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Research Article

Analysis of the Monthly Average Global Solar Radiation of Awka, Anambra State

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Abstract

Global solar radiation is an important parameter necessary for most ecological models and serves as input for different photovoltaic conversion systems. Hence, it is of economic importance to renewable energy alternative. The data for this work were collected from Nigeria meteorological agency (NIMET). The climate parameter data collected were; measured daily global radiation (Hm), the daily extra-terrestrial solar radiation on a horizontal surface (Ho), the daily maximum temperature (Tmax), the daily minimum temperature (Tmin), the daily maximum number of hours of possible sunshine (So). The duration of record was from 2020 to 2022. The daily data were analyzed to obtain the monthly mean values for each of the parameter for the period of study. The results obtained were statistically tested using five statistical indicators, correlation coefficient®, coefficient of determination (R^2), mean bias error (MBE) root mean square error (RMSE) and mean percentage error (MPE). The analysis shows that there is close correlation between the measured mean solar radiation and the estimated global solar radiation using our established models. The models with high value of correlation coefficient and low values of MBE, MPE and RMSE for the state was considered as the best model $\frac{Hm}{Ho} = a + b\left(\frac{Tmin}{Tmax}\right) + c\left(\frac{S}{So}\right)$ proved to be the best regression modal that could be used to measure solar radiation of Awka, Anambra state.

Keywords: Monthly Average Global Solar Radiation; Anambra State; Nigeria Meteorological Agency (NIMET); Photovoltaic Conversion Systems

Introduction

The need for proper measurement of solar radiation in this current age and its comparative approaches are needed for proper understanding of the usage and allocation. Solar radiation has been identified as the largest renewable resource on earth. Solar energy is not available continuously because of the day/night cycle and cloud cover. Its intensity varies according to season, geographical location, and position of the collector (Abdulrahim*et al.*, 2011).Studies on solar radiation have become an important issue for renewable energy issues stemming from oil crises, global warming and other environmental problems, thus increasing the need of reliable measurements of surface solar radiation (Gairaa and Bakelli, 2011). Therefore, measured daily solar radiation is an important factor in most cropping systems and water balance models. Knowledge of solar radiation data is also indispensable for many solar-energy-related applications (Nando, 2012). Comprehensive knowledge of solar radiation of a particular location is a useful tool in studying and designing the economic viability of devices that depend on use of solar energy. The trends of energy indicate that world oil production will reach peak and start a long downward slide when fossil fuel and gas would have been consumed (Augustine and Nnabuchi, 2009). Studies that have gained speed on new and renewable energy sources are encouraged because energy resources used today are rapidly decreasing and causing environmental pollution. The knowledge of the dwindling level of these resources and their related environmental challenges is generating the necessity to shift emphasis from the use of fossil fuels to renewable energy resources such as solar radiation application. Solar radiation is the largest renewable energy source and it has been studied recently due to its importance (Ugwu and Ugwuanyi, 2011).

Solar radiation is the radiant energy that is emitted by the Sun from a nuclear fusion reaction that creates electromagnetic energy. The knowledge of the amount of solar radiation in a given location (area) is essential in the field of solar energy physics. This, in effect, helps one to have a fair knowledge of the insulation power potential over the location. As a result of dwindling supply of natural gas, increase emphasis on the use of solar energy and other renewable energy sources in generating electricity should be developed. Bearing in mind the very well documented problems associated with other forms of energy, the use of solar energy should be paramount now. Solar energy is abundant, free and clean. Now that there is the campaign for the popularization of solar energy for domestic and industrial uses, the need to know how to evaluate insulation levels for any site becomes paramount. When that is done, the introduction and sustainability of solar energy technology will be assured (Chineke and Igwiro, 2002).An accurate knowledge of the solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices and for estimates of their performance. Research has shown that Nigeria as a country has a huge amount of solar radiation present in various parts of the country though in varying quantity. This huge amount of solar radiation depends on some atmospheric parameters which cannot be determined by common sense and thus might limit the exploitation of this natural resource. Thus, the study seeks to analyze the atmospheric parameters responsible for the global solar radiation in Awka, Anambra state of Nigeria, so as to enable the proper and efficient harnessing of the global solar radiation for consumption in the state.

Literature Review

Many studies and analysis have been carried out on the global solar radiation in many parts of Nigeria and in the world at large. Umoh *et al.* (2013) carried out a research on global solar radiation studies due to sunshine hours and other meteorological parameters for a period of 1997-2007. Multiple linear regression models were used to estimate the monthly daily sunshine hours using relative humidity, maximum and minimum temperatures, rainfall and wind speed for locations in South Eastern Nigeria which include Uyo, Calabar, Port Harcourt, Warri, Enugu and Owerri. It was observed that the maximum amount of global solar radiation in the South Eastern part of Nigeria was received in January with its value as 17.03mJm^{-2} and the least amount of global solar radiation was received in July with its value as 12.47mJm^{-2}. Adekunle *et al. (*2015) carried out an analysis of global solar irradiance over 25 locations in five climatic zones in Nigeria for solar energy applications. The zones include the tropical rainforest, Guinea Savannah, Sahel Savannah, Sudan Savannah and Mangrove Swamp. The study used frequency distribution of global solar irradiance for each of the climatic zones. The result of the study showed that 46.88% and 40.60% of the number of days over the tropical rainforest and Mangrove swamp forest, respectively, had irradiation within the range of 20.01-25.01mJm^{-2}. For the Guinea Savannah, Sahel Savannah and Sudan Savannah, 46.19%, 55.84% and 58.53% of the days had total irradiation within the range of 20.01-25.01mJm^{-2}. The contour maps plotted showed that the high and low values of global solar irradiance and clearness index were observed in the Northern and Southern locations of Nigeria, respectively.

Adeola *et al. (*2017) estimated the global solar radiation in Ibadan, Nigeria using Angstrom-Prescott and Glover-Mcculloch's Models for a period of 2008-2012. The study used the mean daily bright sunshine hour for Ibadan obtained from the International Institute of Tropical Agriculture. It was discovered that the month of August has the least amount of measured global solar radiation at 35.172mJm^{-2}day^{-1}. Musa *et al.* (2012) carried out a study on estimation of global solar radiation in Maiduguri, Nigeria using Angstrom Model for the period of 2004 – 2007 and showed that the values of solar radiation for Maiduguri town varied from the range of 16.80mJm^{-2}day^{-1} to 25.04mJm^{-2}day^{-1} under the period of study with mean value of 23.20mJm^{-2}day^{-1}. Innocent *et al.* (2015) carried out a study on estimation of global solar radiation in Gusau, Nigeria. It was observed that the monthly global solar radiation is not uniform throughout the period of study. The maximum global solar radiation is observed in the months of November, February, March and April respectively while the months of June, July and August recorded the least amount of global solar radiation. This can be attributed to peak period of cloud cover due to the rainy season. In general, higher value of global solar radiation is obtained in dry season than wet season. The mean value of global solar radiation for Gusau city during the period of study was estimated to be 18.8015mJm^{-2}day^{-1}. This shows that the level of global solar radiation reaching Gusau can adequately support the development of any form of solar energy system. For example, even with the least value of global solar radiation 16.1676 mJm^{-2}day^{-1}, it means theoretically that for a particular day, solar energy of 4.491kwh can be obtained with a square solar plate of side 1m in one hour. This translates to enormous solar energy with wide solar panels.

Medugu and Yakubu (2011) carried out a study on the estimation of mean monthly global solar radiation in Yola- Nigeria using Angstrom model, the daily sunshine hour data were collected for a period of four years (from 2004-2007) from the meteorological station of Geography Department at Modibo Adama University of Technology, formerly Federal University of Technology, Yola, with the aid of a sunshine recorder. The monthly average values were determined for the period the measurements were taken. It was observed that the monthly global solar radiations are not uniform throughout. The peak of radiation being the months of March, April, May and June with 24.38mJm^{-2}day^{-1}, 24.92mJm^{-2}day^{-1}, 24.54mJm^{-2}day^{-1} and 23.13mJm^{-2}day^{-1}, respectively. On the other hand, least value of global solar radiation was recorded in January with 16.86mJm^{-2}day^{-1}. This was explained in terms of peak of cold harmattan season. The months of August and September with 20.31mJm^{-2}day^{-1} and 20.77mJm^{-2}day^{-1} also had low values of solar radiations; this was also as a result of the peak period of the cloud cover in Yola. In general, higher value of solar radiation was obtained in dry season than wet season. The value of global solar radiation for Yola town over the period of measurement was estimated to be 21.54±0.46mJm^{-2}day^{-1} using the Angstrom equation.

Sani *et al.* (2015) carried out a study on the correlation functions and estimation of global solar radiation studies using sunshine based model for Kano, Nigeria for the years 2006 – 2010 and showed that the highest values of solar radiation was obtained in the months of March and April with an estimated value of 26.50mJm^{-2}day^{-1} while the least solar radiation was obtained in the months of August to October with an estimated value of 19.50mJm^{-2}day^{-1}. Ibrahim and Usman (2016) estimated solar energy potentials of Sokoto State using temperature-based models of A ngstrom empirical equations for a period of 2013-2015. The result showed that the peak value of the estimated radiations is 25111.77kJm^{-2} in the month of August while the peak value of the measured radiations of the period of study is 26666.66kJm^{-2}.

Ndilemeni *et al.* (2013) evaluated the clearness index of Sokoto using estimated global solar radiation. The clearness index was compared with global solar radiation, the transparency of Sokoto sky was investigated and the monthly variation of clearness index was evaluated. The results showed that Sokoto has a clear weather as the clearness index is more than 50% throughout the year. The month of December had the highest clearness index of 62.9% while the month of August has the least value of clearness index of 50.8%. Sanusi and Abisoye (2011) estimated the solar radiation at Ibadan, Nigeria using monthly solar radiation and minimum and maximum temperature for a period of 2001-2006. The best performance for the present data set wad found that Hargreaves model with linear regression, and followed by Hargreaves model with power regression and original Hargreaves model. The study showed that the Hargreaves model with linear regression reasonably predicted global solar radiation and the expected solar radiation in the area of study. Akpootu and Mustapha (2015) carried out a study on the estimation of diffuse solar radiation for Yola, Adamawa State, North-Eastern, Nigeria for the period of 1980 - 2010 and the result showed that the peak of solar radiation was experienced in the month of March with a mean of 25.53mJm^{-2}day^{-1} and the minimum in the month of July with a mean of 18.66mJm^{-2}day^{-1}. Abdullahi and Singh (2014) carried out a work on global solar radiation evaluation for some selected stations of North Eastern Nigeria, the result showed that the maximum values of global solar radiation appear in March, April and May, respectively during dry season while minimum values were observed in August and September, respectively during wet season.

Methodology

This section focuses on the technique developed to realize the objectives of this work. The materials used in carrying out this research were meteorological data obtained by the researcher from the Nigeria Meteorological Agency (NIMET), Abuja. The data include the Sunshine hours duration, Gunn Bellani solar radiation (Hm), and maximum and minimum temperature for the year 2020 - 2022. The daily data for the Sunshine hours radiation, Gunn Bellani solar radiation (Hm), and maximum and minimum temperature were obtained for the year 2020-2022. The daily data were analyzed to obtain monthly mean values for each of the parameters for the years 2020 -2022. The state under study with its latitude and longitude in degrees were (6° 12' 00" N, 7° 00' 00" E). The mean values of the meteorological parameters of the state studied are presented in table 2 to table 4 below.

Models Used for the Estimation

The extraterrestrial solar radiation on a horizontal surface can be determined from the following equation (Iqbal, 1983):

$$H_0 = \frac{24}{\pi} I_{SC} \in_O \{\frac{\pi}{180}\omega_s \sin\phi \sin\delta + \cos\phi \cos\delta \sin\omega_s\} \quad (1)$$

The value of 1367Wm^{-2} has been recommended for the solar constant I_{SC} (Frolich and Brusca, 1981). For our measurement, I_{SC} in mJm^{-2}day^{-1} is given by

$$I_{SC} = \frac{1367 \times 3600}{1000000} \text{ (mJm}^{-2}\text{day}^{-1}\text{)}. \quad (2)$$

The hour angle ω_s for horizontal surface (Duffie and Beckman, 1994) is given as

$$\omega_s = \cos^{-1}(-tan\phi tan\delta) \quad (3)$$

Declination is determined from Cooper's equation (Cooper, 1969).

$$\text{thus; } \delta = 23.45 \sin\{\frac{360}{365}(284 + d_n)\} \quad (4)$$

where d_n is the day of the year from January 1 to December 31 (Cooper, 1969).

The day length, S_O, is the number of hours of sunshine or darkness within 24 hours in a given day. For a horizontal surface, it is determined from the equation of Duffie and Beckman (Duffie and Beckman, 1994) as:

$$S_0 = \frac{2}{15}\cos^{-1}(-tan\phi tan\delta) = \frac{2}{15}\omega_s \quad (5)$$

The eccentricity, $\in_o$ (Nwokoye, 2006) was calculated using:

$$\in_o = (1 + 0.033 \cos\frac{360}{365} d_n) \quad (6)$$

Table 1: Average d_n for the Months of the Year

Months	Average d_n	d_n for the year	Declination (δ)	$\in_o$
January	17	17	-20.92	1.0340
February	16	47	-12.95	1.0251
March	16	75	-2.42	1.0108
April	15	105	9.41	0.9932
May	15	135	18.79	0.9780
June	11	162	23.09	0.9692
July	17	198	21.18	0.9673
August	16	228	13.45	0.9746
September	15	258	2.22	0.9885
October	15	288	-9.60	1.0058
November	14	318	-18.91	1.0222
December	10	344	-23.05	1.0319

The most convenient and widely used correlation for predicting solar radiation was developed by Angstrom (1924) and later modified by Prescott (1940). The formula is:

$$\frac{H}{H_O} = a + b\frac{S}{S_o} \quad (7)$$

Where:
H = the global solar radiation (mJm^{-2}day^{-1});
H_o = the extraterrestrial solar radiation on a horizontal surface (mJm^{-2}day^{-1});
S = the number of hours measured by the sunshine recorder;
S_o = the maximum daily sunshine duration (or day length);

a,bc= the regression coefficients to be determined.

The following first order regression models were estimated in order to obtain the best regression models for the state under study:

$$\frac{H_M}{H_O} = a + b\left(\frac{T_{MIN}}{T_{MAX}}\right) \quad (8)$$

$$\frac{H_M}{H_O} = a + b\left(\frac{T_{MIN}}{T_{MAX}}\right) + c\left(\frac{S}{S_O}\right) \quad (9)$$

Analysis of Parameters Used

The Meteorological data (maximum and minimum temperature, Gunn Bellani Solar radiation, sunshine hours) for this work were collected from the Nigeria Meteorological Agency (NIMET).

Table 1 - 3 gives the monthly averages of extraterrestrial solar radiation (Ho), the measured solar radiation (H_m); the ratio of the measured solar radiation to extraterrestrial solar radiation, which is the clearance index H_m/H_o; hours of bright sunshine (S); the sunshine duration, which is the ratio of the measured sunshine hours to daylight (S/S_o); maximum and minimum temperature(Tmax - Tmin) (measured in degree Celsius), T(°C) for the state over a period of three years (2020 - 2022). Table 3 shows the summary of monthly average of determined data for 2020-2022 of Anambra state.

The accuracy of the estimated values was tested by calculating the Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE).

Statistical Package for Social Science (SPSS) computer software was used in evaluating these model parameters and regression constants and the coefficients were obtained. From these regression coefficients, the predicted values of solar radiation were estimated by calculations using Microsoft Excel software. The accuracy of the estimated values was tested by calculating the Mean Bias Error (MBE), Root Mean Square Error (RMSE), and Mean Percentage Error (MPE). The expression for MBE ($mJm^{-2}day^{-1}$), RMSE ($mJm^{-2}day^{-1}$), and MPE (%) is stated by El- Sebaii and Trabea (2005) as follows:

$$MBE = [\sum(H_{i,cal} - H_{i,meas})] / n \quad (10)$$

$$RMSE = \left[\frac{\sum(H_{i,cal} - H_{i,meas})^2}{n}\right]^{½} \quad (11)$$

$$MPE = [(\frac{H_{i,meas} - H_{i,cal}}{H_{i,meas}} \times 100)] / n \quad (12)$$

Where $H_{i,cal}$ and $H_{i,meas}$ is the calculated (predicted) and measured values and n is the total number of observations. The MBE provides information on the long – term performance of the correlations by allowing a term by term comparison of the actual deviation between calculated and measured values. A positive MBE represent an overestimation whereas a negative MBE shows an underestimation. Almorox *et al. (*2005) recommended that a zero value for MBE is ideal and 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 value of RMSE is always positive. Almorox et al. (2005) have recommended that a zero value of RMSE is ideal and the lower the RMSE, the more accurate is the estimated value. The values of RMSE represent non – systematic error. The MPE test gives long term performance of the examined regression equations. A positive MPE value provides the average amount of overestimation in the calculated values, while a negative values means underestimation. A low value of MPE is desirable (Akpabio & Etuk, 2002). MPE is an overall measure of forecast bias, computed from the actual difference between a series of forecasts and actual data points observed. The differences are expressed as percentage of each observed data point, the summed and averaged (Almorox, 2005). The model with the highest value of R and R^2 and least values of RMSE, MBE and MPE were chosen as the best. The values of the meteorological data and global solar data for Awka, Anambra State are presented in Tables 2-4.

Table 2: Meteorological Data and Global Solar Radiation of Awka, Anambra for the months of the year 2020

Month	H_O(mJm^{-2}day^{-1})	H_M(mJm^{-2}day^{-1})	H_M/H_O	S	S/S_o	T_{MAX} (°C)	T_{MIN} (°C)	T_{MIN}/T_{MAX}
Jan	33.82	16.10	0.476	6.00	0.513	35.83	19.35	0.54
Feb	35.91	16.20	0.451	6.10	0.517	37.03	22.8	0.61
Mar	37.48	15.60	0.416	5.70	0.476	35.41	25.57	0.72
Apr	37.67	14.00	0.372	4.00	0.329	33.48	24.39	0.72
May	36.61	14.10	0.385	4.30	0.350	33.33	24.1	0.72
Jun	35.77	14.60	0.408	4.80	0.389	31.32	23.33	0.74
Jul	35.94	14.10	0.392	4..20	0.341	29.84	23.45	0.78
Aug	36.89	13.00	0.352	3.00	0.246	30.45	22.96	0.75
Sep	36.66	13.75	0.375	3.80	0.316	29.89	23.31	0.77
Oct	36.00	14.70	0.408	4.80	0.405	31.39	22.16	0.70
Nov	34.09	15.60	0.458	5.90	0.503	34.62	24.4	0.70
Dec	32.97	15.90	0.482	6.00	0.515	34.64	23.67	0.68

Table 3: Meteorological Data and Global Solar Radiation of Awka, Anambra for the months of the year 2021

Month	H_O(mJm^{-2}day^{-1})	H_M(mJm^{-2}day^{-1})	H_M/H_O	S	S/S_o	T_{MAX} (°C)	T_{MIN} (°C)	T_{MIN}/T_{MAX}
Jan	33.82	14.50	0.429	5.20	0.445	35.5	23.6	0.66
Feb	35.91	15.60	0.434	6.00	0.508	36.83	24.06	0.65
Mar	37.48	15.30	0.408	5.80	0.485	35.58	25.2	0.70
Apr	37.67	15.00	0.398	5.20	0.428	34.9	24.7	0.70
May	36.61	14.75	0.403	4.70	0.383	32.59	24.19	0.74
Jun	35.77	14.50	0.405	4.50	0.364	31.46	23.12	0.73
Jul	35.94	13.80	0.384	3.70	0.300	30.39	23.57	0.77
Aug	36.89	14.10	0.382	4.00	0.328	30.19	23.27	0.77
Sep	36.66	14.70	0.401	4.50	0.374	30.48	23.34	0.76
Oct	36.00	13.10	0.364	3.20	0.270	32.26	23.43	0.72
Nov	34.09	15.40	0.452	5.60	0.478	32.76	23.75	0.72
Dec	32.97	15.70	0.476	6.10	0.524	34.45	21.2	0.61

Table 4: Meteorological Data and Global Solar Radiation of Awka, Anambra for the months of the year 2022

Month	H_O(mJm^{-2}day^{-1})	H_M(mJm^{-2}day^{-1})	H_M/H_O	S	S/S_o	T_{MAX} (°C)	T_{MIN} (°C)	T_{MIN}/T_{MAX}
Jan	33.82	15.60	0.461	6.00	0.513	34.67	21.85	0.63
Feb	35.91	15.30	0.426	5.60	0.474	36.68	24.17	0.65
Mar	37.48	15.50	0.414	5.90	0.493	35.7	25.89	0.72
Apr	37.67	14.30	0.380	4.20	0.346	32.69	23.89	0.73
May	36.61	14.65	0.400	4.60	0.375	31.6	23.36	0.73
Jun	35.77	14.50	0.405	4.50	0.364	30.62	23.44	0.76
Jul	35.94	14.80	0.412	4.70	0.381	29.76	23.29	0.78
Aug	36.89	14.00	0.380	4.00	0.328	29.18	23.21	0.79
Sep	36.66	13.75	0.375	3.90	0.324	29.97	23.35	0.77
Oct	36.00	13.90	0.386	4.80	0.405	30.92	23.21	0.75
Nov	34.09	15.60	0.458	5.60	0.478	34.03	24.03	0.70
Dec	32.97	15.90	0.482	6.00	0.515	35.05	22.21	0.63

Table 5: Summary of Monthly Average of Determined Data for 2020-2022 for Awka, Anambra

Month	H_M/H_O	S/S_O	T_{MIN}/T_{MAX}

Jan	0.460	0.500	0.610
Feb	0.432	0.496	0.637
Mar	0.410	0.483	0.713
Apr	0.381	0.389	0.717
May	0.391	0.373	0.730
Jun	0.396	0.370	0.743
Jul	0.393	0.341	0.777
Aug	0.377	0.316	0.770
Sep	0.394	0.344	0.767
Oct	0.386	0.360	0.723
Nov	0.456	0.486	0.707
Dec	0.480	0.518	0.640

Results

Table 6-8 shows the Regression Equations and Statistical indicates for Awka, Anambra for the year 2020, 2021 and 2022. Table 9 shows the values of the regression coefficients for the period of study, 2020-2022. Figures 1-6 shows the combined graphs of the global solar radiation using the 1st and 2nd models for the years 2020-2022.

Discussion

The results in fig. 1 shows the 1st model graph of monthly mean global radiation for Awka, Anambra 2020 predicted that solar radiation in 1st model has peak value of 0.49 $mJm^{-2}day^{-1}$ in December and least value of 0.34 $mJm^{-2}day^{-1}$ in Augusta and measured solar radiation has peak value of 0.49 $mJm^{-2}day^{-1}$ in December and least value of 0.34 $mJm^{-2}day^{-1}$ in August. Fig. 2 shows the 2nd model graph of monthly mean global solar radiation plotted against months of the year for Awka, Anambra State in 2020. The result shows that measured solar radiation has peak value of 0.49 $mJm^{-2}day^{-1}$ in December and least value of 0.32 $mJm^{-2}day^{-1}$ in August and predicted solar radiation has peak value of 0.48 $mJm^{-2}day^{-1}$ in December and least value of 0.32 $mJm^{-2}day^{-1}$ in August. Fig. 3 shows the 1st model graph of monthly mean global solar radiation plotted against months of the year for Awka, Anambra State in 2021. The result shows that measured solar radiation in 1st model has peak value of 0.48 $mJm^{-2}day^{-1}$ in December and least value of 0.36 $mJm^{-2}day^{-1}$ in October and predicted solar radiation has peak value of 0.46 $mJm^{-2}day^{-1}$ in December and least value of 0.37 $mJm^{-2}day^{-1}$ in July. Fig.4 shows the 2nd model graph of monthly mean global solar radiation plotted against months of the year for, Awka, Anambra State in 2021. The result shows that measured solar radiation in 2nd model has peak value of 0.47 $mJm^{-2}day^{-1}$ in December and least value of 0.36 $mJm^{-2}day^{-1}$ in October and predicted solar radiation has peak value of 0.45 $mJm^{-2}day^{-1}$ in December and least value of 0.36 $mJm^{-2}day^{-1}$ in October. Fig. 5 shows the 1st model graph of monthly mean global solar radiation plotted against months of the year for Awka, Anambra State in 2022. The result shows that measured solar radiation has peak value of 0.49 $mJm^{-2}day^{-1}$ in December and least value of 0.38 $mJm^{-2}day^{-1}$ in April and predicted solar radiation has peak value of 0.48 $mJm^{-2}day^{-1}$ in December and least value of 0.36 $mJm^{-2}day^{-1}$ in August. Fig. 6 shows the 2nd model graph of monthly mean global solar radiation plotted against months of the year for Anambra state in 2022. The result shows that measured solar radiation has peak value of 0.49 $mJm^{-2}day^{-1}$ in December and least value of 0.36 $mJm^{-2}day^{-1}$ in April and predicted solar radiation has peak value of 0.48 $mJm^{-2}day^{-1}$ in December and least value of 0.35 $mJm^{-2}day^{-1}$ in August.

Table 6: Regression Equations and Statistical indicators for Awka, Anambra year 2020

Model	Equations	R	R^2	RMSE($mJm^{-2}day^{-1}$)	MBE($mJm^{-2}day^{-1}$)	MPE(%)
1	$\frac{H_M}{H_O} = a + b\left(\frac{T_{MIN}}{T_{MAX}}\right)$	0.744	0.553	0.02750	-0.00046	-0.33285
2	$\frac{H_M}{H_O} = a + b\left(\frac{T_{MIN}}{T_{MAX}}\right) + c\left(\frac{S}{S_O}\right)$	0.957	0.916	0.01192	0.00017	-0.11007

Table 7: Regression Equations and Statistical indicators for Awka, Anambra year 2021

Model	Equations	R	R^2	RMSE($mJm^{-2}day^{-1}$)	MBE($mJm^{-2}day^{-1}$)	MPE (%)
1	$\frac{H_M}{H_O} = a + b\left(\frac{T_{MIN}}{T_{MAX}}\right)$	0.745	0.555	0.02012	0.00029	-0.30768
2	$\frac{H_M}{H_O} = a + b\left(\frac{T_{MIN}}{T_{MAX}}\right) + c\left(\frac{S}{S_O}\right)$	0.883	0.780	0.01416	-0.00047	0.00720

Table 8: Regression Equations and Statistical indicators for Awka, Anambra year 2022

Model	Equations	R	R^2	RMSE($mJm^{-2}day^{-1}$)	MBE($mJm^{-2}day^{-1}$)	MPE(%)
1	$\frac{H_M}{H_O} = a + b\left(\frac{T_{MIN}}{T_{MAX}}\right)$	0.826	0.682	0.01913	-0.00016	-0.16814
2	$\frac{H_M}{H_O} = a + b\left(\frac{T_{MIN}}{T_{MAX}}\right) + c\left(\frac{S}{S_O}\right)$	0.889	0.789	0.01558	-0.00070	0.03961

Table 9: Values of the regression coefficients for the 2020, 2021 and 2022

Year	Model	A	B	c
2020	1	0.745	-0.471	-
	2	0.301	-0.070	0.399
2021	1	0.745	-0.467	-
	2	0.367	-0.101	0.284
2022	1	0.787	-0.517	-
	2	0.406	-0.169	0.312

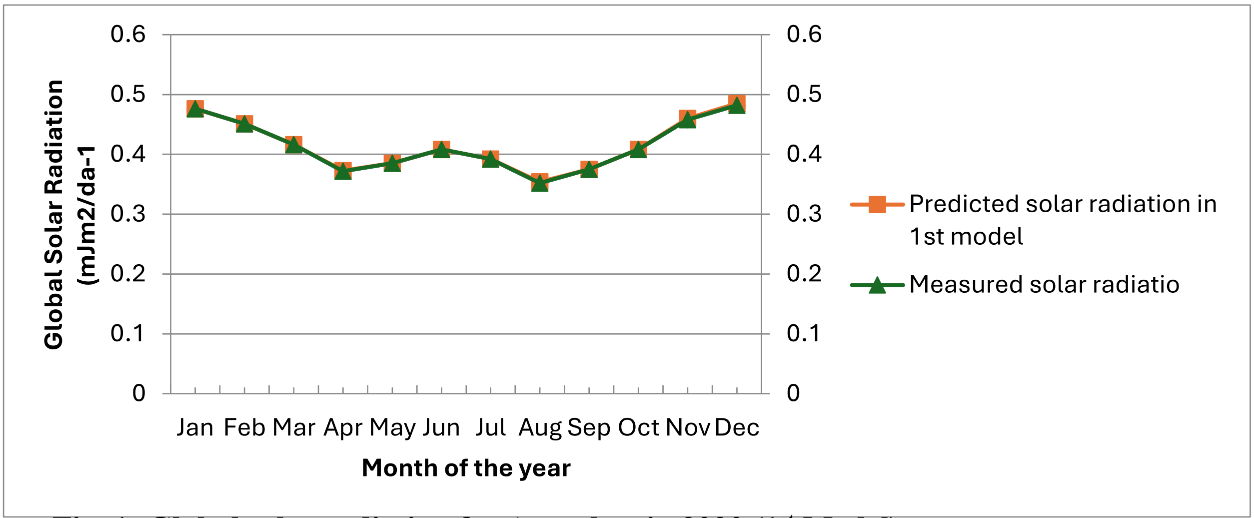

Fig. 1: Global solar radiation for Anambra in 2020 (1st Model)

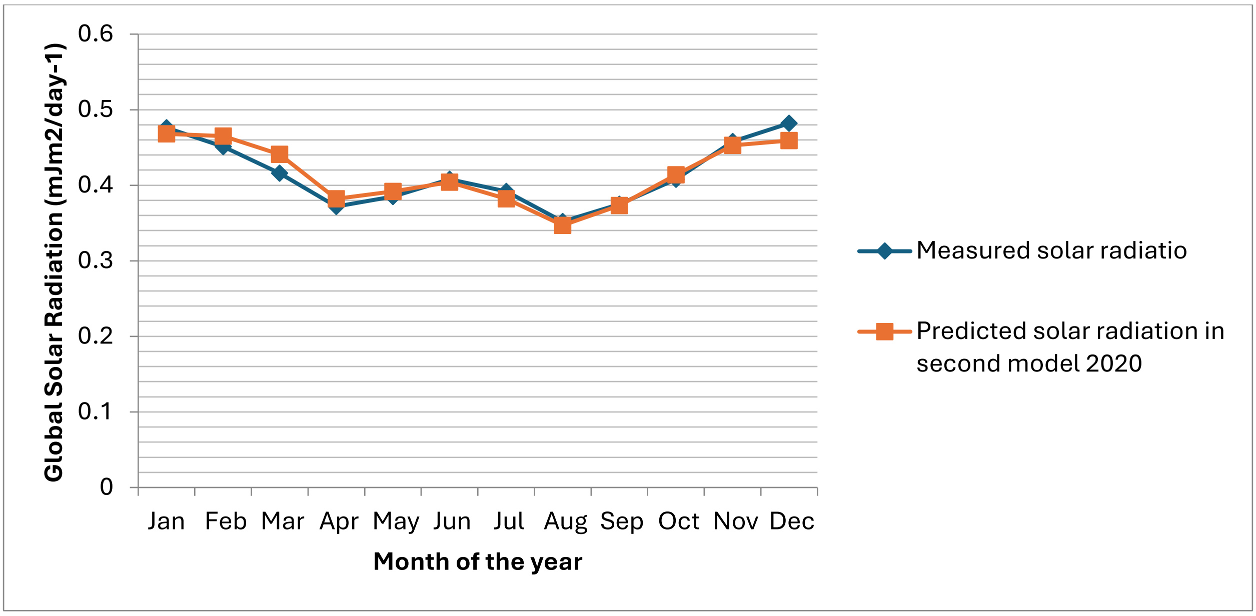

Fig. 2: Global solar radiation for Awka, Anambra in 2020 (2nd Model)

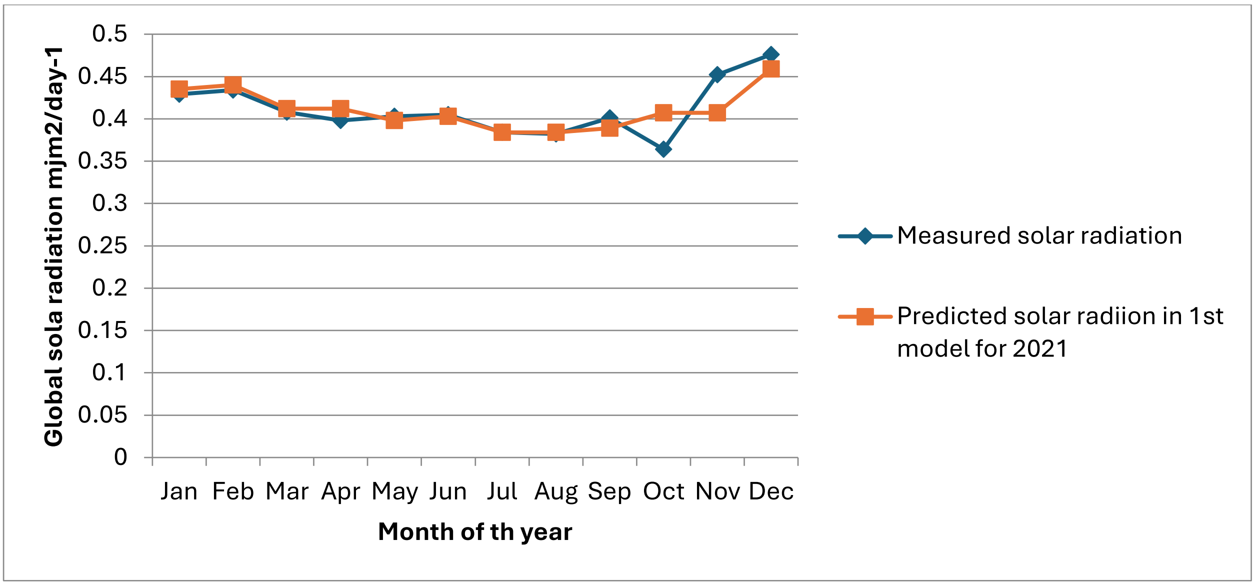

Fig. 3: Global solar radiation for Awka, Anambra in 2021 (1st Model)

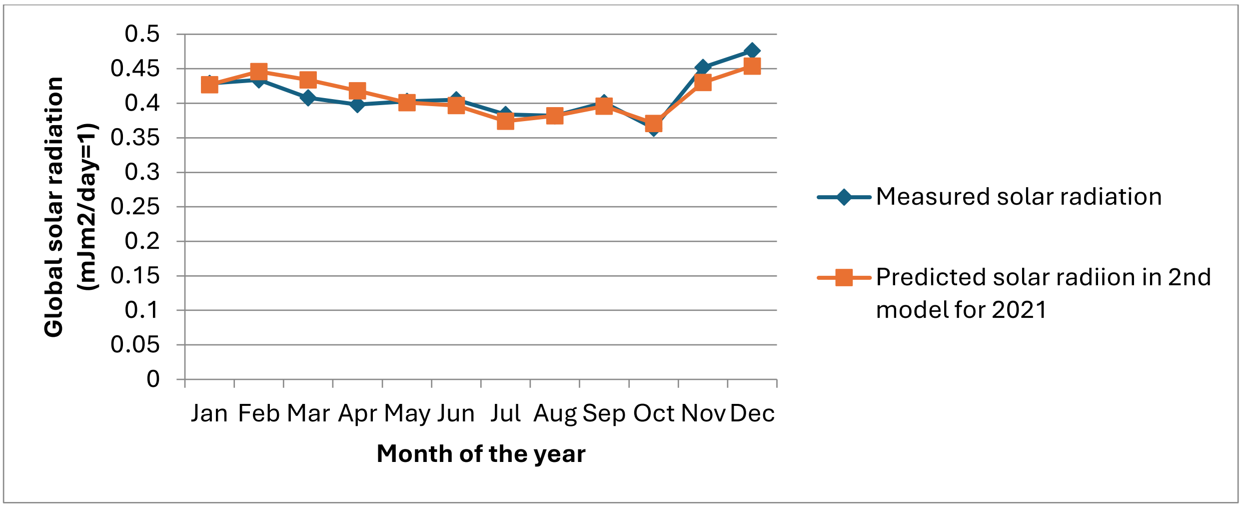

Fig. 4: Global solar radiation for Awka, Anambra in 2021 (2nd Model)

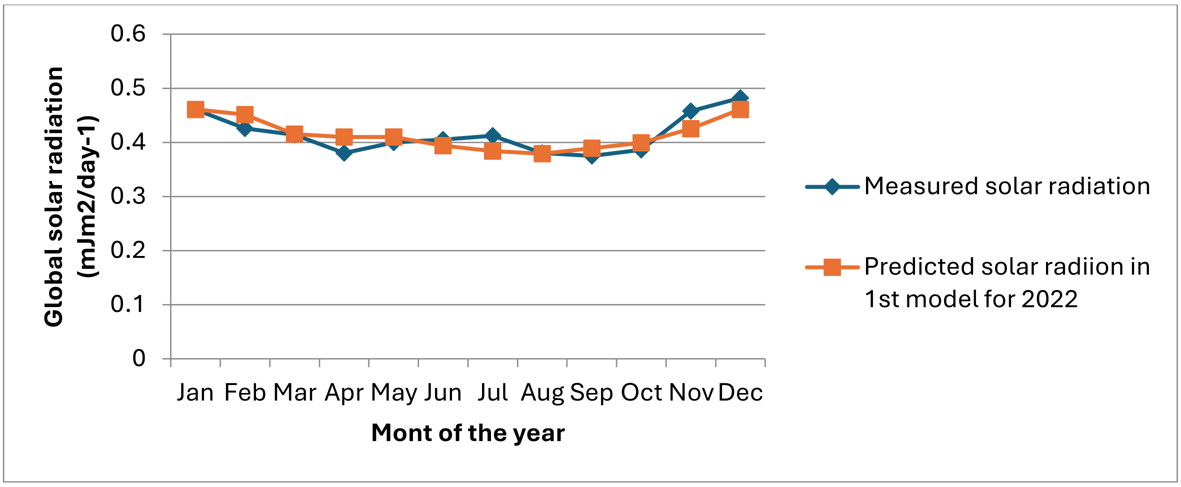

Fig. 5: Global solar radiation for Awka, Anambra in 2022 (1st Model)

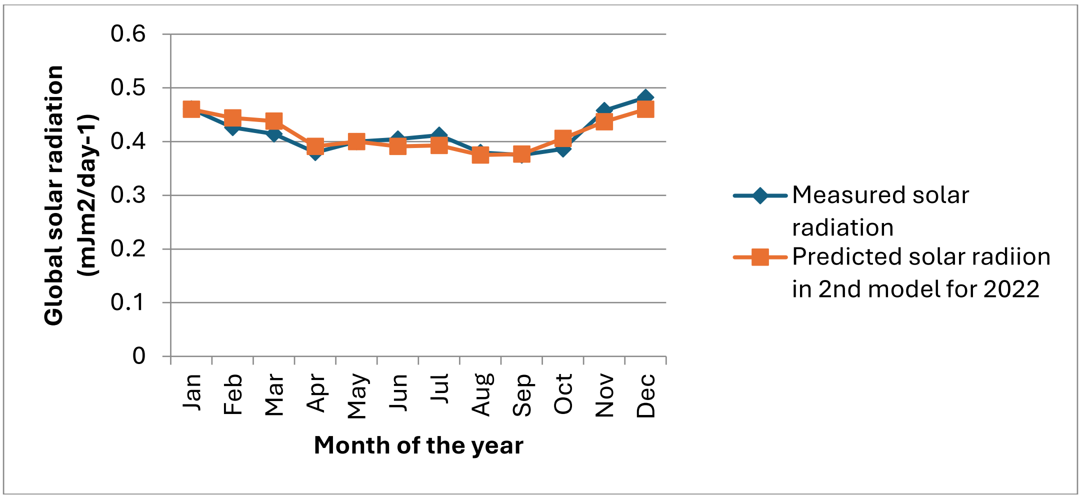

Fig. 6: Global solar radiation for Awka, Anambra in 2022 (2nd Model)

Conclusion

The measured meteorological data were successfully used to estimate and analyze the solar radiation of Awka, Anambra State. The global solar radiation intensity obtained with those models can be used in the design. Analyse and perform evaluation of solar energy conversion systems which is gradually but steadily gaining ground in Nigeria and the world at large. The statistical error analysis carried out were MBE, RME and MPE were chosen as the best regression model that could be used to measure global solar radiation of Awka, Anambra State.

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