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COMPARATIVE ANALYSIS OF GLOBAL SOLAR RADIATION MODELS IN KAZAURE, NIGERIA

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ABSTRACT

Solar radiation plays important role for solar energy system and development of solar energy devices. The purpose of this study is to compare four different global solar radiation model namely Angstrom, Bakirci, El-Metwally and Ogelman model for Kazaure with latitude 12.650N and longitude 8.420E. The regression analysis shows that Ogelman perfom excellently with coefficient of determination R2= 0.997 with respect to other three model, El-Metwally, Angstrom and Bakirci with their coefficient of determination to be R2=0.944, R2 = 0.9229 and R= 0.9162. Other calculated parameter monthly average global solar radiation, monthly average extraterrestrial solar radiation, clearness index, monthly day length.

Keywords: *Monthly Average Global Solar Radiation, Monthly Average Extraterrestrial Solar Radiation, Angstrom Model, Bakirci Model, El-Metwally Model and Ogelman Model.*

INTRODUCTION

Solar power is energy from the sun that is converted into thermal or electrical energy. Solar energy is the cleanest and most abundant renewable energy source available. This energy that comes from the sun can be used with the help of modern technology for different uses, such as generation of electricity, provision of light, heating water for domestic, commercial or industrial use. The exact information of solar radiation distribution of a specific location is very important in order to use the available solar energy economically and efficiently as well as to develop solar energy equipment. The equipment like pyranometer that was require to carry out solar radiation measurement is not available due to high cost involved, as a result the researchers resolved to data acquired from Nigeria meteorological Agency data (NIMET) such as sunshine hours, measured solar radiation, temperature etc. researchers in Nigeria goes through different challenges before they could be able to get data from NIMET, either due to fewer offices they have within the country or processes involved before the data were given out to the researchers.

Researchers have proposed different model for the prediction of solar radiation in different locations within the country using data obtained from NIMET. In this work sunshine hour will be used to obtained calculated values of solar parameters, thereafter the model will be compared to find out the one that work excellently.

LITERATURE REVIEW

(Musa *et al.,* 2012), (Garba*et al.,* 2016), both carried out a study on estimation of global solar radiation in Maiduguri using Angstrom model. The former use daily sunshine duration measurement for five years (2006 to 2010) and later use fifteen years (1996-2010) from which the monthly mean values were determined. The Angstrom model was then used to estimate the global solar radiation based on the monthly mean sunshine hour. The former claims that the values of solar radiation for Maiduguri town vary from the range of 16.80MJm-2day-1 to 25.04MJm-2day-1under the period of study with the mean value of24.20MJm-2day-1. The former concluded that the value can be utilized in the design and performance estimation of solar energy systems, which is gaining significant attention in Nigeria in particular and the world at large. Apart from Angstrom model, Garba *et al.,* also uses quadratic, exponential and power equations. The results of the four models were compared. It was observed that the quadratic model performed better in terms of coefficient of determination than the other three models

(Isikwue*et al.,* 2014), presented evaluations of radiation energy balance in some selected cities like Port Harcourt, Enugu, Markudi and Kano in the tropical forest and savannah zones of Nigeria. The data used for the study were obtained from the Nigerian Meteorological Agency (NIMET) Abuja, (1990-2010). Theoretical formulae were used to obtained solar radiation (SR), net solar radiation (NSR), regression coefficient (RC) and Net terrestrial radiation (NTR).The results among other things show that the albedo was generally high (60 to 64%), in all the locations considered, implying that majority of the solar radiation in these locations did not reach the surface. However, there are increases in the radiation balance in Port Harcourt and Makurdi locations, whereas in Enugu and Kano, the curves indicate negative or decrease in radiation balance. This implies that there is a balance in solar energy radiation budget that could enhance solar energy technologies in Port Harcourt and Makurdi towns. On the other hand, suggestions have been made on the need for seasonal considerations of the radiation balance for more efficient climatic and solar technological planning.

(Auwal&Darma, 2014), modified Angstrom model for the estimation of global solar radiation in Kano, using maximum/minimum temperature and relative humidity based on meteorological data they obtained. Two new models were developed for estimating the monthly-average daily global solar radiation. Regression coefficients a and b of(1.2577,−1.0167) and(0.8317 ,−0.0043) were obtained from the models based on temperature ratios and relative humidity respectively. In order to evaluate the results, three statistical methods have been used namely; Mean bias, root mean square, and mean percentage errors. The temperature based models which has a lower root mean square error is an indication of good agreement between the measured and estimated global solar radiation. Base on the statistical results a new temperature base model is recommended to estimate monthly global solar radiation for Kano state and other locations with similar climate conditions where the radiation data is unavailable.

(Medugu&Yakubu, 2011), studies the estimation of global solar radiation at Yola, Nigeria, for four years (2004 to 2007) using sunshine recorder for measurement of daily sunshine hour. The monthly mean values were determined. The Angstrom model was then used to estimate the global solar radiation based on the available climatic parameters of sunshine hour. From the results obtained, the values of the radiation varies from the range of 13.75 MJm-2day-1 to 25.16 MJm-2day-1 with the mean value of 21.54±0.46 MJm-2day-1

in order to be utilized very efficiently in the design and prediction of the performance of solar energy devices. This method was esmployed since installation of pyranometer is a very costly exercise.
(Gana&Akpootu, 2013), conducted a research on global solar radiation on a horizontal surface and number of bright sunshine hours for Kebbi (Latitude 12.47ºN, Longitude 4.3ºE, Altitude 205m above the sea level) were analyzed. Regression constants for the first order Angstrom-type correlations for Kebbi was calculated and developed using the method of regression analysis. The monthly calculated clearness index and monthly sunshine duration were correlated and modeled using four sunshine-based models i.e. linear, quadratic, and exponential and power equations. When the models were compared, it was observed that the quadratic equation model performed better in terms of coefficient of determination(R^2) and correlation coefficient (r) than the other three models, given R^2 = 100% and r = 1.00

METHODOLOGY

The monthly mean data for sunshine hours in Kazaure was obtained using sunshine recorder. The data obtained covered a period of five years (2011 - 2015) Gana & Akpootu, (2013). Kazaure is located at Latitude 12.650N and Longitude 8.420E. Empirical models is used for estimating the monthly average daily global solar radiation which are Angstrom-Prescott model, Bakirci model, El-Metwally model, and Ogelman model.
Jakhrani*et al.*,(2015), Dalhatu*et al.*,(2014), and Sani,(2014) stated that extraterrestrial solar radiation (H0), declination angle and can be expressed in the following equation

$$Ho = 24 * Gsc \frac{3600}{\pi}\left[1 + 0.33\cos\left(\frac{360n}{365}\right)\right]\left[sin\phi\sin\delta + \cos\phi\cos\delta\sin\omega s\right] \quad (1)$$

Where H0is monthly average extraterrestrial solar radiation, Gsc is solar constant = 1367W/m2, n is the number of days of the year starting from 1st January to 31st December,$\emptyset$ is latitude of the area, (δ) is solar declination angle, and ωs is the mean sunrise hour angle.
The declination angle is given as

$$\delta = 23.45\sin\left[360 * \frac{284+n}{365}\right] \quad (2)$$

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

$$So = \frac{2}{15}ws \quad (4)$$

Where So is monthly average day length.

Gana*et al.,* (2013) and Garba*et al.,*(2016) affirms that Angstrom-Prescott model, El-metwally (power) model, and Bakirci (exponential) model and Ogelman (polynomial) Model can all be expressed as follows:

Angstrom-Prescott model

$$\frac{H}{Ho} = a + b\left(\frac{S}{So}\right) \quad (5)$$

Where H, is monthly average global solar radiation, a and b are regression coefficient which is expressed in equation (6) and (7), (Innocent *et al.,* 2015)

$$a = -0.110 + 0.235cos\phi + 0.323\left(\frac{S}{So}\right) \quad (6)$$

$$b = 1.449 - 0.553 - 0.694\left(\frac{S}{So}\right) \quad (7)$$

(Abdullahi*et al.*, 2014) stated that $Kt = H/Ho$ (8)

El-metwallyModel

$$H/Ho = a^{\left[\frac{1}{\frac{S}{So}}\right]} \quad (9)$$

Bakirci Model

$$H/Ho = a\left(\frac{S}{So}\right)^{b} \quad (10)$$

Ogelman Model

$$\frac{H}{Ho} = a + b\left(\frac{S}{So}\right) + c\left(\frac{S}{So}\right)^{2} \quad (11)$$

RESULT

According to Shukla *et al.,* (2015), the days on which extraterrestrial radiation is equal to monthly mean value is given in table 1. The values are used in calculation of the declination angle(δ).

Monthly average extraterrestrial solar radiation, monthly average global solar radiation clearness index, regression constant was all computed in Table 2. The values for four different models mentioned above were obtained from equations in figure 1-4 and thereafter tabulated in Table 3.

Table 1: Days on which extraterrestrial radiation equal to monthly mean value with declination angle and sunrise hour angle.

Month	Day	Days of the Year	Declination angle (δ) in degree	sunrise hour angle (ωs) in degree
January	17	17	-20.92	85.08
February	16	47	-12.95	87.04
March	16	75	-2.42	89.34
April	15	105	9.41	92.13
May	15	135	18.79	94.38
June	11	162	23.09	95.49
July	17	198	21.18	94.99
August	16	228	13.45	93.08
September	15	258	2.22	90.50
October	15	288	-9.60	87.82
November	14	318	-18.91	85.59
December	10	344	-23.05	84.52

Table 2: Monthly average global solar radiation, monthly average extraterrestrial solar radiation, and monthly average solar radiation with other parameters for years (2011-2015)

Month	S0	S	H0MJm-2day-1	H MJm-2day-1	H/H0	S/S0	a	b
January	11.34	8.20	32.18	22.54	0.65	0.72	0.35	0.41
February	11.61	7.84	35.25	23.96	0.64	0.68	0.34	0.44
March	11.93	7.72	44.92	28.74	0.63	0.65	0.33	0.46
April	12.28	9.38	47.45	30.61	0.65	0.76	0.36	0.38
May	12.58	8.58	45.31	29.96	0.64	0.68	0.34	0.44
June	12.73	8.20	26.19	16.52	0.63	0.64	0.33	0.47
July	12.67	6.92	25.80	15.26	0.59	0.55	0.30	0.53
August	12.41	6.52	28.82	16.61	0.58	0.53	0.29	0.54
September	12.07	7.79	34.33	21.59	0.63	0.65	0.33	0.46
October	11.71	8.75	40.38	26.35	0.65	0.75	0.36	0.39
November	11.41	8.60	43.87	28.28	0.65	0.75	0.36	0.39

December	11.23	8.48	34.74	27.47	0.65	0.76	0.36	0.38

Table 3: Calculated global solar radiation, ratio of monthly average daily hours of sunshine to monthly average daily length, and models (M1- M4)

Month	H (MJm-2day-1	S/S0	Angstrom Model (M1)	Bakirci Model (M2)	El-metwally Model (M3)	Ogelman Model (M4)
January	22.54	0.72	0.65	0.39	0.63	0.65
February	23.96	0.68	0.63	0.38	0.61	0.64
March	28.74	0.65	0.62	0.37	0.60	0.63
April	30.61	0.76	0.66	0.40	0.64	0.65
May	29.96	0.68	0.63	0.38	0.61	0.64
June	16.52	0.64	0.62	0.37	0.59	0.63
July	15.26	0.55	0.60	0.35	0.54	0.59
August	16.61	0.53	0.59	0.34	0.53	0.58
September	21.59	0.65	0.62	0.37	0.60	0.63
October	26.35	0.75	0.65	0.40	0.64	0.65
November	28.28	0.75	0.65	0.40	0.64	0.65
December	27.47	0.76	0.66	0.40	0.64	0.65

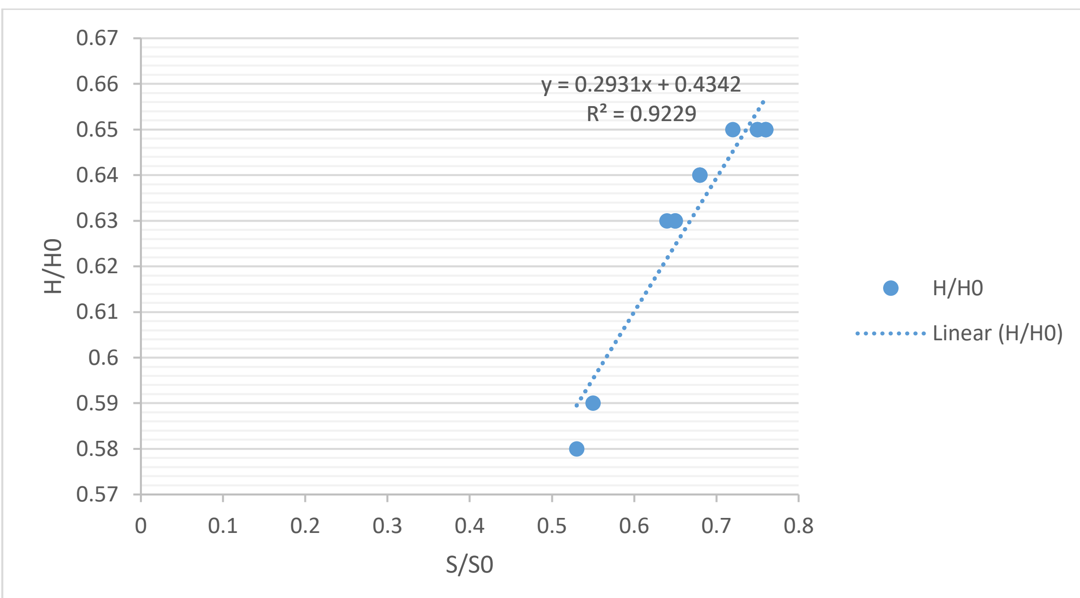

Figure 1: *Clearness index versus ratio of sunshine hour to sunshine day length for Angstrom Model*

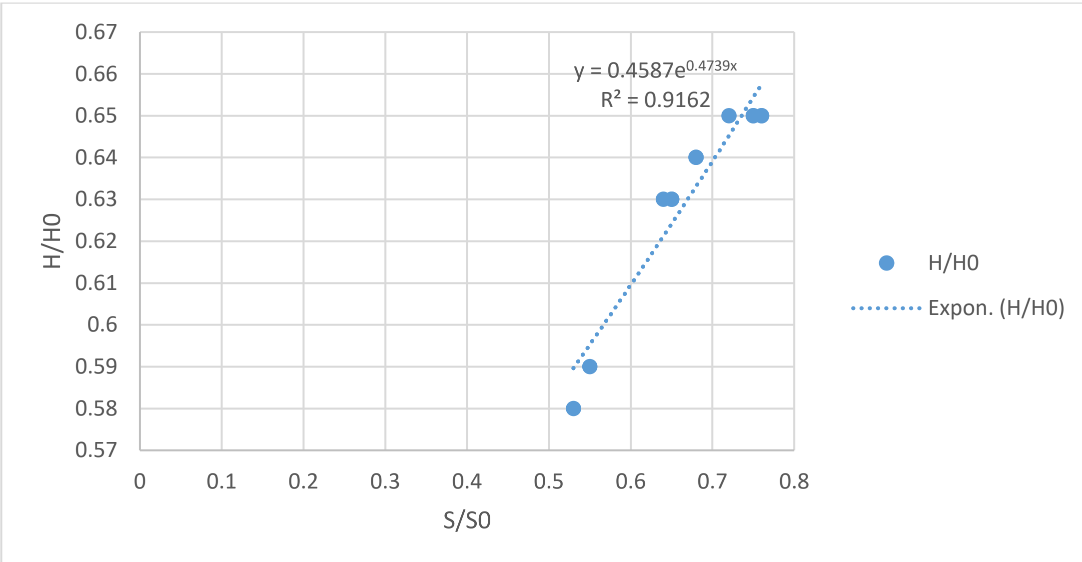

Figure 2: *Clearness index versus ratio of sunshine hour to sunshine day length for Bakirci Model*

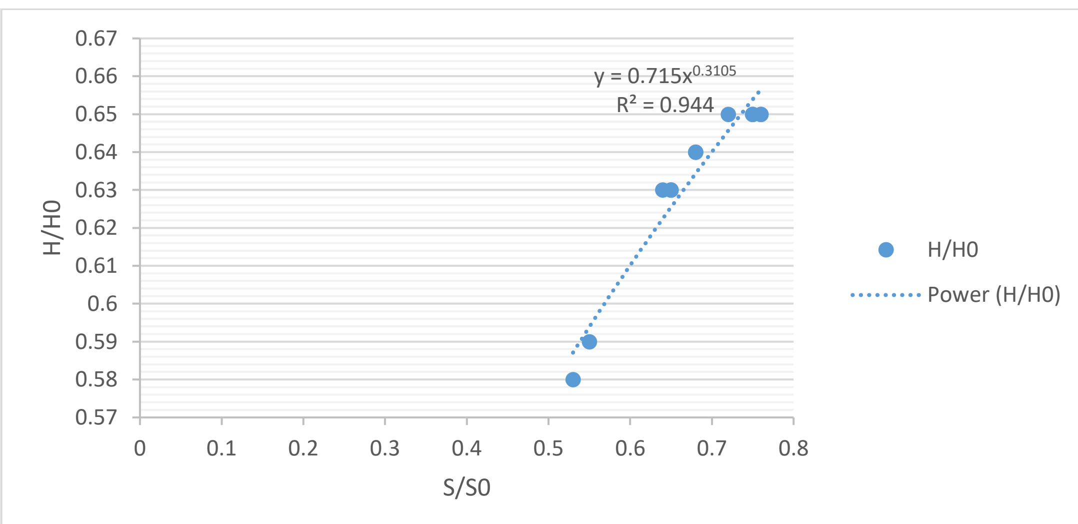

Figure 3: *Clearness index versus ratio of sunshine hour to sunshine day length for El-Metwally Model*

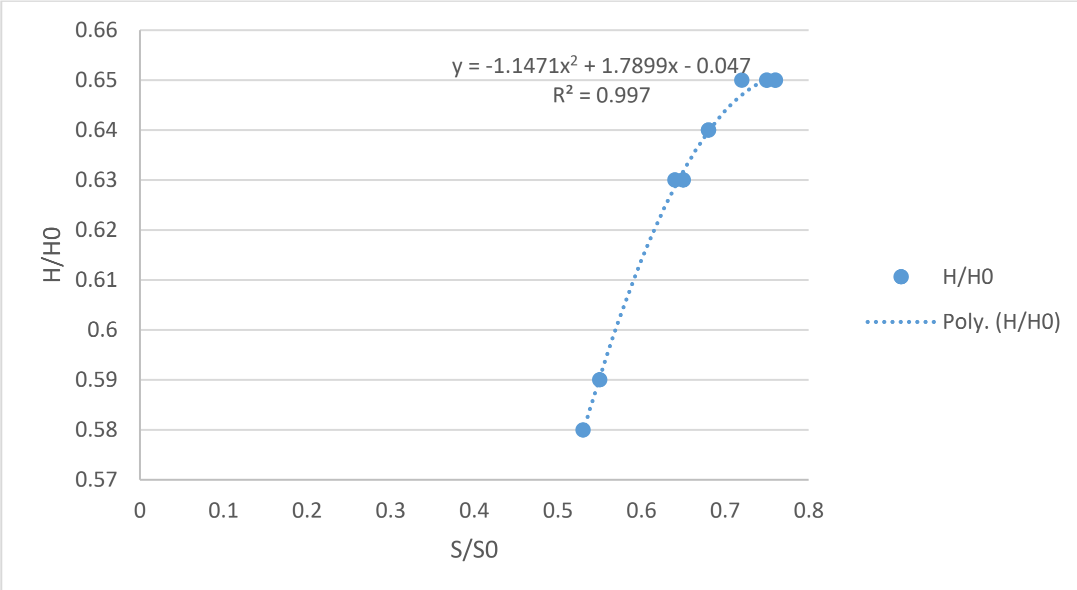

Figure 4: *Clearness index versus ratio of sunshine hour to sunshine day length for Ogelman Model*

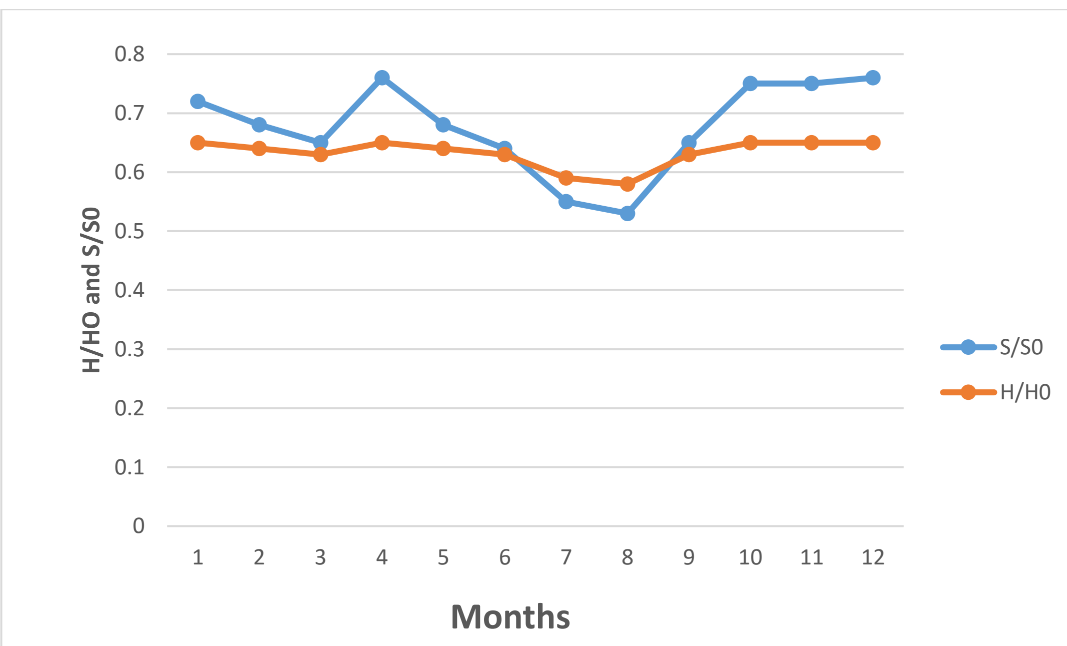

Figure 5: *Clearness index & ratio of sunshine hour to sunshine day length versus Month*

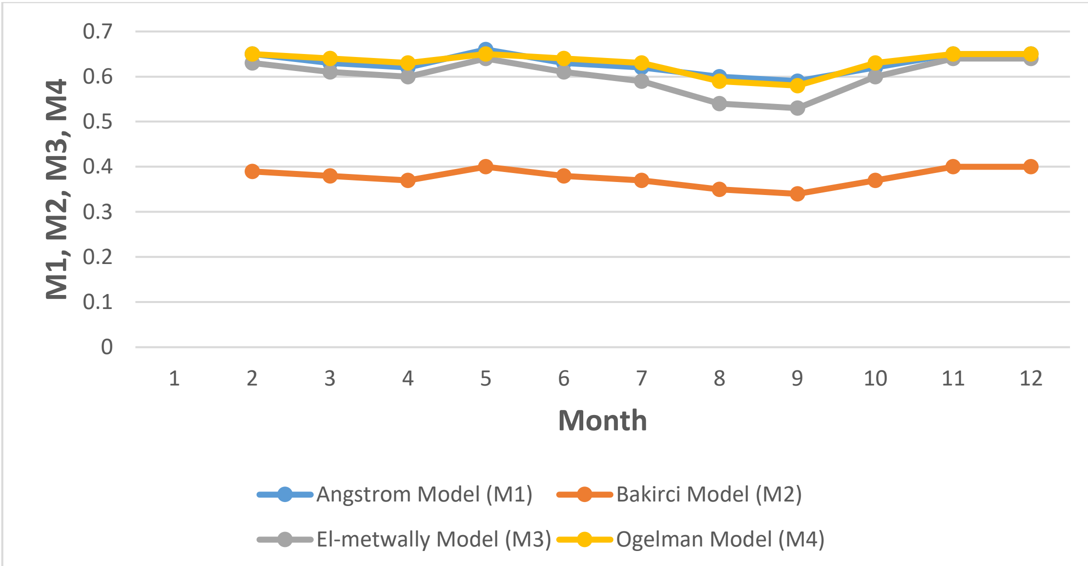

Figure 6: *Model 1- Model4 versus Month*

DISCUSSION OF RESULT

Table 1 shows calculated values of angles of declination and solar hour's angles with highest value of declination to be 23.090 with corresponding solar hour's angle to be 95.490in May while the least value of declination to be -23.050 and 84.520for solar hour's angle in December.

Table 2 shows the calculated global solar radiation, extraterrestrial solar radiation with other input parameters using equations (1) – (7). The highest values of global solar radiation are 28.74 MJm-2day-1, 30.61MJm-2day-1, and 29.96 MJ m-2 day-1for month of March, April and May which is due to the intensity of the sun, while the least values are 16.52 MJm-2day-1, 15.26 MJm-2day-1, and 16.61MJm-2day-1 for month of June, July and August which is due to cloud cover by rainy season. On the other hand, the highest values of extraterrestrial radiation are 44.92 MJm-2day-1, 47.45 MJm-2day-1, and 45.31 MJ m-2 day-1 for the month of March, April and May while the least values were 26.19 MJm-2day-1, 25.80MJm-2day-1and 28.82MJm-2day-1 for month of June, July and August.

Table 3 shows global solar radiation with calculated values for four different model using relationship in figure (1) to (4).

The model equation are

$$H/H0=0.4342+ 0.2931 (S/S0) \qquad (12)$$

The Coefficient of determination, R2 (0.9229) obtained from figure 1 shows that the model is very good for the data in relation to equation (12).

$$H/H0= 0.4587(S/S0) ^ (0.4739) \quad (13)$$

The Coefficient of determination, R2 (0.9162) obtained from figure 2 shows that the model is good for the data in relation to equation (13).

$$H/H0=0.715^ (1/(S/S0)) \quad (14)$$

The Coefficient of determination, R2 (0.9440) obtained from figure 3 shows that the model is better fits for the data in relation to equation (14).

$$H/H0= -0.047 + 1.7899 (S/S0)- 1.147 (S/S0)2 \quad (15)$$

The Coefficient of determination, R2 (0.997) obtained from figure 4 shows that the model is best fits for the data in relation to equation (15).
when the model were compared with each other, Ogelman model shows excellent performance in comparison with other three model as it can be seen in figure 6.
In designing solar energy system for this locality, model 4 (Ogelman model) is best followed by Model 3 (El-Metwally Model), Model 1 (Angstrom Model) and Model 2 (Bakirci Model).

CONCLUSION

Solar radiation models are useful tools for designing solar energy system and solar energy devices. The research shows the importance of comparative study of solar radiation models for estimation of global radiation for a specific location (Kazaure). Although the four models perform well, but Ogelman model perform excellently with coefficient of determination R2 to be 0.997 with respect to three other model. This will assist in the design of solar energy system. It can be seen again that the global solar radiation are highest in month of March, April and May with radiation value at 28.74 MJm-2day-1, 30.61MJm-2day-1, and 29.96 MJ m-2 day-1and lowest at June, July and August with radiation values as 16.52 MJm-2day-1, 15.26 MJm-2day-1, and 16.61MJm-2day-1.

RECOMMENDATION

1. There should be awareness both in urban and rural area on the advantage of use of solar energy.
2. Government should diversify means of electricity generation at federal and state level.

3. Government should create favorable policy that will entice investor in this area.
4. There should more emphasis on research in the designing of solar energy system.

REFERENCES

Garba, A. A., Amusat, R. O., Ngadda, Y. H. (2016). Estimation of Global solar Radiation Using

Sunshine-Based Model in Maiduguri, North-East, Nigeria. *Applied Research Journal vol.2, issue 1, pp 19-26.*

B. Musa, U. Zangina and M. Aminu (2012). Estimation of Global Solar Radiation in Maiduguri, Nigeria Using Angstrom Model. *ARPN Journal of Engineering and Applied Sciences. Vol. 7 no. 12.*

Isikwue, B. C. Akiishi, M. And Utah, E. U (2014). Investigation of Radiation Energy Balance in Some Selected Cities in Nigeria.*IOSR Journal of Applied Physics. Vol. 6, issue 2*

DalhatuAbdulsalam, IkefunaMbamali, Mohammed Usman and KabiruBala (2014). Insolation

Levels Using Temperature Model for Sustainable Application of Photovoltaic Technology in Some Selected Locations of Nigeria. *Journal of Energy Technologies and policy. Vol.4 no.1*

Medugu D. W. andYakubu D. (2011). Estimation of Mean Monthly Global Solar Radiation in Yola - Nigeria using Angstrom Model. *Advance in Applied Science Research. Vol. 2 (2).*

N. N. Gana and **D. O. Akpootu (2013). Estimation of Global Solar Radiation Using Four Sunshine Based Models in Kebbi, North-Western, Nigeria. *Advance in Applied Science Research. Vol.4 no. 5*

K.N. Shukla, SarojRangnekar and K. Sudhakar (2015). Comparative Study of Isotropic and Anisotropic Sky Models to Estimate Solar Radiation Incident on Tilted Surface: A Case Study for Bhopal, India. *Energy Report.*

INNOCENT A. J., JACOB O. E., CHIBUZO G. , JAMES I.& ODEH D. O (2015). Estimation of Global Solar Radiation in Gusau, Nigeria. *International Journal of Research in*

Engineering & Technology. Vol.3, Issue 2.

Abdullahi M., Nasir M. A. and Singh S. K.(2014). Study of the Variability of Atmospheric

Parameters for Yola.*Advance in Applied Science Research. Vol.5, no. 4.*

Auwal Muhammad & T.H. Darma (2014). Estimation of Global Solar Radiation for Kano State Nigeria Based on Meteorological Data. *IOSR Journal of Applied Physics. Vol. 6, issue 6*

Sani Saleh (2014). Maps of Regression Coefficients for Estimation of Global Solar Radiation Using Meteorological Data for Continental Landmasses. *1st International Congress on Environmental, Biotechnology, and Chemistry Engineering.*

A.Q. Jakhrani, A. K. Othman, A. R. H. Rigit, S. R. Samo, L. P. Ling1 and R. Baini. Evaluation of Incident Solar Radiation on Inclined Plane by Empirical Models at Kuching, Sarawak, Malaysia. Unpublished.