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# Estimation of Global Solar Radiation from Monthly Mean Sunshine Hour Data in Some Cities in South Eastern Zone of Nigeria

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## Abstract

In this work, meteoroloogical data for Awka (6.207° N, 7.068° E), Enugu (6.452° N, 7.510° E) and Owerri (5.485° N, 7.036° E) in south eastern Nigeria, for the period of 11 years (2000 – 2010) were used to derive Angstrom type regression equations used for estimation of global solar radiation incident on a horizontal surface in the cities studied. In other to evaluate the significance of the results, three statistical methods have been used for the purpose. The three error formulae are; Mean Bais Error (MBE), Mean Percentage Error (MPE) and Root Mean Square Error (RMSE). The results shows that sunshine based model can be used for estimating global solar radiation in south eastern Nigeria.

## Keywords

Solar Energy, Global Solar Radiation, Sunshine Hours

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## 1. Introduction

The environmental concerns about fossil fuels and their constraints along with energy security concerns led to significant interest in using of renewable sources of energy such as wind and solar energy. The renewable energies are almost inexhaustible and provided from the energy of the sun affecting the earth, which include solar, wind, ocean currents, ocean waves, and ocean thermal energy [1]. [2] noted that the energy transferred from the sun in the form of radiant energy to the earth's surface is called solar radiation. Solar radiation is used in agriculture for crop drying, electricity generation, house heating, and water heating. It is this energy that allows life to flourish. Sunlight determines the rate of photosynthesis in plants and strongly regulates the amount of evaporation from the oceans. It warms the planet and gives us our everyday wind and weather. Without the sun's radiant energy, the earth would gradually cool, in time becoming encased in a layer of ice.

The design and operation of any solar energy system requires a good knowledge of the solar radiation data in a location. Solar radiation passing through the atmosphere to the ground surface is known to be depleted through scattering, reflection and absorption by the atmospheric constituents like air molecules, water vapour, ozone and the clouds [3]. The reflection of solar radiation is mainly by clouds and this plays an overriding part in reducing the energy density of solar radiation reaching the earth surface. Measured values of solar radiation can be in the form of global solar radiation, direct solar radiation, reflected solar radiation and diffused solar radiation.

Global solar radiation is the total amount of solar energy received by the earth's surface. It is the summation of direct, diffuse and reflected solar radiation received by the earth's surface. Direct solar radiation passes directly through the atmosphere to the earth's surface. Diffuse solar radiation is scattered in the atmosphere and reflected solar radiation

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reaches the surface but is reflected to adjacent surfaces. Direct solar radiation depends on the orientation of the receiving surface, atmospheric condition and position in the world, with daily and annual variations depending on the movement of the terrestrial globe. Diffuse solar radiation can be considered the same, regardless of the orientation of the receiving surface, even if, in reality, there are slight differences [4].

In many applications of solar energy, the most important parameters that are often needed are the average global solar irradiation and its components. Unfortunately, the measurements of this parameter are done only at a few places. For this reason there have been attempts at estimating them from theoretical models. These correlations estimate the amounts of monthly average solar radiation from more readily available meteorological parameters such as the sunshine duration, extraterrestrial radiation. Several empirical models have been developed to calculate global solar radiation using various parameters. [5] developed the earliest model used for estimating global radiation, in which the sunshine duration data and clear sky radiation ($H_c$) data were used.

$$\frac{H}{H_c} = a + b\left(\frac{n}{N}\right) \tag{1}$$

Because there may be problems in calculating clear sky radiation accurately, by replacing clear sky radiation with extraterrestrial radiation ( $H_0$), this model was modified to a more convenient form by Prescott in 1940 [6].

Many researchers have used this sunshine based model to develop empirical correlations [7], [8], [9], [10], and [11]. Other empirical models have been developed to calculate solar radiation not only using sunshine duration, extraterrestrial radiation and geographical parameters but also using some other parameters such as; ambient temperature [3], [12], [13], [14], [15] and [16], soil temperature [17], relative humidity [18], [19] and [20], precipitation [21], cloud cover [22], and Evaporation [23].

The purpose of this paper is to use climate data from the archives of National Aeronautics and Space Administration (NASA) for a period of 11 years (2000 – 2010) to generate sunshine based empirical equations for calculating the global solar radiation in Awka, Enugu and Owerri, all in south eastern Nigeria. The solar data obtained from this correlation will be tested for errors using; Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE).

## 2. Methodology

The original Angstrom – type equation as stated in equation (1) is related to the clear day radiation $H_c$ at the location and the average fraction of possible sunshine hours $\frac{n}{N}$, [5]. [6], [24] and others have modified the method using the value of the extraterrestrial radiation $H_0$ on a horizontal surface rather than the clear day radiation $H_c$ [25].

$$\frac{\bar{H}}{\bar{H}_0} = a + b\left(\frac{\bar{n}}{\bar{N}}\right) \tag{2}$$

Where $\bar{H}$ is the monthly average daily global radiation on a horizontal surface ( $MJ.m^{-2}.day^{-1}$ ). $\bar{H}_0$ is the daily extraterrestrial radiation on a horizontal surface $MJ.m^{-2}.day^{-1}$, $\bar{n}$ is the monthly average daily hours of bright sunshine, $\bar{N}$ is the monthly average day length, (a and b) values are known as angstrom empirical constant or regression coefficients. Their values have been obtained from the relationship given by [26] and also confirmed by [27] as

$$a = -0.110 + 0.235\cos\emptyset + 0.235\left(\frac{\bar{n}}{\bar{N}}\right) \tag{3}$$

$$b = 1.449 - 0.553\cos\emptyset - 0.694\left(\frac{\bar{n}}{\bar{N}}\right) \tag{4}$$

The monthly average daily extraterrestrial irradiation $\bar{H}_0$ can be calculated from the equation below.

$$\bar{H}_o = \frac{24}{\pi} I_{sc}\left[1 + 0.0333\cos\left(\frac{360n}{365}\right)\right]\left[\cos\emptyset\cos\delta\cos\bar{h}_s + \frac{2\pi\bar{h}_s}{360}\sin\emptyset\, sin\delta\right]$$

$$\bar{H}_o = \frac{24}{\pi} I_{sc}\, E_0\left[\cos\emptyset\cos\delta\cos\bar{h}_s + \frac{2\pi\bar{h}_s}{360}\sin\emptyset\, sin\delta\right] \tag{5}$$

Where $I_{sc}$ is the solar constants (= 1367 $Wm^{-2}$) and can also be expressed in $Jm^{-2}day^{-1}$ in equation (6),

$$I_{sc} = \frac{1367\times3600}{1000000}\, MJm^{-2}day^{-1} \tag{6}$$

$E_0$ is the eccentricity correction factor expressed in equation (7),

$$E_0 = \left[1 + 0.0333\cos\left(\frac{360n}{365}\right)\right] \tag{7}$$

$\emptyset$ is the latitude of the site under study, $\delta$ is the solar inclination angle given as

$$\delta = 23.45\sin\left(360\left(\frac{n+284}{365}\right)\right) \tag{8}$$

$\bar{h}_s$ is the mean sunrise hour angle for the given month expressed as;

$$\bar{h}_s = \cos^{-1} -tan\emptyset\tan\delta \tag{9}$$

n is the characteristic day number for each month: n = 1 on 1st of January to 365 on 31st of December. The mean day length $\bar{n}$ is expressed as;

$$\bar{n} = \frac{2}{15}\bar{h}_s \quad (10)$$

The expression for the MBE ($MJm^{-2}day^{-1}$), RMSE ($MJm^{-2}day^{-1}$), and MPE (%) as stated by [28] are:

$$MBE = \frac{[\sum(\bar{H}_{ical} - \bar{H}_{imeas})]}{n} \quad (11)$$

$$RMSE = \left[\frac{\sum(\bar{H}_{ical} - \bar{H}_{imeas})^2}{n}\right]^{1/2} \quad (12)$$

$$MPE = \frac{\left[\sum\left(\frac{\bar{H}_{imeas} - \bar{H}_{ical}}{\bar{H}_{imeas}} \times 100\right)\right]}{n} \quad (13)$$

Where $\bar{H}_{ical}$ and $\bar{H}_{imeas}$ are the ith calculated and measured values of global solar rad iation respectively, and $n$ is the total number of observations. In general, MBE provides information on the long term performance of the models. Positive MBE shows overestimation while a negative MBE indicates underestimation. RMSE provides information on the short term performance of the model. It is always positive and a low value of it is desirable. The demerit of this parameter is that a single value of higher error leads to a higher value of RMSE. MPE test provides information on long – term performance of examined regression. A negative value of MPE indicates the average amount of under estimation while a positive value indicates over estimation.

## 3. Results and Discussion

Table 1 shows the climatic data for Awka, Table 2. Shows the climatic data for Enugu while Table 3 shows the climatic data for Owerri. The values of monthly mean of extraterrestrial solar radiation ($\bar{H}_0$), monthly mean measured global solar radiation ($\bar{H}_m$), monthly mean of calculated global solar radiation ($\bar{H}_{cal}$), monthly mean of daily hours of bright sunshine ($\bar{n}$), the monthly mean of day length ($\bar{N}$), monthly values of regression constants (a and b), clearness index K for each month and the monthly ratio of sunshine hours are shown in the tables below.

**Table 1.** Climate Parameters for Awka.

| S/N | MONTH | $\bar{H}_0$ ($MJm^{-2}day^{-1}$) | $\bar{H}_m$ ($MJm^{-2}day^{-1}$) | $\bar{H}_{cal}$ ($MJm^{-2}day^{-1}$) | a | b | $\bar{n}$ (hrs) | $\bar{N}$ (hrs) | K | $\bar{n}/\bar{N}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | January | 33.68 | 20.71 | 19.64 | 0.30 | 0.52 | 6.22 | 11.43 | 0.61 | 0.54 |
| 2 | February | 35.80 | 20.92 | 21.54 | 0.31 | 0.49 | 6.94 | 11.83 | 0.58 | 0.59 |
| 3 | March | 37.47 | 20.55 | 22.95 | 0.32 | 0.47 | 6.92 | 11.27 | 0.55 | 0.61 |
| 4 | April | 37.67 | 19.00 | 21.25 | 0.29 | 0.55 | 6.12 | 12.11 | 0.50 | 0.51 |
| 5 | May | 36.71 | 17.74 | 17.65 | 0.24 | 0.64 | 4.52 | 12.22 | 0.48 | 0.37 |
| 6 | June | 35.89 | 16.15 | 16.86 | 0.24 | 0.65 | 4.38 | 12.35 | 0.45 | 0.35 |
| 7 | July | 36.12 | 14.85 | 15.66 | 0.22 | 0.69 | 3.83 | 12.47 | 0.41 | 0.31 |
| 8 | August | 36.94 | 14.15 | 15.52 | 0.22 | 0.70 | 3.45 | 11.88 | 0.38 | 0.29 |
| 9 | September | 37.20 | 14.85 | 18.93 | 0.26 | 0.61 | 4.78 | 11.63 | 0.40 | 0.41 |
| 10 | October | 36.06 | 16.58 | 18.82 | 0.26 | 0.60 | 4.97 | 11.51 | 0.46 | 0.43 |
| 11 | November | 34.08 | 18.74 | 20.00 | 0.30 | 0.52 | 6.31 | 11.43 | 0.55 | 0.55 |
| 12 | December | 32.85 | 19.93 | 19.91 | 0.32 | 0.48 | 6.95 | 11.63 | 0.61 | 0.60 |

**Table 2.** Climate Parameters for Enugu.

| S/N | MONTH | $\bar{H}_0$ ($MJm^{-2}day^{-1}$) | $\bar{H}_m$ ($MJm^{-2}day^{-1}$) | $\bar{H}_{cal}$ ($MJm^{-2}day^{-1}$) | a | b | $\bar{n}$ (hrs) | $\bar{N}$ (hrs) | K | $\bar{n}/\bar{N}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | January | 33.69 | 20.60 | 19.07 | 0.29 | 0.55 | 5.98 | 11.75 | 0.61 | 0.51 |
| 2 | February | 35.80 | 20.92 | 19.47 | 0.27 | 0.57 | 5.55 | 11.84 | 0.58 | 0.47 |
| 3 | March | 37.47 | 20.55 | 17.71 | 0.24 | 0.65 | 4.29 | 11.97 | 0.55 | 0.36 |
| 4 | April | 37.67 | 19.01 | 18.25 | 0.24 | 0.64 | 4.54 | 12.11 | 0.5 | 0.38 |
| 5 | May | 36.65 | 17.01 | 16.93 | 0.23 | 0.66 | 4.21 | 12.23 | 0.46 | 0.34 |
| 6 | June | 35.89 | 16.15 | 14.65 | 0.21 | 0.71 | 3.24 | 11.72 | 0.45 | 0.28 |
| 7 | July | 36.12 | 14.85 | 14.72 | 0.21 | 0.71 | 3.23 | 11.74 | 0.41 | 0.28 |
| 8 | August | 36.94 | 14.15 | 15.42 | 0.22 | 0.70 | 3.42 | 11.89 | 0.38 | 0.29 |
| 9 | September | 37.20 | 14.85 | 16.29 | 0.22 | 0.68 | 3.75 | 11.98 | 0.40 | 0.31 |
| 10 | October | 36.06 | 16.58 | 18.44 | 0.26 | 0.61 | 4.93 | 11.87 | 0.46 | 0.41 |
| 11 | November | 34.07 | 18.75 | 19.28 | 0.29 | 0.55 | 5.98 | 11.76 | 0.55 | 0.51 |
| 12 | December | 32.84 | 19.93 | 18.18 | 0.28 | 0.56 | 5.68 | 11.71 | 0.61 | 0.49 |

**Table 3.** Climate Parameters for Owerri.

| S/N | MONTH | $\bar{H}_0$ (MJm$^{-2}$ day$^{-1}$) | $\bar{H}_m$ (MJm$^{-2}$ day$^{-1}$) | $\bar{H}_{cal}$ (MJm$^{-2}$ day$^{-1}$) | a | b | $\bar{n}$ (hrs) | $\bar{N}$ (hrs) | K | $\bar{n}/\bar{N}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | January | 34.15 | 20.06 | 19.98 | 0.30 | 0.52 | 6.35 | 11.58 | 0.59 | 0.55 |
| 2 | February | 36.13 | 20.37 | 20.72 | 0.29 | 0.53 | 6.15 | 11.74 | 0.56 | 0.52 |
| 3 | March | 37.55 | 19.55 | 21.10 | 0.29 | 0.55 | 5.99 | 11.95 | 0.52 | 0.50 |
| 4 | April | 37.55 | 18.20 | 19.96 | 0.27 | 0.59 | 5.45 | 12.18 | 0.48 | 0.45 |
| 5 | May | 36.44 | 16.85 | 19.29 | 0.27 | 0.59 | 5.49 | 12.37 | 0.46 | 0.44 |
| 6 | June | 35.56 | 15.06 | 18.51 | 0.26 | 0.60 | 5.35 | 12.46 | 0.42 | 0.43 |
| 7 | July | 35.80 | 13.55 | 15.64 | 0.22 | 0.68 | 3.86 | 12.40 | 0.38 | 0.31 |
| 8 | August | 36.77 | 13.27 | 15.99 | 0.22 | 0.68 | 3.78 | 12.24 | 0.36 | 0.31 |
| 9 | September | 37.21 | 13.87 | 17.90 | 0.24 | 0.64 | 4.45 | 12.02 | 0.37 | 0.37 |
| 10 | October | 36.31 | 15.36 | 18.66 | 0.26 | 0.61 | 4.94 | 11.79 | 0.42 | 0.42 |
| 11 | November | 34.47 | 17.52 | 18.85 | 0.28 | 0.57 | 5.50 | 11.61 | 0.51 | 0.47 |
| 12 | December | 33.31 | 19.07 | 19.87 | 0.31 | 0.50 | 6.63 | 11.54 | 0.57 | 0.57 |

**Table 4.** Latitude, Longitude and Statistical Error Indicators of the Cities.

| Cities | Lat. (°) | Long. (°) | MBE | RMSE | MPE | R | $R^2$ |
|---|---|---|---|---|---|---|---|
| Awka | 6.207 | 7.068 | 1.212 | 4.199 | -0.570 | 0.996 | 0.991 |
| Enugu | 6.452 | 7.510 | -0.410 | 1.432 | -0.200 | 0.998 | 0.996 |
| Owerri | 5.485 | 7.035 | 1.978 | 6.851 | 0.873 | 0.996 | 0.991 |

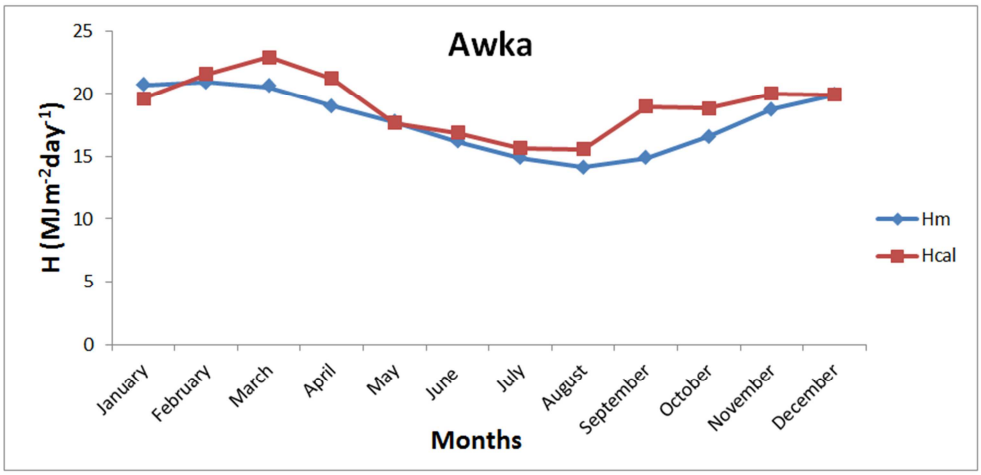


**Fig. 1.** Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Awka.

The measured global solar radiation and calculated value of global solar radiation obtained from the model equation were plotted against months of the year as shown in Fig. 1, Fig. 2 and Fig. 3, they show almost the same pattern of curves. This revealed that the proposed sunshine based model equation can be used to predict the global solar radiation of the three cities of Awka, Enugu and Owerri in south eastern part of Nigeria. This model can also be used to predict global solar radiation of any part of the world that has climatological factors similar to the three cities studied.

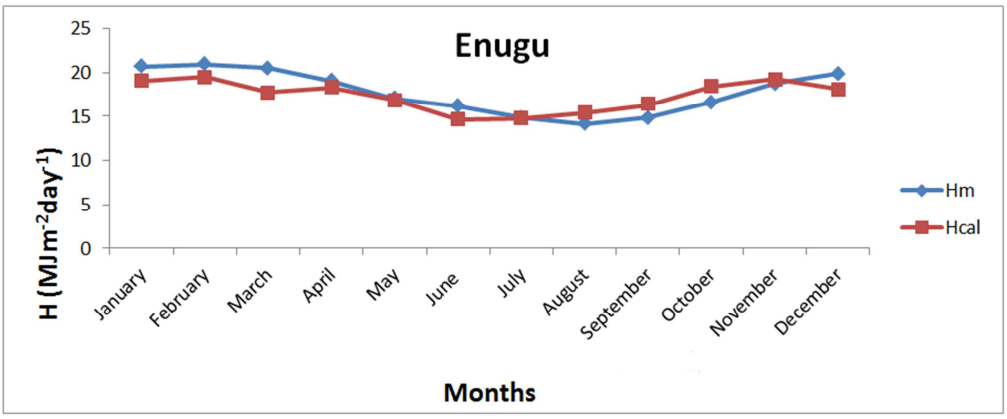


**Fig. 2.** Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Enugu.

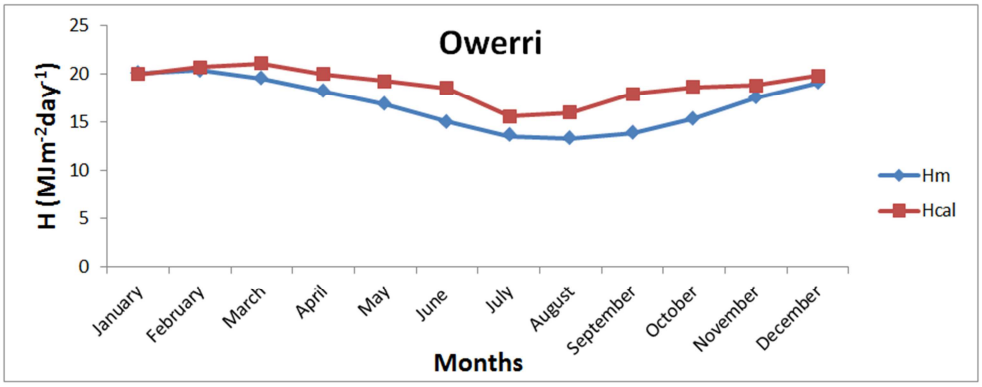


**Fig. 3.** Graph of Global Solar Radiation versus Months of the Years (2000 – 2010) for Owerri.

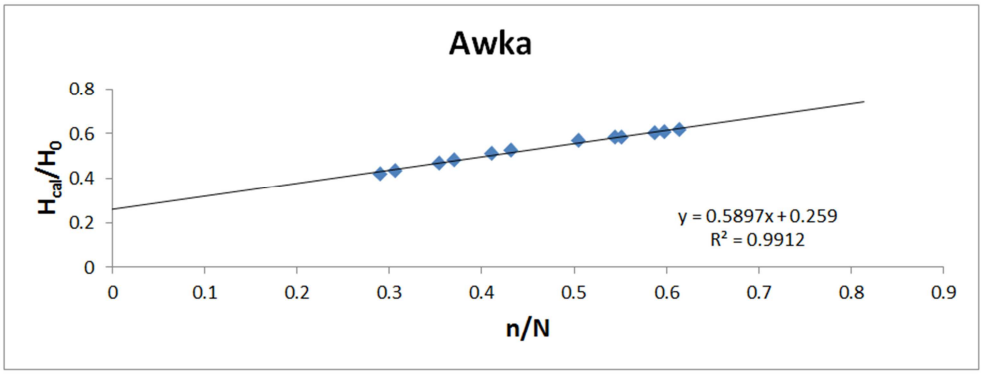


**Fig. 4.** Graph of Clearness Index (K) versus Ratio of Sunshine Hours for Awka.

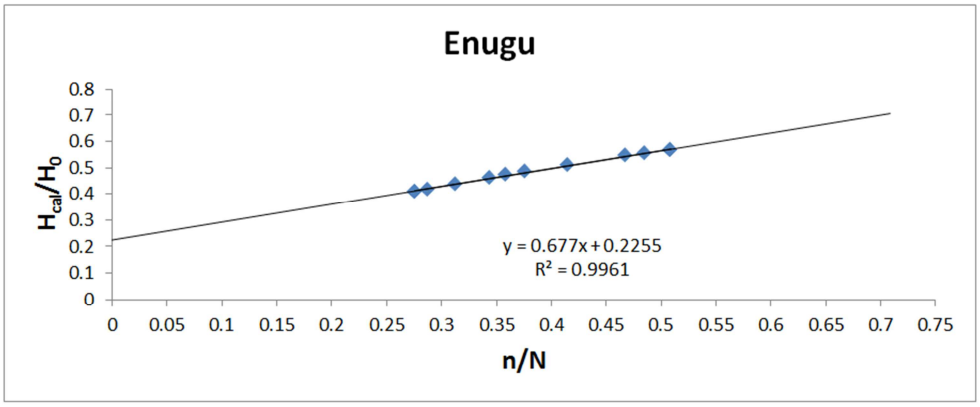


**Fig. 5.** Graph of Clearness Index (K) versus Ratio of Sunshine Hours for Enugu.

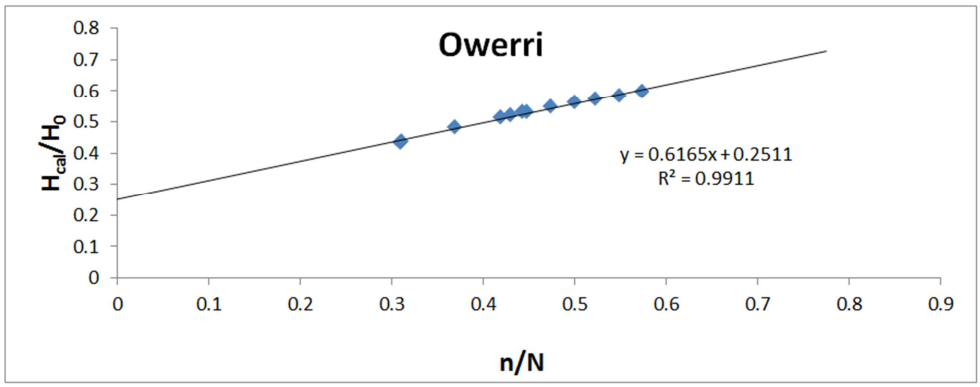


**Fig. 6.** Graph of Clearness Index (K) versus Ratio of Sunshine Hours for Owerri.

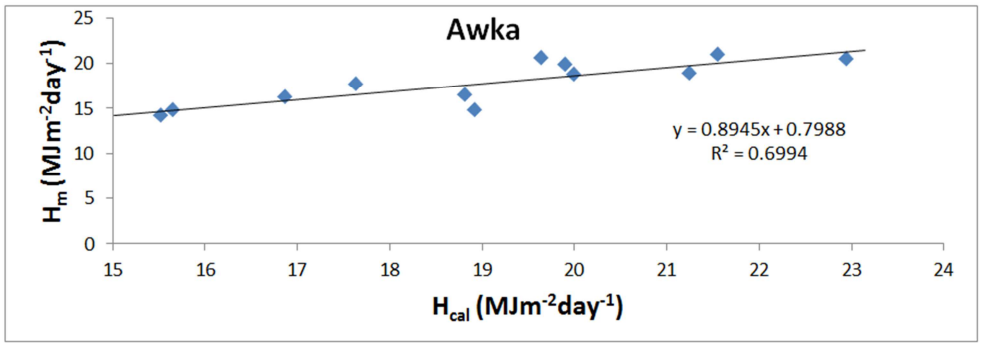


**Fig. 7.** Graph of Measured Global Solar Radiation versus Calculated Global Solar Radiation for Awka.

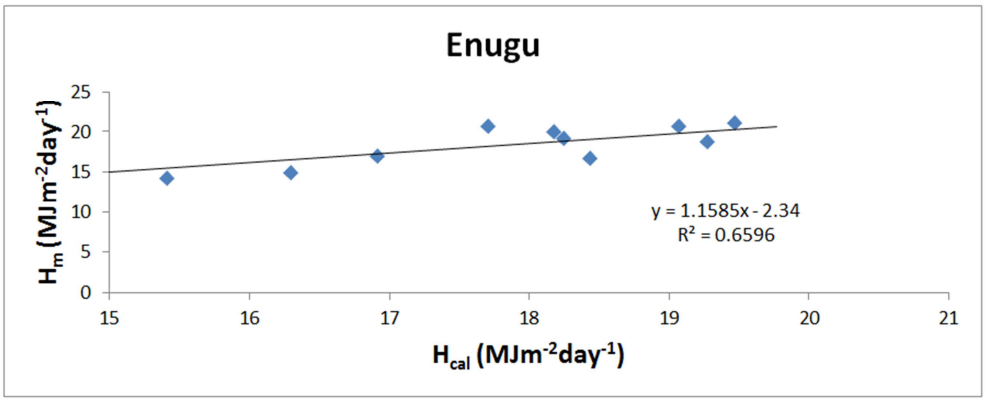


**Fig. 8.** Graph of Measured Global Solar Radiation versus Calculated Global Solar Radiation for Enugu.

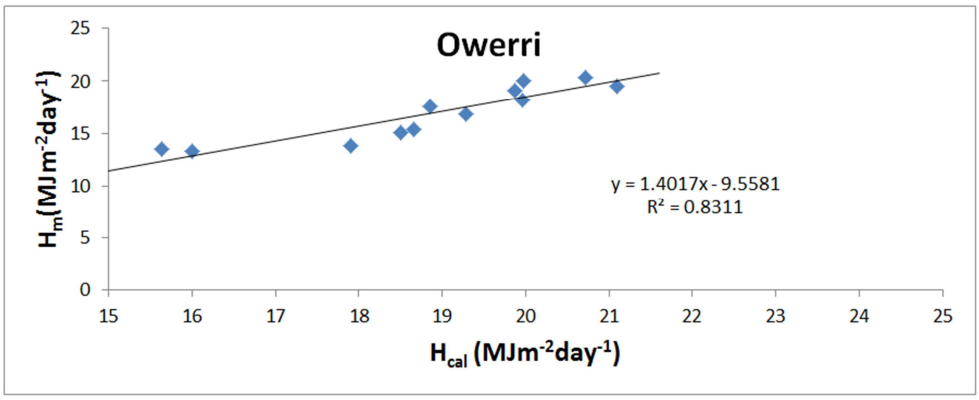


**Fig. 9.** Graph of Measured Global Solar Radiation versus Calculated Global Solar Radiation for Owerri.

In the sunshine based model proposed for the study, the model was used to show the relation between the relative sunshine duration and clearness index for the cities in south east of Nigeria for the period of eleven years (2000 – 2010). Fig. 4, Fig. 5 and Fig. 6 show the results of the performance of the sunshine based model in terms of regression constant (a and b) and coefficient of determination ($R^2$) for the cities. The empirical correlation equations were developed for the three cities and given as

I) For Awka $$\frac{\bar{H}}{\bar{H}_0} = 0.259 + 0.589\left(\frac{\bar{n}}{\bar{N}}\right) \quad (14)$$

II) For Enugu $$\frac{\bar{H}}{\bar{H}_0} = 0.226 + 0.677\left(\frac{\bar{n}}{\bar{N}}\right) \quad (15)$$

III) For Owerri $$\frac{\bar{H}}{\bar{H}_0} = 0.251 + 0.617\left(\frac{\bar{n}}{\bar{N}}\right) \quad (16)$$

The coefficient of determination ($R^2$) is a statistical measure which gives some information about how well the regression line approximates the real data points. $R^2$ of 1 indicates that the regression line perfectly fits the data points. In this work, $R^2$ values of 0.991, 0.996 and 0.991 were obtained for Awka, Enugu and Owerri respectively in Fig. 4, Fig. 5 and Fig. 6 which show excellent fittings between the clearness index and the relative sunshine duration. These results imply that 99.10% of clearness index can be accounted for using relative sunshine duration at Awka and Owerri. 99.6% of clearness index can be accounted for using relative sunshine duration at Enugu.

The validating of the calculated data were tested using MBE, RMSE and MPE for each of the sites. The formulae stated in equations (11), (12) and (13) were used to calculate these error values for each site as show in table 4 above.

## 4. Conclusion

The regression parameters of Angstrom – Page sunshine based model for estimating global solar radiation have been determined for Awka, Enugu and Owerri using climate data from the archives of National Aeronautics and Space Administration (NASA) for a period of 11 years (2000 – 2010). The Angstrom – Page sunshine based model equations determined are expressed as shown in equations (14), (15) and (16) respectively. Our equations for the estimation of global solar radiation are comparable with other equations obtained for these cities studied. The estimated global solar radiation data and correlation will provide a useful source of information to designers of renewable energy and air-conditioning systems for these cities in south eastern Nigeria. It could also enrich the National Energy data bank of the nation.

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