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Empirical Model for the Estimation of Global Solar Radiation in Makurdi, Nigeria

By Isikwue, B.C., Amah, A.N., Agada, P. O.
Federal University of Agriculture Makurdi, Benue State, Nigeria

Abstract - This work proposes the coefficients for Angstrom - Prescott type of model for the estimation of global solar radiation in Makurdi, Nigeria using relative sunshine duration alongside the measured global solar radiation data (2001-2010). The model constants a and b obtained in this investigation for Makurdi are .138 and 0.488 respectively. The correlation coefficient of 89% (P=0.00) between the clear sky index and relative sunshine duration, as well as the coefficient of determination, R2 of 79.5 obtained shows that this model fits the data very well. Hence, the very low mean standard error of 0.025 showed a good agreement between the measured and estimated global solar radiation. Consequently, the developed model in this work can be used with confidence for Makurdi, and other locations with similar climate conditions.

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EMPIRICAL MODEL FOR THE ESTIMATION OF GLOBAL SOLAR RADIATION IN MAKURDI, NIGERIA

Strictly as per the compliance and regulations of :

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Isikwue, B.C. [α], Amah, A.N. [Ω], Agada, P. O. [β]

Abstract - This work proposes the coefficients for Angstrom - Prescott type of model for the estimation of global solar radiation in Makurdi, Nigeria using relative sunshine duration alongside the measured global solar radiation data (2001-2010). The model constants a and b obtained in this investigation for Makurdi are .138 and 0.488 respectively. The correlation coefficient of 89% (P=0.00) between the clear sky index and relative sunshine duration, as well as the coefficient of determination, R^2 of 79.5 obtained shows that this model fits the data very well. Hence, the very low mean standard error of 0.025 showed a good agreement between the measured and estimated global solar radiation. Consequently, the developed model in this work can be used with confidence for Makurdi, and other locations with similar climate conditions.

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I. Introduction

The high dependence on the depleting fossil fuel energy in Nigeria may not meet up with the increasing demand for energy, hence the need for the alternating source of energy. The widely used renewable resources are solar and wind energies

However, the facilities for global solar radiation measurement are available only in few locations in the country. Consequently, there in need to use some empirical relations to estimate global solar radiations from some measured meteorological parameters, such as relative sunshine hours.

There are various models for estimating solar radiation using relative sunshine durations and other meteorological data. The commonly used model which relates the global solar radiation to sunshine duration was first developed by Angstrom [1]. Subsequently, other models [2, 3] were developed.

In Nigeria several researches have been carried out for estimating solar radiation at different locations [4 - 9]. However, none has been found in the literature of the models developed for estimating global solar radiation for Makurdi and its environs of similar meteorological parameters. Hence this work is aimed at developing an Angstrom-type of empirical model for the estimation of global solar radiation for Makurdi and other surrounding towns of similar meteorological conditions.

Makurdi, having an area of about 33.16 km^2 is located at latitude 7°.41' N and longitude 8°.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 °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.

II. Methodology

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

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

$\bar{H}_m$ is the monthly average daily global solar radiation measured on a horizontal surface (M J m^{-2} day^{-1}); $\bar{H}_o$ is the monthly average daily extraterrestrial solar radiation measured on a horizontal surface (M J m^{-2} day^{-1}); $\bar{n}$ is the monthly average daily number of hours of bright sunshine; $\bar{N}$ is the monthly average daily maximum number of hours of possible sunshine (or day length); and **a** and **b** are regression constants to be determined.

Values of $\bar{N}$ are computed from Cooper's formula [10]:

$$\bar{N} = \left(\frac{2}{15}\right)\cos^{-1}\left(-\tan\Phi\tan\delta\right) \quad (2)$$

$\bar{H}_o$ was obtained from [7] as

$$\bar{H}_o = \frac{24}{\pi} I_{sc}\left(1+0.33\cos\frac{360\bar{n}}{365}\right)\left(\cos\Phi\cos\delta\sin w_s + \frac{2\pi w_s}{360}\sin\Phi\sin\delta\right) \quad (3)$$

$w_{s\ and\ \delta}$ are sunset hour angle and solar declination respectively and are defined as

$$w_s = \cos^{-1}\left[\cos(-\tan\Phi\tan\delta)\right) \quad (4)$$

$$\delta = 23.45\sin\left(360\,\frac{284+d}{365}\right) \quad (5)$$

Author [α Ω] : Department of Physics, Federal University of Agriculture Makurdi, Benue State, Nigeria.
Author [β] : Department of Maths /Statistics /Computer science, Federal University of Agriculture Makurdi, Benue State, Nigeria.

d is the day of year (known as the Julian day).Usually, the solar declination is calculated on the 15th of each month.

In this work, $\overline{H}_o$ and $\overline{N}$ were computed for each month using equations (2) and (3). The values of the monthly average daily global solar radiation, $\overline{H}_m$ and $\bar{n}$ were obtained from daily measurements covering a period of nine (9) years. The SPSS computer software was applied to obtain the regression constants **a** and **b**. Mean Bias Error (MBE) was also obtained to assess the validity of estimation made through equations (1)

III. Result and Discussion

The input parameters used in this analysis are presented in Table 1.

Month	$\overline{H}_m$	$\overline{H}_o$	$\frac{\overline{H}_m}{\overline{H}_o}$	$\frac{\bar{n}}{\overline{N}}$
Jan	14.055	33.255	0.423	0.620
Feb	15.618	35.572	0.439	0.563
Mar	15.555	37.446	0.415	0.578
Apr	14.792	38.085	0.389	0.603
May	14.355	37.271	0.385	0.558
June	13.655	36.462	0.375	0.495
July	12.009	37.348	0.322	0.402
Aug	11.355	37.490	0.303	0.348
Sept	13.064	37.566	0.348	0.399
Oct	14.864	36.015	0.413	0.517
Nov	15.691	33.666	0.467	0.592
Dec	15.264	32.379	0.471	0.648

Table 1 : input parameters for estimation of monthly daily global solar radiation for Makurdi, Nigeria

The model constants, **a** and **b** obtained in this investigation were **0.138** and **0.488** respectively. Hence the first order polynomial developed for Makurdi is

$$\frac{\overline{H}_m}{\overline{H}_o} = 0.138 + 0.488\left(\frac{\bar{n}}{\overline{N}}\right) \quad (6)$$

The coefficient of determination, R^2 of **79.5** obtained for this analysis shows that this model fits the data very well. The relationship between the relative sunshine duration, $\frac{\bar{n}}{\overline{N}}$ and clear sky index (K_T) or $\frac{\overline{H}_m}{\overline{H}_o}$ for Makurdi are presented in Figure 1

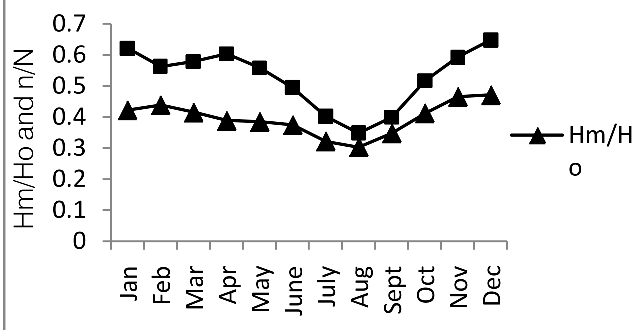

Fig. 1 : Relationship between the clearness index and the relative sunshine duration in Makurdi, Nigeria

The value of K_T (=0.303) corresponding to the lowest value of $\frac{\bar{n}}{\overline{N}}$ (=0 .348) and $\overline{H}_m$ (=11.355 (M J m $^{-2}$ day $^{-1}$) in the month of August indicate poor sky conditions. These conditions correspond to the wet or rainy season (June -September) observed in Nigeria during which there is much cloud cover. Hence, the correlation coefficient between K_T and $\frac{\bar{n}}{\overline{N}}$ is as high as 89% (p=0.00). Figure 2 demonstrates the relationship between the measured and the estimated global solar radiation

Observation from Fig. 2 shows that both the estimated and the measured vary correspondingly except in February, May and April, where they respectively exhibit under estimation and over estimation of the predicted values. This could be due to variability in atmospheric parameters during the measurement. However, the estimated value of the global solar radiation correlates well with the measured, hence, the Means Standard Error (MSE) between the measured and the estimated global solar radiation is as 0.025. This shows a good agreement between the measured and estimated values.

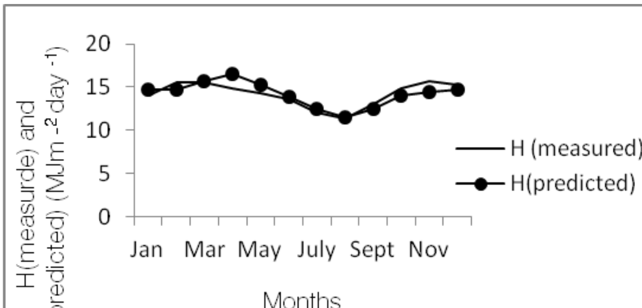

Fig. 2 : Relationship between the and measured the estimated monthly average daily global solar radiations in Makurdi, Naigeria

Figure 2 also shows that the maximum solar radiation in Makurdi, were obtained for the period 2001-2010 in (February – March) and (October- November). In the rainy season, the lowest solar radiation was obtained in August (probably due to rain bearing clouds which pervaded the sky), where as in the dry season, the highest was measured in November and the lowest in December and January (probably due to hamartan dust which scattered the solar radiation at that time.

Under clear perfect sky condition, the transmission of the atmosphere for global; solar radiation is given as the sum of the regression coefficients a + b, where as the transmissivity of an over cast atmosphere is interpreted as the intercept a. From this investigation, the atmosphere transmissivity, under clear sky for Makurdi is obtained as 0.63 which compares well with the values of 0. 67, 0.70 reported for humid to tropics [7].

The best month, November with $\bar{H}_m$ of 15.69 M J m $^{-2}$ day $^{-1}$ contributed about 9 % of the annual total, while the worst month, August, with $\bar{H}_m$ of 11.36 M J m $^{-2}$ day $^{-1}$ contributed 7 % of the annual total.

Finally our model fits adequately with the radiation data presented in Table 1. Consequently, equation (6) can be used with confidence for Makurdi, and other locations with similar climate conditions.

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