International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 5 Issue 5, July-August 2021 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Comparative Studies of the Measured and Predicted Values of Global Solar Radiation for Awka, Nigeria using Selected Seven Models

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ABSTRACT

This study was aimed at utilizing the monthly mean values of global solar radiation, sunshine hours, rainfall, wind speed, atmospheric pressure and cloud cover to develop an empirical equation for estimation global solar radiation on a horizontal surface for Awka (6.2 °N, 7.0^°E) for nine year period (2005 – 2013). The regression constants were obtained using regression analysis and the predicted values of global solar radiation calculated. The measured values of global solar radiation were compared with the predicted using different models. The result showed that the deviations were minimal. Validation of the results was tested using MBE, RMSE and MPE. The values of R and R2 were also determined for each model. Of all these meteorological parameters: sunshine hours, rainfall, wind speed, atmospheric pressure and cloud cover used in this study only sunshine hours was found to have a direct correlation with global solar radiation. Result obtained show that all the models except model 4 were in good agreement with the measured global solar radiation considering their MBE, RMSE and MPE values. However, considering the RMSE, models 5 and 6 gave better predictions of R which indicate that about 94.8% of variation in the monthly mean solar radiation on a horizontal surface can be accounted for by the models. Therefore, either model 5 or model 6 can be used for predicting global solar radiation for Awka and other locations with similar climate conditions.

KEYWORDS: *Solar radiation, sunshine hours, wind speed and root mean square error*

How to cite this paper: Nwokoye, A. O. C. | Mbadugha, A. O. "Comparative Studies of the Measured and Predicted Values of Global Solar Radiation for Awka, Nigeria using Selected Seven Models" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-5 | Issue-5, August 2021, pp.649-654, URL: www.ijtsrd.com/papers/ijtsrd43919.pdf

IJTSRD43919

1. INTRODUCTION

Energy certainly is vital in development of the society. There exists a direct correlation between the development of a country and its consumption of energy (Mohammad, 2013). The quantity of solar energy that reaches the surface of the earth per hour is greater than quantity used by the Earth's population over an entire year and of all the energy sources available, solar is perhaps the most promising (Brown, 1988).

Clearly, solar energy is a resource of the future. It is an ideal, alternative source of energy, abundant and inexhaustible (Bolaji, 2005). Solar energy is a renewable resource and is environmentally friendly. Unlike fossil fuels that are only found in selected regions of the world, it is available just about everywhere on earth (Duffie and Beckman, 1994). Because solar energy has been used by human beings, it has been looked upon as a serious source of energy for many years due to vast amounts of energy that are made freely available if harnessed by modern technology.

Solar energy is received on any surface as solar radiation but the amount that is received by any horizontal surface in Nigeria depends on the geographical latitude of such surface and therefore varies from place to place (Innocent *et al.,* 2015).

In many solar energy applications, solar radiation data play vital roles in areas such as in solar water heating, wood drying, stoves, photovoltaic and is essential for proper prediction, design and the study of energy systems to be installed in that geographic location. The basic need for the knowledge of the quantity of solar radiation that can be received and transformed into useful energy at a given time interval at a given geographical place or region led to the need for measuring and maintaining solar radiation data (Munawwar, 2002).

This measurement of data for a given location can be obtained by the use of an instrumentsuch as pyranometer. Due to high cost, maintenance, and calibration requirement of solar radiation measuring equipment the stations measuring solar radiation is sparse in Nigeria (Chineke, 2007).Thus Researchers in this country, in order to overcome this defect, use theoretical value of meteorological data toestimate the global solar radiation with the help of some models incorporating the available meteorological parameters as input. The resultant correlation may then be used for locations of similar meteorological characteristics (Medugu*et al.,* 2011).

Several models have been used to predict amount of solar radiation in some places using various meteorological parameters such as (Okonkwo and Nwokoye, 2014)

This paper aims at using some solar parameters for a period of nine year (2005 – 2013), as an independent variable for the Angstrom-type correlation, to generate empirical equations for predicting global solar radiation inAwka Nigeria. The predicted solar radiation data obtained from study will be tested for error using the RMSE, MBE and MPE to compare the measured with the predicted values. The model with highest value of Rwill be recommended for predicting global solar radiation for Awka.

2. METHODLOGY

The most commonly method used in this study was based on correlation in predicting linear relation between monthly mean global solar radiation and clearness index developed by Angstrom (1924) and modified by Prescott (1940). The Angstrom-Prescott regression model which forms the basis of most models used in this study was given by Iqbal (1983); Ahmads and Tiwari (2010); Gadiwal et al., (2013) as:

$$\frac{\overline{H}_m}{\overline{H}_o} = a + b\left(\frac{\overline{n}}{\overline{N}}\right) \quad (1)$$

$\overline{H}_m$is the measured inmJ/m^2/day. $\overline{H}_o$ is the monthly mean extraterrestrial solar radiation on a horizontal surface is computed from

$$H_o = \frac{24}{\pi} \times 13673 \times 10^{-4}\ E\ o \left[\frac{\pi}{180}\, Ws\, sin\varphi sin\delta + cos\varphi cos\delta sin Ws\right] \quad (2)$$

(Duffie and Beckmann, (1994); Nwokoye (2006), Okonkwo and Nwokoye (2014).

where

$$\epsilon_o = 1+0.033\cos\left[\frac{360\ dn}{365}\right] \quad (3)$$

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

(Cooper (1969); Salima and Chavula (2012)

$$W_s = \cos{-1}\left[-tan\varphi\ tan\delta\right] \quad (5)$$

$\varphi$is the latitude of the location in question.

The dn is the characteristic day length for each month of the year from 1st January to 31st December (365 days) or (366 days for a leap year). It is also called Julian day of the month. It was calculated for fifteen day of the month according to Iqbal (1983), Duffie and Beckmann (1991) and Okonkwo and Nwokoye (2014).

The sunshine duration/hours (n) is a climatologically indicator in a given period for a given location on Earth. It is a clear indicator of cloudiness of a place. Sunshine duration is measured in hours (hrs).

Mean daylength, N for horizontal surface is the number of hours of sunshine or darkness within 24 hours in a given day. For this study it was calculated using equation given by(Duffie and Beckmann (1994) and Umoh*et al.*, (2014).

$$N = \frac{2}{15} W_s = \frac{2}{15} cos^{-1}\left[-tan\theta\ tan\delta\right] \quad (6)$$

Sunshine fraction (n/N) is the ratio of sunshine duration to the corresponding values of mean day length. It has no unit. The 'a'and'b' are regression constants which are determined using a computer statistical software program, (IBM SPSS 21).The clearness index, K_T is ratio of measured solar radiation calculated solar radiation. This was obtained using the equation of this form as:

$$K_T = \frac{\overline{H}_m}{\overline{H}_o}$$

Observation showed that clearness index had high values in clear atmospheres and low values in cloudy atmosphere and vice-versa.

In this work, the monthly values of sunshine hours, atmospheric pressure, wind speed, rainfall and cloud cover are obtained from Nigerian Meteorological Agency (NIMET), Awka while the measured solar radiation data used are the one given by Okonkwo and Nwokoye (2012).

The data covered a period of nine years (2005-2013) for rainfall, wind speed, cloud cover and atmospheric pressure and six years (2008-2013) for sunshine hours/duration.

3. STATISTICAL METHODS

Satistical test methods used to determine the proposed models of solar radiation in this studyinclude, Root Mean Square Error (RMSE), Mean Bias Error (MBE), Mean Percentage Error (MPE), Correlation of determination (R^2) and Coefficient of correlation, (R).

Root Mean Square Error

It is always positive and a low RMSE is desirable. The RMSE may be computed from the following equation, Akpabio and Etuk, (2013).

$$RMSE = [\sum (\overline{H}_{ipred} - \overline{H}_{i\ meas})^2/n]^{1/2} \quad (8)$$

Mean Bias Error

The ideal value of the MBE is zero.. It was recommended that a zero value for MBE is ideal Iqbal, (1983). The MBE is given by,

$$MBE = [\sum (\overline{H}_{i\ pred} - \overline{H}_{i\ meas}]/n \quad (9)$$

Mean Percentage Error

$$MPE = [\, [(\overline{H}_{imeas} - \overline{H}_{ipred})/\ (\overline{H}_{imeas})\ ]\ /n\ ]\ x100 \quad (10)$$

(Akpabio and Etuk, (2013); Okonkwo and Nwokoye (2014).

where$\overline{H}$ipred and $\overline{H}$imeas are the ith predicted and measured values respectively of solar radiation. n is the total number of observations.

Coefficient of determination (R^2) AND Coefficient of correlation(R) were determined using software programme.

Table1 showed that the highest and lowest rainfall occurred in August and November respectively. This was expected since August is characterized by heavy rainfall .It was also observed that sunshine fraction was highest in November while the lowest value occurred in August. This is attributed to the highest and lowest values of clearness index obtained for these months, respectively. This again is expected since according to Augustine and Nnabuchi (2010), and Okonkwo and Nwokoye (2014). Again, it was observed that the global solar radiation was highest in November while the lowest value occurred in August. Table 2 showed the 7 proposed models for this study while Table 3 displayed the regression constants obtained for each models.

From the Table 4, it was observed that the values of the global solar radiation predicted by models 1, 2, 5, 6 and 7 were related to the measured values. The values predicted by models were either highly overestimated or underestimated except model 4. This again was reflected in Table 5, where the MBE and RMSE values were lowest for all the models 1, 2, 3, 5, 6 and 7. Also the MPE values for these models were low with the exception of model 4 which indicates overestimation.

Model 4 had the highest MBE, RMSE though with low MPE values was the worst performed model. Models 1, 2, 5, 6 and 7 were adequately for predicting global solar radiation in Awka. Model 4 overestimated the global solar radiation in the months except December while the other models either slightly overestimated or slightly underestimated the global solar radiation. Therefore, models 5 and 6 were the best models for Awka.

Table1: Monthly mean solar radiation and solar parameters for Awka, Nigeria (2005 -2013)

Month	$\overline{n}$ (hrs)	$\overline{N}$ (hrs)	$\overline{n}/\overline{N}$	$\overline{c}$ (octas)	$\overline{c}/C$	$\overline{RF}$ (mm)	$\overline{A}$	$\overline{w}$ (m/s)	$\overline{H}_m$ (mJ/m^2/day)	$\overline{H}_o$ (mJ/m^2/day)	$\overline{KT}_m = \overline{H}_m/\overline{H}_O$	$\overline{H}_P$ (mJ/m^2/day)	KTp= Hp /Ho
January	5.080	11.680	0.435	6.870	0.0687	0.800	24.330	9.720	18.320	33.590	0.545	18.94	0.56
February	6.220	11.800	0.527	6.370	0.064	0.800	29.030	9.520	20.010	35.730	0.560	20.28	0.57
March	6.830	11.960	0.488	6.450	0.065	1.790	29.080	8.110	19.980	37.370	0.534	20.71	0.55
April	5.520	12.140	0.455	5.780	0.058	4.820	30.130	8.920	19.820	37.630	0.527	19.85	0.53
May	4.620	12.280	0.376	4.590	0.046	5.260	30.860	7.870	18.880	38.700	0.488	19.59	0.51
June	3.830	12.360	0.310	4.740	0.047	6.110	30.030	7.780	18.250	35.720	0.511	17.27	0.48
July	3.410	12.330	0.277	3.030	0.030	8.080	29.920	9.070	16.470	35.950	0.458	16.54	0.46
August	2.870	12.200	0.235	2.720	0.027	9.000	30.020	9.820	14.960	36.930	0.405	16.24	0.44
September	3.770	12.030	0.313	3.560	0.036	8.070	28.900	8.410	15.720	37.260	0.422	17.60	0.47
October	5.230	11.860	0.441	2.790	0.028	5.700	28.640	6.830	18.760	36.080	0.520	18.88	0.52
November	7.740	11.710	0.661	2.010	0.020	0.500	27.770	5.400	20.140	34.010	0.592	20.54	0.60
December	5.420	11.650	0.465	5.650	0.057	1.200	23.410	7.820	19.220	32.970	0.583	18.37	0.56

Table 2 shows the various models used

S/N	Models
1.	$\frac{\overline{H}_m}{\overline{H}_o}$=a+ b ($\overline{n}/\overline{N}$)
2.	$\frac{\overline{H}_m}{\overline{H}_o}$=a+ b($\overline{n}/\overline{N}$) - c ($\overline{n}/\overline{N}$)^2
3.	$\frac{\overline{H}_m}{\overline{H}_o}$ = a + b ($\overline{c}$/C) + c ($\overline{RF}$)
4.	$\frac{\overline{H}_m}{\overline{H}_o}$ = a + b ($\overline{n}/\overline{N}$) + c ($\overline{RF}$)
5.	$\frac{\overline{H}_m}{\overline{H}_o}$= a + b ($\overline{RF}$) + c ($\overline{W}$) + d ($\overline{A}$)
6.	$\frac{\overline{H}_m}{\overline{H}_o}$= a + b ($\overline{n}/\overline{N}$) +c ($\overline{RF}$) +d($\overline{W}$)
7.	$\frac{\overline{H}_m}{\overline{H}_o}$= a + b($\overline{n}/\overline{N}$) +c ($\overline{A}$) +d ($\overline{W}$)

The $\overline{H}_m$ is monthlymean measured solar radiation, $\overline{H}_o$is monthly mean calculated solar radiation, $\overline{n}/\overline{N}$ is monthly mean sunshine fraction, $\overline{A}$is monthly mean atmospheric pressure, $\overline{c}/C$ is monthly mean cloudiness index, $\overline{RF}$ is monthly mean rainfall, and $\overline{W}$ is the monthly mean wind speed.

Results and discussions

Table 3 shows Regression equations, (models 1-7) obtained in this study

1.	$\frac{\overline{H}_m}{\overline{H}_o}$= 0.331 + 0.435 ($\overline{n}/\overline{n}$)
2.	$\frac{\overline{H}_m}{\overline{H}_o}$ = 0.205 + 1.062 ($\overline{n}/\overline{N}$) – 0.723 ($\overline{n}$ /$\overline{N}$)^2
3.	$\frac{\overline{H}_m}{\overline{H}_o}$ = 0.615 - 0.488 ($\overline{C}$/C) – 0.019 ($\overline{RF}$)
4.	$\frac{\overline{H}_m}{\overline{H}_o}$= 0.500 + 0.156 ($\overline{n}/\overline{N}$) - 0.012($\overline{RF}$)
5.	$\frac{\overline{H}_m}{\overline{H}_o}$= 0.676 - 0.016 ($\overline{RF}$) – 0.011($\overline{w}$) + 0.000 ($\overline{A}$)
6.	$\frac{\overline{H}_m}{\overline{H}_o}$ = 0.663 + 0.008($\overline{n}/\overline{N}$) - 0.016 ($\overline{RF}$) -0.010($\overline{w}$)
7.	$\frac{\overline{H}_m}{\overline{H}_o}$ = 0.547 + 0.384 ($\overline{n}/\overline{N}$)- 0.007($\overline{A}$) – 0.001 ($\overline{w}$)

Table 4: Monthly mean measured and predicted values of global solar radiation

Month	H_m	H_1	H_2	H_3	H_4	H_5	H_6	H_7
Jan	18.32	18.37	18.61	19.02	19.34	18.69	18.71	18.73
Feb	20.01	20.02	20.15	20.30	20.75	19.95	19.98	19.18
Mar	19.98	20.29	20.59	20.48	21.39	20.86	20.82	19.53
Apr	19.82	19.90	20.26	18.49	21.12	18.84	18.83	18.88
May	18.88	19.14	19.44	18.90	21.21	19.55	19.47	18.10
Jun	18.25	16.64	16.60	16.82	19.15	17.60	17.50	16.00
Jul	16.47	16.22	15.94	15.83	18.95	16.07	16.01	15.63
Aug	14.96	16.00	15.32	15.64	19.16	15.66	15.61	15.41
Sep	15.72	17.41	17.39	16.31	19.85	16.92	16.85	17.01
Oct	18.76	18.86	19.22	17.63	20.11	18.39	18.29	18.37
Nov	20.14	21.04	20.10	20.25	20.48	20.70	20.62	20.44
Dec	19.22	17.59	17.89	18.58	18.80	18.32	18.77	18.26

Table 5: Statistical Error Indicators of the Models.

MODEL	MBE	RMSE	MPE	R	R^2
$\frac{\overline{H}_m}{\overline{H}_o} = a + b\,(\overline{n}/\overline{N})$	0.0801	2.2936	-0.6343	0.7740	0.599
$\frac{\overline{H}_m}{\overline{H}_o} = a + b(\overline{n}/\overline{N}) - c(\overline{n}/\overline{N})^2$	-1.4696	2.3312	-0.5507	0.816	0.6659
$\frac{\overline{H}_m}{\overline{H}_o} = a + b(\overline{c}/C) + c(\overline{RF})$	-0.1899	2.3248	0.9216	0.930	0.864
$\frac{\overline{H}_m}{\overline{H}_o} = a + b(\overline{n}/\overline{N}) + c(\overline{RF})$	1.6480	5.9520	-9.6857	0.935	0.874
$\frac{\overline{H}_m}{\overline{H}_o} = a + b(\overline{RF}) + c(\overline{W}) + d(\overline{A})$	0.1270	2.0872	-0.8169	0.948	0.889
$\frac{\overline{H}_m}{\overline{H}_o} = a + b(\overline{n}/\overline{N}) + c(\overline{RF}) + d(\overline{W})$	0.0776	2.0853	-0.5403	0.948	0.899
$\frac{\overline{H}_m}{\overline{H}_o} = a + b(\overline{n}/\overline{N}) + c(\overline{A}) + d(\overline{W})$	-0.4159	2.8612	2.0695	0.912	0.832

4. CONCLUSION

The monthly mean global solar radiation, sunshine hours, rainfall, wind speed, cloud cover) had been employed to develop the Angstrom-Prescott type equations (models) had successfully obtained a model for estimated global solar radiation for Awka Nigeria.

Result obtained show that all the models except model 4 were in good agreement with the measured global solar radiation and gave very good results in predicting global solar radiation, considering their MBE, RMSE and MPE values. However, considering the RMSE, models 5 and 6 gave better predictions of R which indicate that about 94.8% of variation in the monthly mean solar radiation on a horizontal surface can be accounted for by the models. Therefore, either model 5 or model 6 could be used for predicting global solar radiation for Awka.

ACKNOWLEDGEMENTS

We wish to acknowledge the management and staff of Nigerian Meteorological Agency, Awka for supplying the solar parameters required for this study.

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