International Journal of Applied Science and Engineering Review

ISSN: 2582-6271

Vol. 3, Issue.6, Nov-Dec 2022, page no. 173-185

To cite this article: Hamza, B and Garba, S. (2022). ESTIMATION OF GLOBAL SOLAR RADIATION USING SUNSHINE HOURS IN SOKOTO NIGERIA, International Journal of Applied Science and Engineering Review (IJASER) 3 (6): 173-185

ESTIMATION OF GLOBAL SOLAR RADIATION USING SUNSHINE HOURS IN SOKOTO NIGERIA

Hamza, B[1] and Garba, S.[2]

[1]Department of Physics,
Usmanu Danfodiyo University,
Sokoto, Nigeria.

[2]Formerly At Department of Educational Management and Administration
Faculty Of Education,
Islamic University in Uganda

DOI: http://dx.doi.org/10.52267/IJASER.2022.3610

ABSTRACT

Inadequate installations of materials such as solar water heater, solar still, solar dryer, and solar cooker etc. Which required solar radiation and maximally, in the area location of is a major problem and this hinders the abundant utilization of solar energy as it can be harnessed directly without any requirement of external energy such as electricity. It is the lack of the information that limits the number of installations in the study area. Therefore, it is compulsory to study and analyzed the solar radiation of our environment to get better view of monitoring the performance of solar energy conversion system in Sokoto State, so that companies and government should know what period or seasons can therefore utilize the abundant solar energy. A new model was developed for estimation the monthly average daily global solar radiation. In this research a modified angstrom model for estimation of global solar radiation in Sokoto, Nigeria using sunshine duration based on meteorological data were used. However, solar radiation estimates are too local since they rely on weather stations or have a resolution that is too satellites. In this work, a model was developed for estimation of global solar radiation on horizontal surface for Sokoto at latitude of m13 13.00E and longitude of 5.250N. Global solar radiation and maximum temperature data for Sokoto were used to fit the Angstrom model, Regression coefficient a, b, and c. 1.12, 0.65, and 0.32 respectively were obtained from the models base on sunshine duration respectively. In order to evaluate the results, three statistical methods have been used namely: mean bias, root mean square, and percentage errors of values -6.47, 6.47 and 41.20% respectively. It was found from statistical model's performance indicators that the model provides reasonably high degree of precision in the estimation of average global solar radiation on horizontal surfaces.

KEYWORDS: Renewable energy, Solar radiation, Sunshine hours, Statistical tests and Temperature.

1. INTRODUCTION

Solar radiation is one of the most promising renewable sources because it is environmentally friendly, abundant and easy to utilize. Among the renewable resources, solar energy has the greatest potentiality, availability and is free from environmental hazards. The knowledge of the amount of the available solar energy and its variability over geographical location is paramount for solar radiation data analysis (Duffie et at¬¬., 1980).

Meteorological data obtained from direct measurement provide necessary information of radiation and weather parameters. However, in the developing countries, such as Nigeria, lack of sufficient and reliable measuring instruments and poor maintenance culture, has led to poor data records and more often, unreliable solar radiation data (Akpobiom 2004).

In the absence of these measurements theoretical models have become the alternative tools to predict and estimate the global solar radiation of a location using some metrological parameters such as temperature, sunshine hours.

For country like Nigeria, the economical and efficient application of solar energy seems inevitable because of abundant sunshine available throughout the year. Solar radiation data are available for most developed part of the world but not available for many under-developed countries that cannot afford the measuring equipment.

Global solar radiation in Nigeria has been measured in few stations, even in these few stations the use of estimate from theoretical modules is important with a view to authenticate and collaborate with the measured data.

The estimation of monthly global solar radiation has been reviewed in most of the researchers based on the metrological parameters, identifying the best model and determining different coefficient for several locations. (Falayi et al., 2008; Augustine, and Nwabuchi, 2009; Medugu and Yakubu, 2011; Agbo and Baba, 2011; Namarata et al. 2012).

In this study a model base on sunshine hour’s data, to estimate mean monthly global solar radiation in Sokoto and environs was developed.

Sokoto State is located in the extreme north –western part at latitude 13.01 °N and Longitude 5.23 °E. The ecological zone area of the area is Sudan savannah agro-ecological of Nigeria. There are two major seasons in the area namely wet and dry seasons. Sokoto State is bordered with Zamfara State to the east and south by Kebbi State with Niger republic in the north (Muhammad, 2005).

The convention hydropower supply is glossily inadequate, coupled with the high cost of maintaining a dam makes the vision of uninterrupted power supply a mirage for developing countries of the world. The knowledge of solar radiation data will provide the mass assessing the viability of utilization of solar energy in Sokoto state as a renewable energy alternative.

The aim of this work is to develop and analyze the performance of a model for estimation of global solar radiation in Sokoto and environs.

1.1 Solar Radiation

Solar radiation is radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy. The spectrum of solar radiation is close to that of a black body with a temperature of about 5800 K. About half of the radiation is in the visible short-wave part of the electromagnetic spectrum. The other half is mostly in the near-infrared part, with some in the ultraviolet part of the spectrum. Solar radiation can briefly be described as energy transmitted in form of rays from the sun. This solar radiation measurements were carried out with the help of an apparatus called pyranometer.

A solar radiation sensor used to measure the broad band solar radiation flux density (e.g. in watt per square meter) from a field of view of 180 degrees. The first correlation proposed for establishing the average monthly solar radiation of Sokoto based on the method of angstrom.

1.2 Sun as a Source of Solar Radiation

The sun lies at the heart of the solar system, where it is by far the largest object. It holds 99.8 percent of the solar system's mass and is roughly 109 times the diameter of the Earth — about one million Earths could fit inside the sun (Falayi, 2008).

The visible part of the sun is about 10,000 degrees Fahrenheit (5,500 degrees Celsius), while temperatures in the core reaches more than 27 million F (15 million C), driven by nuclear reactions. One would need to explode 100 billion tons of dynamite every second to match the energy produced by the sun, according to NASA.

The sun is one of more than 100 billion stars in the Milky Way. It orbits some 25,000 light-years from the galactic core, completing a revolution once every 250 million years or so. The sun is relatively young, part of a generation of stars known as Population I, which are relatively rich in elements heavier than helium. An older generation of stars is called Population II, and an earlier generation of Population III may have existed, although no members of this generation are known yet.

1.3 Measurement of Solar Radiation

Everything in nature emits electromagnetic energy, and solar radiation is energy emitted by the sun. The energy of extraterrestrial solar radiation is distributed over a wide continuous spectrum ranging from ultraviolet to infrared rays. In this spectrum, solar radiation in short wavelengths (0.29 to 3.0 um) accounts for about 97 percent of the total energy.

Energy from the sun reaching the earth derives almost every known physical and biological cycle in the earth system. By making solar radiation calculations and examining radiation measurement, we can make a better understanding of many physical cycles and concept associated with the earth system can be obtained.

Felayi et al., (2005) define solar radiation as the electromagnetic radiation of the sun. The radiation from the sun is the primary natural energy source of the planet of the earth. Other natural energy sources are the cosmic radiation, the natural terrestrial radioactivity and the geothermal heat flux from the interior to the surface of the earth but these sources are energetically negligible as compared to solar radiation source. As the solar radiation passes through the atmosphere, undergoes and scattering by various constituent of the atmosphere. The amounts of solar radiation depend quite significantly on the concentration of airborne particulate matter. The gaseous pollutants and water (vapour or liquid) in the sky which can further attenuate the solar energy reaching the surface of the ground.

2.0 Materials and Method

2.1 Data Source

To estimate the global solar radiation H, data consisting of mean monthly sunshine hours in percentage were obtained from Nigeria Meteorological Agency (NIMET). The data obtained covered a period of 15 years (2001-2016) the geographical location of Sokoto, Nigeria is show in the table below.

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Station	Latitude	longitude	Altitude
Sokoto	13.01^0N	5.23^0E	281

The monthly average daily extraterrestrial radiation on a horizontal surface (H0) in (MJm-2 day-1) can be calculated for days giving average of each month (iqbal, 1983)

Table 2.1 Sunshine based Models

Model No.	Regression	Model Type	Source
1	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right)$	Linear	Angstrom (1924) and Prescott (1940)
2	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + \boldsymbol{c}\left(\frac{S}{S_0}\right)^2$	Quadratic	Akinoglu and Ecevit (1940).
3	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + \boldsymbol{c}\left(\frac{S}{S_0}\right)^2 + \boldsymbol{d}\left(\frac{S}{S_0}\right)^3$	Cubic	Samuel (1991)

$$H_0 = \frac{24\times3600}{\pi} Isc\left(1 + 0.033\, cos\left(\frac{360n}{365}\right)\right)[sin\delta\, sin\varphi + cos\delta\, cos\varphi \cos w] \quad (1)$$

Where ISC is the solar constant (= 1367 Wm-2), φ is the latitude of the site, δ is the solar declination and ws is the mean sunrise hour angle for the given month and n is the number of days of the year starting from 1st of January to 31st of December.

The solar declination, δ and the mean sunrise hour angle, Ws can be calculated using the following equation (Iqbal, 1983.; Amitabh et at, 2014).

$$= \delta = 23.45\, sin\left\{360^0\left(\frac{284+n}{365}\right)\right\} \quad (2)$$

$$W_S = cos^{-1}(-tan\varphi\, tan\delta) \quad (3)$$

A linear regression analysis of three parameters was employed to estimate the global solar radiation. The parameter

$\frac{H}{H_0}, \frac{n}{N}$ where $\frac{H}{H_0}$ is cleanness index, $\frac{n}{N}$ Sunshine duration. The proposed model is expressed as

$$H = H_0\left[a + bIn\ \frac{n}{N} + c\right] \quad (4)$$

In regression analysis $X = a + by + cz$

Let $\frac{H}{H_0} = X$ (dependent variable). Where *a*,*b* and *c* are regression parameter's

By matrix, we can solve the linear equation as follow

$$= \begin{bmatrix} n & \sum y & \sum z \\ \sum y & \sum y^2 & \sum yz \\ \sum z & \sum yz & \sum z^2 \end{bmatrix} = \begin{bmatrix} a \\ b \\ c \end{bmatrix} \begin{bmatrix} \sum x \\ \sum xy \\ \sum xz \end{bmatrix} \quad (5)$$

Equation six (6) is use to obtained the values of a, b, and c by using Gaussian elimination method

Solution

$$\begin{bmatrix} 12 & -5.91 & -11.85 \\ -5.91 & 3.06 & 5.68 \\ -11.85 & 5.68 & 14.52 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} 5.84 \\ -2.83 \\ -4.96 \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} 12 & -5.91 & -11.85 & 5.84 \\ -5.91 & 3.06 & 5.68 & -2.83 \\ -11.85 & 5.68 & 14.52 & -4.96 \end{bmatrix} \quad (7)$$

Subtract $\frac{-5.91}{12}$ times the first row from the second row also subtracts $\frac{-11.85}{12}$ times the first row from the third row.

$$\begin{bmatrix} 12 & -5.91 & -11.85 & 5.84 \\ 0 & 0.149325 & -0.156125 & 0.0462 \\ 0 & -0.156125 & 2.818125 & 0.807 \end{bmatrix} \quad (8)$$

Subtract $\frac{-0.156125}{0.149525}$ times the second row from the third row

$$\begin{bmatrix} 12 & -5.91 & -11.85 & 5.84 \\ 0 & 0.149325 & -0.156125 & 0.0462 \\ 0 & 0 & 2.818125 & 0.8553038674 \end{bmatrix} \quad (9) \quad .$$

$$\begin{bmatrix} 12 & -5.91 & -11.85 \\ 0 & 0.1493225 & -0.156125 \\ 0 & 0 & 2.6548903401 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} 5.84 \\ 0.0462 \\ 0.8553038674 \end{bmatrix} \quad (10)$$

$$2.6548903401c = 0.8553038674 \quad (10a)$$

$$0.149325b - 0.156125c = 0.0462 \quad (10b)$$

$$12a - 5.91b - 11.85c = 5.84 \quad (10c)$$

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From equation one making c the subject of the formula and obtained c = 0.32
Putting the value of c into equation (10b) and obtained b = 0.65. Similarly, a = 1.12

Thus, the regression constant a, b and c are 1.12, 0.65, and 0.32 respectively. Therefore

$$H = H_0 (1.12 + 0.32\frac{n}{N} + O.65)$$

2.2 Statistical Test

The testing process involved generating estimated values of global solar radiation from the proposed model. The estimated values were compared with actual values through error analysis. In order to evaluate the accuracy of the developed models, three statistical tests namely Root Mean Square (RMSE), Mean Bias Error (MBS) and Mean Percentage Error (MPE) were used in evaluating performance of the model. These error terms are calculated using the following equations (Hamza and Abdulmuminiu, 2021).

$$\text{RMSE} = \left\{ \sum (H_{pred} - H_{meas})^2 / n \right\}^{½} \qquad (11)$$

$$\text{MBE} = \left\{ \sum (H_{pred} - H_{meas}) \right\} \qquad (12)$$

$$\text{MPE} = \left\{ \sum \frac{\left(\frac{\text{Hpred} - \text{Hmeas}}{\text{Hmeas}} X\ 100\right)}{n} \right\} \qquad (13)$$

Where H_{pred} *and* H_{meas} the nth is calculated (predicted) and measured (observed) values and n is the total number of observation (Akpootu and Sunusi, 2015). The MBE test provides information on the long term performance of a given correlation. A model is more efficient when R^2 is closer to 1.

A positive MBE signifies an over estimation. In the calculated value while a negative MBE stands for an underestimation. A low MBE indicates good estimation (Isikwue *et al*., 2012). .

The RMSE test provides information on the short-term performance of a correlation. It allows terms by term comparison of the actual deviation between the calculated and the actual values. The smaller the RMSE value the better the performance of the model. The MPE is a relative measure of the forecasting error. It is subject to the averaging of the positive and negative error. MPE gives long term performance of the examined regression equation, a positive MPE values provides the average amount of overestimation in the calculate values, while negative values underestimation. A low value of MPE is desirable (Augustine and Nwabuchi, 2009).

Correlation is the degrees of relationship between variables and to describe the linear or other

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mathematical model explain the relationship. The regression is a method of the linear or non-linear mathematical models between a dependent and a set of independent variables. The square root of the coefficient of determination is define as the coefficient of correlation r. It is a measure of the relationship between variables based on scale ± 1. Whether r is positive or negative depends on the inter-relationship between x and y i.e. whether they are directly proportional (y increases and x increase) or vice versa (Firoz and Intikhab, 2004).

3.0 RESULT AND DISCUSSIONS

3.1 Result

Table 3.1 Computed measure value of the average mean monthly solar radiation, extraterrestrial radiation and clearness index respectively

MONTH	H_{mea}	H_o	S_{hour}	S_o	K_T	K_S
JANUARY	20.83	30.33	11.97	11.54	0.6867	1.05
FEBRUARY	22.39	32.28	12.42	11.68	0.6936	1.0634
MARCH	22.94	37.35	12.2	11.99	0.6142	1.0175
APRIL	22.65	38.55	13.6	12.38	0.5875	1.0985
MAY	21.56	38.75	18.72	12.54	0.5564	1.4928
JUNE	19.6	37.75	23.87	12.61	0.5192	1.8929
JULY	17.01	37.54	24.78	12.32	0.4531	2.0114
AUGUST	14.77	35.68	38.23	12.2	0.414	3.1336
SEPTEMBER	19.5	34.48	19.8	12.35	0.5655	1.6032
OCTOBER	20.05	33.16	15.56	11.6	0.6046	1.3414
NOVEMBER	21.6	30.1	12	11.29	0.7176	1.0629
DECEMBER	20.7	29.44	11.78	11.14	0.7031	1.0575

ISSN: 2582-6271

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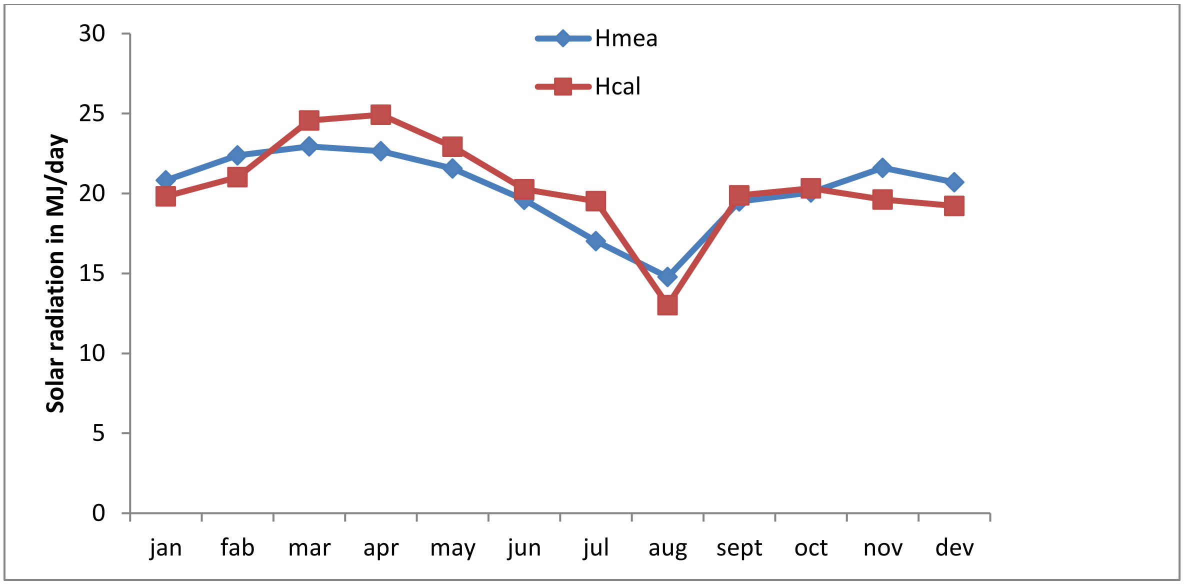

Fig 3.1 Comparison between measured data and months of the year.

Table 3.2: Comparison between measured and predicted global solar radiation for sunshine the model.

MONTH	H_{mea}	H_{cal}
January	20.83	19.81
February	22.39	21.03
March	22.94	24.57
April	22.65	24.92
May	21.56	22.93
June	19.6	20.25
July	17.01	19.52
August	14.77	13.01
September	19.5	19.88
October	20.05	20.32
November	21.6	19.61
December	20.7	19.22

International Journal of Applied Science and Engineering Review

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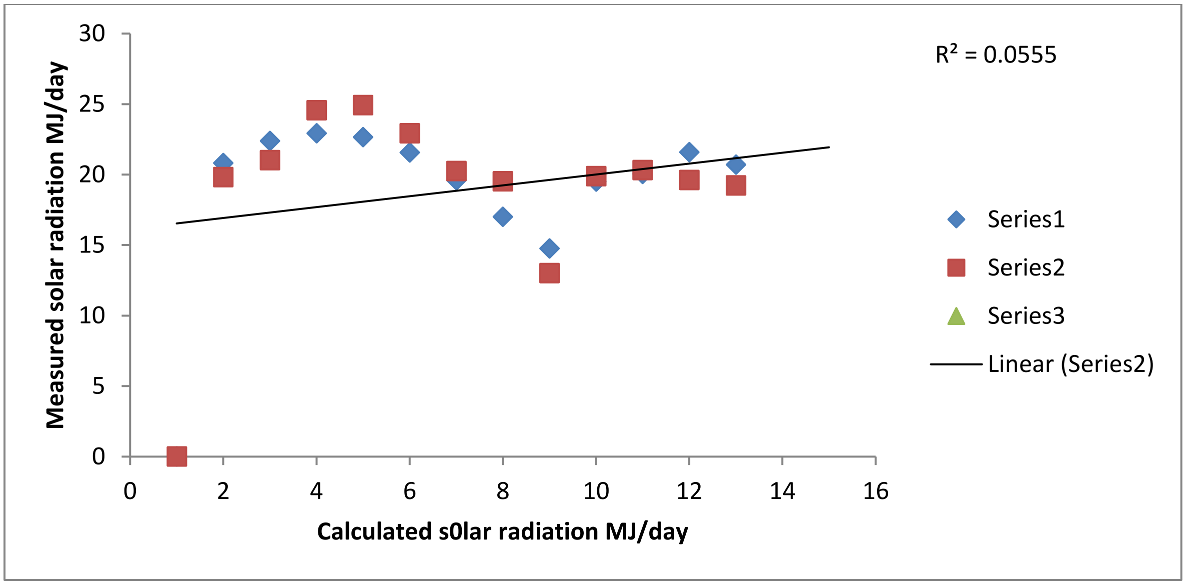

Fig 3.2 Comparison between measured and predicted solar radiation

To evaluate the performance of the models the statistical methods of root mean square error (RMSE) and mean percentage error (MPE) were used. The root mean square error (RMSE) and mean percentage error (MPE) are given by Larry (2000).

Where H_{pred} is the predicted solar radiation, H_{meas} is the measured solar radiation and N is the number of months in a Year.

Table 3.3: - Regression coefficient, root mean square error (RMSE), mean percentage error (MPE), measured and predicted value.

MONTH	H_{meas}	H_{pred}	M.P.E	R.M.S.E
January	18.80	18.50	0.01	0.3
February	20.13	19.86	0.01	0.27
March	20.62	21.81	-0.05	1.19
April	23.81	23.58	0.09	0.23
May	24.54	2.87	0.02	0.67
June	23.98	23.22	0.03	0.76
July	21.53	22.68	-0.05	1.15
August	20.10	23.19	-0.15	3.09
September	23.19	23.24	-0.02	0.05
0ctober	23.21	22.06	0.04	1.15
November	20.88	19.91	0.04	O.97
December	18.36	17.83	0.02	0.53

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TOTAL	259.5	259.75	-0.01	10.36

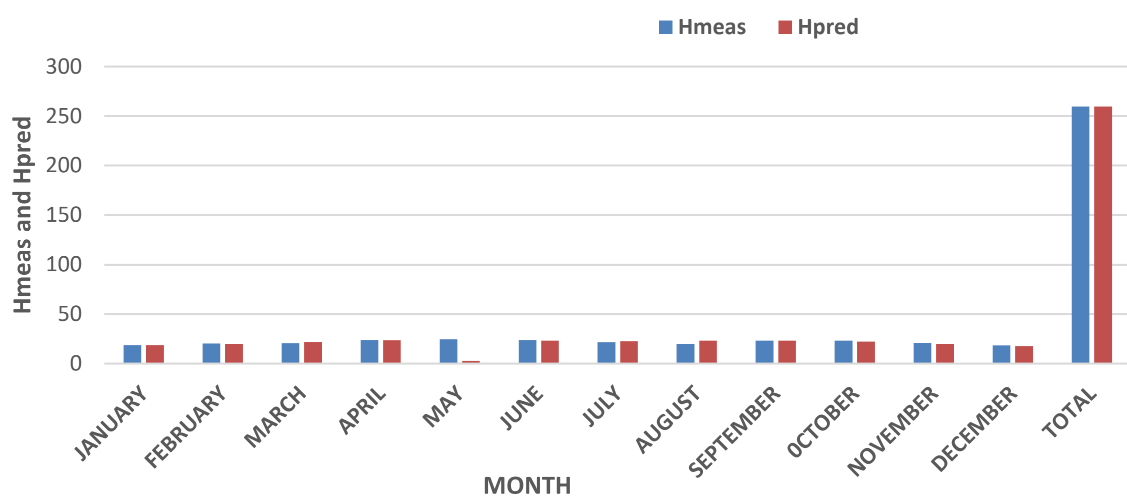

Fig 3.3 Comparison between measuured and predicted value with months of th year

3.2 Discussion

From the table observed the correlation of the global solar radiation with the meteorological data which shows that the models have the function and is good.

On the (RMSE) and (MPE) testing from figure 4.4 and 4.5 it was observed that the curve correlation from January, the graph of the predicted increase to March at March continuously to August, from August it was attenuated to December, which the graph of measured solar radiation increase from January to March from March slightly reduced to August at August reduced to December, therefore the graph of measured solar radiation that increase from January to March shows that there are much hot in Sokoto, due to higher diffused solar radiation and attenuation of cloudiness that form in the atmosphere during dry season.

At August decreased to December which is shown that there are much cloudiness form in atmosphere during rainy season and attenuation of diffuse radiation.

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The months of March and August are closed agreement between the graph of predicted and measured solar radiation.

4.0 CONCLUSION

In this study, solar radiation models for estimation of monthly average global radiation on horizontal surface were reviewed. Data of global solar radiation sunshine duration are analyzed from 1987 to 2003 respectively. The modified angstrom model was developed to estimate the monthly average daily global solar radiation on a horizontal surface for Sokoto, Nigeria. A model is developed for estimating the monthly average daily global solar radiation. Regression coefficient a, b, and c of (1.12, 0.65 and 0.32) were obtained from the models based on sunshine duration and relative humidity respectively, in order to validate the result three statistical methods have been used namely :(MBE), (RMSE), and (MPE) of -6.47, 6.76 and 41.20. The errors evaluated in the global solar radiation sunshine duration-based models have lower RMSE, an indication of the good agreement between the measured and estimated global solar radiation. It can be deduced from the result that, the new developed global solar radiation sunshine duration based linear model is found to be reasonably reliable for estimating or predicting the monthly global solar radiations of location that has the same geographical location information as Sokoto in the north part of Nigeria.

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