AN EMPIRICAL MODEL FOR THE ESTIMATION OF GLOBAL AND DIFFUSE SOLAR RADIATION OVER YOLA, NORTH-EASTERN NIGERIA BASED ON AIR TEMPERATURE

***[1]Alkasim, A., Dikko, A.B. and Eyube, E.S.**

Department of Physics, Modibbo Adama University of Technology PMB 2076, Yola, Nigeria

[1]Corresponding Author; *E-mail: alkasimabbat@gmail.com

ABSTRACT

Accurate measurement of solar radiation distribution over any geographical location is desirable for the development of many solar thermal devices and their performance. A simple model for prediction of monthly mean daily solar radiation on a horizontal surface for Yola (longitude 10°E; latitude 9.23°N) was developed using a six (6) years data of daily maximum/minimum temperature records at the recently installed NECOP meteorological station in MAUTECH, Yola. The data was used to assess the applicability of global and diffused solar radiation. The clearness index, K_T for the study period indicated that the solar radiation is available throughout thee year with a maximum value of 0.75 and minimum value of 0.66 indicating that solar appliance can work in Yola throughout the year. The regression constants a, b are 0.46, -0.82 respectively. The proposed model showed a very good agreement with the measured data with RMSE, MBE, and MPE values as 1.983 MJm^{-2}, -1.623 MJm^{-2} and 6.18% respectively

Key Words: Global radiation, Diffused radiation, maximum/minimum daily temperatures, clearness index, Empirical model

INTRODUCTION

Solar radiation is the energy emitted by the sun. It is the direct form of abundant energy resource available on earth, due to nuclear fusion that take place in the interior of the Sun. It provides about 99.97% of the heat energy required for chemo physical processes in the atmosphere, ocean, land and other bodies (Emmanuel *et al.*, 2014). Earth surface is receiving about one hundred thousand of this renewable energy of solar power at earth's surface at each moment. Clouds, gases, pollution (including aerosol) and other factor decreases this available power on surface and thus, earth gets about 800 times less solar energy from the Sun at each moment. About one thousand watts per square meters of solar energy reaches landmass of the earth. Solar Radiation and Sunshine duration are two of the most important variables in the energy budget of the earth (Gadiwal and Usman 2013). They play an important role in the performance evaluation of renewable energy systems and in many other applications like health, agriculture, and construction. The economical and efficient application of solar energy seems inevitable because of abundant sunshine available throughout the year. Solar radiation data is available for most parts of the world, but is not available for many countries which cannot afford the measuring equipment and techniques involved Hence depends on the estimation from models (Alkasim *et al*., 2017).

Almost all known physical and biological cycles in the Earth system are driven by the solar radiation reaching the Earth. Solar radiation is also the cause of climate change that is truly exterior to the Earth system, it radiate energy at the rate of $3.8x10^{26}$ W. In a developing country like Nigeria which is affected by poor/inadequate equipment of measuring solar radiation data, in order to curtail the persistence of inadequate solar data devices the need for an empirical model to predict and estimate global solar radiation seems inevitable. It will also help the energy strategists and planners to utilize the solar energy potentials to solve the solar crises of this area of abundant sunshine and air temperature (Alkasim et al., 2017).

There are various models for estimating solar radiation using the difference in the maximum and minimum daily temperatures and other meteorological data. In Nigeria for instance, many researchers proposes estimation models for solar radiation at different locations e.g. Yola, Maiduguri, Kano, Abeokuta, Owerri and Enugu (Falayi and Rabiu, 2005, Agbo *et al*., 2010, Medugu and Yakubu, 2011, Kaltiya *et al*., 2014, Muhammad and Darma, 2014). The commonly used model which relates only one variable, the surface temperature to global solar radiation was the one developed by Hargreaves and Samani, 1982. Hence this work is aimed at developing this type of model for the estimation of global and diffused solar radiation for Yola and environs as well as any other region with similar climatic condition from the available measured surface temperature.

METHODOLOGY

The global solar radiation parameters were collected for the period of six years (2010-2016) from the Nigerian Environmental Climatic Observation Programme NECOP Meteorological Station, located at the Department of Physics Modibbo Adama University of Technology, Yola, in order to estimate the global solar radiation of Yola, Adamawa state Nigeria using (i) The daily measured global solar radiation (ii) the daily surface temperature.(iii) the maximum and minimum daily temperatures were calculated each day for the period.

The maximum and minimum daily temperatures were recorded and the monthly averages were calculated. Also, the daily global solar radiation were recorded from the meteorological station and the monthly average noted. This was done for the period of six (6) years. The averages of which were presented in table 1.

Empirical Equations for Predicting the Availability of Global Solar Radiation

Global solar radiation is the sum of direct, diffuse, and reflected solar radiation. Direct solar radiation passes directly through the atmosphere to the Earth's surface, diffuse solar radiation is scattered in the atmosphere, and reflected solar radiation reaches a surface and is reflected to adjacent surfaces. The linear regression for Angstrom-Prescott model which has been used to estimate the monthly average daily global solar radiation on a horizontal surface of the Yola, Adamawa Nigeria or other places with similar climatic parameters

The Angstrom-Prescott model formula is given by

$$\frac{\overline{H}_G}{\overline{\overline{H}}_O} = a + b\left(\frac{\overline{n}}{\overline{\overline{N}}}\right) \qquad (1)$$

where H_G (MJm^{-2} day^{-1}) is the predicted mean global solar radiation, H_O (MJm^{-2}day ^{1}) the extraterrestrial solar radiation on the horizontal surface, n average number of hours measured by the sunshine recorder and N the maximum daily sunshine duration (Hours) ***a, b*** are the regression constants specific to the location to be determine from the measured solar radiation data.

The monthly average daily extraterrestrial irradiance, Ho in KWhm^{-2}day^{-1} can be computed (Cheggar and Chibani, 1999) using

$$H_0 = \frac{24 \times 3600}{\pi} I_{SC} \left[\left(\frac{\pi}{180} \right) \omega_S \sin\phi \sin\delta + \cos\phi \sin\omega_S \right] \quad (2)$$

where I_{sc} is the solar constant ω_s and δ are sunset hour angle and solar declination respectively defined as

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

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

dn is the day number of year with 1st January = 1 and 31st December =365. The units in KWh m^{-2} day^{-1} may be converted into MJ m^{-2} day^{-1} using a factor of 3.6 as proposed by Hargreaves and Sanmani (1982).

The linear regression techniques was used for the estimation of global solar radiation using the computed maximum and minimum temperatures from which the mean monthly solar radiation fluxes were determined for the months of January through to December each year for sex years (2010 – 2016) based on Hargreaves and Samani (1982) model thus;

$$H_p = H_o \alpha (\Delta T)^n \quad (5)$$

where H_p and H_o are as described by (1), ΔT(K) = T_{max} - T_{min} with T_{max}, T_{min} as the daily maximum, minimum temperature respectively, α is the dimensionless empirical parameter ranging from 0.16 for interior regions and 0.19 for coastal regions (Gopinathan, 1992). The model suggested *n* to be 0.5. However a linear regression was used in correlating the measured global solar radiation data with temperature difference between the maximum and minimum temperatures yielding

$$\frac{H_p}{H_o} = \alpha (\Delta T)^n \quad (6)$$

which reduces to

$$\log\left(\frac{H_p}{H_o} \right) = n \log(\Delta T) + \log\alpha \quad (7)$$

Using (7) the indices *n* and *α* were determine for the station.

From (1), the ratio H_G/H_o represents the clearness of the sky or clearness index, K_T (Duffie and Beckman, 1994) thus

$$K_T = \frac{H_G}{H_0} \qquad (8)$$

Predicting the Diffused Solar Radiation

The diffuse or sky solar radiation, H_D is the solar radiation which reaches the Earth's surface after having been scattered from the direct solar beam by molecules or suspensions in the atmosphere (Tiwari, 2004). The diffuse solar radiation can be estimated from the widely used empirical relation developed by (Page, 1964) and adopted by (Alkasim *et al.*, 2017) in (9). The formula correlates H_D to the daily total global solar radiation available at the location, H_G thus

$$H_D = H_G\left(1 - \frac{13}{10}K_T\right) \qquad (9)$$

Statistical Evaluation of the Model

In this work, the global solar radiation predicted values are compared with the measured data obtained from the station. The model were statistically tested by calculating the mean bias error **(MBE)**, root mean square error **(RMSE)**, mean percentage error **(MPE)**. These errors are defined as follows

$$MPE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{H_{im} - H_{iP}}{H_{im}} \times 100\right) \qquad (9)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(H_{iP} - H_{im}\right) \qquad (10)$$

$$RMSE = \sqrt{\frac{1}{N}\left[\sum_{i=1}^{N}\left(H_{ip} - H_{im}\right)^2\right]} \qquad (11)$$

Where H_{iP} is the ith predicted global solar radiation value, H_{im} is the ith measure global solar radiation and N is the total number of observation (months of the year) for the period considered.

RESULTS AND DISCUSSION

The monthly mean extraterrestrial solar radiation on horizontal surface for Yola were calculated by the used of declination angle, latitude and hour angle at sunset using equation (2). The declination angle and hour angle were calculated using equations (3) and (4) respectively. The Input parameters for estimating the global solar radiation which includes the measured solar irradiance, the minimum and maximum daily temperatures averaged over six (6) years (2010 – 2016) as presented in table 1.

Table 1: The computed monthly mean daily solar parameters for the temperature based model for the period (2010 to 2016)

Month	H_G	H_O	T_{max} °C	T_{min} °C	ΔT °C	$K_T = \left(\frac{H_G}{H_O}\right)$	H_D	H_P	ln (ΔT)	$R = \left(\frac{H_P}{H_O}\right)$
Jan	21.21	32.29	34.10	24.10	34.1	0.6569	3.0984	25.1693	3.5293	0.7795
Feb	23.18	34.79	36.10	26.20	36.1	0.6663	3.1022	28.4448	3.5863	0.8176
Mar	25.76	36.99	39.00	29.12	39.0	0.6964	2.4388	31.9604	3.6636	0.8640
Apr	26.42	37.88	37.98	28.96	38.0	0.6975	2.4648	32.3514	3.6371	0.8541
May	27.88	37.40	34.25	27.66	34.3	0.7455	0.8617	30.0205	3.5337	0.8027
Jun	24.26	36.78	32.98	25.61	33.0	0.6596	3.4576	28.7954	3.4959	0.7829
Jul	26.82	36.90	31.14	24.85	31.1	0.7268	1.4784	27.9462	3.4385	0.7574
Aug	29.51	38.82	29.48	23.98	29.5	0.7602	0.3474	28.7240	3.3837	0.7399
Sep	27.38	37.11	31.43	24.38	31.4	0.7378	1.1185	28.2876	3.4478	0.7623
Oct	25.61	35.27	32.35	27.19	32.4	0.7261	1.4355	27.0969	3.4766	0.7683
Nov	23.82	32.78	33.01	28.96	33.0	0.7267	1.3182	25.1336	3.4968	0.7667
Dec	21.20	31.43	34.06	29.66	34.1	0.6745	2.6104	24.3486	3.5281	0.7747

The results of the regression constant as well as the statistical test for the temperature based model were presented in Table 2.

The modified linear regression constants *a*, *b* as well as the statistical test results based on one variable, temperature model for the period of study (2010 – 2016) were obtained from the (Hargreaves and Samani, 1982) using Microsoft excel 2007, the values were presented in Table 2. From the Table, the statistical test indicated that the low RMSE value of 1.9832 MJm^{-2} indicated a good correlation, a positive MBE show over estimation, while a negative MPE indicates an under estimation.

Table 2: linear regression constants from the Modified temperature based model and (2010 to 2016)

Author	R^2	*R*	*MBE* (MJm^{-2})	*RMSE* (MJm^{-2})	*MPE %*	*a*	*b*	Model
Hargreaves and Samani (1982)	0.927	0.963	1.1709	3.8835	-6.7255	0.017	-0.837	$y = a\ln(\Delta T)^{0.5} + b$
Propose Model	0.945	0.972	-1.6233	1.9832	6.1823	0.456	-0.815	$y = a\ln(\Delta T) + b$

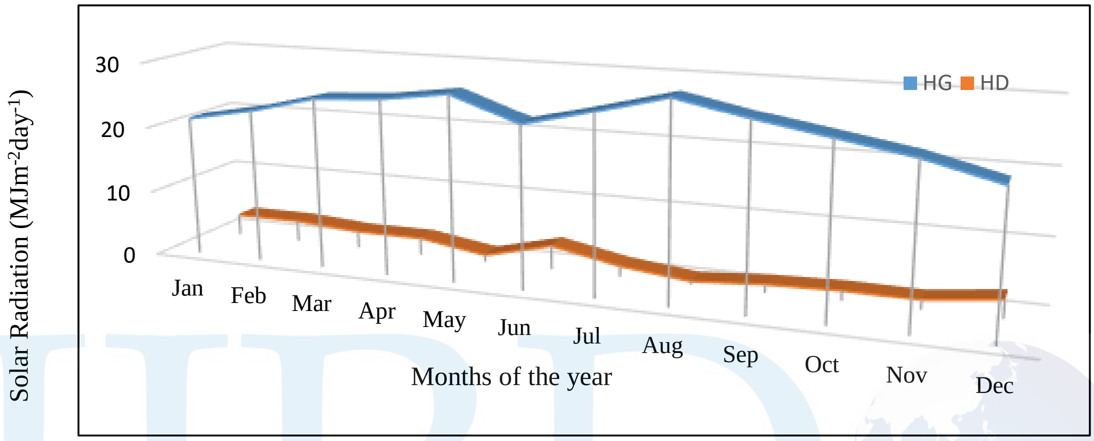

Figure 1: Comparison between the Average Global and Diffused solar radiation in Yola for the one variable temperature based model

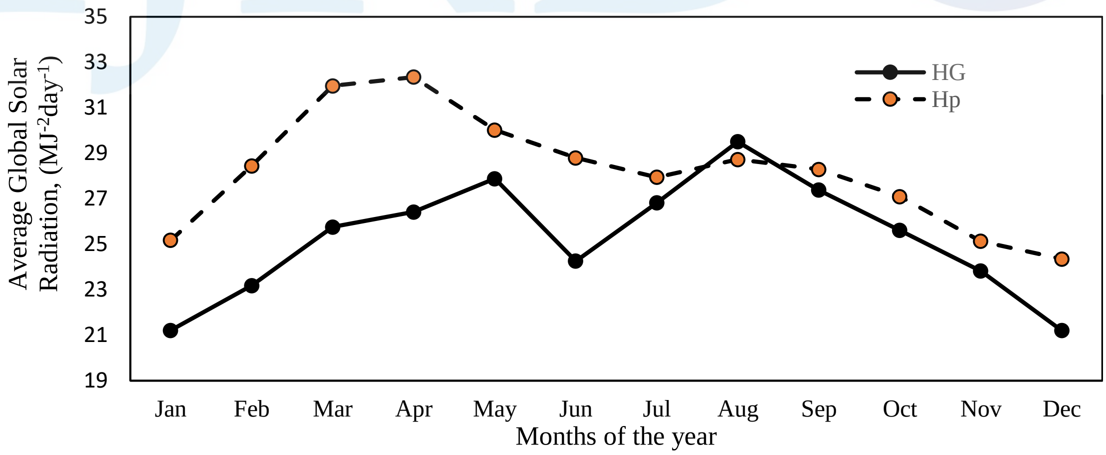

Figure 2: Comparison between the monthly averages daily estimate, H_G and predicted, H_P solar radiation in Yola for the one variable temperature based model.

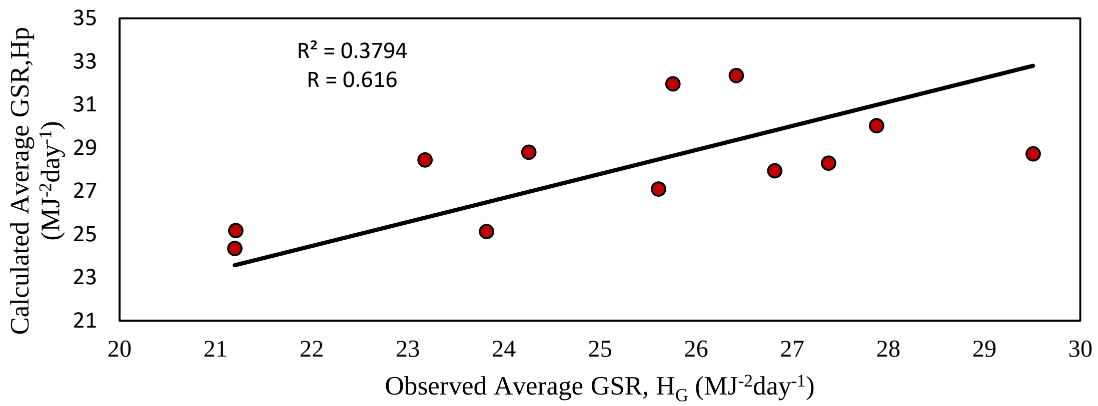

Figure 3: Linear regression between the calculated and observed Average global solar radiation for the period (2010 – 2017).

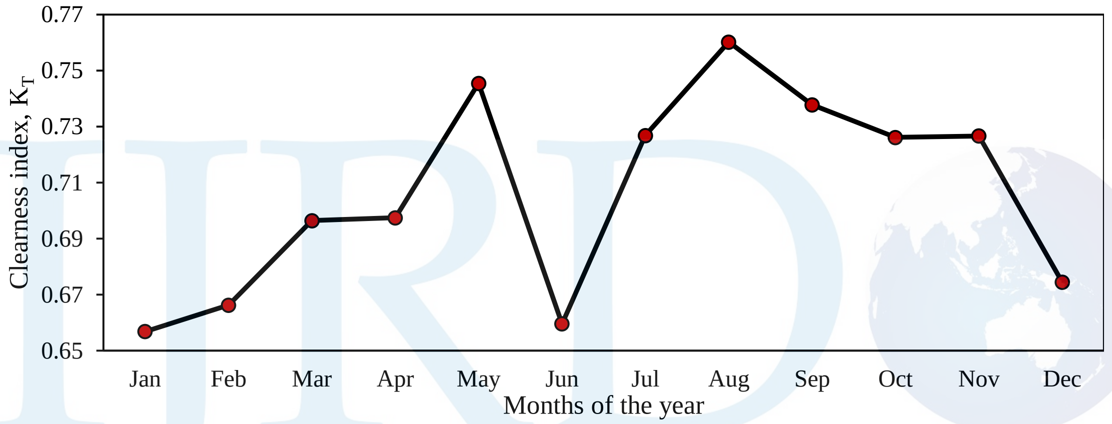

Figure 4: Average monthly clearness index, K_T for the one variable temperature based model covering the period (2010 – 2017) in Yola

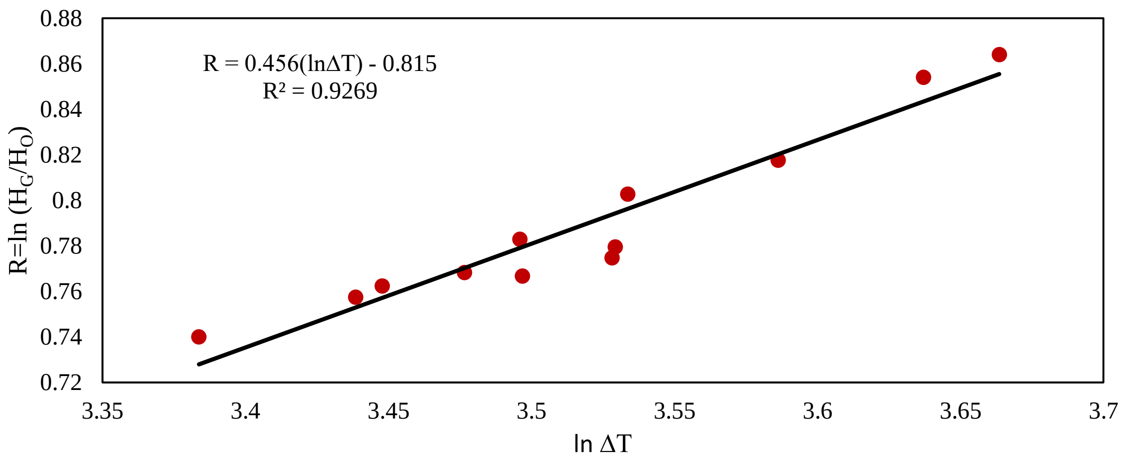

Figure 5: The Linear regression line based on the proposed model

The Global and diffused solar radiation one variable temperature based model, were compared (Fig. 1). The figure indicates a constant difference of approximately 19 MJm^{-2} with global radiation being higher. Also the comparison between the observed and the predicted solar radiation based on the model was presented in figure 2. The regression line (Fig.3) showed an R value of 0.62 indicating a good agreement between the measured and the predicted solar radiation values.

Figure (4) presents the variation of clearness index throughout the year averaged for the study period. The month with the highest value is August (0.76) and the one with the lowest value is the months of January and June (0.65). This is due to the hamatan activities in the months of December – January and July is characterized with heavy rainfall.

The fitness of the proposed model was presented in (fig. 5). The linear equation as well as the R-squared value were presented. The R^2 = 0.93 means that the model is very well fitted for the location based on the available data. The proposed model is $R = (0.456) * \ln(\Delta T) - 0.815$ where R is the natural log (H_G/H_o).

Figure (2) indicated that the maximum global solar radiation in Yola was predicted in the months of (April) while the minimum global solar radiation was predicted in the months of (December and January) this is expected since these months experienced heavy hamatan.

Conclusion

The results obtained indicates the appropriateness of using the daily maximum and minimum temperatures for estimating the global, diffuse solar radiation as well as calculating the clearness index for Yola and environs. The results indicated that the minimum monthly average global solar radiations (21.20 and 21.21) MJm^{-2} were measured in the months of December and January, while and the maximum (29.51 and 27.38) MJm^{-2} were measured in the months of August and July respectively. It is possible for any solar dependent appliance to work perfectly in Yola throughout the year with a negligible low performances in some days during the wet season based on the minimum clearness index, K_T value of 0.66. Hargreaves and Samani, –type model, was employed for this the estimation. The modified linear regression constants **a** and **b** as well as the errors was obtained using Microsoft excel 2007. The RMSE, MBE and MPE were determined with values as 1.9832 MJm^{-2}, -1.6233 MJm^{-2} and 6.182% respectively. Therefore, a new simple linear model $R = 0.456\ln(\Delta T) - 0.815$ can be adopted.

REFERENCES

Agbo, G.A., Baba, A. and T. N. Obickezeie, T.N. (2010) “Empirical model for the correlation of the monthly average global solar radiation with sunshine hours at Mina Niger State, Nigeria”. *Journal of Basic Physical Research* Vol. 1No.1, pp. 41 – 47.

Alkasim, A., Suberu, A.A. and Baba, M.T. (2017), “Empirical Model for the Estimation of Global and Diffuse Solar Radiation in Yola-Nigeria, based on Sunshine Hours” *International Journal of Scientific and Engineering Research* vol. 8 No. 2 pp. 360 – 366.

Cheggar, M. and Chibani, A. (1999). “Method for Computing Global Solar Radiation” *Rev. Ren.; Valorization 105-108.*

Duffe, J.A. and Beckman, W.A. (1994, “Engineering of Thermal Processes”, John Wiley, New York, USA 2nd ed pp. 234 – 367.

Emmanuel, Q, Leonard, K.A., Kwasi, P., Jeffrey, A., Osei, R.B., Dziewornu, B. and Mubarick, R.S. (2014) Empirical Models for Estimating Global Solar Radiation over the Ashanti Region of Ghana, Journal of Solar Energy vol 1 pp 1-6

Falayi, E.O. and Rabiu, A.B. (2005) “Estimation of global solar radiation using cloud cover and surface temperature in some selected cities in Nigeria.” *Archives of Physics Research*, vol.2 No. 3 pp 99-109

Gadiwal, M. S., Usman, A. Akhtar, M. and Jamila, K. (2013), *Empirical Model For The Estimation of Global Solar Radiation With Sunshine Hours* on Horizontal Surface in Various Cities in Pakistan, Vol *9, Issue 18*

Goody and Hu, H. (2003), *Absorption and Thermal Emission*, Harvard University, Cambridge, MA, USA 1859.

Gopinathan, K.K., (1992), “Solar Sky Radiation Estimation Techniques” *Solar Energy* vol. 49 No. 1, pp 9-11.

Hargreaves, G.H. and samani, Z.A. (1982), Estimating Potential Evapotraspiration, “*Journal of Irrigation and Drainage Division*”, 108(3), pp 225 – 230

Kaltiya, M.S., Abubakar, M.S. and Itodo, I.N. (2014) “Prediction of Global Solar Radiation Using Angstrom-Page Equation Model for Benue State, Nigeria” *American Journal of Energy Research (AJER), Vol.03, No.23, pp 145-150.*

Muhammad, A. and Darma, T.H. (2014) “Estimation of Global Solar Radiation for Kano State, Nigeria. Base on Meteorological data” *IOSR Journal of Applied Physics* vol. 6 No. 6, pp.19-23.

Medugu D. W. and Yakubu, D. (2011). "Estimation of Mean Monthly Global Solar Radiation in Yola-Nigeria" *Advances in Applied Science Research 2 (2): pp 414-421*.

Page, J.K. (1964), Proceedings of UN-conference on New Sources of Energy, 1:4 paper S/98.378

Tugment I.T Togrul H (2002). "Global Solar Radiation over Turkey Comparison of predicted and measured data" *Renewable energy* Vol. 25, pp. 55-67.

Tiwari, G.N. (2004). "*Solar Energy Fundamentals Design*, *Modeling and Applications*", Norsa Publishing House, New Delhi