

Correlation Between Sunshine Hours and Global Solar Radiation in Warri, 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 Warri, Nigeria:
$$\frac{\bar{H}}{\bar{H}_0} = 0.29 + 0.42 \frac{\bar{n}}{\bar{N}}$$

where \bar{H}_0 is the monthly mean extraterrestrial solar radiation, \bar{n} is the monthly mean daily number of hours of bright sunshine, and \bar{N} is the maximum possible monthly mean daily sunshine.

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 maximum and minimum values of the monthly mean daily global solar radiation on a horizontal surface are $15.98 \text{MJm}^{-2}\text{day}^{-1}$ and $12.19 \text{MJm}^{-2}\text{day}^{-1}$, respectively. The model could be employed in estimating global solar radiation of location that has the same geographical location information as Warri.

(Keywords: sunshine duration, clearness index, solar radiation)

INTRODUCTION

The solar radiation received at a particular location on the Earth's surface must be known in order to evaluate the performance of any solar system at a given location. This energy depends on two main factors, namely the extraterrestrial solar irradiance and the state of the atmosphere.

The extraterrestrial solar irradiance is the rate at which solar energy arrives on a horizontal surface at the top of the atmosphere. It varies according to the latitude of the location, the distance of the

Earth from the Sun, and the time of the year. On any particular day, it varies from zero at sunrise to a maximum at noon and back zero at sunset (Liou, 1980).

When solar radiation enters the atmosphere, a part of the incident energy is removed through the processes of scattering, absorption, and reflection. The scattering of solar radiation is mainly by atmospheric molecules and aerosols. The absorption of solar radiation is mainly by ozone, water vapor, oxygen, carbon (IV) oxide, as well as clouds.

The reflection of solar radiation is mainly by clouds and this plays an overriding part in reducing the energy density of the solar radiation reaching the surface of the Earth (Exell, 2000).

The encounter of solar radiation particularly with clouds lead to the variation in intensity of sunshine and the number of sunshine hours at the ground surface. The variation, however, is not due only to the clouds but also to the angle of incidence of the Sun's rays with the ground surface and its azimuth (Babatunde, 1988). These in turn, are due to the rotation of the Earth around the Sun and the inclination of its axis with the plane of its orbit round the Sun. The results is the variation in the number of hours of sunshine and its intensity on the Earth's surface.

The variation is from latitude to latitude. Thus, a solar radiation measurement parameter is obtained and defined as the ratio of the actual number of hours of sunshine received at a site to the number possible in the day i.e the length of the day. The ratio is know as fraction of sunshine

hours, $\frac{\bar{n}}{\bar{N}}$. It is found to vary daily and seasonally (Igbal, 1979) and (Shears et al., 1981).

Ideally, the best solar radiation information is that obtained from experimental measurements of the global and diffuse components of the solar insolation at the location in question. However, due to very few locations conducting such measurements and the high cost of solar radiation measuring devices, efforts are made to develop various models for the prediction of solar radiation at all sites of interest.

Several researchers have used one or more meteorological data to estimate global solar radiation on horizontal surface. Akpabio and Etuk (2002) have developed a multiple linear regression model with ten variables to estimate the monthly average daily global solar radiation for Onne. Okogbue, and Adedokun (2002) developed modified models for estimating global solar radiation with meteorological data from 24 stations in Nigeria. Chandel et al. (2005) developed a new correlation to estimate the monthly average global solar radiation on horizontal surface using the sunshine hour and

temperature data. Falayi and Rabi (2005) used sunshine duration data to estimate global solar radiation.

This work aims at proposing a model that can correlate sunshine hours and global solar radiation for Warri, Nigeria.

MATERIALS AND METHODS

The monthly mean daily data for sunshine hours were collected from the Nigerian Meteorological Agency, Federal Ministry of Aviation, Oshodi, Lagos, Nigeria. The global solar radiation data were collected courtesy of Renewable Energy for Rural Industrialization and Development in Nigeria. The data obtained covered a period of seventeen years (1991 – 2007) for Warri, Nigeria (5.02°N, long 7.88°E). The monthly averages data processed in preparation for the correlation are presented in Table 1.

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

MONTH	\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	4.72	11.74	0.4020	11.02	34.21	0.3221
FEB	4.80	11.65	0.4120	12.55	35.06	0.3579
MAR	4.61	11.34	0.4066	13.76	37.72	0.3648
APR	4.92	11.24	0.4377	15.94	36.48	0.4369
MAY	4.89	12.34	0.3963	11.30	36.22	0.3119
JUN	3.86	12.86	0.3002	12.31	34.13	0.3607
JUL	2.27	11.32	0.2005	12.91	35.81	0.3605
AUG	2.31	11.42	0.2289	12.19	35.05	0.3478
SEPT	2.57	11.23	0.2289	13.55	36.26	0.3737
OCT	4.15	11.21	0.3702	14.56	36.68	0.3969
NOV	5.23	11.43	0.4952	13.91	34.58	0.4023
DEC	5.66	11.26	0.4645	15.98	32.49	0.4918

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

There are several types of empirical formulae for predicting the monthly mean daily global solar radiation as a function of readily measured climatic data (Iqbal, 1983; Sayigh, 1977; Klien, 1977). Among the existing correlations, the simplest being the Angstrom–Prescott regression equation, which relates the monthly mean daily global solar radiation to the number of hours of bright sunshine. In addition to its simplicity, it has also been found to a great extent, to predict global solar radiation in several locations (De Carlo, 1986). The equation is of the form:

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

where \overline{H}_M is the measured monthly mean daily global solar radiation on a horizontal surface, \overline{n} is the monthly mean daily bright sunshine hours, \overline{N} is the maximum possible monthly mean daily sunshine ($\text{MJm}^{-2}\text{day}^{-1}$), \overline{H}_O is the monthly mean extraterrestrial solar radiation on horizontal surface ($\text{MJm}^{-2}\text{day}^{-1}$), \overline{n} is the monthly mean daily number of hours of possible sunshine, and a and b are regression constants whose significance will be discussed later.

The monthly mean daily extraterrestrial irradiation \overline{H}_O and monthly mean day length \overline{N} can be derived from the following formulae:

$$\overline{H}_O = \frac{24}{\pi} I_{sc} E_0 \left(\frac{\pi}{180} \omega_s \sin \phi \sin \delta + \cos \phi \cos \delta \sin \omega_s \right) \quad (2)$$

$$\overline{N} = \frac{2}{15} \text{Cos}^{-1}(-\tan \phi \tan \delta) \quad (3)$$

where δ is the solar angle of declination and is approximately given as:

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

I_{sc} is the solar constant ($4.921\text{MJm}^{-2}\text{day}^{-1}$), N is the characteristic day number, ϕ is the latitude angle and ω_s is the sunset hour angle given as:

$$\omega_s = \text{cos}^{-1}(-\tan \phi \tan \delta) \quad (5)$$

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 .

A close examination 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 5.66 hours and $15.98\text{MJm}^{-2}\text{day}^{-1}$, respectively, and they occur in the month of December. This value is within what is expected of a tropical site (Exell, 2000 and Okogbue and Adedokun, 2005).

The month of occurrence is not expected because of the harmattan season when aerosol mass loading greatly reduces the intensity of solar radiation (Babatunde, 2001 and Babatunde and Aro, 2000). However, it should be noted that insolation instrument records hours of bright sunshine when solar radiation flux density is above the threshold value of 210Wm^{-2} . Hence, during the month of November, a very high mean daily sunshine hours is obtained because it has a high clearness index.

Another point worthy of note is that the minimum values of the monthly mean daily sunshine hours and the monthly mean daily global radiation on a horizontal surface are 2.31 hours and $12.19\text{MJm}^{-2}\text{day}^{-1}$, respectively, and they occur in the month of August. Again this value is within what is expected of a tropical site (Exell, 2000 and Okogbue and Adedokun, 2005).

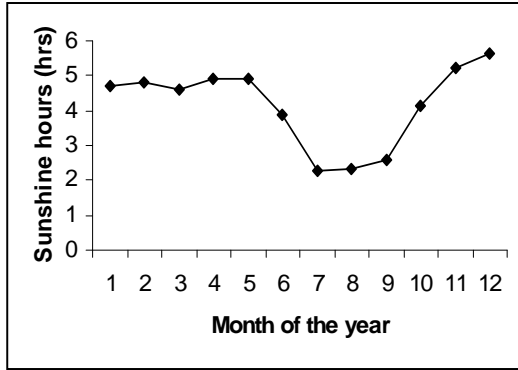


Figure 1: Monthly Variation of Sunshine Hours.

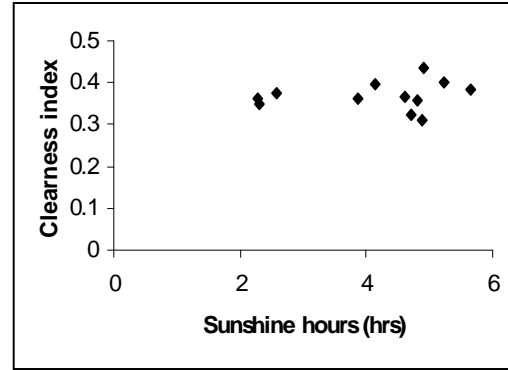


Figure 3: Scatter Diagram Showing Clearness Index and Sunshine Hours.

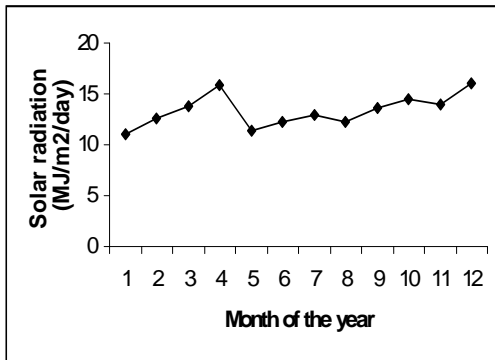


Figure 2: Monthly Variation of Solar Radiation.

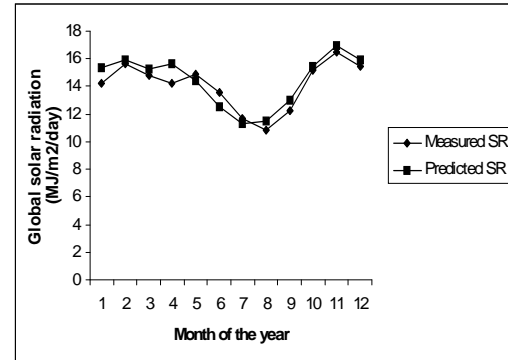


Figure 4: Comparison between Measured and Predicted Solar Radiation.

The month they occur is also well expected. This is the month that is characterized by heavy rainfalls. It is pertinent to state here that from the records of temperature made during the seventeen year period, August has the lowest monthly mean daily average temperature of 28.69°C .

Figure 3 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. The smaller the value, the greater the reduction in the magnitude of the extraterrestrial global solar radiation. Maximum attenuation occurred in August and minimum in December.

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:

$$\frac{\bar{H}}{H_0} = 0.29 + 0.42 \frac{\bar{n}}{N} \quad (6)$$

The values of the regression constants (0.29, 0.42) are in close agreement with those reported as average (0.3, 0.4) for the tropics. Similar results (0.28, 0.39) have also being obtained by Fagbenle (1990).

The sum of the regression coefficients (a+b) is interpreted as the transmissivity of the atmosphere for global solar radiation under perfectly clear sky conditions (Revfein, 1983). Similarly the intercept “a” is interpreted as the transmissivity of an overcast atmosphere. It is therefore important to examine the regression

relation we have developed and compare it with others in terms of the value of the atmospheric transmissivity under clear skies for Warri compares favorably with the figure of 0.6 -0.7 reported for the tropics (Turton, 1987). In general the clear sky transmissivity of most tropical regions seems to lie between 0.68 - 0.75 (Ibrahim, 1985; Turton, 1987; Abdalla, 1987; Sambo, 1986; Bakhah et al., and Iqbal, 1983).

Equation (6) has been used to predict the monthly mean daily global solar radiation on a horizontal surface from measured values of hours of sunshine. The data used in the estimation are given in Table 1.

The values of the correlation coefficient $R = 0.897$ and the coefficient of determination $R^2 = 0.795$ were also evaluated using SPSS computer program.

The value of $R(0.897)$ indicates that there is a high positive correlation between the measured monthly mean daily fraction of sunshine hours $\frac{\bar{n}}{\bar{N}}$ and the monthly mean daily clearness index \bar{K}_T and hence the monthly mean daily global solar radiation on a horizontal surface. Also, the value of $R^2(0.795)$ indicates that 79.5% of the variation in the monthly mean daily solar radiation on a horizontal surface \bar{H}_M can be explained by the model.

CONCLUSION

The main conclusion of the present work is that the monthly mean daily global irradiation incident on a horizontal surface in Warri, Nigeria may be estimated by the correlation equation:

$$\frac{\bar{H}}{\bar{H}_0} = 0.29 + 0.42 \frac{\bar{n}}{\bar{N}}$$

The maximum and minimum values of the global solar radiation are found to be $(15.98 \text{MJm}^{-2} \text{day}^{-1})$ and $(12.19 \text{MJm}^{-2} \text{day}^{-1})$, respectively. The correlation coefficient and coefficient of determination were also found to be (0.897) and (0.795) , respectively. The values of the global solar radiation estimated by the model were computed and a good agreement exist when considering the measured values.

This work gives further support to the suggestion by Turton that a single correlation $(\frac{H}{H_0} = 0.3 + 0.4 \frac{n}{N})$ be used to predict global solar radiation for all the tropics. Both the equation proposed by Turton, Folayan, and that developed in this work gives estimates that are close to each other.

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