 ISSN: 2321-8169
62 – 67

# Estimation of Global Solar Radiation in Ibadan, Nigeria using Angstrom - Prescott and Glover - Mcculloch's Model

Adeola S.O, Aro T. O And Akinpelu J.A,
Department of Physics and Solar Energy Bowen University, Iwo, Osun State, Nigeria.

***Abstract:-*** In this study, the data of mean daily bright sunshine hour for Ibadan was obtained from the International Institute of Tropical Agriculture (IITA) at Ibadan. It was used to estimate the monthly mean global solar radiation for Ibadan (latitude $7.3775^0 N$ and longitude $3.9470^0 E$). The data considered were for a period of 2008 to 2012. Angstrom-Prescott, and Glover & McCulloch's Models were then used to estimate the mean monthly global solar radiation at Ibadan based on the monthly mean bright sunshine hour data of Ibadan.

A new sunshine based model is also proposed to estimate global solar radiation at Ibadan for a period of five years (2008 – 2012). The performance of the models are evaluated by some statistical analysis like mean bias errors, root mean square error, mean percentage error, Nash-Sutcliffe error and coefficient of correlation in order to know the most suitable model.

It was discovered that the month of August is the least amount of measured global solar radiation averaged for five years (2008 – 2012) at Ibadan is 9.77kW/m$^2$. The most suitable model for Ibadan is Model 2 (Glover & McCulloch's Model).

The results obtained were validated with data of monthly mean global solar radiation data for Ibadan, obtained from the International Institute of Tropical Agriculture, Ibadan

***Keywords:*** *Global solar radiation, Clearness index, Extraterrestrial radiation.*

*****

## I. INTRODUCTION

Solar radiation has been identified as the largest renewable energy resource on earth. The energy source is more evenly distributed in the sunbelt of the World than wind or biomass, allowing for more site locations (Muller, 2003). The maximum intensity of solar radiation at the earth's surface is about 1.2 kW/m$^2$ but it is encountered only near the equator on clear days at noon. Under these ideal conditions the total energy received is from 6 - 8 kWh/m$^2$ per day (Halacy, 1980; Androsky, 1973 and Spillman, 1979). Solar energy is not available continuously because of the day/night cycle and cloud cover and its intensity varies according to season, geographical location, and position of the collector (Abdulrahim, et al., 2011).

The encounter of solar radiation, particularly with clouds leads 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 result is the variation in the number of hours of sunshine and its intensity on the earth's surface.

The amount of solar radiation which reaches the earth's surface varies from one place to another owing to the attenuation properties of the atmosphere and the diverse geographical characteristics of the earth's surface. Hence detailed study of solar radiation under local climate conditions is essential. There are many locations in the world where there are lack of measuring instruments for solar radiation. Even some of those existing instruments are out of use for lack of sustainability. In such a situation, knowledge of intensity of solar radiation at a given location is acquired through theoretical techniques (Tamirat, 2007).

## II. METHODOLOGY

The data used for these study were obtained from the International Institute of Tropical Agriculture

(IITA) Ibadan. The data covered the period of five (5) years from 2008 to 2012 of daily data of sunshine duration and solar radiation at Ibadan.

In this study, two models were used to estimate monthly mean values of global solar radiation. MatLab tool and Microsoft Excel was used for the data analysis The two models used are as presented in Table 1.

**Table 1: Sunshine based models used in the study**

| Model no | Regression | Source |
|---|---|---|
| 1 | $\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right)$ | Angstrom-Prescott (1940) |
| 2 | $\frac{H}{H_0} = a\cos\varphi + b\left(\frac{S}{S_0}\right)$ | Glover & McCulloch (1958) |

$H$ is daily mean values of global radiation (MJ/m$^2$day), $S_0$ is the daily average value of day length, S is the number of bright sunshine hour and 'a' and 'b' values are known as Angstrom constants and they are empirical. $H_0$ is daily mean values of extraterrestrial radiation (MJ/m$^2$day), calculated using Eq. (1) as described by (Prescott, 1940, Togrul, 2009); Medugu and Yakubu, 2011):

$$H_0 = \left(\frac{24\times3600}{\pi}\right) I_{SC} E_0 \left[\cos(\varphi)\cos(\delta)\sin(\omega_s) + \frac{\pi\omega_s}{180}\sin(\varphi)\sin(\delta)\right] \tag{1}$$

$$I_{SC} = \frac{1367\times3600}{1000000} MJm^{-2}hour^{-1} = 1.367 MJm^{-2}hour^{-1} \tag{2}$$

is the solar constant,

$E_0$ represents the eccentricity correction, and described using Eq. (3) in Eq. (1)

$$E_0 = 1 + 0.033\cos\left(\frac{360 n_d}{365}\right) \tag{3}$$

$n_d$ is the day number of the year /Julian day (1 Jan, $n_d$ = 1 and 31st December, $n_d$ = 365), $\varphi$ is the latitude of the site, $\delta$ the solar declination and, $\omega_s$, the mean sunset hour angle for the given month. The solar declination ($\delta$) and the mean sunset hour angle ($\omega_s$) can be calculated as suggested by (Duffie and Beckman (1991):

$$\delta = 23.45\sin\left[360\left(\frac{284+n_d}{365}\right)\right] \tag{4}$$

And

$$\omega_s = \cos^{-1}\left(-\tan\varphi\tan\delta\right) \tag{5}$$

For a given day, the maximum possible sunshine duration (monthly values of day length, ( $S_0$ ) can be computed by using (Duffie and Beckman, 1991):

$$S_0 = \frac{2}{15}\omega_s \tag{6}$$

The constants a and b in table 1 are regression coefficients given as:

$$a = -0.110 + 0.235\cos(\varphi) + 0.323\left(\frac{S}{S_0}\right) \tag{7}$$

ISSN: 2321-8169
62 – 67

$$b = 1.449 - 0.553(\varphi) - 0.694\left(\frac{S}{S_0}\right) \tag{8}$$

To compute estimated values of daily mean global solar radiation (*H*), the values of a and b computed from equations 7 and 8 were used for the models in Table 1.

The daily mean value of global solar radiation (*H*) was normalized by dividing with daily mean values of extraterrestrial radiation ($H_0$). Clearness index ($K_t$) can be defined as the ratio of the values of the monthly mean global radiation *H*, to the calculated/predicted horizontal/extraterrestrial solar radiation ($H_0$) (Falayi *et al*., 2011).

$$K_t = \frac{H}{H_0} \tag{9}$$

In this study, $H_0$ and $S_0$ were computed for each day in a month by using Equations 1 and 6, respectively.

## III. RESULTS AND DISCUSSIONS

Table 2 presents mean relative sunshine hour, estimated clearness index and measured Clearness index ($K_{tm}$) over 2008-2012 and and Figure 1 presents comparison of mean actual and estimated Clearness index over 2008 -2012 ; Table 3 presents estimated and measured global solar radiation ($H_m$) and sunshine hour (*S*) averaged over (2008 - 2012) ; Figure 2 shows Monthly variations of measured and estimated global solar radiation and sunshine hour (*S* averaged over 2008 – 2012

From Table 2 and Figure 1, the maximum measured clearness index ($K_{tm}$) of value 0.43 occurred in March which indicates partly cloudy sky and the relative sunshine hour for the month of September which is of value 0.51 suggest scattered clouds sky for March, the month of March has the highest clearness index value which is responsible for the maximum amount of measured global solar radiation of value 16.00 kW/m$^2$ occurring in March as shown in Table 3 and Figure 2, while the minimum measured clearness index of value of 0.26 occurred in August which indicates overcast sky for August and the relative sunshine hour for the month of August which is of value 0.23 suggest cloudy sky for August. Hence the month of August is characterized by overcast and cloudy sky condition which is responsible for August having the least amount of measured global solar radiation of value 9.77 kW/m$^2$ as shown in Table 3 and Figure 2.

Using Model 1, Table 2 and Figure 1, shows the maximum estimated clearness index of value 0.618 occurred in December which indicate partly cloudy sky, the month of December has the maximum estimated clearness index value but the maximum amount of estimated global solar radiation of value 20.50 kW/m$^2$ occurred in April as shown in Table 3 and Figure 2, while the minimum estimated clearness index of value of 0.32 occurred in August which indicates overcast sky for August. Hence the month of August is characterized by overcast sky which is responsible for August having the least amount of estimated global solar radiation of value 12.10 kW/m$^2$ as shown in Table 3 and Figure 2.

Figures 1 and 2, shows the lines representing the estimated values of clearness index and global solar radiation for Model 1 are above the lines representing the estimated values of clearness index and global solar radiation. This implies that Model 1 gave overestimation of the measured clearness index values and measured global solar radiation values.

Model 2 presents Table 2 and Figure 1, with the maximum estimated clearness index of value 0.47 occurred in December which indicates partly cloudy sky, the month of December has the maximum estimated clearness index value which is responsible for the maximum amount of estimated global solar radiation of value 15.25 kW/m$^2$ occurring in December as shown in Table 3 and Figure 2, while the minimum estimated clearness index of value of 0.23 occurred in August which indicates overcast sky for August. Hence, the month of August is characterized by overcast sky which is responsible for August having the least amount of estimated global solar radiation of value 8.88 kW/m$^2$ as shown in Table 3 and Figure 2. Information from Figures 1 and 2 imply that Model 2 (Glover and McCulloch's model) is the best suitable model for estimation of global solar radiation at Ibadan.

From Figures 1 and 2, the lines representing the estimated values of clearness index and global solar radiation for Model 2 intercepts the lines representing the measured values of clearness index and global solar radiation at different points. This implies that Model 2 gave overestimation and underestimation of the measured clearness index values and measured global solar radiation values.

**Table 2:** Relative Sunshine hour, estimated clearness index and measured Clearness index ($K_{tm}$) at Ibadan averaged over 2008-2012

| IBADAN | | | | | | | |
|---|---|---|---|---|---|---|---|
| MONTH | $S/S_o$ | $K_t$ MODEL 1 | $K_t$ MODEL 2 | $K_t$ MODEL 3 | $K_t$ MODEL 4 | $K_t$ MODEL 5 | $K_{tm}$ |
| JANU/ | 0.608439 | 0.59344 | 0.453919 | 0.580799 | 0.27221 | 0.32526 | 0.361711 |
| FEBRUARY | 0.597818 | 0.560522 | 0.42306 | 0.550148 | 0.266595 | 0.31085 | 0.405066 |
| MARCH | 0.517692 | 0.513152 | 0.386242 | 0.570951 | 0.240833 | 0.26952 | 0.430199 |
| APRIL | 0.547098 | 0.544428 | 0.413876 | 0.522671 | 0.248692 | 0.270812 | 0.419639 |
| MAY | 0.542735 | 0.541106 | 0.412018 | 0.522203 | 0.247051 | 0.258846 | 0.42448 |
| JUNE | 0.535482 | 0.539404 | 0.410809 | 0.513172 | 0.245843 | 0.259 | 0.407849 |
| JULY | 0.352448 | 0.423411 | 0.319778 | 0.382917 | 0.176306 | 0.172553 | 0.328803 |
| AUGUST | 0.231591 | 0.326048 | 0.239327 | 0.288828 | 0.129487 | 0.118703 | 0.263498 |
| SEPT | 0.300427 | 0.377744 | 0.283402 | 0.385339 | 0.16227 | 0.162105 | 0.375229 |
| OCTOBER | 0.481425 | 0.487603 | 0.363747 | 0.521325 | 0.22834 | 0.250881 | 0.38625 |
| NOVEMBER | 0.642533 | 0.599259 | 0.455175 | 0.597398 | 0.284933 | 0.335968 | 0.416186 |
| DECEMBER | 0.670193 | 0.618614 | 0.471767 | 0.602123 | 0.293138 | 0.348673 | 0.364504 |

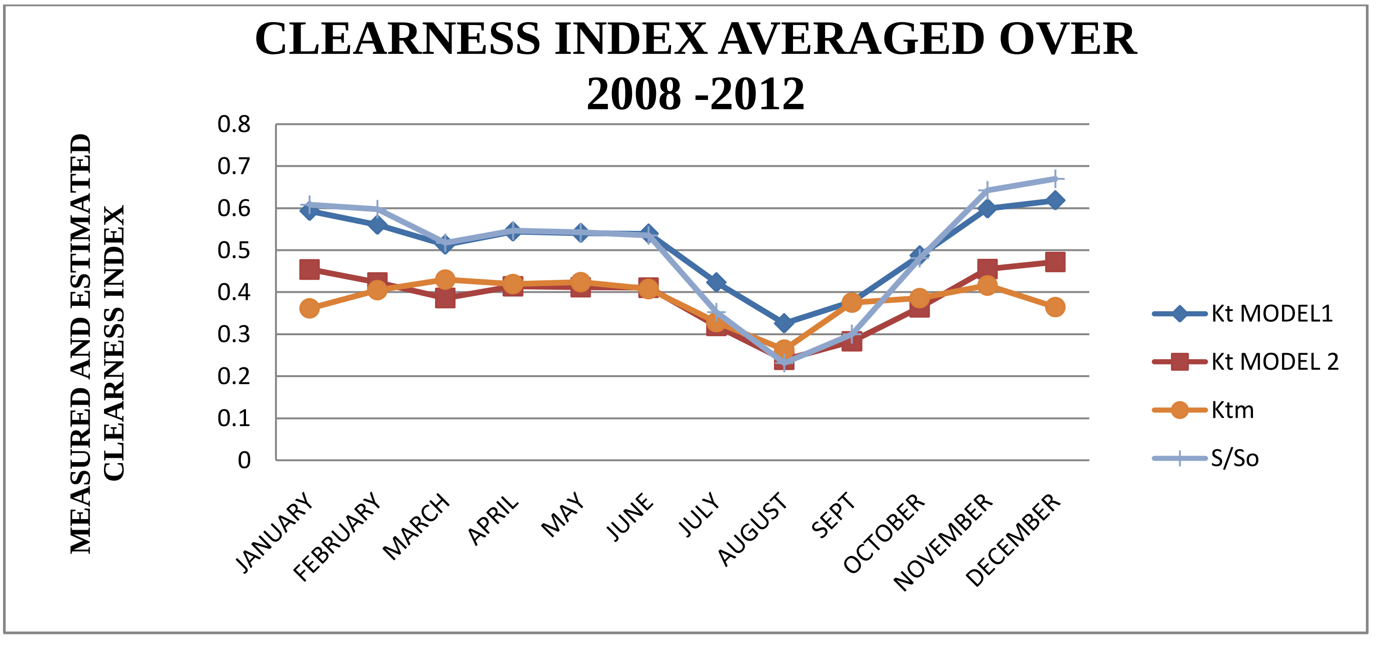


**Figure 1**: Monthly variations of Relative sunshine hour estimated clearness index and measured clearness index ($K_{tm}$) at Ibadan averaged over 2008 – 2012

**Table 3**: Estimated and measured global solar radiation ($H_m$) and sunshine hour ($S$) at Ibadan averaged over (2008 - 2012)

| MONTH 2008-2012 | $S$ (h) | $a$ | $b$ | $Ho$ (kW/m$^2$) | MODEL 1 (kW/m$^2$) | MODEL 2 (kW/m$^2$) | $H_m$ (kW/m$^2$) |
|---|---|---|---|---|---|---|---|
| JANUARY | 7.0720 | 0.32150 | 0.3626 | 33.1693 | 19.6840 | 15.0562 | 11.9977 |
| FEBRUARY | 6.8629 | 0.3180 | 0.3711 | 35.3103 | 19.7922 | 14.9383 | 14.3030 |
| MARCH | 6.1888 | 0.2921 | 0.3388 | 37.1968 | 19.0876 | 14.3669 | 16.0020 |
| APRIL | 6.6582 | 0.3016 | 0.3204 | 37.6549 | 20.5004 | 15.5844 | 15.8014 |
| MAY | 6.6951 | 0.3002 | 0.3326 | 36.864 | 19.9473 | 15.1886 | 15.6480 |
| JUNE | 6.6515 | 0.2979 | 0.2976 | 36.1346 | 19.4911 | 14.8444 | 14.7374 |
| JULY | 4.3649 | 0.2388 | 0.2890 | 36.3536 | 15.3925 | 11.6251 | 11.9532 |
| AUGUST | 2.8314 | 0.1997 | 0.3197 | 37.1119 | 12.1002 | 8.8818 | 9.77892 |
| SEPT | 3.6118 | 0.2220 | 0.3430 | 37.1148 | 14.0199 | 10.5184 | 13.9265 |
| OCTOBER | 5.6901 | 0.2804 | 0.3314 | 35.6447 | 17.3805 | 12.9656 | 13.7677 |
| NOVEMBER | 7.5417 | 0.3325 | 0.3711 | 33.4989 | 20.0745 | 15.2478 | 13.9418 |
| DECEMBER | 7.7593 | 0.3414 | 0.3602 | 32.3449 | 20.0090 | 15.2592 | 11.7898 |

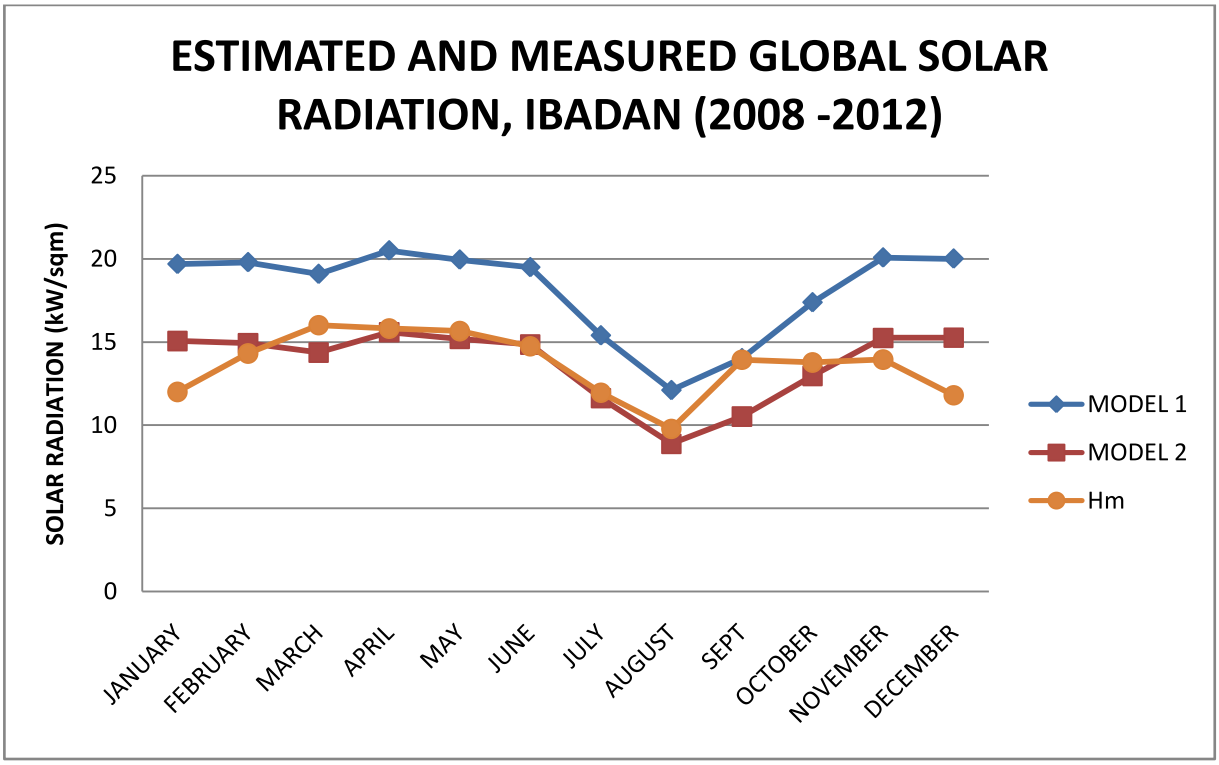


**Figure 2:** Monthly variations of measured and estimated global solar radiation and sunshine hour ($S$) at Ibadan averaged over 2008 – 2012

To assess the performance of the model equations, six statistical tests have been employed. These are the correlation coefficient (R), mean bias error (MBE) and the root mean square error (RMSE), mean percentage error, coefficient of determination ($R^2$), T test. Table 4 presents the results of the statistical test for the Model

ISSN: 2321-8169
62 – 67

**Table 4: Statistical Test for the Models**

| | MBE | RMSE | MPE | NSE(R - SQUARED) | R | T TEST |
|---|---|---|---|---|---|---|
| MODEL 1 | 4.483395 | 12.58059 | 0.382091 | -1.24258 | 0.071375 | 14.55354 |
| MODEL 2 | 0.069017 | 11.2467 | 0.041572 | -0.79224 | 0.062922 | 0.252982 |

## IV. CONCLUSION

In order to design solar energy systems, it is important to know the least amount of solar radiation reaching the solar collectors at the location of interest, and use this least amount of solar radiation to do calculations required to design the system, also important to know is the average number of bright sunshine hour for solar energy system design at a location of interest. For Ibadan, the average number of bright sunshine hour is six (6) hours.

For an averaged period (2008-2012) at Ibadan, Table 3 shows that the least amount of measured global solar radiation available at Ibadan is 9.77 kW/m$^2$ so for the estimation of global solar radiation at Ibadan, the best suitable model for Ibadan is Model 2 because they gave estimations that are lesser than the least amount of the actual measured global solar radiation, Model 2 had a lesser value of 8.88 kW/m$^2$. It is therefore better to use 8.88kW/m$^2$ as the available solar radiation for Ibadan when designing solar energy systems in Ibadan. Using an estimated amount of global solar radiation solar radiation that is lesser than the measured amount of global solar radiation in solar energy systems design will have an implication on the cost of installation, it will increase the cost.

Model 2 performed excellently well than Model 1 for Ibadan. Model 2 is hereby recommended for solar energy system designs.

## REFERENCES

[1] Abdulrahim, A.T., Diso I.S., El-Jummah A.M., (2011). Solar Concentrators' Developments in Nigeria: A Review. Continental Journal of Engineering Sciences, 6(3), 30-37.
[2] Androsky A., (1973). Uses of the Sun in the Service of Man. Aerospace Corporation El Segundo, CA, Report No: ATR –74 – (9470) .
[3] Babatunde E.B., (1988). Solar Radiation Modeling for a Tropical Station, Ilorin, Nigeria. Ph.D. thesis pp. 32-34.
[4] Donald C.A., (1982). Meteorology Today: An Introduction to Weather, Climate and the Environment. West Publishing Co.
[5] Duffie, J.A. and Beckman, W.A., (1991). Solar Engineering of Thermal Processes, 3rd edition. John Wiley and Sons, New York.
[6] Exell R.H.B., (2000). The Intensity of Solar Radiation. King Mongkut's University of Technology Press: Thonburi, Thailand.
[7] Falayi E.O., Rabiu A.B. and Teliat R.O., (2011). Correlations to Estimate Monthly mean of daily diffuse solar radiation in some selected cities in Nigeria. Advances in Applied Science Research 2(4): 480-490.
[8] Gairaa K, Bakelli Y, (2011). International Journal Of Energy And Environment, 2(2), 255-260.
[9] Glover J., McCulloch J.S. 1958. The empirical relation between solar radiation and hours of sunshine, Journal of Royal Meteorological Society, 84, 172–175.
[10] Halacy D.S., (1980). Engineering Fundamentals, New York.
[11] Medugu D.W. and Yakubu D., (2011). Estimation of Mean Monthly Global Solar Radiation in Yola (Nigeria) using Angstrom Model. Advances in Applied Science Research, 2 (2): 414-421.
[12] Muller- Steinhagen H., (2003). A Vision for Sustainable Electricity Generation, Namrata, K., Sharma, S.P. and Saksena, S.B.L., 2012: Comparison of Estimated Daily Global Solar Radiation Using Different Empirical Models. International Journal of Science and Advanced Technology (ISSN 2221-8386), Vol. 2, No 4.
[13] Spillman C.K., Robbins F.V, Hines R.H, (1979): Kansas State University, Manhattan, KS.
[14] Tamirat B., (2007). Comparative Analysis of Feasibility of Solar PV, Wind and Micro Hydro power Generation for Rural Electrification in the Selected Sites of Ethiopia.
[15] Torgrul I., 2009: "Estimation of Solar Radiation from Angstroms Coefficients by Using Geographical and Meteorological Data in Bishkek, Kyrgyzstan. "Journal of Thermal Science and technology. 29 (2): 99-108.