

# Empirical Model for the Estimation of Global and Diffuse Solar Radiation in Yola-Nigeria, based on Sunshine Hours

Alkasim, A., Suberu, A.A. and Baba, M.T.

**Abstract** - This study uses the modified Angstrom model based on the available sunshine hours for the estimation of monthly average global as well as the diffuse solar radiation in Yola (longitude 100E; latitude 9.230N). An Empirical model was developed using a Seven years (7) years available sunshine hours recorded at the recently installed NECOP station in MAUTECH, Yola. The monthly mean daily values were used to assess the applicability of solar radiation data in the area. The clearness index,  $K_T$  values indicate a clear sky between the months of February to July as well as October to November. The regression constants "a" and "b" are 0.54 and 0.23 respectively. Solar energy can be utilized throughout the year in Yola with the exception of monsoon months of August and September which is characterized with heavy rains and cloud cover. The recorded values of the RMSE, MBE and MPE were 0.030, -5.388 and 9.9 % respectively.

**Index terms:** Global solar radiation, Sunshine hours, Diffuse radiation, clearness index, Angstrom, Empirical Model, Solar Energy

## INTRODUCTION

Everything in nature emits electromagnetic energy and solar radiation is energy emitted by the sun. Solar radiation is the direct form of abundant permanent solar energy resource available on earth, due to nuclear fusion that take place in the interior of the Sun. 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 (Gadiwal and Usman 2013).

Solar radiation is the electromagnetic radiation emitted by the Sun. 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  $3.8 \times 10^{26} \text{w}$  (Goody and Hu, 2003).

The first empirical correlation using the idea of employing sunshine hours for the estimation of global solar radiation was proposed by Angstrom as reported by (Prescott, 1940; Page, 1964)

$$\frac{\overline{H_g}}{\overline{H_c}} = a + b \left( \frac{\overline{n}}{\overline{N}} \right) \quad (1)$$

Where,  $\overline{H_g}$  is the monthly average of the daily global solar

radiation on a horizontal surface at a location ( $\text{kJ/m}^2\text{day}$ ).  $\overline{H_c}$  is the monthly average of the daily global radiation on a horizontal surface at the same location on a clear day ( $\text{kJ/m}^2\text{day}$ )  $\overline{n}$  is the monthly average of the sunshine hours per day at the location (h).  $\overline{N}$  is the monthly average of the maximum possible sunshine hours per day at the location that is the day length on a horizontal surface (h) while a and b are regression constant.

A basic difficulty with (1) is deciding what constitute a clear day. Page in 1964 and others modified the method to base it on extraterrestrial radiation on a horizontal surface rather than on a clear day radiation (Kaltiya et al, 2014).

$$\frac{\overline{H_g}}{\overline{H_o}} = a + b \left( \frac{\overline{n}}{\overline{N}} \right) \quad (2)$$

where  $\overline{H_o}$  is the extraterrestrial radiation.

The commonly used model which relates the global solar radiation to sunshine duration includes the following (Kaltiya et al., 2014):

(i) Quadratic

$$\frac{H}{H_o} = a + b \left( \frac{S}{S_o} \right) + c \left( \frac{\overline{n}}{\overline{N}} \right)^2 \quad (3)$$

(ii) Cubic

$$\frac{H}{H_o} = a + b \left( \frac{S}{S_o} \right) + c \left( \frac{\overline{n}}{\overline{N}} \right)^2 + d \left( \frac{\overline{n}}{\overline{N}} \right)^3 \quad (4)$$

(iii) linear logarithmic

$$\frac{H}{H_o} = a + b \left( \frac{\bar{n}}{\bar{N}} \right) + c \log \left( \frac{\bar{n}}{\bar{N}} \right) \quad (5)$$

(v) linear exponential

$$\frac{H}{H_o} = a + b \left( \frac{\bar{n}}{\bar{N}} \right) + c \exp \left( \frac{\bar{n}}{\bar{N}} \right) \quad (6)$$

(v) exponential

$$\frac{H}{H_o} = a + b \exp \left( \frac{\bar{n}}{\bar{N}} \right) \quad (7)$$

(vi) Linear, latitude related

$$\frac{H}{H_o} = 0.29 \cos \phi + 0.52 \left( \frac{\bar{n}}{\bar{N}} \right) \quad (8)$$

where  $\phi$  is the latitude of the location.

In Nigeria, researchers have carried out in investigation based on models for the estimation of solar radiation at different location, for instance Yola-Nigeria, Maiduguri, Kano, Abeokuta, Owerri, and Enugu (Kaltiya et al, 2014)

This work is aimed at modified Angstroms Prescott type of empirical model for the estimation of global solar radiation for Yola and other surrounding towns of similar meteorological condition. In this work Angstrom model will be used to develop new model for the estimation of global solar radiation for Yola, Adamawa State, Nigeria based on the available climatic parameters of sunshine hour and the computed values of the extraterrestrial solar radiation and maximum day light duration. Yola has been choosing for this study due to it climatic condition which varies significantly with the season of the year.

**METHODOLOGY**

In this work, the monthly average daily data for the sunshine duration and solar radiation were obtained from the Nigerian Environmental Climatic Observation Programme (NECOP) meteorological station, Department of Physics MAUTECH, Yola. The data obtained covers a period of Seven (7) years (2008-2015). The parameters used are:

- (i) The daily global solar radiation
- (ii) The sunshine hours

**Empirical Equations for Predicting the Availability of Solar Radiation**

The linear regression for Angstrom-PreScott model used to estimate the monthly average daily global solar radiation on a horizontal surface of Yola, Adamawa Nigeria or other places with similar climatic parameters is given by

$$\frac{H_g}{H_o} = a + b \left( \frac{S}{S_o} \right) \quad (\text{PreScott, 1940}) \quad (9)$$

$$H_g = H_o \left[ a + b \left( \frac{S}{S_o} \right) \right] \quad (10)$$

Where

$H_g$  = the global solar radiation ( $\text{MJm}^{-2} \text{day}^{-1}$ )

$H_o$  = the extraterrestrial solar radiation on the horizontal surface ( $\text{MJm}^{-2} \text{day}^{-1}$ )

$S$  = number of sunshine hours measured by the sunshine recorder (in hours)

$S_o$  = the maximum daily sunshine duration (Day length in hours)

$a, b$  = the regression constant to be determine

The value of  $S_o$  is computed as

$$S_o = \left( \frac{2}{15} \right) \cos^{-1} (-\tan \phi \tan \delta) = \frac{2 \omega_s}{15} \quad (11)$$

(Duffie and Beckman, 1994)

where  $\phi, \delta$  and  $\omega_s$  are the location latitude, solar declination angle and sunset hour angle. The sunset hour angle and the solar declination are defined as

$$\omega_s = \cos^{-1} (-\tan \phi \tan \delta) \quad (12)$$

$$\delta = 23.45 \sin \left( 360 \frac{(284 + d)}{365} \right) \quad (\text{Cooper, 1969}) \quad (13)$$

**Empirical Equations for Predicting the Availability of Solar Radiation**

The extraterrestrial solar radiation,  $H_o$  which is the solar radiation outside the atmosphere incident on a horizontal surface is computed using the expression

$$H_o = \frac{24}{\pi} I_{sc} \times 3600 \left[ \left( 1 + 0.33 \cos \frac{360n}{365} \right) \left( \cos \phi \cos \delta \sin \omega_s + \frac{2\pi \omega_s}{360} \sin \phi \sin \delta \right) \right] \quad (14)$$

where  $I_{sc}$  is the solar constant given by (Klein, 1977; Frolich and Brusca, 1981) as  $1367 \text{Wm}^{-2}$ ;  $n$  is the day number of a year with  $n=1$  for first January.

In this study, the linear regression techniques (Muhammed and Darma 2014) was used for the estimate as relative sunshine based model, with the format as equation (10) thus

$$\frac{H_g}{H_o} = a + b \left( \frac{S_{\min}}{S_{\max}} \right) \quad (15)$$

where  $H_g$  is the monthly mean of the daily global solar radiation falling on the horizontal surface at the location,  $H_o$  is the monthly mean daily radiation on the same surface in the absence of atmosphere,  $S_{\min}$  is the number of the monthly mean observed sunshine hours,  $S_{\max}$  is the monthly mean day length at the particular location,  $a$  and  $b$  are the climate regression constant, which is to be determined as the intercept and the slope of the plot of  $(H_g/H_o)$  against  $(S_{\min}/S_{\max})$ .

From (15)  $H_g/H_o$  represents the clearness index,  $K_T$  (Duffie and Beckman, 1994) that is

$$K_T = \frac{H_g}{H_o} \quad (16)$$

while the ratio  $S_{\min}/S_{\max}$  is often called percentage possible sunshine hours (Black et al., 1954).

**Prediction of the Diffuse Solar Radiation**

The Diffuse solar radiation,  $H_D$  can be estimated from the widely used empirical relation developed by (Liu and Jordan, 1961; Page, 1964) and adopted by (Abdullahi and Nasir, 2014). The empirical formulae correlates  $H_D$  to the daily total radiation,  $H$  as thus

$$\frac{H_D}{H_g} = 1 - 1.3 \left( \frac{H}{H_o} \right) = 1 - 1.3K_T \tag{17}$$

or

$$H_D = H_g [1 - 1.3K_T] \tag{18}$$

where  $H_D$  is the monthly mean daily diffuse solar radiation,  $H_g$  is the mean daily total solar radiation available at the location.

**Statistical Analysis and regression constants**

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

$$MBE = \left( \sum \frac{H_p - H_m}{n} \right) \tag{19}$$

$$RMSE = \sum \left( \sum \frac{(H_p - H_m)^2}{n} \right)^{\frac{1}{2}} \tag{20}$$

$$MPE = \sum \left( \sum \frac{\left( \frac{H_p - H_m}{H_m} \right) \times 100}{n} \right) \tag{21}$$

Where  $H_p$  is the predicted global solar radiation value,  $H_m$  is the measure global solar radiation value and  $n$  is the total number of observation (months of the year).

The monthly mean extraterrestrial solar radiation on horizontal surface for Yola was calculated using the parameters which include declination angle, latitude and hour angle at sunset from equation (14). The declination angle and hour angle were calculated using equations (13) and (12) respectively.

The global solar radiation were estimated by the used of equation (10). The relations are very vital for the prediction of global solar radiation which was tested in different part of Nigeria and other countries. But in this research the modified model were chosen for the first time to predict the global solar radiation in Yola, Adamawa State, Nigeria using the NECOP data.



**RESULTS**

**Table1:** The computed monthly mean daily solar parameters for the Sunshine hours based model for the period (2008 to 2015)

MONTHS	$H_g$ (MJm <sup>-2</sup> day <sup>-1</sup> )	$H_o$ (MJm <sup>-2</sup> day <sup>-1</sup> )	$H_p$ (MJm <sup>-2</sup> day <sup>-1</sup> )	$S_{max}$ (hours)	$S_{min}$ (hours)	$\frac{S_{min}}{S_{max}}$	$K_T = \left(\frac{H_g}{H_o}\right)$	$H_D$ (MJm <sup>-2</sup> day <sup>-1</sup> )	$\frac{H_D}{H_g}$	$\frac{H_D}{H_o}$
JAN	19.75	32.29	20.74	11.52	7.48	0.65	0.61	6.10	0.31	0.19
FEB	22.85	34.79	21.16	11.70	6.89	0.59	0.66	5.89	0.26	0.17
MAR	25.20	36.99	21.37	11.94	6.33	0.53	0.68	5.80	0.23	0.16
APR	25.44	37.88	22.97	12.20	6.00	0.49	0.67	6.13	0.24	0.16
MAY	15.05	37.40	16.75	24.84	7.36	0.30	0.40	8.21	0.55	0.22
JUN	26.11	36.78	22.39	12.53	7.43	0.59	0.71	5.16	0.20	0.14
JUL	20.86	36.90	17.66	12.48	5.31	0.43	0.57	7.53	0.36	0.20
AUG	31.10	38.82	19.29	12.30	4.73	0.38	0.80	2.95	0.09	0.08
SEP	30.89	37.11	19.10	12.04	5.01	0.42	0.83	1.83	0.06	0.05
OCT	23.54	35.27	20.90	11.78	6.54	0.56	0.67	5.79	0.25	0.16
NOV	21.70	32.78	22.91	11.57	8.75	0.76	0.66	5.47	0.25	0.17
DEC	21.53	31.43	18.53	11.46	6.52	0.57	0.69	4.86	0.23	0.15

Table 2: Regression constant and statistical test for the one variable sunshine based model

Period	a	b	MBE (MJm <sup>2</sup> )	RMSE (MJm <sup>2</sup> )	MPE (%)
2009-2016	0.5400	0.2308	-5.9388	0.0300	9.900

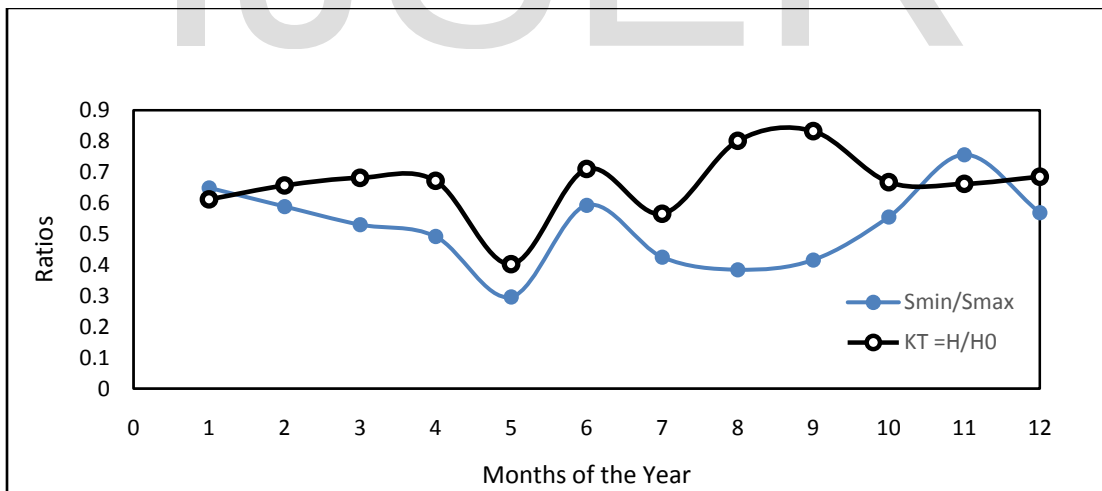


Figure 1: The variation of the ratio  $S_{min}/S_{max}$  and  $K_T$  (clearness index) for one variable sunshine based model

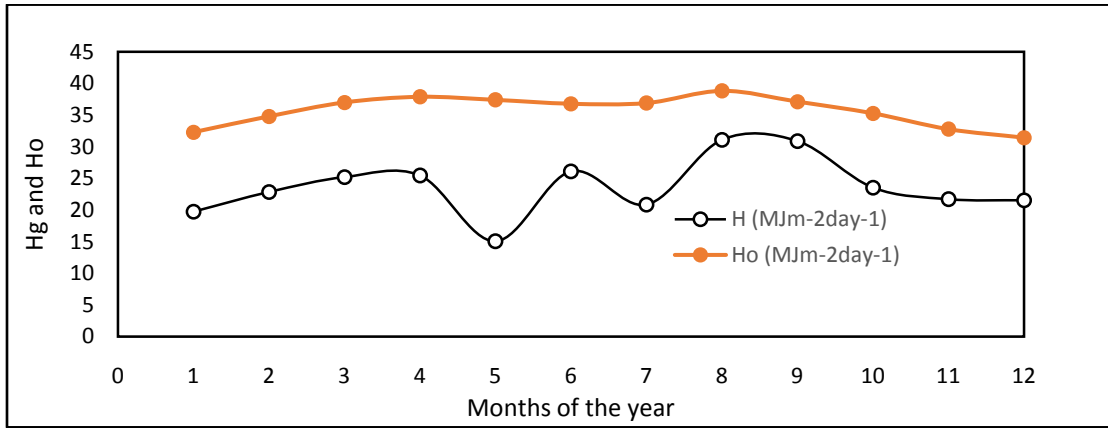


Figure 2: Monthly variation of Global and extraterrestrial solar radiation for one variable sunshine based model in Yola

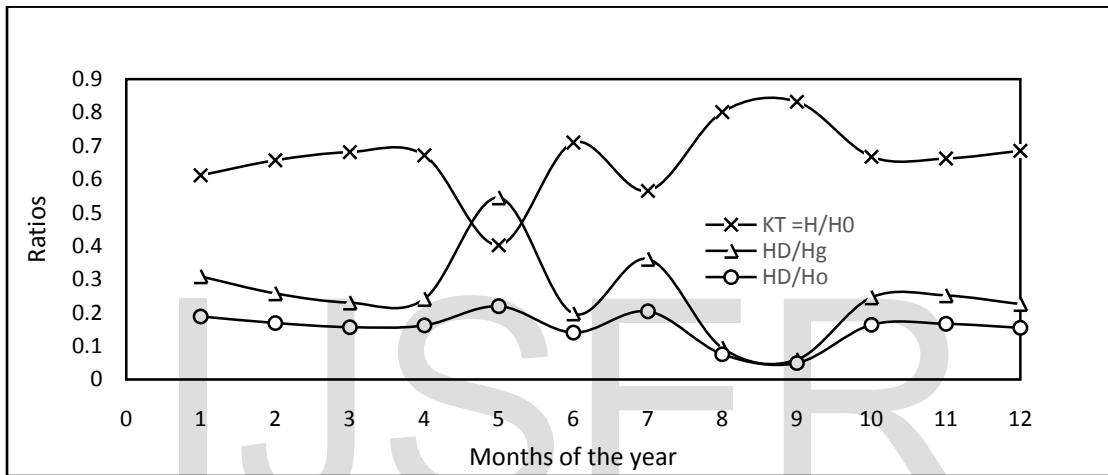


Figure 3: Comparison between the clearness index and the ratios ( $H_D/H_g$ ), ( $H_D/H_o$ ) for one variable sunshine based model

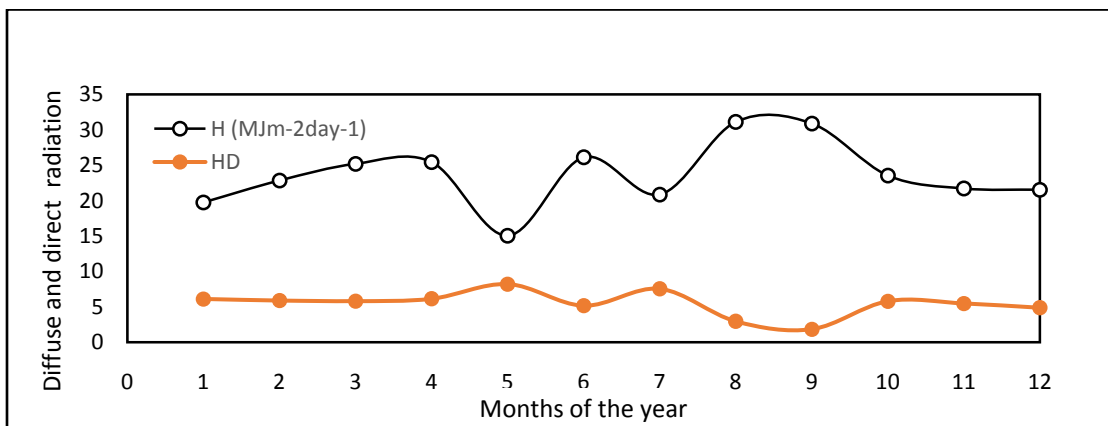


Figure 4: Comparison between the Diffused and Direct solar radiation for one variable sunshine based model

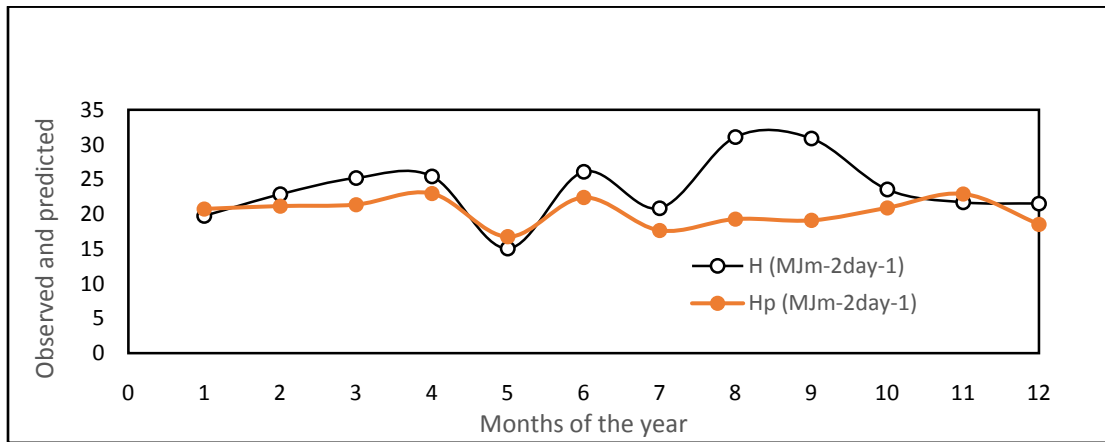


Figure 5: Comparison between measured and predicted monthly global solar radiation for one variable sunshine based model

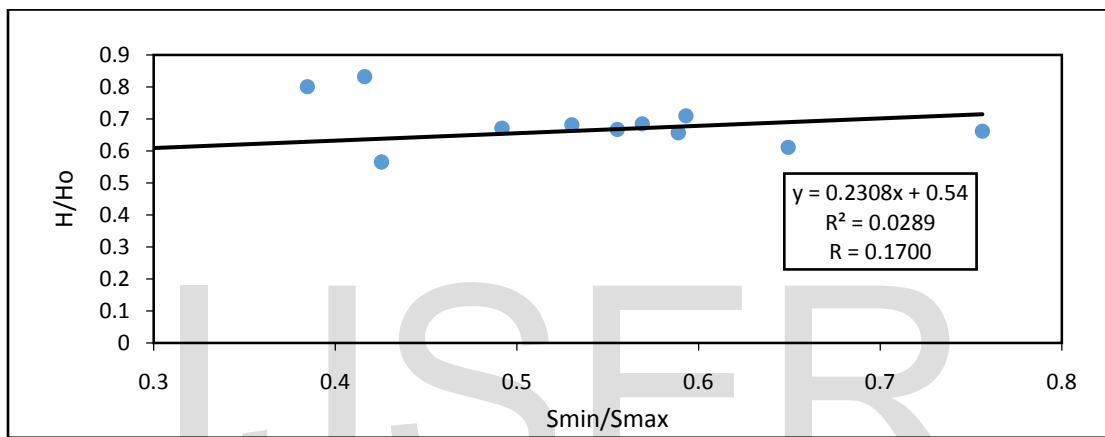


Figure 6: Plot of ratios  $H_g/H_o$  against  $S_{min}/S_{max}$  for determination of the regression constant as indicated on the graph for one variable sunshine based model

**DISCUSSIONS**

The monthly mean solar radiation data in Yola for the period of seven years (2008 - 2016) is as shown in table 1. The result for the regression constants for sunshine based model for the range of time considered is presented in Table 2. The statistical test show that low (RMSE) of 0.03 is the deviation from the reality, an MBE = -5.9388 show an underestimate from the mean, while a MPE = 9.9% provide an average percentage amount of overestimate calculated values. The regression constants 'a' and 'b' were evaluated as 0.54 and 0.23 respectively.

Figure 1 indicates that the maximum global solar radiation was measured in the month of August while the minimum global solar radiation was measured in the month of May. This is expected since the month of August is normally characterized by heavy rainfall. the ratios  $H_D/H_g$  and  $H_D/H_o$  as shown in fig. (3) indicate that the diffuse and global solar radiation follows the same terrain over the years with exact values between the months of August and September which indicates rare or no cloud cover during the period as indicated by the clearness index on the same figure. The compared plot of direct and diffused radiations shown in fig. (4) indicate that the two are in alternate throughout the year. The maximum global solar radiation was predicted in the month of November and the minimum in May as presented in fig 5. Judging from the

observation, the comparison between the measured and the predicted global solar radiation gives vital information for the model used in the analysis. From the calculated results, it is clear that the contribution of the diffused radiation is very low throughout the year. from the observation of the clearness index and the diffuse to global radiation ratio, it indicate that the presence of cloud cover is very rare even during the monsoon months infers that it's a favorable condition for solar radiation utilization.

**CONCLUSION**

The research indicates the prospects of solar radiation utilization in Yola and environs. The estimated values of the global solar radiation can be effectively used in this area. Liu and Jordan (1960) and Page (1964) methods can be used for the estimation of diffused solar radiation in Yola. With the exception of the months of May, solar energy can be utilized throughout in this area based on the clearness index value.

From the studies, the availability of solar radiation in Yola, North-eastern Nigeria, can be calculated from linear relation thus:

$$\left(\frac{H_g}{H_o}\right) = 0.54 + 0.23 \left(\frac{S_{\min}}{S_{\max}}\right) \quad (22)$$

## REFERENCES

Abdullahi, M. and Nasir, M.A. (2014), Evaluation of Monthly Total Global and Diffuse Solar radiation in Ibi, Taraba State, Nigeria, *Advances in Applied Science Research*, 5(2); pp 144-148.

Cooper, P.I. (1969), Model for Calculating Solar Declination angle, *Solar Energy*, 12, 333.

Duffie, J.A. and Beckman, W.A. (1994), *Engineering of Thermal Processes*, John Wiley, New York, USA 2nd pp 234-367.

Frolich, C. and Brusca, R. W. (1981) *Solar Physics*, 74, 209 USA

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, 9(18), pp 18-20

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

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)*, 3(23), pp 145-150.

Klein, S.A. (1977), Calculation of Monthly average Insolation on tilted Surface, *Energy*, 9:pp 322-325.

Muhammad, A. and T.H. Darma, T.H. (2014), Estimation of Global Solar Radiation for Kano State, Nigeria. Base on Meteorological data, *IOSR Journal of Applied Physics*, 6 (6), pp.19-23.

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

Prescott, J.A. (1940), Evaporation from a water surface in Relation to Solar Radiation, *Trans. R.Soc. Sciences, Australia*, 64, pp 114-125

- *Dr Alkasim, A. is a Senior Lecturer in the Department of Physics, Modibbo Adama University of Technology Yola, Nigeria.  
E-mail: alkasimabbat@gmail.com*
- *Suberu, A. A. is currently pursuing his Bachelor Degree in Physics at Modibbo Adama University of Technology Yola, Nigeria.*
- *Baba, M. T. is a Senior Lecturer in the Department of Mechanical Engineering, Federal Polytechnic Mubi, Adamawa State, Nigeria.  
E-mail: muhammادتankobaba@gmail.com*