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Correlation between Sunshine Hours and Global Solar Radiation for Lagos, Nigeria

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Abstract *- A correlation equation of the Angstrom type has been developed to predict the monthly mean daily global solar radiation incident on a horizontal surface in Lagos (06^0 25', 03^0 27'). The monthly mean data for global solar radiation and sunshine hours for a period of eleven years (1999 – 2009) for Lagos have been used to develop a regression equation. The values of the global solar radiation estimated by the model and the measured solar radiation were tested using the Mean Bias Error (MBE), Root Mean Square Error (RMSE), and Mean Percentage Error (MPE) statistical techniques. The values of the correlation coefficient (R) and coefficient of determination (R^2) were also determined for the correlation. Measurements of global solar radiation have been compared with those predicted using the equation. A good agreement was observed between the measured values and the predicted ones. The model could be employed in estimating global solar radiation of locations with similar latitudinal variations as Lagos.*

Keywords - sunshine hours, clearness index, global solar radiation, lagos, solar radiation model

1. INTRODUCTION

The knowledge of global solar radiation is extremely important for the optimal design and prediction of the performance of solar energy conversion systems. The best way of knowing the amount of global solar radiation at a site is to install pyranometers at many locations in the given region and look after their day-to-day maintenance and recording, which is a very costly exercise. The alternative approach is to correlate the global solar radiation with the meteorological parameters at place where the data is collected. The resultant correlation may then be used for locations of similar meteorological and geographical characteristics for which solar radiation data are not available.

The first correlation proposed for estimating the monthly mean daily global solar radiation on a horizontal surface using the sunshine duration data is due to Angstrom (1924). Prescott (1940) had put the Angstrom correlation in a more convenient form as:

$$\frac{\overline{H}_M}{\overline{H}_O} = a + b\frac{\overline{n}}{\overline{N}} \qquad (1)$$

$\overline{H}_M$ is the measured global solar radiation (MJm^{-2}day^{-1}) $\overline{H}_O$ is the monthly mean daily extraterrestrial radiation (MJm^{-2}day^{-1}) , $\overline{n}$ is the monthly mean daily bright sunshine hours, $\overline{N}$ is the maximum possible monthly mean daily sunshine hours or the day length, (a) and (b) are regression constants. The ratio $\frac{\overline{H}_M}{\overline{H}_O}$ is a possible measure of the transparency of the atmosphere to solar radiation. Thus, the ratio is used to define the coefficient of transmission or transmittance of the atmosphere (Babatunde et al., 1990).

A number of correlations involving global solar radiation and sunshine hours for different locations in Nigeria have been studied by different researchers. For example, (Sambo, 1985) developed a correlation with solar radiation using sunshine hours for Kano with the regression coefficient a = 0.413 and b = 0.241 for all months between 1980 -1984, (Arinze and Obi, 1983) developed a correlation solar radiation using sunshine hours in Northern Nigeria with regression coefficient a = 0.2 and b = 0.74 (Burari et al., 2001) developed a model for estimation of global solar radiation in Bauchi with regression coefficients a = 0.24 and b = 0.46. Other researchers (Ojosu, 1984; Fagbenle, 1990; Folayan, 1983; Adebiyi, 1988; Turton, 1987; Bamiro, 1983, Akpabio and Etuk, 2002; Udo, 2002; Falayi and Rabiu, 2005; Augustine and Nnabuchi, 2009a&b; Chukwuemeka and Nnabuchi, 2009; Agbo and Obiekezie, 2010; Ogolo, 2010; Falayi et al., 2011; Yakubu, 2012) developed theoretical and empirical correlations of broad applicability to provide solar data for systems design in most Nigerian cities. We observed that the regression coefficients are not universal but depends on the climatic conditions. This work aims at proposing a model that can correlate sunshine hours and global solar radiation radiation for Lagos, Nigeria.

2. METHODOLOGY

The monthly mean daily data for sunshine hours were collected from the Nigerian Meteorological Agency, Federal Ministry of Aviation, Oshodi, Lagos, Nigeria. The data obtained covered a period of eleven

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years (1999-2009) for Lagos, Nigeria (06° 25', 03° 27'). The monthly averages data processed in preparation for the correlation is presented in Table 1.

Table 1: Meteorological Data and Global Solar Radiation for Lagos.

MONTHS	$\bar{n}$ (hours)	$\bar{N}$ (hours)	$\frac{\bar{n}}{\bar{N}}$	$\bar{H}_M$ (MJm^{-2}day^{-1})	$\bar{H}_O$ (MJm^{-2}day^{-1})	$\bar{K}_T = \frac{\bar{H}_M}{\bar{H}_O}$
JAN	5.15	11.60	0.4440	19.008	33.696	0.5641
FEB	5.82	11.80	0.4932	19.764	35.784	0.5523
MAR	5.14	11.90	0.4319	19.656	37.440	0.5250
APR	5.82	12.10	0.4810	18.756	37.440	0.5010
MAY	5.80	12.30	0.4715	17.136	36.360	0.4713
JUN	4.35	12.30	0.3537	14.544	35.892	0.4052
JUL	3.18	12.30	0.2585	14.220	36.000	0.3950
AUG	2.95	12.20	0.2418	14.328	36.720	0.3902
SEPT	3.93	12.00	0.3275	14.724	37.080	0.3971
OCT	5.39	11.80	0.4568	16.380	36.000	0.4550
NOV	6.23	11.70	0.5325	17.820	34.056	0.5233
DEC	5.96	11.60	0.5138	18.612	32.796	0.5675

SPSS computer software program was used to develop the correlation equation in this study.

To develop the model, the global solar radiation data measured in (KWhm^{-2}) were converted to (MJm^{-2}day^{-1}) using a conversion factor of 3.6 proposed by Iqbal (1983).

The Angstrom-Page linear regression model used in correlating the measured global solar radiation data ($\bar{H}_M$) with the fraction of sunshine ($\frac{\bar{n}}{\bar{N}}$) is already given in Equation (1).

The possible daily maximum number of hours of insolation, also called the length of day, is given by Iqbal (1983):

$$\bar{N} = \frac{2}{15}\omega_s \qquad (2)$$

where ω_s is the hour angle, expressed as:

$$\omega_s = \text{Cos}^{-1}(-\tan\phi \tan\delta) \qquad (3)$$

where ϕ and δ are the latitude and declination angles, respectively. The declination δ is given by:

$$\delta = 23.45\text{Sin}\left(360\left(\frac{N+284}{365}\right)\right) \qquad (4)$$

where N is the day number of the year. The mean monthly daily extraterrestrial radiation $\bar{H}_O$ on horizontal surface is given by the expression:

$$\bar{H}_O = \frac{24}{\pi} I_{SC} E_o\left(\frac{\pi}{180}\omega_s Sin\phi Sin\delta + Cos\phi Cos\delta Sinw_s\right) \qquad (5)$$

where Isc is the solar constant (4.921 MJm^{-2}day^{-1}), N is the characteristic day number, ϕ is the latitude angle and ω_s is the sunset hour angle. E_o is the eccentricity correction factor of the Earth's orbit. The value of E_o is given by Liou (1980):

$$E_{o} = 1 + 0.033\text{Cos}\left(\frac{360N}{365}\right) \qquad (6)$$

The accuracy of the calculated values was tested by calculating the mean bias error (MBE), root mean square error (RMSE), and mean percentage error (MPE), using the expression stated by El –Sebaii et al; (2005) as follows:

$$\text{MBE} = \left[\sum\left(\bar{H}_{cal} - \bar{H}_{meas}\right)\right]/n \qquad (7)$$

$$\text{RMSE} = \left[\sum\left(\bar{H}_{cal} - \bar{H}_{meas}\right)^2/n\right]^{\frac{1}{2}} \qquad (8)$$

$$\text{MPE} = \left[\sum\left(\frac{\overline{H}_{meas} - \overline{H}_{cal}}{\overline{H}_{meas}} X100\right)\right]/n \qquad (9)$$

where $\overline{H}_{meas}$ and $\overline{H}_{cal}$ are the measured and calculated (predicted) values respectively, and n is the total number of observation.

Iqbal (1983), Halouani (1993), Almorox (2005), Che et al. (2007) have recommended that a zero value for MBE is ideal and a low RMSE is desirable. The RMSE test provides information on the short-term performance of the studied model as it allows a term by term comparison of the actual deviation between the calculated values and the measured values.

The MPE test gives long-term performance of the examined regression equations, a positive MPE values provide the averages amount of underestimation in the calculated values, while the negative values give the overestimation. A low value of MPE is desirable.

The performance of four other sunshine based models especially those believed to be applicable universally and those developed for the Lagos environment was tested. This is to find out whether any of these models gave a better result than the newly developed model. The four models were:

Turton's model: A model developed for the humid tropical countries:

$$\frac{H}{H_o} = 0.30 + 0.40\left(\frac{\overline{n}}{\overline{N}}\right) \qquad (10)$$

Rietveld's model: An interesting correlation which is believed to be applicable anywhere in the world:

$$\frac{H}{H_o} = 0.18 + 0.62\left(\frac{\overline{n}}{\overline{N}}\right) \qquad (11)$$

Fagbenle's model: This is a correlation model that is believed to be suitable for the rain climatic zone of south Nigeria

$$\frac{H}{H_o} = 0.28 + 0.39\left(\frac{\overline{n}}{\overline{N}}\right) \qquad (12)$$

McCulloch's model: A model that takes into account the latitude effect:

$$\frac{H}{H_o} = 0.29Cos\phi + 0.52\left(\frac{\overline{n}}{\overline{N}}\right) \qquad (13)$$

The four models listed above were applied to the sunshine data at Lagos. 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.

3. RESULTS AND DISCUSSION

Table 1 shows the calculated values of measured monthly mean daily sunshine hours $\overline{n}$, possible fraction of sunshine $\frac{\overline{n}}{\overline{N}}$, global solar radiation on a horizontal surface $\overline{H}_M$, extraterrestrial solar radiation on a horizontal surface $\overline{H}_O$, as well as the clearness index $\overline{K}_T$.

Figure 1 shows the graph (scattered diagram) showing clearness index against the monthly mean daily fraction of sunshine hours. The correlation coefficient of 0.845 existing between the clearness index and monthly mean daily fraction of sunshine duration indicate that there is a high positive correlation between the measured monthly mean daily fraction of sunshine duration and the monthly mean daily clearness index. Also the value of coefficient of determination of 0.7139 implies 71.4% of clearness index can be accounted for by relative sunshine duration using Angstrom equation model:

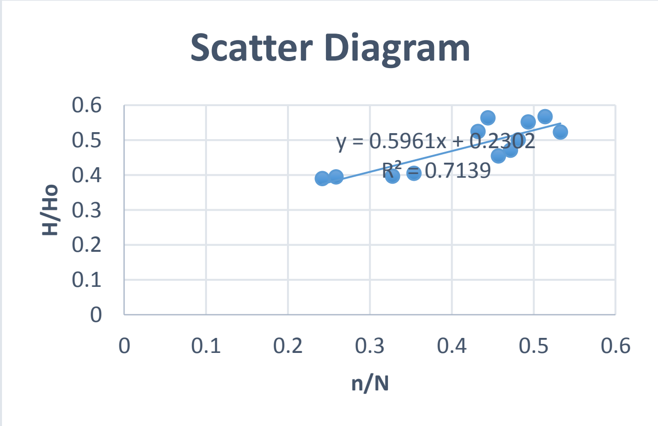

Fig. 1: Monthly average Clearness Index against mean Daily Fraction of Sunshine Hours

$$\frac{\overline{H}}{\overline{H}_o} = 0.2302 + 0.5961\left(\frac{\overline{n}}{\overline{N}}\right) \qquad (14)$$

Table 2 shows regression equation and statistical indicator for the study

Table 2: regression equation and statistical indicator

Equation	R	R^2	MBE	RMSE	MPE
$\frac{\overline{H}}{\overline{H}_0} = 0.2302 + 0.5961\frac{\overline{n}}{\overline{N}}$	0.845	0.714	0.017	0.060	-0.008

Furthermore, there is a remarkable agreement between the observed and the calculated values of global solar radiation for eleven years of our correlation (Figure 2)

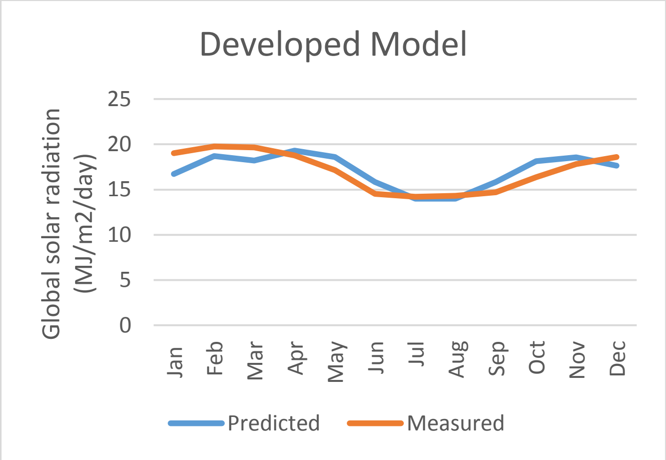

Fig. 2**:** Comparison of the Measured and the Predicted/Calculated Values of Global Solar Radiation $\overline{H}_{cal}$ for Lagos

Figure (3a) and (b) show the performance of the other chosen models

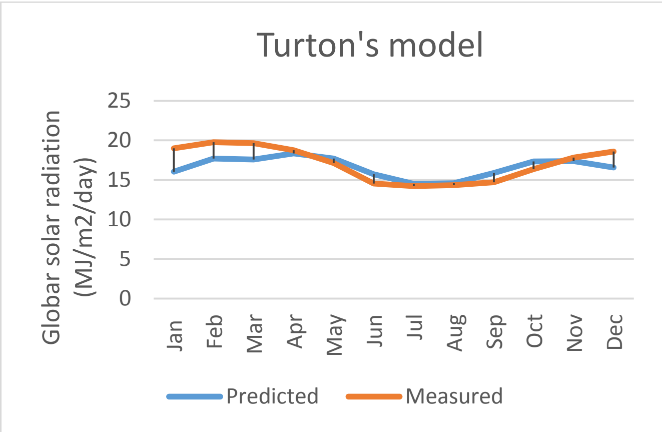

Fig. 3a(i)

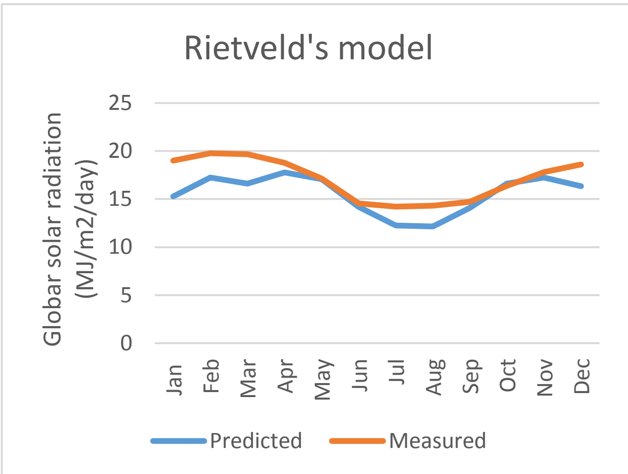

Fig. 3a(ii)

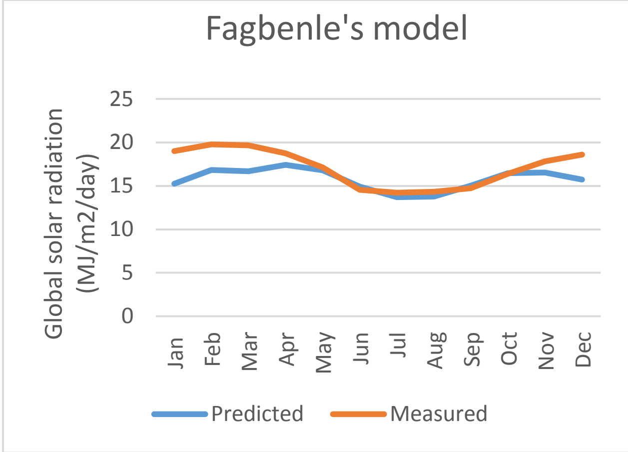

Fig. 3a(iii)

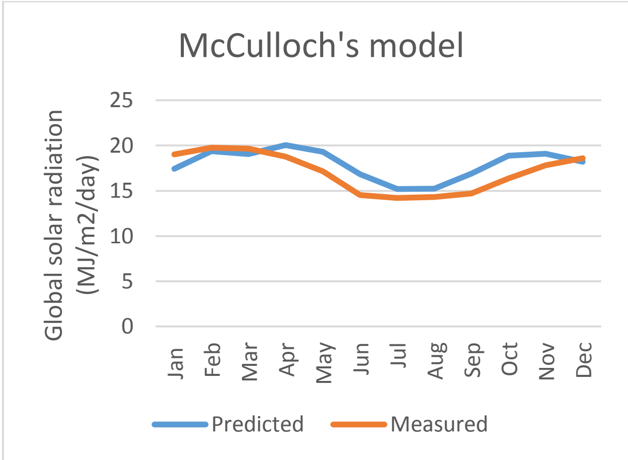

Fig. 3a(iv)

Figure 3a (i -iv) **:** Comparison of the measured and predicted values of correlation equations

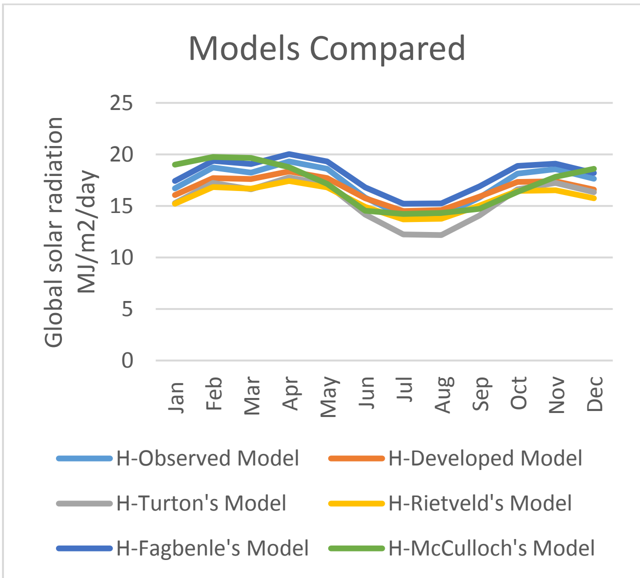

Fig. 3b: Comparison of the Measured and Predicted Values (From Different Models) of Monthly Average Daily Global Solar Radiation.

Table 3: Statistical test results of models applied for Lagos

MODELS	MBE	RMSE	MPE	R	R^2
Turton	-0.4573	1.4721	1.8856	0.82	0.67
Rietvield	-1.5104	1.9429	8.623	0.75	0.56
Fagbenle	-1.3200	1.9235	7.0007	0.81	0.66
McCulloch	0.8837	1.5575	-5.8436	0.70	0.49
Developed	0.017	0.060	-0.008	0.845	0.714

From Table 3, the MBE values obtained from the models are positive in some cases and negative in others, which show that these models vary between under and over estimate of global solar radiation. However, values of MBE from most of the models (Turton, Rietvield, and Fagbenle) indicate an underestimation while that from McCulloch's gives serious overestimation and our model only has very little overestimation. The RMSE values, which are a measure of the accuracy of estimation, have been found to be approximately the lowest for our model (0.060), as shown in Table 3. The transmissivity of the atmosphere for global solar radiation under perfectly clear sky conditions is given as the sum of the regression coefficients a+b[4]. Also, the transmissivity of an overcast atmosphere is interpreted as the intercept a. Hence, the need to compare our regression relation with others in terms of the atmospheric transmissivity value. From our regression constants (a = 0.2302 and b = 0.5961), it is observed that the atmospheric transmissivity under clear skies for Lagos is 0.82.

Lagos, like most towns of West Africa, experiences two major weaker regimes in a year, namely the dry and wet seasons (Anonymous, 2012). During the dry season (January, February, March, October, November, December), the prevailing winds are dry and dust laden north-east trades (locally called harmattan) blowing from the Sahara desert. In the wet season (April, May, June, July, August, September), the moist south-west monsoon winds blow inland from the Atlantic Ocean. These sea borne winds influence the available solar radiation in the location in several ways amongst which are: They are heavily moisture laden most of the time, thus giving rise to precipitation almost all the year round. This invariably limits the number of days of clear sky. The moisture laden atmosphere is highly humid leading to cloud formation and subsequent extinction of solar radiation. The sea sprays and wind contribute in carrying fine droplets containing sodium chloride salts, dissolved organic compounds and other organic matter resulting in high turbidities within the locality of Lagos (Chendo, et al., 1994; Reindl et al., 1990).

4. CONCLUSION

The monthly mean daily global solar radiation and fraction of sunshine hours have been employed in this study to develop correlation equation using SPSS computer software program. It was observed that the equation $\frac{\overline{H}}{\overline{H}_o} = 0.2302 + 0.5961\left(\frac{\overline{n}}{\overline{N}}\right)$ has the highest value of correlation coefficient and coefficient of determination for Lagos and gives good results when considering statistical indicators like MBE, RMSE, and MPE. Good agreement has been found between measured values and calculated values using the above equation. This equation is therefore recommended for estimating global solar radiation in Lagos using sunshine hours.

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