Turk J Phys
27 (2003) , 161 – 167.


# Relationship Between Global Solar Radiation and Sunshine Duration for Onne, Nigeria

**Louis E. AKPABIO, Sunday E. ETUK**
*Department of Physics, University of Uyo, Uyo-NIGERIA*
*e-mail: sunetuk2002@yahoo.com*

Received 10.07.2002

**Abstract**

Measurements of global solar radiation and sunshine duration data during the period from 1984 to 1999 at Onne (within the rainforest climatic zone of southern Nigeria) were used to establish an Angstrom-type correlation equation. Five other commonly used correlations between global solar radiation and sunshine duration were also used to estimate global solar irradiation for Onne and their results are compared with our model. A good agreement (greater than 90% in most cases) was observed between the measured and the predicted values of our model.

**Key Words:** Global solar radiation, Sunshine duration, relationship.

## 1. Introduction

Knowledge of global solar radiation is essential in the prediction, study and design of the economic viability of systems which use solar energy. Information on global solar radiation received at any site (preferably gained over a long period) should be useful not only to the locality where the radiation data is collected but also for the wider world community [1]. A global study of the world distribution of global solar radiation requires knowledge of the radiation data in various countries and for the purpose of world wide marketing, the designers and manufacturers of solar equipment will need to know the average global solar radiation available in different and specific regions [2].

Obviously, measured data is the best form of this knowledge. Unfortunately, there are very few meteorological stations that measure global solar radiation, especially in developing countries. For such stations where no measured data are available, the common practice is to estimate global solar radiation from other measured meteorological parameters like relative sunshine duration.

There are several correlations available for such estimation in developing countries [3–8]. The objective leading to this paper is to continue in the effort to develop predictive techniques for as many regions as possible to provide a basis for future regional (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. The result of this correlation is also compared to the results of five other commonly used correlations.

## 2. Methodology

The global solar radiation and sunshine duration data reported in this paper were supplied by the IITA (International Institute of Tropical Agriculture) station of Onne, Nigeria, a high rainfall station located at latitude 4° 46'N, Longitude 7° 10' E with an altitude of 10 m.

The extraterrestrial solar radiation on a horizontal surface $H_\circ$ is a function only of Latitude and independent of other locational parameters. As the solar radiation passes through the earth's atmosphere, it is further modified by processes of scattering and absorption due to the presence of cloud and atmospheric particles. Hence, the daily global solar irradiation incident on a horizontal surface $H$ is very much location-specific and less than the extraterrestrial irradiation.

Various climatic parameters have been used in developing empirical relations for predicting the monthly average global solar radiation [1–9]. Among the existing correlations, the following relation is the generally accepted modified form of the Angstrom-type regression equation, relating the monthly average daily global radiation to the average daily sunshine hours [14]:

$$\frac{\overline{H}}{\overline{H}_\circ} = a + b\frac{\overline{S}}{\overline{S}_\circ} \tag{1}$$

Regression Equation (1) has been found to accurately predict global solar radiation in several locations [1–9]. Here, $\overline{H}$ is the monthly average daily global radiation on a horizontal surface (MJm$^{-2}$ day$^{-1}$), $\overline{H}_\circ$ is the monthly average daily extraterrestrial radiation on a horizontal surface (MJm$^{-2}$ day$^{-1}$), $\overline{S}$ is the monthly average daily number of hours of bright sunshine, $\overline{S}_\circ$ is the monthly average daily maximum number of hours of possible sunshine (or day length) and $a, b$ are regression constants to be determined.

The extraterrestrial solar radiation on a horizontal surface was calculated from the following equation [14]:

$$H_\circ = \frac{24 \times 3.6 \times 10^{-3} \times I_{SC}}{\pi}\left(1 + 0.033\cos\left(360\frac{\overline{D}}{365}\right)\right)\cos\phi\cos\delta\sin w + w\sin\phi\sin\delta, \tag{2}$$

where $\overline{D}$ is the Julian day number, $I_{SC} = 1367$ Wm$^{-2}$ is the solar constant, $\phi$ is the latitude of the location, $\delta$ is the declination angle given as

$$\delta = 23.45\sin\left(360\frac{248 + \overline{D}}{365}\right), \tag{3}$$

and $w$ is the sunset hour angle given as

$$w = \cos^{-1}(-\tan\phi\tan\delta). \tag{4}$$

The maximum possible sunshine duration $\overline{S}_\circ$ is given by [6,14]:

$$\overline{S}_\circ = \left(\frac{2}{15}\right)w. \tag{5}$$

In this paper, $\overline{H}_\circ$ and $\overline{S}_\circ$ were computed for each month by using Equations (2) and (5), respectively. The regression coefficients $a$ and $b$ in Equation (1) have been calculated from values of $\overline{H}/\overline{H}_\circ$ and $\overline{S}/\overline{S}_\circ$. The values of the monthly average daily global radiation $\overline{H}$ and the average number of hours of sunshine were obtained from daily measurements covering a period of 16 years. The method of least squares was used to obtain the constants $a$ and $b$ as follows [3]:

$$a = \frac{\sum\frac{\overline{H}}{\overline{H}_\circ}\sum\left(\frac{\overline{S}}{\overline{S}_\circ}\right)^2 - \sum\frac{\overline{S}}{\overline{S}_\circ}\sum\frac{\overline{S}}{\overline{S}_\circ}\frac{\overline{H}}{\overline{H}_\circ}}{M\sum\left(\frac{\overline{S}}{\overline{S}_\circ}\right)^2 - \left(\sum\frac{\overline{S}}{\overline{S}_\circ}\right)^2}, \tag{6a}$$

$$b = \frac{M \sum \frac{\overline{S}}{\overline{S}_\circ} \frac{\overline{H}}{\overline{H}_\circ} - \sum \frac{\overline{S}}{\overline{S}_\circ} \sum \frac{\overline{H}}{\overline{H}_\circ}}{M \sum \left(\frac{\overline{S}}{\overline{S}_\circ}\right)^2 - \left(\sum \frac{\overline{S}}{\overline{S}_\circ}\right)^2}, \tag{6b}$$

where $M$ is the number of data points.

To compute values of $\overline{H}_{\text{est}}$ (also known as estimated $\overline{H}$), the values of $a$ and $b$ were used in Equation (1). The deviation between the estimated and measured values was determined using the following statistical parameters [3]:

$$\text{Mean Bias Error, MBE (\%)} = 100\left(\frac{1}{\overline{H}_m}\right)\left(\sum \frac{E_i}{M}\right) \tag{7}$$

$$\text{Root Mean Square Error, RMSE (\%)} = 100\left(\frac{1}{\overline{H}_m}\right)\left(\sum \frac{E_i}{M}\right)^{0.5}, \tag{8}$$

where $E_i = H_{\text{estimated}} - H_{\text{measured}}$, $i = 1, 2 \ldots M$; $M$ was the total number of observation points and $\overline{H}_m$ was the arithmetic mean value of the $M$ measured values of the global solar radiation.

The correlation coefficients $r$ between estimated and measured radiation values was defined by:

$$r = \frac{\sum(\overline{H}_{\text{estimated}} - \overline{H}_e)(\overline{H}_{\text{measured}} - \overline{H}_m)}{\sqrt{(\sum(\overline{H}_{\text{estimated}} - \overline{H}_e)^2)(\sum(\overline{H}_{\text{measured}} - \overline{H}_m)^2)}}, \tag{9}$$

were $\overline{H}_e$ is the arithmetic mean value of the $m$ estimated values of the global solar radiation.

The result of our model was compared with five other previously reported models. The five models were:

Turton's model [4], which developed an average regression constants for the humid tropical countries as

$$\overline{H}/\overline{H}_\circ = 0.30 + 0.40(\overline{S}/\overline{S}_\circ).$$

Rietveld's model [9]: An interesting correlation which is believed to be applicable anywhere in the world:

$$\overline{H}/\overline{H}_\circ = 0.18 + 0.62(\overline{S}/\overline{S}_\circ).$$

Fagbenle's model: Akpabio [6] quoted a correlation developed by Fagbenle which was believed to be suitable for the rain forest climatic zone of Southern Nigeria (where Onne is situated) as

$$\overline{H}/\overline{H}_\circ = 0.28 + 0.39(\overline{S}/\overline{S}_\circ).$$

Fre're's model: This model is quoted by Nguyen [3] as

$$a = -0.27 + 1.75(\overline{S}/\overline{S}_\circ) - 1.34(\overline{S}/\overline{S}_\circ)^2$$

$$b = 1.32 - 2.90(\overline{S}/\overline{S}_\circ) + 2.30(\overline{S}/\overline{S}_\circ)^2.$$

McCulloch's model, which relates a correlation, model that takes into account the latitude effect as quoted by DeMiguel [12] via

$$\overline{H}/\overline{H}_\circ = 0.29\cos\phi + 0.52(\overline{S}/\overline{S}_\circ).$$

The five models listed above were applied to the sunshine data at Onne. The calculated and measured valued 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 as shown in Tables 1 and 2.

# 3. Results and Discussion

As can be seen in Table 1, Turton, Fagbenle and our model has the best correlation coefficient with $r =$ 0.80, while the McCulloch model has a correlation coefficient of $r = 0.79$ followed by Rietveld model with correlation coefficient $r = 0.75$; and the lowest correlation coefficient $r = 0.70$ is from Fre're's model. The accuracy of each model used in the estimation of global solar radiation was tested by calculating the mean bias errors (MBE%) and the root mean square errors (RMSE%) from Equations (7) and (8), respectively. It was observed that the lower the RMSE%, the more accurate the equation used. Positive MBE% shows over estimation and a negative MBE% shows under estimation.

**Table 1.** Statistical test results of models applied for Onne.

| Models | a | b | % MBE | % RMSE | r |
|---|---|---|---|---|---|
| Turton | 0.30 | 0.40 | 17.24 | 18.14 | 0.82 |
| Rietveld | 0.18 | 0.62 | 4.89 | 9.95 | 0.75 |
| Fagbenle | 0.28 | 0.39 | 12.49 | 13.79 | 0.81 |
| Fre're's | -0.27 + 1.75 $(\overline{S}/\overline{S}_o)$ -1.34 $(\overline{S}/\overline{S}_o)^2$ | 1.32 – 2.93 $(\overline{S}/\overline{S}_o)$ + 2.30 $(\overline{S}/\overline{S}_o)^2$ | -11.33 | 27.94 | 0.70 |
| McCulloch | 0.29 cos $\phi$ | 0.52 | 21.92 | 82.09 | 0.79 |
| Our Model | 0.23 | 0.38 | -1.04 | 8.26 | 0.80 |

From Table 1, the MBE% values obtained from the models are positive in some cases and negative in others, which shows that these models vary between under and over estimate of global solar radiation. However, values of MBE% from most of the models (Turton, Rietveld and Fagbenle) indicates an over estimation. While those from Fre're's model gives serious under estimation and our model only has very little under estimation. The RMSE% values, which are a measure of the accuracy of estimation, have been found to be the lowest for our model (8.26), as shown in Table.1

The transmissivity of the atmosphere for global solar radiation under perfectly clear sky conditions is given as the sum of the regression coefficients, $a + b$ [10]. 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 ($a = 0.23$ and $b = 0.38$), it is observed that the atmospheric transmissivity under clear skies for Onne is 0.61. This result compares well with the figure of 0.67 0.70 reported for the humid tropics [4]. The clear-sky transmissivity of most tropical regions in general seems to lie between 0.68 and 0.75 [1–8].

Furthermore, Table 2 shows the comparison between measured and estimated global solar radiation at Onne. Once again, this table indicates that our model is most suitable for the estimation of monthly average daily global radiation, from monthly average daily sunshine hours in the rain forest climatic zone of southern Nigeria as against what is given by Fagbenle. It is observed from the results that the percentage error between the measured and predicted values rarely exceeds 11% and, in general, is very low. Also from Table 2, the values of the clearness index $K_T$ for the atmosphere in Onne is partly cloudy throughout the year. Values of $K_T$ range from 0.30 to 0.40. This indicates that a large fraction of the global solar radiation is diffuse.

Figure 1 shows that in the overall average years (1984–1999), there were two maxima (major and minor) and two corresponding minima (major and minor). This idea of two maxima and minima has also been observed recently by Udo [13]. The major maximum occurred between February-April during the dry season (November–April) and the minor maximum occurred between November-December. In the rainy season (May-October), we have the major minima in the months July-August. While the minor minima was in the month of January due to the harmattan dust haze that covers the atmosphere at that period of the year [6,11].

The best month, April, with $H$ of 14.99 MJm$^{-2}$ contributed 10.0% and the worst month, August, with $H$ of 10.36 MJm$^{-2}$ contributed 6.9% of the annual total. The result also shows that global solar irradiation values for Onne in the rain forest climatic zone is between 10 and 15 MJm$^{-2}$. These values of irradiation were also reported for the extreme south of Nigeria [11].

Figure 1 also indicates the trend of global solar irradiation at Onne, with high values during the dry season. While minimum irradiation is obtained during the rainy season, as the rain bearing clouds pervade the sky.

**Table 2.** Comparison between measured and estimated values of H for Onne.

| Month | $\overline{H}_\circ$ (MJm$^{-2}$ day$^{-1}$) | $\overline{S}/\overline{S}_\circ$ | $\overline{H}$ (MJm$^{-2}$ day$^{-1}$) Measured | Calculated | $K_T = \overline{H}/\overline{H}_\circ$ | Error % |
|---|---|---|---|---|---|---|
| JANUARY | 34.52 | 0.342 | 11.23 | 12.43 | 0.325 | 10.69 |
| FEBRUARY | 36.37 | 0.397 | 14.10 | 13.85 | 0.388 | -1.77 |
| MARCH | 37.61 | 0.309 | 13.67 | 13.07 | 0.364 | -4.39 |
| APRIL | 37.42 | 0.331 | 14.99 | 13.31 | 0.401 | -11.21 |
| MAY | 36.09 | 0.340 | 13.82 | 12.96 | 0.383 | -6.22 |
| JUNE | 35.11 | 0.273 | 13.24 | 11.72 | 0.377 | -11.48 |
| JULY | 35.40 | 0.178 | 10.66 | 10.54 | 0.301 | -1.13 |
| AUGUST | 36.61 | 0.135 | 10.36 | 10.30 | 0.283 | -0.58 |
| SEPTEMBER | 37.30 | 0.219 | 11.36 | 11.68 | 0.305 | 2.82 |
| OCTOBER | 36.53 | 0.299 | 11.89 | 12.55 | 0.326 | 5.55 |
| NOVEMBER | 34.83 | 0.384 | 12.27 | 13.09 | 0.352 | 6.68 |
| DECEMBER | 33.81 | 0.375 | 12.08 | 12.59 | 0.357 | 4.22 |

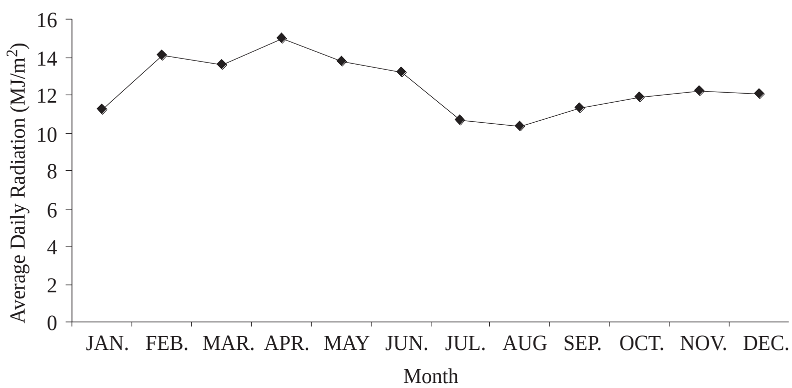


**Figure 1.** Monthly average daily global radiation (1984–1999).

As can be seen from Figure 2 the monthly variation of average daily sunshine duration is the same trend curve as that of global solar radiation. Hence, the explanation and reason will obviously be the same as that of Figure 1, due to the fact that sunshine duration has direct correlation with global solar radiation.

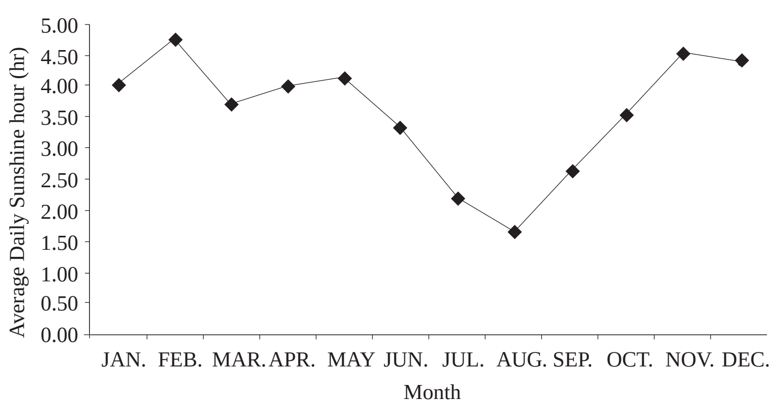


**Figure 2.** Monthly average daily sunshine duration (1984–1999).

Finally, considering the regression analysis, the following correlation (our model) was found to adequately fit the radiation data presented in Table 2. And this correlation can also be used in estimating global solar radiation for the rain forest climatic zone of Southern Nigeria:

$$\overline{H}/\overline{H}_\circ = 0.23 + 0.38(\overline{S}/\overline{S}_\circ).$$

# 4. Conclusion

The main conclusion of the present work is that the linear regression analysis of the global solar radiation and sunshine duration data by means of the least-squares technique gives our model to be the best correlation for the Onne location. Hence the monthly average daily global irradiation incident on horizontal surfaces in Onne, Nigeria, may be estimated by the correlation.

$$\overline{H}/\overline{H}_\circ = 0.23 + 0.38(\overline{S}/\overline{S}_\circ).$$

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) especially in the rain forest climatic zone of extreme southern Nigeria, as against what was suggested by Fagbenle [6].

The global solar radiation at Onne exhibits monthly and seasonal variation, with two maxima (major and minor) in February–April and November–December, respectively. While in the months of July–August and January, we have the minima (major and minor) variations, respectively.

This gives credence to two types of global solar radiation at the location. First, the high irradiation values in the dry season associated with long duration of sunshine hours (above 4 hours/day) and less cloudy skies. Second, the low irradiation values are in the rainy season (when the rain bearing clouds pervade the sky) associated with least sunshine hour (less than 2 hours/day).

# References

[1] J.G.M. Massaquoi, Global solar radiation in Sierra Leone (West Africa). Solar Wind Technol., 5, (1988), 281–283.

[2] S.M.A. Ibrahim, Predicted and measured global solar radiation in Egypt. Solar Energy 35, (1985), 185–188.

[3] B.T. Nguyen and T. L. Pryor, The relationship between global solar radiation and sunshine duration in Vietnam. Renewable Energy, II, (1997), 47–60.

[4] S.M. Turton, the relationship between total irradiation and sunshine duration in the humid tropics. Solar energy, 38, (1987), 353–354.

[5] Y.A.G. Abdalla and M.K. Baghdady, global and diffuse radiation in Doha (Qotar), Solar Wind Technol., 2, (1985), 209-212.

[6] L.E. Akpabio, Comparison between solar radiation energy and the characteristic of Wind power calculations in South eastern Nigeria. Nig. J. Phys., 4, (1992), 15–20.

[7] M.B. Sukhara, A.R. Pasha and M.S. Naveed, Solar radiation over Pakistan-Comparison of measured and Predicted data. Solar Wind Technol., 3, (1986), 219–221.

[8] A.S. Sambo, empirical models for the correlation of global solar radiation with meterological data for Northern Nigeria. Solar Wind Technol., 3, (1986), 89–93.

[9] M.R. Rietveld, A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine Agricultural Meteorology, 19, (1978), 243–252.

[10] K.J.A. Revfeim, An interpretation of the coefficients of the Angstrom equation. Solar Energy, 31, (1983), 415.

[11] C.I. Ezekwe, The solar radiation climate of Nigeria. Solar Wind Technol., 5, (1988), 563–571.

[12] A. DeMiguel, J. Bilbao, S. Salson and A. Lage. Solar radiation and Sunshine hour maps in Castilla and Leon region (Spain). Renewable Energy. 4, (1994), 933–940.

[13] S.O. Udo and T.O. Aro. Measurement of global solar, global photosynthetically-active and downward infrared radiation at Ilorin, Nigeria. Renewable Energy 17, (1999) 113–122.

[14] J.A. Duffie and W.A. Beckman, Solar Engineering of thermal Processes, $2^{nd}$ Edn. John Wiley, New York (1994).