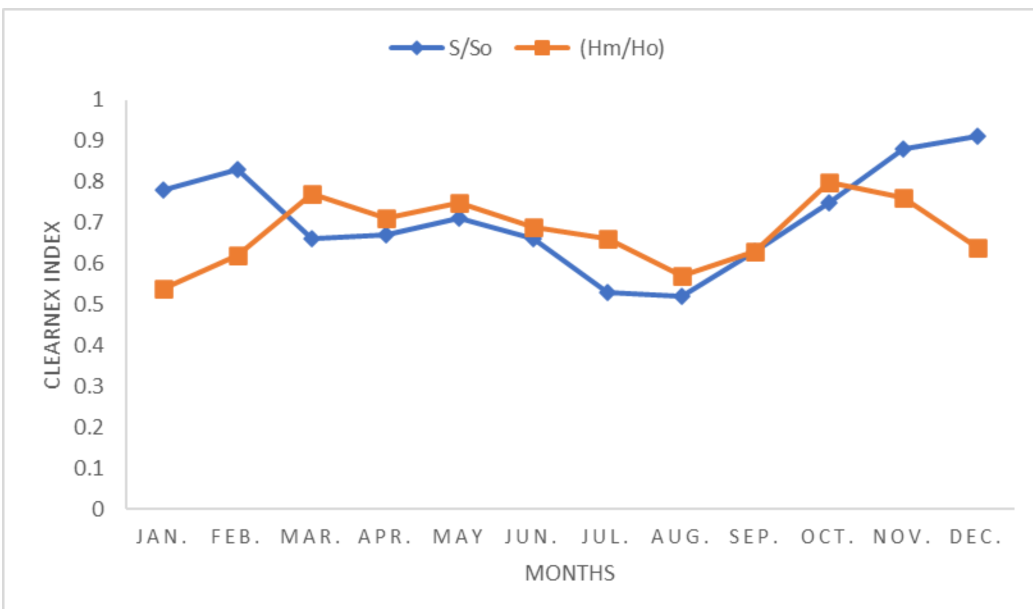

Fig. 3. Clearness index and Sunshine hours.

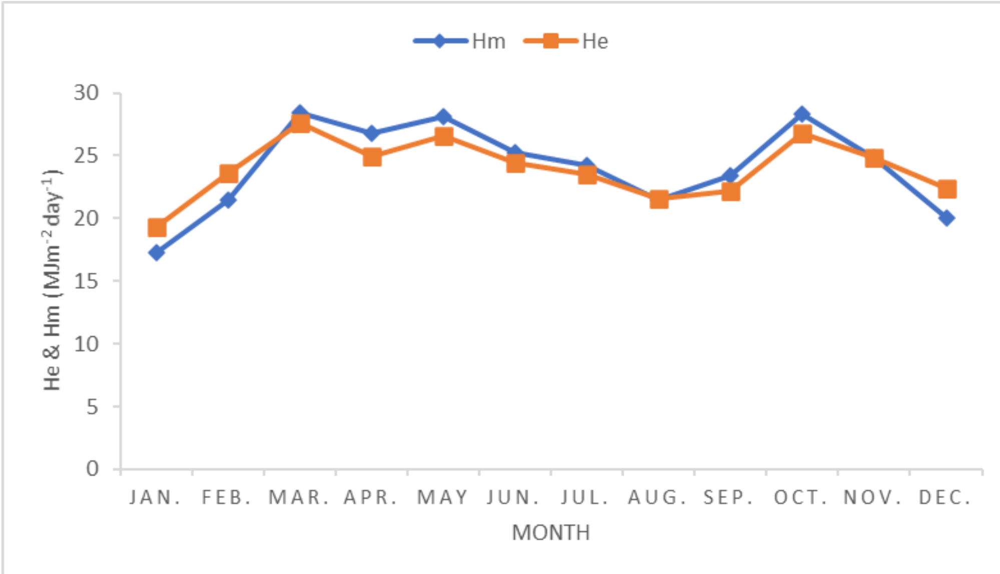

Fig. 4: Comparison between measured and predicted Solar Radiation

From Table 2 as well as Figure 4, it is observed that the monthly global solar radiation is not uniform throughout the period of study. Peak solar radiation is observed in the months of February, March and May with values of 26.81 $MJm^{-2}day^{-1}$, 27.58 $MJm^{-2}day^{-1}$, and 27.54 $MJm^{-2}day^{-1}$. On the other hand, the months of August and September recorded least amount of solar radiation average values of 21.62 $MJm^{-2}day^{-1}$ and 22.23 $MJm^{-2}day^{-1}$ respectively. This is as a result of the peak period of the cloud cover in Maiduguri due to the rainy season. In general, higher value of solar radiation is obtained in dry season than wet season. From Table 2, It was observed from the results that the percentage error between the measured and predicted values hardly exceeds 11.7%, which is very low as expected. The relationship between the relative sunshine duration $(\frac{S}{S_o})$, and clear sky index (K_T) or $(\frac{Hm}{H_o})$ for Yola are presented in Figure 3 which shows the variation of the clearness index, a measure of the attenuation of the extraterrestrial global radiation in passing through the turbulent atmosphere before reaching the ground surface. Figure 4 shows the variation of the measured and predicted solar radiation during the year. From the regression analysis the following correlation was found to adequately fit the radiation data presented in Table 1, the values of the regression coefficients a and b as 0.34 and 0.42, which substituted in equation 1 becomes:

$$\frac{\bar{H}_m}{\bar{H}_o} = 0.34 + 0.42\frac{\bar{S}}{\bar{S}_o} \qquad (13)$$

The statistical error estimations such as RMSE, MPE and MBE used to test the correlation between the measured global solar radiation and the calculated global solar radiation. The RMSE was found to be 0.05 as low as expected, the MBE was also found to be 0.015 and MPE to be 0.062 values are low. It is indicated that our model is suitable for the estimation of monthly average daily global radiation, from monthly average daily sunshine hours in Maiduguri. Equation (12) has been used to predict the monthly mean daily global solar radiation on a horizontal surface from measured values of hours of sunshine.

CONCLUSION

In line with world concern about the economic importance of global solar radiation as an alternative renewable energy, the models for estimating monthly global solar radiation of Maiduguri, Nigeria have been developed to be: $\frac{\bar{H}_m}{\bar{H}_o} = 0.34 + 0.42\frac{\bar{S}}{\bar{S}_o}$. The estimated global solar radiation data and its correlation will provide a useful source of information to designers of renewable energy, air conditioning systems and other solar energy related systems.

The Angstrom model developed in this study can also be applied to other cities to predict 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 the world at large.

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