International Research Journal of Advanced Engineering and Science
ISSN (Online): 2455-9024

Estimation of Global Solar Radiation Using Sunshine Based Models in Bauchi State, North-Eastern Nigeria

Nuhu R.[1], Vandi T.[1], Ogbaka D. T[1]*
[1]Department of Pure and Applied Physics, Faculty of Science. Adamawa State University, P.M.B 25 Mubi. Adamawa State, Nigeria
*Corresponding email: dtogbaka @ gmail.com

Abstract— *Bauchi is located between latitudes 9° 3' and 12° 3' North and longitudes 8° 50' and 11° East. Three sunshine based models were used for the study. It is very encouraging to observe a very fine agreement between the measured and estimated values from model 1. The results of the performance of each model in terms of regression of coefficient (R^2). The coefficient of determination for Angstrom-Prescott model, R^2 (92.77%) obtained for this analysis shows that the model is excellently fits for the data, model 1 performed excellently in regression (R^2) than model 2 and 3. The global solar radiation predicted in this study can also be utilized in design, analysis and performance estimation of solar energy systems, which is gaining significant attention in Bauchi state, Nigeria and the world at large.*

Keywords— Global solar radiation, Sunshine duration, Bauchi, Angstrom-Prescott, Models.

I. INTRODUCTION

The design and operation of any solar energy system requires a good knowledge of the solar radiation data in a location. This data finds application in agriculture, climatology, meteorology, etc. Since the solar radiation reaching the earth's surface varies with climatic conditions of a place, a study of solar radiation under local climatic condition is essential. Measured values of solar radiation can be in the form of global solar radiation, diffused solar radiation or beam solar radiation. The average daily values of these three parameters are sought after (Falayi and Rabiu, 2005) for various applications. Unfortunately, these parameters are not measured or not reliably estimated in many parts of the world especially in the developing nations because of the lack of the measuring facilities. Solar radiation data for many parts of these countries are extrapolated

An alternative to a weather station is the use of solar radiation predicting models. This requires the correlation of some climatic and meteorological parameters with the global solar radiation. One advantage of this approach is that some of the meteorological parameters, for example, ambient temperature can easily be measured in most places. Many researchers across the globe have predicted global solar radiation with high accuracy using data from sunshine duration, relative humidity, cloud cover and ambient temperature (Glover and McCulloch, 1958; Ododo *et al.*, 1996; DeMiguel *et al.*, 1994; Ibrahim, 1985; Ahmad and Ulfat, 2004; Fariba *et al.*, 2013; Hacer and Harun, 2012).

In Nigeria, global solar radiation has been estimated using ambient temperature, cloud cover and relative sunshine duration for different locations (Awachie and Okeke, 1990; Ododo *et al.*, 1996; Sambo, 1988; Udo and Aro, 1999; Yohanna, 2011). New model equations for the estimation of solar radiation in Nigeria arising from a linear superposition of the effects of relative sunshine duration, maximum air temperature and relative humidity have been proposed and used in Maiduguri, and other locations in north-eastern Nigeria (Ododo, 2006; Ododo *et al.*, 2006; Muyiwa, 2012).

Solar energy occupies one of the most important places among the various possible alternative energy sources. It is the energy provided by the sun. Nigeria receives abundant solar energy that can be usefully harnessed with an annual average daily solar radiation of about 5250 Whm^{-2} day^{-1}. This varies between 3500 Whm^{-2} day^{-1} at the coastal areas and 7000 Whm^{-2} day^{-1} at the northern boundary. The average amount of sunshine hours all over the country is about 6.5 hours (Chineke and Igwiro, 2008, Yakubu and Medugu, 2012).

According to Augustine and Nnabuchi (2009), Sambo (1985) developed correlation with solar radiation using sunshine hours for Kano with the regression coefficients a = 0.413 and b = 0.241 for all the months between 1980- 1984, Arinze and Obi, (1983) developed a correlation with solar radiation using sunshine hours in Northern Nigeria with regression coefficients a = 0.2 and b = 0.74, Burari *et al.*, (2001) developed a model for estimation of global solar radiation in Bauchi with regression coefficients a = 0.24 and b = 0.46. Other workers (e.g. Ojosu, 1984; Fagbenle, 1990; Folayan, 1988; Adebiyi, 1988; Turton, 1987; Bamiro, 1983) developed theoretical and empirical correlations of broad applicability to provide solar data for system design in most Nigeria cities. They observed that the regression coefficients are not universal but depends on the climatic conditions.

In the absence and scarcity of trustworthy solar radiation data, the need for an empirical model to predict and estimate global solar radiation seems inevitable. These models use climatological parameters of the location under study. Among all such parameters, sunshine hours are the most widely and commonly used. The models employing this common and important parameter are called sunshine-based models (Ahmad and Ulfat, 2004). However, the main objective of this study is to develop empirical correlation model capable of predicting the mean monthly global solar radiation for Bauchi, the North-Eastern Nigeria.

II. MATERIALS AND METHOD

Bauchi State occupies a total land area of 49,119 km^2 (18,965 sq mi) representing about 5.3% of Nigeria's total land mass and is located between latitudes 9° 3' and 12° 3' north and longitudes 8° 50' and 11° east. The following parameters were collected from the Archives of Nigerian meteorological Agency, National Weather Forecasting and Climate Research Centre Abuja for the period of ten years, from two thousand and one to two thousand and ten (2001-2010). Mainly daily global solar radiation and Sunshine hour.

The Angstrom- Prescott regression equation which has been used to estimate the monthly average daily solar radiation on a horizontal surface in Nigeria or other places is given by (Angstrom, 1924; Prescott, 1940) as:

Model 1: $\frac{H_m}{\mathrm{H_o}} = a + b\frac{S}{S_0}$ (1)

Where H_m is the monthly average global solar radiation ($MJM^{-2}day^{-1}$), S is the monthly average daily bright sunshine hour, $S_0$is the maximum possible monthly average daily sunshine hour or the day length, a and b are coefficients of Angstrom's formula. H_o, is the monthly average daily extraterrestrial radiation which can be expressed as:

$$H_o = \frac{24}{\pi} I_{sc}\left[1 + 0.033\cos\frac{360n}{365}\right]\left[\cos\emptyset\cos\delta\sin\omega_s + \frac{\pi}{180}\omega_s\sin\emptyset\sin\delta\right] \quad (2)$$

as described by (Neuwirth, 1980; Duffie and Beckman, 1991). Where n is the Julian day number, I_{sc} = 1367Wm^{-2} is the solar constant, $\emptyset$ is the latitude of the location, δ is the declination angle given as:

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

And ω is the sunset hour angle as

$$\omega = \cos^{-1}(-\tan\emptyset\tan\delta) \quad (4)$$

For a given day, the maximum possible values of day length can be computed by using Cooper's formula (Cooper, 1969):

$$\bar{S}_o = \frac{2}{15}\cos^{-1}(-\tan\varphi\tan\delta) \quad (5)$$

The regression models proposed in the literature based on sunshine hour-based models are listed below:

Model 2: Akinoglu and Ecevit obtained a second order polynomial given as:

$$\frac{H_m}{\mathrm{H_o}} = 0.145 + 0.845\frac{S}{S_0} + 0.280\left(\frac{S}{S_0}\right)^2 \quad (6)$$

Model 3: Samuel obtained a third order polynomial equation given as:

$$\frac{H_m}{\mathrm{H_o}} = -0.14 + 2.52\frac{S}{S_0} - 3.71\left(\frac{S}{S_0}\right)^2 + 2.24\left(\frac{S}{S_0}\right)^3 \quad (7)$$

The method of least squares was used to obtain the constants a and b as follows (Nguyen and Pryor, 1997):

$$a = \frac{\Sigma\frac{H_m}{H_0}\Sigma\left(\frac{S}{S_0}\right)^2 - \Sigma\frac{S}{S_0}\Sigma\frac{S}{S_0}\frac{H_m}{H_0}}{M\Sigma\left(\frac{S}{S_0}\right)^2 - \left(\Sigma\frac{S}{S_0}\right)^2} \quad (8)$$

$$b = \frac{M\Sigma\frac{S}{S_0}\frac{H_m}{H_0} - \Sigma\frac{S}{S_0}\Sigma\frac{H_m}{H_0}}{M\Sigma\left(\frac{S}{S_0}\right)^2 - \left(\Sigma\frac{S}{S_0}\right)^2} \quad (9)$$

Where coeffecient of determinaion R^2 was used to evaluate the performance of the models used in the study.

III. Results and Discussion

The global solar radiation on a horizontal surface H_m ($MJM^{-2}day^{-1}$), extraterrestrial solar radiation H_o ($MJM^{-2}day^{-1}$), sunshine hour, S (hr) and the monthly day length S_o (hr), as well as the clearness index $K_T = H_m/H_o$, were computed for each month using equations (2) - (5), the input parameters for the calculation of the mean monthly global solar radiation for Bauchi, Taraba State (2001 - 2010) are shown in the Table 1.

Table 1: Meteorological Data and Global Solar Radiation for Bauchi

Months	S (hr)	S_o (hr)	S/S_o	H_m	H_o	H_m/H_o
Jan.	7.9	12.35	0.64	13.4	32.32	0.42
Feb.	7.5	12.16	0.62	21.8	34.71	0.63
Mar.	6.5	11.93	0.55	22.8	36.99	0.62
Apr.	8.7	11.72	0.74	21.7	37.91	0.57
May	7.5	11.57	0.65	23.6	37.46	0.63
Jun.	6.7	11.53	0.58	23.2	36.74	0.63
Jul.	4.3	11.64	0.37	23.6	36.89	0.64
Aug.	5.3	11.85	0.45	20.4	37.46	0.55
Sep.	6.8	12.07	0.56	20.3	37.16	0.56
Oct.	6.8	12.28	0.55	23.1	35.35	0.66
Nov.	8.5	12.43	0.68	21.0	32.79	0.64
Dec.	6.4	12.44	0.52	18.4	31.42	0.59

Table 2: Measured and calculated monthly average daily Global Solar Radiation

Months	H_m	Model 1	Model 2	Model 3
Jan.	13.4	20.00	18.42	17.64
Feb.	21.8	21.13	19.44	19.37
Mar.	22.8	22.90	20.96	19.80
Apri.	21.7	21.35	23.19	22.56
May	23.6	23.31	21.48	20.43
Jun.	23.2	22.64	20.18	21.85
Jul	23.6	23.36	15.30	19.67
Aug.	20.4	20.11	17.05	18.43
Sept.	20.3	20.51	20.57	19.06
Oct.	23.1	23.29	19.42	22.43
Nov.	21.0	21.94	15.07	18.29
Dec.	18.4	18.56	17.95	12.69

The relationship between the relative sunshine duration ($\frac{S}{S_o}$), and clear sky index (K_T) or ($\frac{H_m}{H_o}$) for Bauchi are presented in Figure 1 above. The value of K_T (= 0.55) corresponding to the lowest value of $\frac{S}{S_o}$ (= 0.45) in the month of August indicate poor sky conditions. These conditions correspond to the wet or rainy season (June - September) observed in Nigeria during which there is much cloud cover. Using these parameters, the regression constants 'a' and 'b' were evaluated as 0.29 and 0.50 respectively. Substituting these values into equation (1), we now established the empirical correlation for the estimation developed for Bauchi as:

$$\frac{H_m}{H_o} = 0.267 + 0.461\frac{S}{S_o} \quad (10)$$

The monthly average daily global solar radiation was estimated through equations (1) to (9) for Bauchi from the three models used in the study are given in tables 1-2, along with the measured values, are also plotted with the measured data in figure 2. It is very encouraging to observe a very fine agreement between the measured and estimated values shown in table 2 and figure 3.

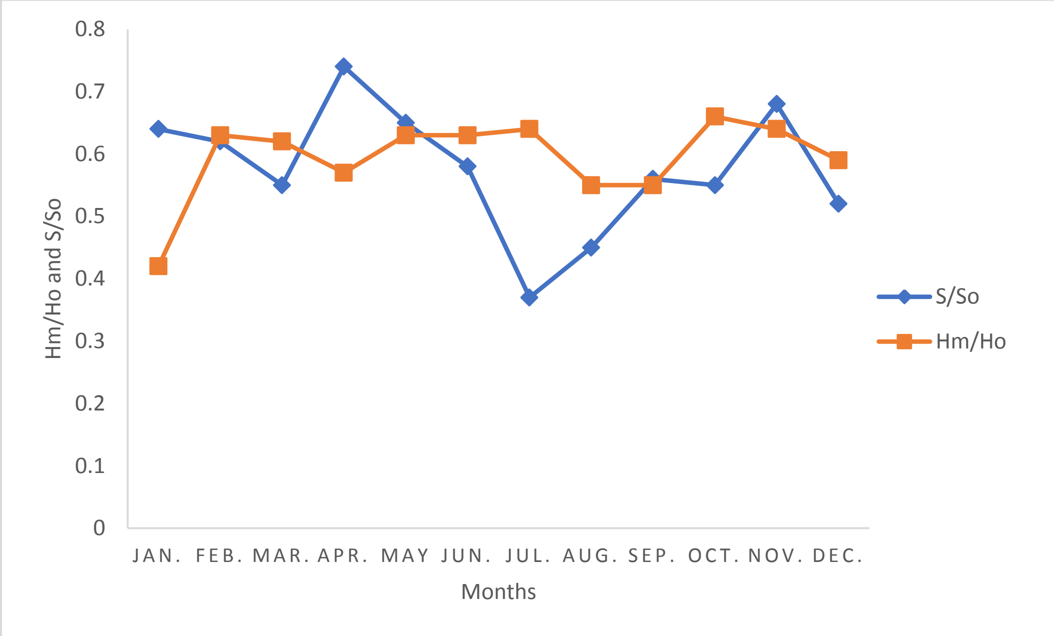

Figure 1: Variation of H_m/H_o and S/S_o (The clearness index) for Bauchi

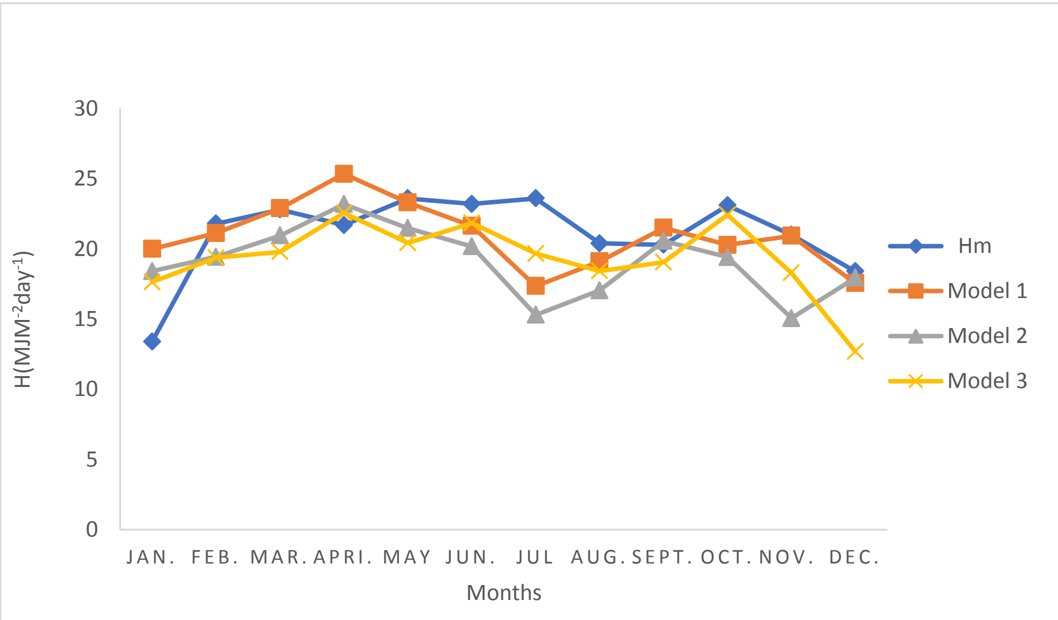

Figure 2: Comparison of the estimated value of monthly average daily global solar radiation from 3 models and measured values.

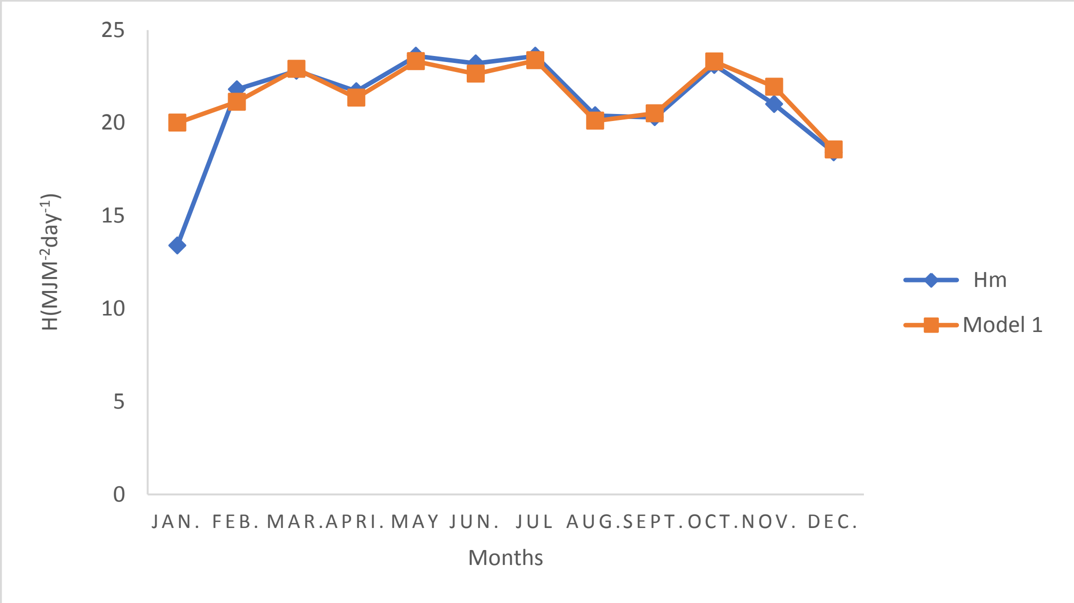

Figure 3: Comparison of the estimated value of monthly average daily global solar radiation from 3 models and measured values

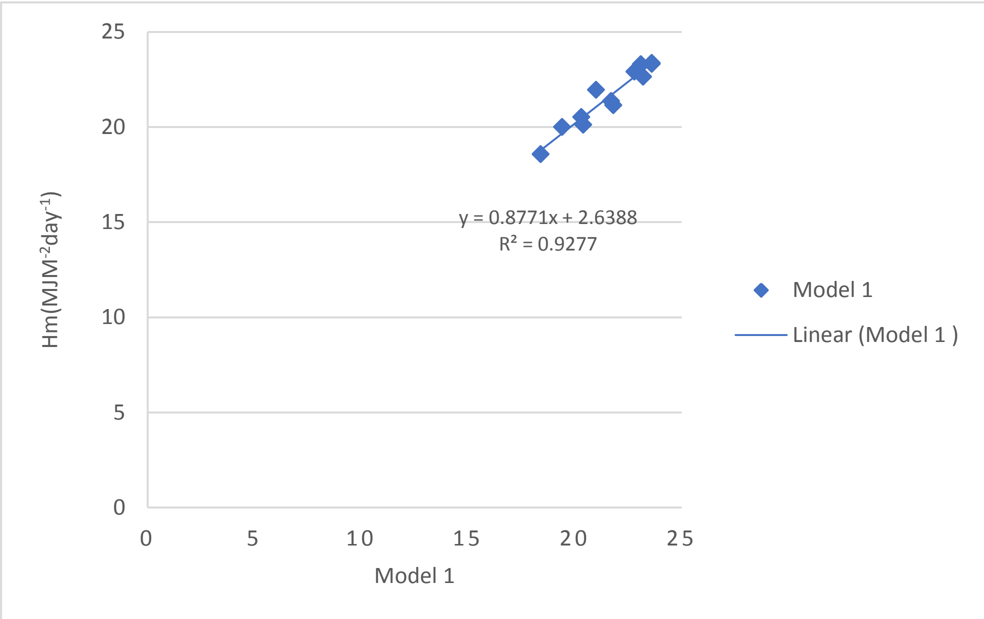

Figure 4: Model 1 fitting for variation of measure and estimated values for Bauchi

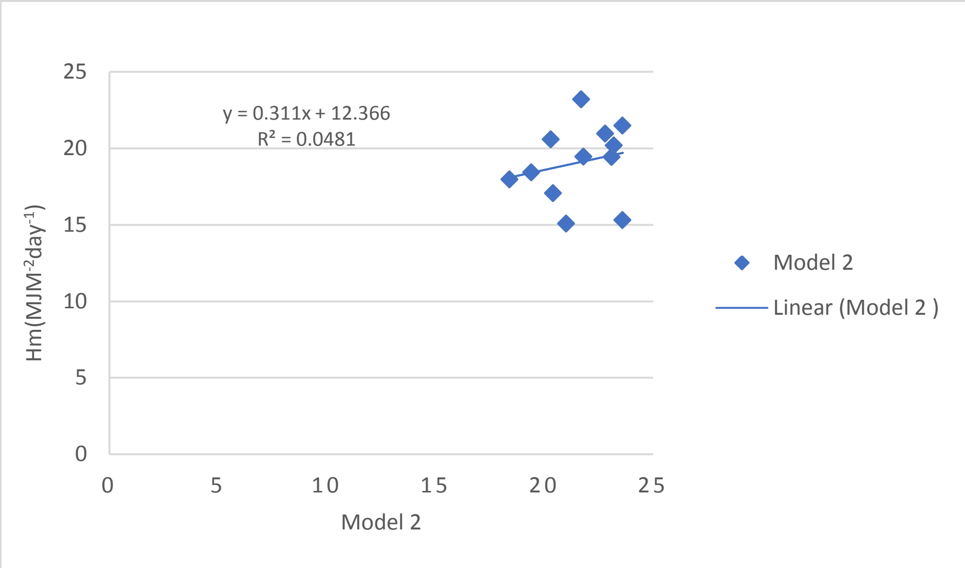

Figure 5: Model 2 fitting for variation of measure and estimated values for Bauchi

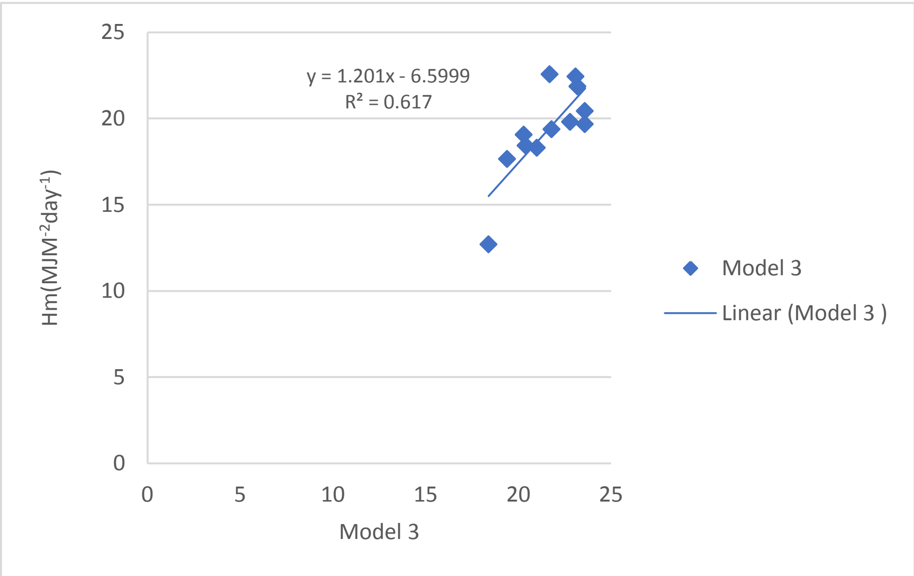

Figure 6: Model 2 fitting for variation of measure and estimated values for Bauchi

In the sunshine-based models proposed for this study were used to show the validation of relative sunshine duration and clearness index for Bauchi. Figure 4-6 show the results of the performance of each model in terms of regression of coefficient (R^2). The coefficient of determination for Angstrom-Prescott model, R^2 (92.77%) obtained for this analysis shows that the model is excellently fits for the data (Figure 4), while Akinoglu and Ecevit model was R^2 (4.18 %) and Samuel Model was found to be was R^2 (61.7 %). In summary, model 1 performed excellently in regression (R^2) than model 2 and 3.

IV. Conclusion

The Bauchi State is enriched with solar radiation and large rural residents living in villages without sufficient infrastructure for the construction of an electricity grid, the use of photovoltaic solar is considered an attractive alternative because of its modular characteristics, namely its ability to produce electricity at the point of use, Its low maintenance requirements and the non-polluting functionality. Solar radiation models are ideal for the design of solar energy systems and for successful thermal environment assessments in buildings. It was observed that model 1 (linear) performed better for estimating global solar radiation for Bauchi state than model 2 (second order polynomial equation) and model 3 (third order polynomial equation).

ACKNOWLEDGEMENT

The authors wish to acknowledge the management of the Nigeria Meteorological Agency, Abuja, Nigeria, for making the data of global solar radiation and sunshine hour available.

REFERENCES

[1] Adebiyi, G.A (1988). An empirical correlation of solar radiation data for Nigeria. *The Nigerian Engineer* 32(2): 50 - 57.
[2] Ahmad, F and Ulfat, I. (2004). Empirical models for the correlation of monthly average daily global solar radiation with hours of sunshine on a horizontal surface at Karachi, Pakistan. *Turkish J. Physics*, 28, 301-307.
[3] Angstrom, A.S (1924), Solar and Terrestrial Radiation. Met. Soc. 50, Pp. 126.
[4] Arinze, E.A and Obi, S.E (1983). Solar energy availability and prediction in Northern Nigeria. Nig. J. Solar Energy 3: 3 -10.
[5] Augustine, C and Nnabuchi, M.N (2009). Relationship between Global Solar Radiation and Sunshine hours for Calabar, Port-Harcourt and Enugu, Nigeria. *International Journal of Physical Sciences* 4(4): Pp 182-188.
[6] Awachie, I.R.N and Okeke, C.E. (1990). New empirical solar model and its use in predicting global solar irradiation. *Nigerian J. Solar Energy,* 9, 143-156.
[7] Bamiro, O.A (1983). Empirical relations for the determination of solar in Ibadan, Nigeria. Sol. Energy 31(1): 85 - 94.
[8] Burari, F.W, Sambo, A.S, Mshelia, E.D (2001). Estimation of Global Solar Radiation in Bauchi. *Nig. J. Renewable Energy* 9: 34 - 36.
[9] Cooper, P.I (1969). "The Absorption of Radiation on Solar Stills", Solar Energy, vol. 12, no. 3, pp 333 – 346.
[10] Chineke, T.C and Igwiro, E.C (2008). Urban And Rural Electrification: Enhancing the Energy Sector in Nigeria Using Photovoltaic Technology. *African Jour Science and Tech*. Vol. 9, No. 1, pp. 102 – 108.
[11] DeMiguel, A, Bilbao,J Salson, S and Lage, A. (1994). Solar radiation and sunshine hour maps in Castilla and Leon region (Spain). *Renewable Energy*, 4, 933-940.
[12] Duffie, J. A. and Beckman, W. A., (1991). Solar Engineering of Thermal Processes, 2nd edition, New York: Wiley.
[13] Fagbenle, R.O (1990). Estimation of total solar radiation in Nigeria using Meteorological data. Nig. J. Renewable Energy 1: 1-10.
[14] Falayi, E.O and Rabiu, A.B. (2005). Modelling global solar radiation using sunshine duration Data. Nigerian J. Physics, *17S, 181-186.*
[15] Falayi, E.O, Rabiu, A.B and Teliat, R.O (2011). Correlations to estimate monthly mean of daily diffuse solar radiation in some selected cities in Nigeria. Advances in Applied Science Research 2(4): 480-490.
[16] Fariba B, Ali A. D and Ahmad R. F (2013). Empirical models for estimating global solar radiation: A review and case study. *Renewable and Sustainable Energy Reviews*, 21, 798-821.
[17] Glover, J and McCulloch, J.S.G. (1958). The empirical relation between solar radiation and hours of sunshine. *Q.J.R Meteorol. Soc.* 84, 172-175.
[18] Hacer D and Harun A. (2012). Sunshine-based estimation of global solar radiation on horizontal surface at Lake Van region (Turkey). *Energy Conversion and Management*, 58, 35-46.
[19] Ibrahim, S.M.A. (1985). Predicted and Measured global solar radiation in Egypt. *Solar Energy*, 35, 185-188.
[20] Muyiwa S. A. (2012). Estimating global solar radiation using common meteorological data in Akure, Nigeria. *Renewable Energy*, 47, 38-44.
[21] Neuwirth, F., (1980). The estimation of global and sky radiation in Austria. Sol. Energy 24, 421 – 426.
[22] Nguyen, B.T. and Pryor, T. L. (1997): The relationship between global solar radiation and sunshine duration in Vietnam. Renewable Energy, II, 47 (60).
[23] Ododo, J.C, Agbakwuru, J.A and Ogbu, FA. (1996). Correlation of solar radiation with cloud cover and relative sunshine duration. *Energy Conversion and Management,* 37 (10), 1555-1559.
[24] Ododo, J.C, Aidan, J and Ogbu, FA. (2006). Modelling of solar radiation in North-Eastern Nigeria. *Nigerian J. Solar Energy,* 16, 61-78.
[25] Ododo, J.C. (2006). New models for the prediction of solar radiation in Nigeria. *Nigerian J. Solar Energy, 16, 5-14.*
[26] Ojosu, J.O (1984). Solar Radiation Maps of Nigeria. Nig. J. Solar Energy 8: 370 - 384.
[27] Prescott, J.A., (1940). Evaporation from a water surface in relation to solar radiation. Trans. R. Soc. Sci. Australia 64, 114 – 125.
[28] Sambo, A.S. (1988). The measurement and prediction of global and diffuse components of solar radiation for Kano in Northern Nigeria, *Solar Wind Technology*, 5(1), 1-5.
[29] Turton, S.M.A (1987). "The relationship between total irradiation and sunshine in humid tropics". Solar Energy 38: 353-354.
[30] Udo, S.O and Aro, T.O. (1999). Measurement of global solar, global photosynthetically-active and downward infra-red radiation at Ilorin, Nigeria. *Renewable Energy*, 17, 113-122.
[31] Yakubu, D. and Medugu, D. W (2012). Relationship between the Global Solar Radiations and the Sunshine Duration in Abuja, Nigeria. *Ozean Journal of Applied Sciences* 5(3).
[32] Yohanna, J. K, Itodo, I. N. and Umogbai, V I. (2011). A model for determining the global solar radiation for Makurdi, Nigeria. *Renewable Energy,* 36(7), 19891992.