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RELATIONSHIP BETWEEN GLOBAL SOLAR RADIATION AND SUNSHINE DURATION FOR YOLA, NIGERIA

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ABSTRACT
In this paper, the value of monthly average global solar radiation for Yola area have been estimated using different empirical models, measurements of sunshine duration and global solar radiation were used to establish an Angstrom – type correlation equation. The predictive efficiency was validated and compared based on mean percentage error (MPE), mean biased error (MBE) and root mean square error (RMSE). On comparison, a good agreement was observed between the measured value and the predicted value that of our model, $\frac{\bar{H}}{\bar{H}_o} = 0.27 + 0.34\frac{\bar{S}}{\bar{S}_0}$ *and may be used reasonably well for estimating the solar radiation at a given location and possibly in elsewhere with similar climatic conditions.*

KEY WORDS: *Global solar radiation, Empirical model, Regression constant, predictive efficiency, climatic condition*

1. INTRODUCTION

Global solar radiation data are necessary at various steps of the design, simulation, engineers, agricultural scientists and performance evaluation of any project involving solar energy. It is needed for designing collectors for solar heaters and other photovoltaic equipment that depend on solar energy. Incoming solar radiation has a significant role in hydrological and crop growth modelling. For instance, it is a key input for estimating potential evapotranspiration which play a major role in the design of water supply storage reservoirs and irrigation systems [1]. In spite of the importance of global solar radiation data, its measurements are not frequently available especially in developing countries [2].

Akpabio et al., [3] 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.

It is pertinent to note that many researchers who have done similar work to estimate incoming solar radiation in Nigeria [3-4] in different locations concentrated on one model, either with artificial neural network or in most cases with empirical model of different modeling.

The main objective of this work is to use different models for estimating global solar radiations in Yola, Adamawa State and continue in the effort to compare different models for predicting solar radiation for as many regions as possible to provide a basis for future (sub-saharan) iso-radiation maps. The correlation developed in this paper will then be used to estimate global solar radiation for places where only sunshine records are available

2. METHODOLOGY

Yola, Nigeria is at 9°14'N, 12°28'E, 186 m (611 ft). Yola has a tropical wet and dry/ savanna climate with a pronounced dry season in the low-sun months, no cold season, wet season is in the high-sun months. According to the Holdridge life zones system of bioclimatic classification Yola is situated in or near the tropical dry forest biome. The annual average temperature is 28.1 degrees Celsius (82.5 degrees Fahrenheit).

The solar radiation data comprising of monthly mean daily global solar radiation and sunshine hours for Yola Adamawa State, Nigeria were obtained for the period of fifteen years (1999-2013) from the Nigeria Meteorological Agency, Federal Ministry of Aviation, Yola, Adamawa State. The most convenient and widely used correlation for predicting solar radiation was developed by Angstrom and later modified by Prescott. According to [5, 9, 12], the Angstrom formula is given by:

$$\frac{\bar{H}}{\bar{H}_o} = a + b\frac{\bar{S}}{\bar{S}_0} \quad (1)$$

Where $\bar{H}$ is the monthly average global solar radiation [$MJm^{-2}day^{-1}$], $\bar{H}_o$ is the monthly average daily extraterrestrial radiation [$MJm^{-2}day^{-1}$], $\bar{S}$ is the monthly average daily bright sunshine hour, $\bar{S}_0$ is the maximum possible monthly average daily sunshine hour or the day length, a and b are the regression constant to be determined.

The monthly average daily extraterrestrial radiation on a horizontal surface (H_o) can be computed from the following equation [5, 10]:

$\bar{H}_o$, is the monthly average daily extraterrestrial radiation which can be expressed as:

$$H_o = \frac{24\times360}{\pi} I_{sc}\left[1+0033\cos\left(360\frac{dn}{365}\right)\right]\left[\frac{2\pi\omega}{360}\right] Sin\,\emptyset\, Sin\,\delta\, \sin\omega + Cos\,\emptyset\, Cos\,\delta\, Sin\,\omega \quad (2)$$

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

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

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

$$\bar{S}_0 = \left(\frac{2}{15}\right)\omega \quad (5)$$

2.1 Data Analysis

In this work, 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), Mean Bias Error (MBE) and Percentage Error. These tests are applied most commonly in comparing the models of solar radiation estimations.

$$\text{where } MPE = \frac{[\Sigma(H_{i,m}-H_{i,c})/H_{i,m}]100}{N} \quad (6)$$

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. Root Mean Square Error: The root mean square error is defined as:

$$RMSE = \left(\left[\frac{\Sigma\{H_{i,c}-H_{i,m}\}^2}{N}\right]\right)^{1/2} \quad (7)$$

Mean Bias Error: The mean bias error is defined as:

$$MBE = \frac{[\Sigma\{H_{i,c}-H_{i,m}\}]}{N} \quad (8)$$

2.2 Models

Rietveld Model [8] examined several published values of the a and b from following equations, respectively:

$$a = 0.10 + 0.24\frac{\bar{n}}{\bar{N}} \quad (9)$$

$$b = 0.38 + 0.08\frac{\bar{n}}{\bar{N}} \quad (10)$$

$$\frac{\bar{H}}{\bar{H}_o} = 0.18 + 0.62\frac{\bar{n}}{\bar{N}} \quad (11)$$

Glover and McCulloch model [6] included latitude effect and presented the correlation:

$$\frac{\bar{H}}{\bar{H}_o} = 0.29\cos\emptyset + 0.52\frac{\bar{n}}{\bar{N}} \quad (12)$$

Ahmad and Ulfat model [9] have suggested to first order polynomial equations developed for Karachi of Pakistan:

$$\frac{\bar{H}}{\bar{H}_o} = 0.324 + 0.405\frac{\bar{n}}{\bar{N}} \quad (13)$$

Our model, $$\frac{\bar{H}}{\bar{H}_o} = 0.27 + 0.34\frac{\bar{S}}{\bar{S}_0} \quad (14)$$

The coefficients for developing these model was derived from Rietveld Model and Neuwirth, [8, 12].

a = - 0.110 + 0.235cos∅ + 0.323$\frac{\bar{S}}{\bar{S}_0}$

(15)

b = 1.449 – 0.553cos∅ − 0.694$\frac{\bar{S}}{\bar{S}_0}$

(17)

3. RESULTS AND DISCUSSIONS

The four models listed above were applied to the sunshine data at Yola. The calculated and measured values of average daily global radiation on the horizontal surface were compared, to find the best correlation that will fit the measured global solar radiation. The results are shown in the tables and graphs below.

The regression constants have been generally computed using observations of sunshine hours and monthly average daily global radiation of the given location.

Table 1: Impute parameters for the estimation of monthly average daily global solar at Yola for the period of fifteen years (1999 – 2013).

Month	$\bar{H}$ [MJm^{-2}day^{-1}]	$\bar{H}_o$ [MJm^{-2}day^{-1}]	$\bar{n}/\bar{N}$	$\bar{H}/\bar{H}o$
JAN	17.22	36.58	0.45	0.56
FEB	20.09	37.13	0.47	0.54
MAR	21.21	37.96	0.50	0.58
APR	22.02	39.14	0.55	0.62
MAY	23.68	39.78	0.52	0.59
JUN	17.29	38.49	0.43	0.45
JUL	18.38	39.29	0.37	0.46
AUG	14.31	37.76	0.29	0.37
SEP	16.42	37.88	0.38	0.43
OCT	18.84	38.74	0.39	0.49
NOV	20.38	39.59	0.53	0.51
DEC	19.22	36.96	0.51	0.52

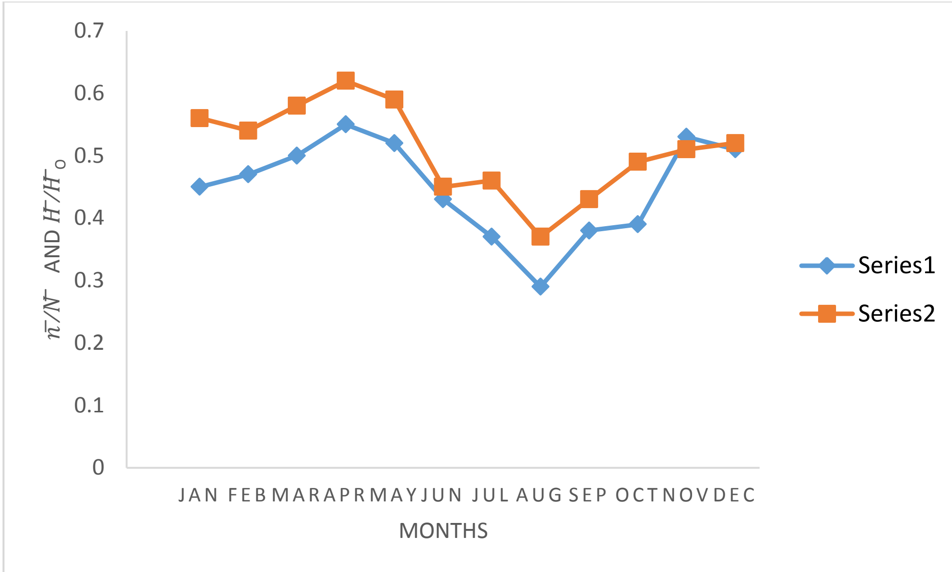

Figure 1. Variation of $\bar{n}/\bar{N}$ (series 1) and $\bar{H}/\bar{H}$o (series 2) for Yola

Figure 1 shows the variation of $\bar{n}/\bar{N}$ and $\bar{H}/\bar{H}$o, the clearness index (overcast skies) for Yola. The dip in the months of June-August indicates poor sky conditions where $\bar{n}/\bar{N}$ goes as low as 0.29 and K_T values reaches minimum i.e 0.37 (for August) and 0.43 (for September).

Table 2: Estimation of monthly average daily global solar radiation from various models for Yola for the period of fifteen years (1999 – 2013).

Month	H_m	Rietveld Model	Glover and McCulloch Model	Ahmad and Ulfat Model	Equation (14)
JAN	17.22	16.46	19.03	18.51	17.28
FEB	20.09	18.44	19.44	20.55	21.57
MAR	21.21	19.50	20.07	20.59	21.72
APR	22.02	20.02	22.39	21.39	22.12
MAY	23.68	19.89	22.14	23.26	23.03
JUN	17.29	18.83	19.62	19.17	17.14
JUL	18.38	15.28	18.80	18.61	19.38
AUG	14.31	13.21	16.50	16.66	14.79
SEP	16.42	15.53	18.32	18.10	17.26
OCT	18.84	16.35	19.04	18.76	19.04
NOV	20.38	19.79	21.24	21.32	20.37
DEC	19.22	18.12	20.38	19.61	19.18

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

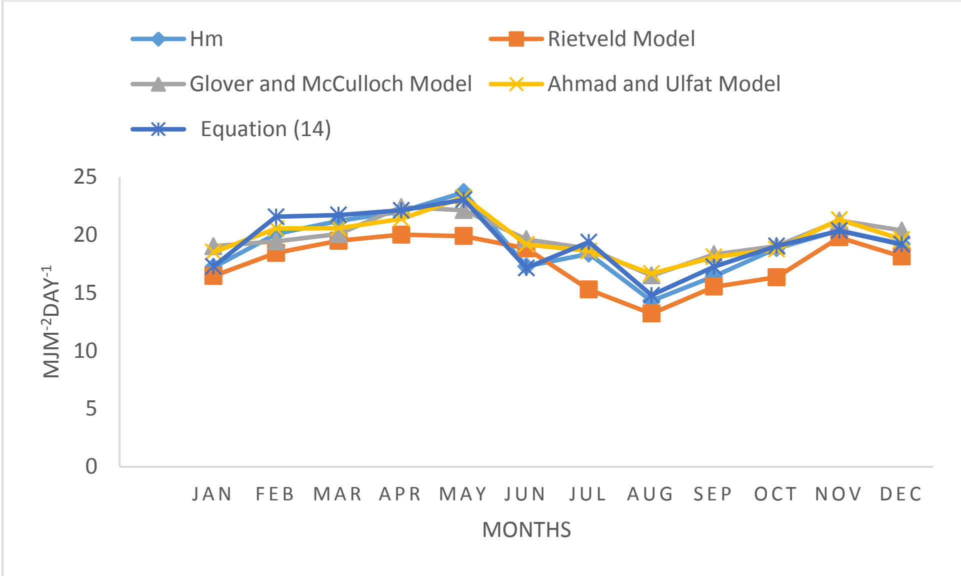

Figure 2: Estimated value of monthly average daily global solar radiation of all the models used and measured value.

Table 3: Comparison between measured monthly average daily global solar radiation and calculated monthly average daily global solar radiation based on Equation (14)

Month	H_m	Equation (14)
JAN	17.22	17.28
FEB	20.09	21.57
MAR	21.21	21.72
APR	22.02	22.12
MAY	23.68	23.03
JUN	17.29	17.14
JUL	18.38	19.38
AUG	14.31	14.79
SEP	16.42	17.26
OCT	18.84	19.04
NOV	20.38	20.37
DEC	19.22	19.18

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

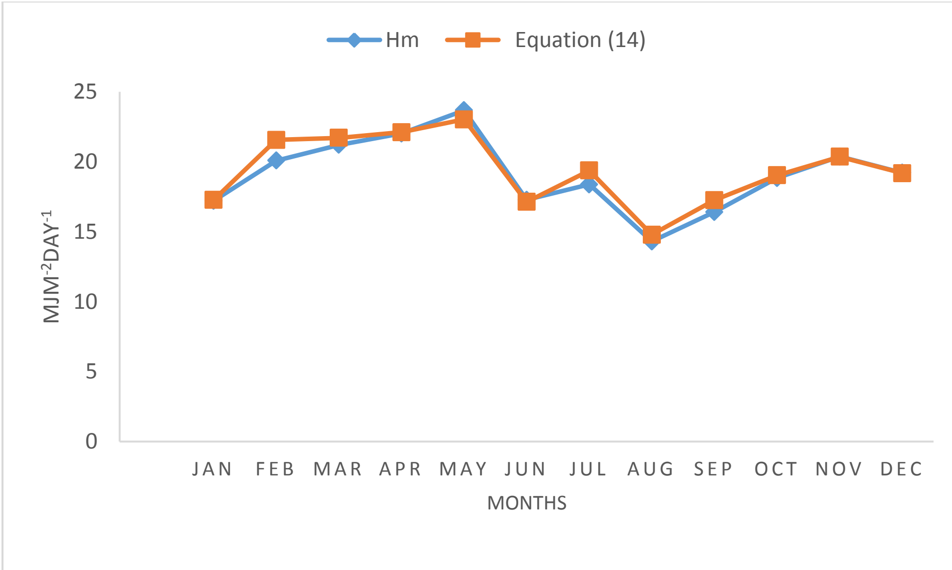

Figure 3: Estimated value of monthly average daily global solar radiation of equation (14) and measure value.

Comparing the models it is realized that the performance of the Glover and McCulloch model is worst, while models of Rietveld, Ahmad and Ulfat are poorer (Figure 2). However, the performance of Equation (14) is better than the rest of the models. It is very encouraging to observe a very fine agreement between measured and estimated values obtained from our correlation.

Table 4: Comparison of Error values for the estimated monthly average daily global solar radiation from different models.

Error terms	Rietveld Model	Glover and McCulloch Model	Ahmad And Ulfat Model	Equation (14)
MPE	1.244	- 0.600	- 0.568	- 0.1139
MBE	2.717	1.614	0.464	- 0.0217
RMSE	10.524	6.251	5.990	- 0.0841

In the present work, the validation of these models has been performed by using MPE, MBE, and RMSE. According to the results in table 3, our model (Eq. 14) was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola. With respect to MPE, Equation (14) gives the best correlation, while Rietveld model present the worst. On the whole, low MPE value is desirable. However, an over estimation of MPE may be cancelled by an under estimation. The MBE and RMSE values were given as 0.0217 [$MJm^{-2}day^{-1}$] and 0.0841 [$MJm^{-2}day^{-1}$] which is low compare to what is obtained from other models. A low value of MBE and RMSE is expected and acceptable. Finally, considering the regression analysis, the following correlation (our model) was found to adequately fit the radiation data present in Table 3. And this correlation can also be used in estimating global solar radiation in any part of Nigeria with similar climatic conditions.

4. CONCLUSION

The main conclusion of the present work is that, sunshine based models are employed for estimation global solar radiation for any location. Hence the monthly average daily global irradiation incident on horizontal surface in Yola, Nigeria may be estimated by the correlation. $\frac{\bar{H}}{\bar{H}_0} = 0.27 + 0.34\frac{\bar{S}}{\bar{S}_0}$ Good agreement has been found between measured values and data estimated by the above mentioned equation, which makes it useful in estimating global solar radiation (where there is no data). The development of the Angstrom-type correlation will enable the solar energy research worker to use the estimated data with confidence because of its fine agreement.

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