VOL 8, NO 1, JUNE 2022.
ISSN: 2276-7924
www.ijssyabatech.com

EVALUATION OF MODELS FOR GLOBAL SOLAR RADIATION PREDICTION IN THE SIX GEOGRAPHICAL ZONES OF NIGERIA

Oba, M. O. and Akande, M. O.

Department of Physical Science, Yaba College of Technology, Yaba, Lagos

Corresponding Author: obamichael300@gmail.com, +234-08034228420

ABSTRACT

Estimation of solar radiation is considered as the most important parameter for the design and development of various solar energy systems. However, the availability of the required data is very scarce and often not readily accessible. The limited availability of solar radiation data makes it vital to develop models to estimate these data. This study assessed the performance of different solar radiation models namely: Angstrom-Prescott, Badescu, Pandey and Katiyar, Okundamiya and Nzeako, Fagbenle's and lastly Glover-McCulloch's model. The aim of this study was to determine the most accurate model, for evaluating models to predict global solar radiation in the six geographical zones of Nigeria. The data used in the analysis consist of monthly global solar radiation, sunshine hours, relative humidity and temperature collected from the Nigerian Meteorological Agency (NIMET) over a period of five years (2014-2018). The performances of the models were compared on the basis of statistical error tests, namely: mean percentage error (MPE), root mean square error (RMSE), mean bias error (MBE), and regression coefficient (R). Regression constants are determined for each of the model for each month of the year. This study reveals that the Okundamiya-Nzeako model gives the best estimation of the global solar radiation in North East, South South, North West, North Central and South West zones since it has the least value of RMSE and MPE. The values of RMSE and MPE for Bauchi, Delta, Kano, Kwara and Lagos states are: (0.704, -0.129); (0.722, -0.139); (0.923, -0.262); (0.629, -0.110) and (0.755, -0.148) respectively.

KEYWORDS: Solar radiation, sunshine hours, relative humidity, temperature

INTRODUCTION

Solar radiation is the most abundant and evenly distributed energy resource on earth. The amount of energy released by the sun (captured by earth) during one hour may be sufficient to cover the world's energy needs for one year. Part of this radiation can be used directly to produce heat (solar thermal) or electricity called photovoltaic solar energy. This mode of production does not require network distribution, because it can generate electricity and can be consumed in places such as villages, detached houses (one third of the world's population lacks access to electricity), water pumping, and refuges (Gronewold, 2009). The sun discharges continuously an enormous amount of energy radiant in the solar system. Earth intercepts a small portion of this energy radiated into space. An average of 1367 watts per square meter reaches the edge outside of the terrestrial atmosphere (for an average distance Earth sun 150 million kilometers), this quantity is called the solar constant. The energy received by Earth's surface depends on the thickness of the atmospheric crossing, which is the function of air mass (Abedelak *et al.*, 2013).

The usage of renewable energy resources has risen largely in the last years owing to the ever increasing need for electrical energy, the limited fossil fuel resources needed for generation of conventional electrical power, and the global environmental concerns over the use of fossil fuels. (Gielen and Gorini, 2019). Solar energy is one of the most promising renewable sources. It is environmentally friendly, plentiful and easy to utilize. A detailed and accurate knowledge of the local solar radiation is essential for the optimum design and study of solar energy conversion system. The global solar radiation can be divided into two components: diffuse solar radiation, which results from scattering caused by gases in the Earth's atmosphere, dispersed water droplets and particulates; and direct solar radiation, which have not been scattered. Global solar radiation is the algebraic sum of the two components used measurements of global and diffuses solar radiations (Oliveira *et al*., 2002).

The use of solar energy, like any other natural resources, requires detailed information on availability of the amount of total solar radiation striking the earth surface. This total amount of solar radiation incidents on the earth surface is called global solar radiation. Global solar radiation data are necessary at various steps of the design, engineering, simulation and performance evaluation of any project involving solar energy. Solar radiation provides the energy for photosynthesis and transpiration of crops and is one of the meteorological factors determining potential yields. Crop growth models, which have been developed since the 1960s, have been regarded as important tools of interdisciplinary research and have since been used in a number of areas such as the assessment of agriculture potential of a given region in the field of crop yield forecasting or as a climate change impact assessment tool. (Falayi *et al.*, 2019). Actually, the mapping of the solar radiant energy on the Earth's surface is a requirement not only in the studies of climate change, environmental pollution but also in agriculture, hydrology, food industry and non-conventional energy development programs (Iqbal 1983).

In developing countries namely Ghana, India, Nigeria etc, the facility for global radiation measurement is available at a few places while bright sunshine hours are measured at many locations. Some cannot even afford the equipment's and techniques involved. For such countries it is essential that correlations be developed so as to predict global solar radiation from readily measured data (Augustine *et al.*, 2010).

The best way of knowing the amount of global solar radiation at a site is to install pyranometer at different locations in the given region and look after their day-to-day maintenance and recording but this method is very expensive. An alternative approach is to correlate the global solar radiation with the meteorological parameters at the place where the data is collected. The resultant correlation may then be used for locations of similar meteorological and geographical characteristics at which solar data are not available.

This work, apart from predicting the best model for global solar radiation especially, for regions that encounter difficulties in harnessing solar radiation data due to lack of good equipment's, it will help the energy strategists and planners to utilize the solar potentials to solve the energy crises of this area of abundant sunshine.

The best way of knowing the amount of global solar radiation at a site is to install pyranometers at different locations in the given region and look after their day-to-day maintenance and recording but this method is very expensive. An alternative approach is to correlate the global solar radiation with the meteorological parameters at the place where the data is collected. The resultant correlation may then be used for locations of similar meteorological and geographical characteristics at which solar data are not available.

The aim of this study is to identify suitable models for global solar radiation in the six geographical zones in Nigeria.

MATERIALS AND METHODS

Data Acquisition

The data for this study was acquired from Nigeria Meteorological Agency (NIMET), Abuja, Nigeria. The data obtained were from the six geographical zones in Nigeria: North East (Bauchi), South South (Delta), South East (Enugu), North West (Kano), North Central (Kwara) and South West (Lagos) for the period of five years (2014-2018)

.

Fig 3.1: Nigeria map showing the six geopolitical zones

The datasets includes:

1. Solar radiation (2014-2018)
2. Temperature (2014-2018)
3. Relative humidity (2014-2018)
4. Sunshine hours. (2014-2018)

Data Processing

Working with Meteorological Data

The data obtained from NIMET, were monthly data of solar radiation, temperature, relative humidity and sunshine hours for six different stations over a period of 5 years (2014-2018).

For the various stations, the local data from NIMET was compared with the global solar radiation and an analysis was carried out using statistical method.

The linear regression model used in correlating the measured global solar radiation data (H) data with relative sunshine duration (S/S_o) was given after Angstrom (1924) and later modified by Prescott (1960):

$$\frac{H}{H_o} = \left[a + b\left(\frac{S}{S_O}\right)\right] \quad (1)$$

Where: a and b are regression constants,
H is the measured monthly mean daily global solar radiation,
H_o is the monthly mean horizontal daily total extraterrestrial solar radiation.

Extraterrestrial solar radiation is the maximum amount of solar radiation available to the earth at the top of the atmosphere. The monthly average daily extraterrestrial radiation on a horizontal surface (H_o) can be calculated for days giving average of each month:

$$H_o = \left(\frac{24}{\pi}\right) I_{SC}\left[1 + 0.033 Cos\left(\frac{360n}{365}\right)\right]\left[Cos\varphi Cos\delta Sin W_s + \left(\frac{2\pi W_s}{360}\right) Sin\varphi Sin\delta\right] \qquad (2)$$

Where:
I_{sc} is the solar constant (=1367 Wm^{-2}),
φ is the latitude of the site,
δ is the solar declination and
W_s is the mean sunrise hour angle for the given month and
n is the number of days of the year starting from January to December.
The solar declination δ and the mean sunrise hour angle W_s can be calculated using the following equation (Iqbal, 1983; Zekai, 2008):

$$\delta = 23.45 \sin\left[360\left(\frac{284+n}{365}\right)\right] \qquad (3)$$

$$W_s = Cos^{-1}(-\tan\varphi \tan\delta) \qquad (4)$$

For a given month, the maximum possible sunshine duration (monthly average day length) S_o in hours can be computed (Iqbal, 1983; Zekai, 2008) by

$$S_o = \frac{2}{15} W_s \qquad (5)$$

The clearness index (K_T) is defined as the ratio of the observed/measured horizontal terrestrial solar radiation H, to the calculated horizontal extraterrestrial solar radiation H_o. The clearness index (K_T) gives the percentage deflection by the sky of the incoming global solar radiation and therefore indicates both the level of availability of solar radiation and changes in atmospheric conditions in a given locality (Falayi *et al.*, 2011).

$$K_T = \frac{H}{H_o} \qquad (6)$$

In this study, H_o and S_o will be computed for each month using equations (1) and (5) respectively. The correctness among the models will be determined using the data measured between the periods of 2014-2018. After analysis, the regression constants a, b, c and d for the stations will be determined by correlating the global solar radiation with the meteorological data. (Muzathik, 2011). The accuracy of the estimated values will be tested by calculating the expression forr MBE, Mean Bias Error ($MJm^{-2}day^{-1}$) Root Mean Square Error RMSE, Root Mean Square Error ($MJm^{-2}day^{-1}$) ; and MPE, Mean Percentage Error (%) as stated by El – Sebaii and Trabea (2005) as follows:

Statistical Analysis:

$$MBE = \sum(H_{cal} - H_{meas})/n \qquad (7)$$

$$RMSE = \left[\sum(H_{cal} - H_{meas})^2/n\right]^{1/2} \qquad (8)$$

$$MPE = \left[\sum\left(H_{meas} - \frac{H_{cal}}{H_{meas}} \times 100\right)\right]/n \qquad (9)$$

RESULTS

The regression constants a, b, c and d for the six geographical zones in Nigeria were determined by correlating the global solar radiation with the meteorological data.

The proposed models for this study are shown below:

1. **Angstrom – Prescott (1940):** $\frac{H}{H_o} = a + b\frac{S}{S_o}$
2. **Badescu (1999):** $\frac{H}{H_o} = a + bT_{max}$
3. **Pandey &Katiyar (2010):** $\frac{H}{H_o} = a + b\frac{S}{S_o} + c\,T_{max}$
4. **Okundamiya&Nzeako (2010) :** $\frac{H}{H_o} = a + b\frac{S}{S_o} + c\,T_{max} + dRH$
5. **Fagbenle (1992):** $\frac{H}{H_o} = a + b\frac{S}{S_o} + c\left(\frac{S}{S_o}\right)^2$
6. **Glover & McCulloch's (1958):** $\frac{H}{H_o} = a\cos\varphi + b\frac{S}{S_o}$

RMSE and MBE statistical indicators are commonly used in comparing the models of solar radiation predictions. Low values of RMSE are desirable (*Slavica and Blanka, 2018*), but few errors in the sum can produce a significant increase in the indicator. Low values of MBE are desirable (*Slavica and Blanka, 2018*), but overestimation of an individual data element will cancel underestimation in a separate observation. It is also possible to have large RMSE values at the same time a small MBE or vice versa. The use of RMSE and MBE statistical indicator is not adequate for the evaluation of models performance and we concluded that MPE is used in addition to RMSE and MBE to give more reliable result. MPE gives long term performance of the examined regression equations, a positive MPE values provides the averages amount of overestimation in the calculated values, while the negatives value gives underestimation. A low value of MPE is desirable. (*Slavica and Blanka, 2018*)

Measured solar radiation and the calculated solar radiation from all the five models were compared using graphical representations as presented in figure 1 to figure 5

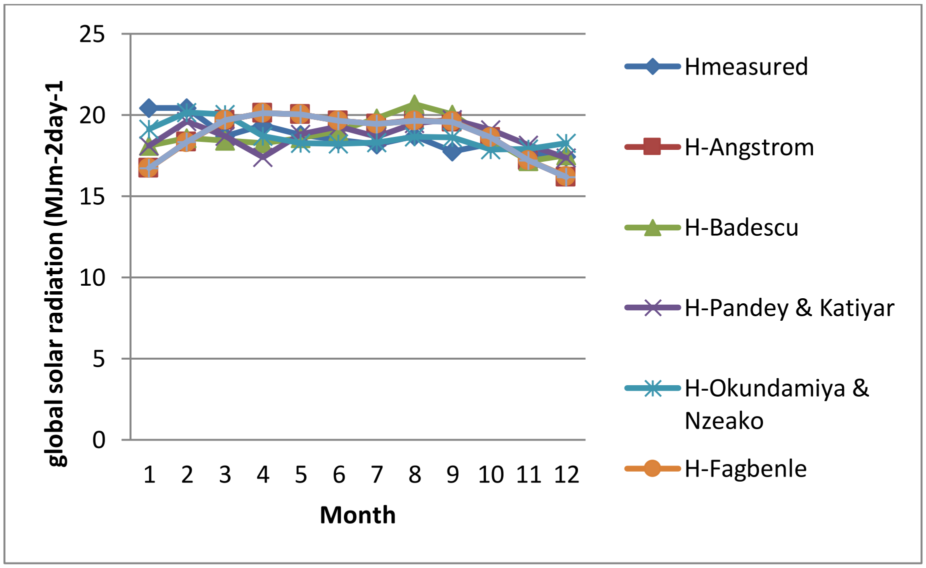

Fig 1: Comparison between the measured and calculated global solar radiation for Bauchi

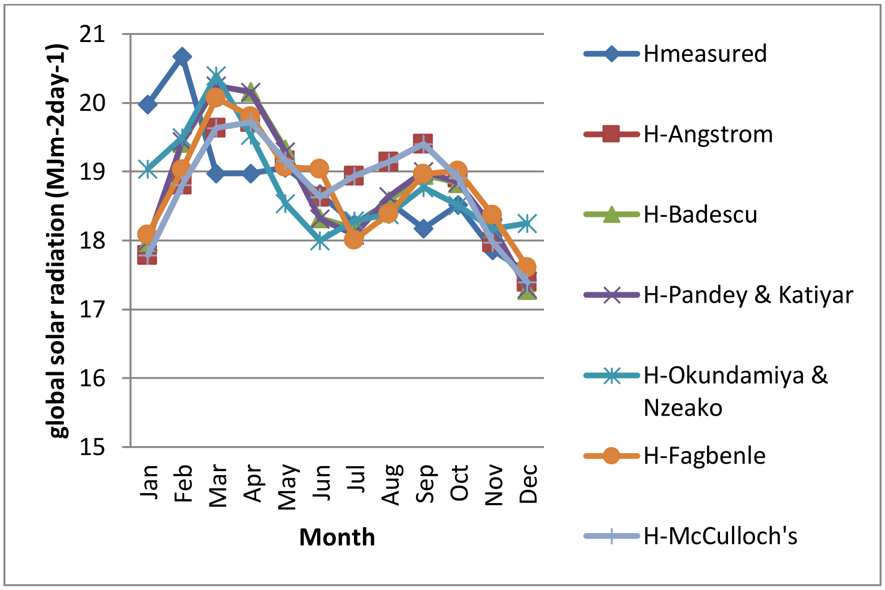

Fig 2: Comparison between the measured and calculated global solar radiation for Delta

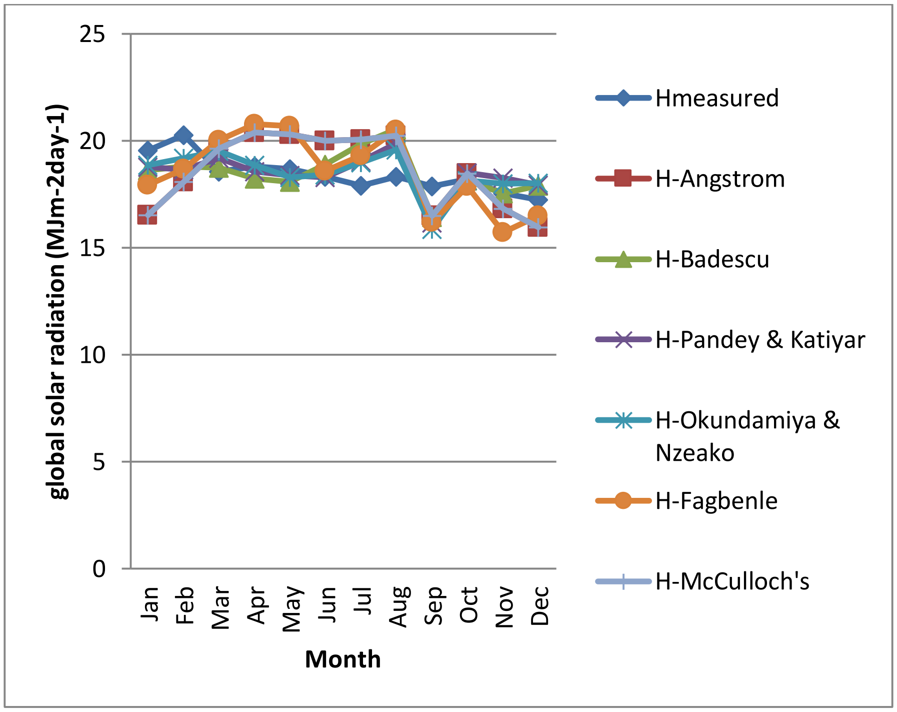

Fig 3: Comparison between the measured and calculated global solar radiation for Kano

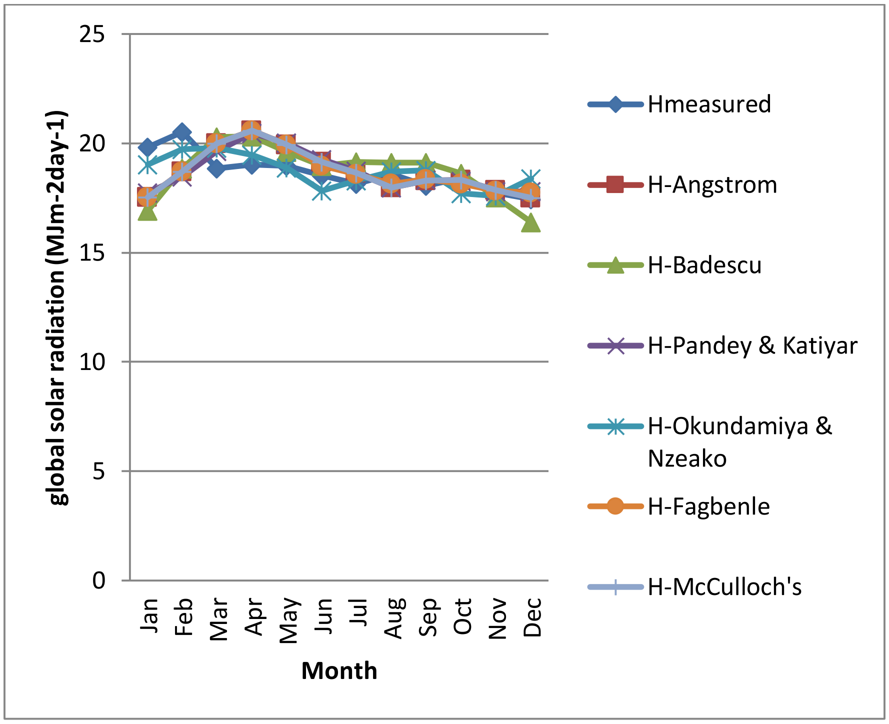

Fig 4: Comparison between the measured and calculated global solar radiation for Kwara

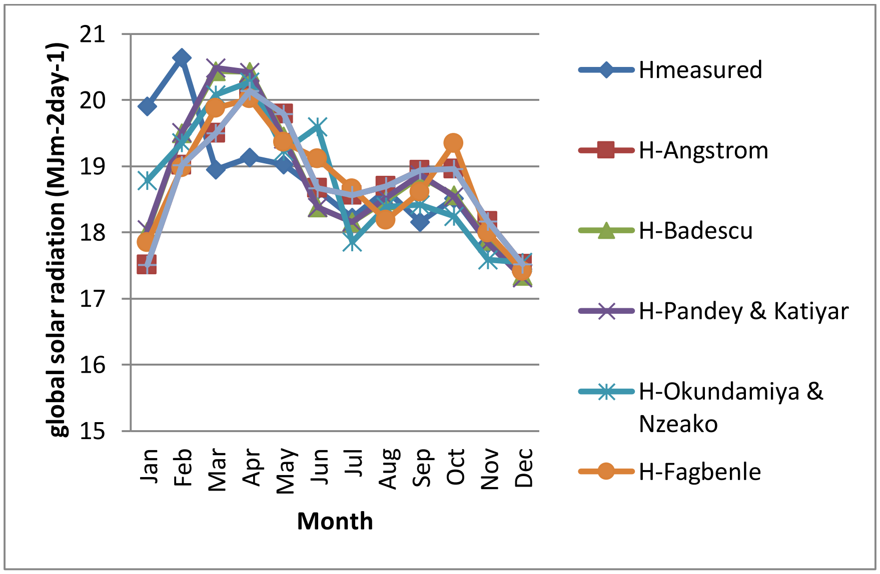

Fig 5: Comparison between the measured and calculated global solar radiation for Lagos

Table 1: Regression equation and statistical indicators for Bauchi State (2014-2018)

Model	a	B	C	d	R	R^2	MBE	RMSE	MPE
Angstrom-Prescott	0.495	0.062			0.079	0.006	0.093	1.584	-0.720
Badescu	0.831	-0.011			0.566	0.321	0.047	1.369	-0.500
Pandey &Katiyar	0.733	0.379	-0.016		0.704	0.500	0.025	1.170	-0.362
Okundamiya&Nzeako	0.886	0.045	-0.011	-0.152	0.901	0.811	0.001	0.704	-0.129
Fagbenle	0.442	0.244	-0.154		0.080	0.006	0.093	1.585	-0.720
Glover & McCulloch's	0.503	0.062			0.996	0.992	0.093	1.584	-0.720

Table 2: Regression equation and statistical indicators for Delta State (2014-2018)

Model	a	b	c	d	R	R^2	MBE	RMSE	MPE
Angstrom-Prescott	0.514	0.028			0.082	0.007	0.020	0.990	-0.269
Badescu	0.203	0.011			0.438	0.191	0.021	0.898	-0.218
Pandey &Katiyar	0.201	-0.015	0.012		0.439	0.193	0.021	0.898	-0.218
Okundamiya&Nzeako	0.969	0.033	-0.007	-0.329	0.699	0.488	0.007	0.722	-0.139
Fagbenle	0.368	0.824	-1.031		0.443	0.197	0.015	0.893	-0.215
Glover & McCulloch's	0.516	0.029			0.999	0.997	0.020	0.990	-0.269

Table 3: Regression equation and statistical indicators for Kano State (2014-2018)

Model	a	b	C	d	R	R^2	MBE	RMSE	MPE
Angstrom-Prescott	0.536	0.004			0.004	1.72E-05	0.138	1.709	-0.847
Badescu	0.855	-0.011			0.771	0.594	0.042	1.124	-0.349
Pandey &Katiyar	0.703	0.305	-0.013		0.816	0.665	0.010	0.975	-0.282
Okundamiya&Nzeako	0.799	0.110	-0.011	-0.059	0.831	0.691	0.033	0.923	-0.262
Fagbenle	-3.542	12.897	-10.110		0.464	0.216	0.124	1.543	-0.677
Glover & McCulloch's	0.548	0.004			0.996	0.991	0.138	1.709	-0.847

Table 4: Regression equation and statistical indicators for Kwara State (2014-2018)

Model	a	b	c	d	R	R^2	MBE	RMSE	MPE
Angstrom-Prescott	0.418	0.205			0.585	0.342	0.037	1.087	-0.321
Badescu	0.281	0.009			0.287	0.083	0.063	1.262	-0.457
Pandey &Katiyar	0.545	0.245	-0.005		0.599	0.359	0.032	1.073	-0.313
Okundamiya&Nzeako	0.834	-0.049	-0.003	-0.310	-0.003	-0.310	0.006	0.629	-0.110
Fagbenle	0.505	-0.169	0.382		0.592	0.350	0.035	1.077	-0.317
Glover & McCulloch's	0.423	0.205			0.998	0.996	0.037	1.087	-0.321

Table 5: Regression equation and statistical indicators for Lagos State (2014-2018)

Model	a	b	c	d	R	R^2	MBE	RMSE	MPE
Angstrom-Prescott	0.479	0.111			0.365	0.134	0.023	0.971	-0.261
Badescu	0.142	0.014			0.547	0.300	0.025	0.795	-0.212
Pandey &Katiyar	0.129	-0.011	0.014		0.548	0.300	0.025	0.892	-0.212
Okundamiya&Nzeako	0.777	0.016	0.003	-0.409	0.713	0.507	0.017	0.755	-0.148
Fagbenle	0.308	1.001	-1.094		0.470	0.221	0.021	0.928	-0.234
Glover & McCulloch's	0.482	0.111			0.999	0.997	0.023	0.971	-0.261

Table 6 to 10 shows how the measured and calculated solar radiation relatively agreed in values for Bauchi, Delta Kano, Kwara, and Lagos state.

Table 6: Monthly mean daily measured and calculated values of global solar radiation for Bauchi state

Month	H_M	H_1	H_2	H_3	H_4	H_5	H_6
Jan	20.43	16.73	18.09	18.09	19.15	16.75	16.73
Feb	20.45	18.35	18.6	19.61	20.15	18.32	18.35
Mar	18.71	19.68	18.42	18.70	20.02	19.69	19.68
Apr	19.37	20.11	18.27	17.41	18.70	20.11	20.11
May	18.78	20.02	18.58	18.81	18.28	20.03	20.02
Jun	18.47	19.65	19.03	19.29	18.21	19.64	19.65
Jul	18.2	19.46	19.8	18.68	18.3	19.44	19.46
Aug	18.7	19.67	20.66	19.49	18.66	19.63	19.66
Sep	17.76	19.57	20.05	19.74	18.64	19.6	19.57
Oct	18.23	18.62	18.5	19.09	17.86	18.62	18.62
Nov	17.62	17.21	17.18	18.14	17.9	17.19	17.21
Dec	17.42	16.19	17.51	17.38	18.28	16.21	16.19

Table 7: Monthly mean daily measured and calculated values of global solar radiation for Delta state

Month	H_M	H_1	H_2	H_3	H_4	H_5	H_6
Jan	19.98	17.79	17.98	17.99	19.04	18.08	17.79
Feb	20.68	18.81	19.42	19.44	19.50	19.03	18.81
Mar	18.98	19.64	20.24	20.25	20.4	20.07	19.64
Apr	18.98	19.72	20.17	20.16	19.53	19.8	19.72
May	19.06	19.16	19.33	19.29	18.54	19.07	19.16
Jun	18.68	18.63	18.33	18.32	18.00	19.04	18.63
Jul	18.24	18.94	18.18	18.08	18.29	18.01	18.94
Aug	18.56	19.14	18.58	18.64	18.38	18.39	19.14
Sep	18.18	19.40	18.96	19.00	18.77	18.97	19.4
Oct	18.52	18.91	18.84	18.85	18.51	19.01	18.91
Nov	17.86	17.97	18.2-	18.20	18.17	18.37	17.97
Dec	17.54	17.40	17.29	17.3	18.25	17.61	17.40

Table 8: Monthly mean daily measured and calculated values of global solar radiation for Kano state

Month	H_M	H_1	H_2	H_3	H_4	H_5	H_6
Jan	19.54	16.53	18.62	18.76	18.86	17.94	16.53
Feb	20.26	18.08	18.80	18.67	19.20	18.68	18.08
Mar	18.58	19.64	18.75	19.19	19.53	20.02	19.64
Apr	18.80	20.40	18.24	18.56	18.86	20.79	20.40
May	18.70	20.29	18.09	18.40	18.29	20.68	20.29
Jun	18.34	20.00	18.89	18.30	18.41	18.60	20.00
Jul	17.90	20.06	19.86	19.03	18.98	19.31	20.06
Aug	18.34	20.23	20.54	19.88	19.57	20.52	20.23
Sep	17.88	16.51	16.45	16.16	15.86	16.20	16.51
Oct	18.22	18.47	18.15	18.52	18.15	17.87	18.47
Nov	17.54	16.83	17.54	18.28	17.99	15.73	16.83
Dec	17.24	15.96	17.90	17.94	18.02	16.49	15.96

Table 9: Monthly mean daily measured and calculated values of global solar radiation for Kwara state

Month	H_M	H_1	H_2	H_3	H_4	H_5	H_6
Jan	19.82	17.55	16.92	17.73	19.02	17.54	17.55
Feb	20.52	18.72	18.85	18.49	19.74	18.71	18.72
Mar	18.86	20.01	20.3	19.64	19.78	20	20.01
Apr	19.04	20.59	20.32	20.48	19.47	20.58	20.59
May	18.96	19.95	19.61	20.02	18.88	19.93	19.95
Jun	18.54	19.14	18.98	19.28	17.83	18.97	19.14
Jul	18.14	18.66	19.15	18.74	18.3	18.59	18.66
Aug	18.58	17.97	19.12	17.97	18.71	18.15	17.97
Sep	18.08	18.3	19.12	18.32	18.78	18.36	18.3
Oct	18.42	18.34	18.61	18.28	17.71	18.16	18.34
Nov	17.74	17.85	17.55	17.79	17.6	17.84	17.85
Dec	17.44	17.50	16.39	17.79	18.39	17.75	17.5

Table 10: Monthly mean daily measured and calculated values of global solar radiation for Lagos state

Month	H_M	H_1	H_2	H_3	H_4	H_5	H_6
Jan	19.91	17.51	18.01	18.04	18.79	17.85	17.51
Feb	20.64	19.02	19.5	19.51	19.36	18.98	19.02
Mar	18.95	19.5	20.44	20.49	20.08	19.88	19.5
Apr	19.13	20.14	20.43	20.42	20.27	20.02	20.14
May	19.03	19.79	19.45	19.41	19.23	19.37	19.79
Jun	18.64	18.67	18.38	18.38	19.6	19.11	18.67
Jul	18.22	18.56	18.16	18.16	17.86	18.66	18.56
Aug	18.64	18.7	18.49	18.52	18.39	18.19	18.7
Sep	18.16	18.94	18.84	18.87	18.42	18.61	18.94
Oct	18.51	18.96	18.56	18.54	18.24	19.35	18.96
Nov	17.84	18.17	17.88	17.84	17.59	17.99	18.17
Dec	17.51	17.52	17.34	17.32	17.55	17.41	17.52

DISCUSSION

From the previous tables it was found that Okundamiya and Nzeako model is the most appropriate, to predict index clearance in Bauchi, Delta Kano, Kwara and Lagos states since it has the smallest value of RMSE and MPE. Figures.1-.5 show the input parameters of the models for Bauchi, Delta, Kano, Kwara state between 2014-2018. From figure 1 it was observed that the highest and lowest temperatures occurred in April and January respectively in Bauchi state, from figure 2 it was observed that the highest and lowest temperatures occurred in February and August for Delta state, from figure 3 it was observed that the highest and lowest temperatures occurred in May and January respectively for Kano state. From figure 4 it was observed that the highest and lowest temperatures occurred in March and August respectively for Kwara, from figure 5 it was observed that highest and lowest temperatures occurred in February and August for Lagos state. This is expected, since the months February and August are characterized by heavy sunshine and dry atmosphere respectively, the month of July is characterized by heavy rainfall while the month of December is characterized by harmattan haze which greatly reduces the intensity of solar radiation (Ekpe and Nnabuchi, 2012). It is also observed that the global solar radiation has highest values in the month of February for all states while the lowest values were recorded in the month of December for all states also.

Tables 1 to 5 show the regression equation and statistical indicators for Bauchi, Delta, Kano, Kwara and Lagos states between 2014-2018 revealing that the Okundamiya-Nzeako model shows the best estimation of the global solar radiation in the states, since it has the least value of RMSE and MPE. The values of RMSE and MPE for Bauchi, Delta, Kano, Kwara and Lagos states are: (0.704, -0.129); (0.722, -0.139); (0.923, -0.262); (0.629, -0.110) and (0.755, -0.148) respectively.Hence, Okundamiya &Nzeako model with regression coefficients a, b, c and d as (0.886, 0.045, -0.011, -0.152), (0.969, 0.033, -0.007, -0.329), (0.799, 0.110, -0.011, -0.059), (0.834, -0.049, -0.003, -0.310) and (0.777, 0.016, 0.003, -0.409) is recommended to estimate monthly average global solar radiation for Bauchi, Delta, Kano, Kwara and Lagos respectively.

Tables 6 to 10 show how the measured and calculated solar radiation relatively agreed in values for Bauchi, Delta, Kano, Kwara and Lagos states. Figures 1 to 5 shows the graphical representations between measured solar radiation and the calculated solar radiation by comparing the five models for Bauchi, Delta, Kano, Kwara and Lagos states from January to December (2014-2018).

As noticed the calculated values of error indices of studied models (shown in Tables 1 – 5) vary from one place to another. The difference is perhaps due to seasonal variations of the solar radiation caused apparently by the degree of cloud cover, presence of water vapour and ozone, and atmospheric dust in the atmosphere that differs from one place to another. The highest RMSE values (0.971, 0.990, 1.262, 1.585, and 1.709 $MJm^{-2}day^{-1}$) are produced respectively by Angstrom-Prescott, Glover & McCulloch's, Badescu, Fagbenle and Angstrom-Prescott models for the geographical zones but Okundamiya & Nzeako model provides the lowest range (0.629 – 0.923 $MJm^{-2}day^{-1}$) throughout the studied locations. The MBE values vary between under-estimation and over-estimation. The MBE achieved in this study are in the acceptable range.

The results have been compared with those obtained by Ogolo (2010) who investigated the performance of some predictive models for estimating global solar radiation across the varying climatic conditions in Nigeria. Ogolo (2010) carried out model evaluation to determine which model(s) is/are more suitable for a given climatic condition. His results revealed that temperature and sunshine hour dependent models are more suitable for the simulation of global solar radiation in Sahelian Guinea Savannah climatic conditions, respectively; while all the models exihibited the tendency to perform suitably well in the Midland and Coastal areas.

According to this study, Okundamiya and Nzeako model which is temperature and sunshine hours dependent shows the best evaluation of the global solar radiation for all sites in agreement with the findings of Ogolo (2010). Also, Olomiyesan *et al* (2017) carried out evaluation of some global solar radiation models in selected locations in Northwest, Nigeria. They discovered that Angstrom-Prescott model is not suitable for estimating global solar radiation in the study area in agreement with our study that shows Angstrom—Prescott with highest RMSE which indicates less suitability for the study area.

CONCLUSION

Model calculations were carried out using a few models (sunshine hour, temperature, relative humidity and latitude dependent) for the estimation of monthly mean global solar radiation for various geographical zones in Nigeria. The study assessed the performance of different solar radiation models namely: Angstrom-Prescott model, Badescu model, Pandey and Katiyar model, Okundamiya and Nzeako model, Fagbenle model and lastly Glover-McCulloch's model. The performances of the models were compared on the basis of statistical error tests, namely: mean percentage error (MPE), root mean square error (RMSE), mean bias error (MBE), and regression coefficient (R). The study reveals that the Okundamiya-Nzeako model gives the best estimation of the global solar radiation in the study areas. The results of this work show clearly the importance of developing empirical approaches for formulating the global solar radiation field reaching the earth at different locations. Based on the statistical results, a new simple linear model $H/H_o = 0.886 + 0.045(S/S_o) - 0.011(T_{max}) - 0.152(RH)$, $H/H_o = 0.969 + 0.033(S/S_o) - 0.007(T_{max}) - 0.329(RH)$, $H/H_o = 0.799 + 0.110(S/S_o) - 0.011(T_{max}) - 0.059(RH)$, $H/H_o = 0.834 - 0.049(S/S_o) - 0.003(T_{max}) - 0.310(RH)$, $H/H_o = 0.777 + 0.016(S/S_o) + 0.003(T_{max}) - 0.409(RH)$ based on Okundamiya and Nzeako model are highly recommended to estimate global solar radiation for all the geographical zones in Nigeria and elsewhere with similar climatic conditions, and also some areas if the radiation data is missing or unavailable.

ACKNOWLEDGEMENT

The authors wish to thank the Nigerian Meteorological Agency, Oshodi, Lagos, Nigeria for releasing all the data used for carrying out this study.

REFERENCES

Abedelhak, B.J., Souad, R., Najib, E., Abdelaziz, H., Faicel, H., and Farouk, Y. (2013). Estimation of Global Solar Radiation using three simple methods. Journal of Energy Procedia 42:406 – 415.

Akpabio, L.E., Udo S.O. and Etuk, S.E. (2004). Empirical Correlations of Global Solar Radiation with meteorological data for Onne, Nigeria. Turkish Journal of Physics. 2:5-12

Angstrom, A.S. (1924). Solar and Terrestrial Radiation. Meteorological Society. 50: 121-126.

Augustine, C and Nnabuchi, M.N. (2010). Analysis of some Meteorological data for some selected cities in the Eastern and Southern zone of Nigeria. Africa Journal of Environmental Science and Technology. 2(1):92-99.

Badescu, V. (1999). Correlations to estimate monthly mean daily solar global irradiation: application to Romania. Energy 24(10):883–893.

Bahel V., Bakhsa, H., and Srunivasan, R. (1987). A Correlation for the Estimation of Global Solar Radiation . Energy 12(2):131-135.

Bernedette, I., Salisu, D. and Moses, A. (2013). Testing the performance of some Empirical

Models for Estimating Global Solar Radiation over Makurdi, Nigeria. Journal of Natural Sciences Research 3(5):165-171.

Besharat, F., Dehghan, A.A. and Faghih A.R. (2013). Empirical models for estimating global solar radiation: a review and case study. Renewable and Sustainable Energy Reviews 21:798–21.

Ekpe, J. E. and Nnabuchi, M. N. (2012). Solar Radiation in Onitsha: A Correlation with Average Temperature. Scholarity Journal of Biotechnology. 1(5):101-107

El – Sebaii, A. A. and Trabea, A. A., (2005). Estimation of Global Solar Radiation on Horizontal Surface over Egypt. Egypt Journals of Solids. 28(1): 163–175.

Falayi, E. O. and Rabiu, A. B., (2011), Estimation of Global Solar Radiation using Cloud Cover and Surface Temperature in some Selected Cities in Nigeria, Archives of Physics Research. 2(3):99–109.

Gielen, D. and Gorini, R. (2019). The Role of Renewable Energy in the Global Energy Transformation. Energy Strategy Reviews 24:38-50

Hargreaves, G. H. and Samani, Z. A. (1982). Estimating potential evapotranspiration. Journal of Irrigation and Drainage Engineering 108:225–230.

Iqbal M., (1983). An Introduction to Solar Radiation, Academic Press New York.

Katiyar, A.K. and Pandey, C.K. (2010). Simple Correlation for Estimating the Global Solar Radiation on Horizontal Surfaces in India. Energy. 35(12):5043-5048

McCulloch, J.S. and Glover, J. (1958). The Empirical Relation between Solar Radiation and Hours of Sunshine. Journal of Royal Meteorological Society. 84:172-175.

Muzathik, A.M. (2011). Daily Global Solar Radiation Estimate based on Sunshine Hours. International Journal of Mechanical and Materials Engineering. 6(1):75-80.

Ogolo, E.O. (2010). Evaluating the Performance of some Predictive Models for Estimating Global Solar Radiation across the varying Climatic Conditions in Nigeria. Pacific Journal of Science and Technology. 11(1):60-72

Okundamiya, M. S. (2014). Modeling and Optimization of Hybrid Energy System for GSM BTS Sites in Emerging Cities, unpublished Ph.D.thesis, Benin City, Nigeria: University of Benin.

Okundamiya, M. S. and Nzeako A. N. (2010). Empirical model for estimating global solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria. Research Journal of Applied Science, Engineering and Technology 2(8):805–812.

Olayinka S. (2011). Estimation of Global and Diffuse Radiations for selected cities in Nigeria. International Journal of Energy and Environmental Engineering. 2(3):13-33.

Oliveira, A.P., Escobedo, J.F., Machado, A.J., and Soares, J. (2002). Correlation models of Diffuse Solar-Radiation applied to the city of São Paulo, Brazil. Applied Energy. 71(1):59-73.

Olomiyesan, B.M, Oyedun, O.D., and Ugwuoke, P.E. (2017). Evaluation of Some Global Solar Radiation Models in Selected Locations in Northwest, Nigeria. MOJ Solar Photoen System. 1(1):1-6

Palz, W. (1977). Solar Electricity. Sambo, A. S. (2005). Solar Radiation in Kano. A Correlation with Meteorological Data Nigeria. Solar energy 4:59-64.

Prescott, J.A. (1940). Evaporation from a Water Surface in Relation to Solar Radiation. Transaction of the Royal Society of South Australia. 64:114-125.

Slavica, B. and Blanka T. (2018). Estimation of Global Solar Radiation from Sunshine Duration for Mosta, Bosnia and Hefzegovina. Journal of Scientific and Engineering Research 5(11):265-273

Zekai, S. (2008). Solar Energy Fundamentals and Modeling Techniques. Springer London. 978-1-84800-134-3. 151.