Estimation of Monthly Diffuse Solar Radiation for Potiskum, Yobe State, North- Eastern Nigeria.

Suleman M. Ngaram* and Ibrahim B. Mohammed
Department of Physics, Federal University Gashua, Yobe State, Nigeria
College of Health Technology Maiduguri, Maiduguri, Borno State, Nigeria

*Corresponding Author E-mail: ngaramsuleiman@fugashua.edu.ng

Abstract

This study utilized the data obtained from achieves Meteorological agency for the period of eight years (2010 - 2018) to estimate monthly average daily values of global solar radiation and sunshine hour for Potiskum Yobe State, Nigeria to assess the applicability of solar energy utilization for the area. The clearness index K_T values are recorded in the months of June to September, but high during October to February. The result obtained shows the variation of direct and diffuse component of solar radiation in summer and winter months. The sunshine duration, range from 55% to 85%, throughout a year. From result also it appears that the contribution of diffuse solar radiation is very low throughout the year. The regression constants "a" and "b" for the location were also calculated as 0.42 and 0.75 respectively. From the analyses, it has been found that the months of August and September, were the months that solar energy can be utilized. This shows that the generation of electric power from solar energy in Potiskum is viable.

Keywords: Diffuse radiation, Clearness Index, Global Solar Radiation, Sunshine Hour.

1. Introduction

Solar radiation means the electromagnetic radiation from the sun. The radiation from the sun is the primary natural energy source of the planet Earth. Other natural energy sources are the cosmic radiation, the natural terrestrial radioactivity and the geothermal hear flux from the interior to the surface of the earth. These other sources however, are energetically negligible as compared to solar radiation. As the solar radiation passes through the atmosphere, the global solar radiation can be divided into two components namely diffuse solar radiation, which results from scattering caused by gases in the Earth's atmosphere, dispersed water droplets and particulates; and direct solar radiation, which has not been scattered. Global solar radiation is the algebraic sum of the two components (Falayi *et al*, 2011). Value of global and diffuse radiations are essential for research and engineering applications. Ahmad and Intikhab (2004) indicated that the non-conventional energy resources, solar energy, wind energy and Biomass have emerged as most prospective option for the future.

Energy requirement in the North Eastern Nigeria is increasing due to rapid increase in the energy demand. Fossil fuel which is the main source of energy supply is being exhausted day by day (Akhlaque *et al*, 2011). The measuring equipment involved in this process is not available in many countries. Therefore, it is rather important to develop method to estimate the global and diffuse solar radiation using climatological parameters because detailed information about the availability of solar radiation on horizontal surface is very essential for the design and study of solar energy convention system (Akhlaque *et al*, 2011). Present day energy crisis has therefore resulted in the search for alternate energy resources in order to cope with the drastically changing energy picture of the World. With the rapid industrialization and fast growth rate of energy consumption, the World will soon run out of its conventional fuel.

The problem demands an urgent and serious attention, especially by the inhabitants of developing and underdeveloped countries, not only to the husbanding of present resources, but also to the short and long-term development of future energy resources. This is important because the social and economic development of these countries heavily lie on the consumption and harnessing of their energy resources.

For a country like Nigeria, the economical and efficient application of solar energy seems inevitable because of abundant sunshine available throughout the year. It has been found that there is an estimated 3,000 h of annual sunshine Augustine and Nnabuchi (2010) and average solar radiation received in Nigeria per day is as high as 20MJ/m^2 depending on the time of the year and location Offiong (2003). Despite this abundant availability of solar energy, Nigeria with over 97,000 rural communities, has a population that is characterized with deprivation from conventional energy, arising from poor development of infrastructure as only about 18% only of the rural population had access to electricity by 1991/1992 FOS (1996). Where conventional energy is available, its supply is unreliable. The readily available and widely utilized energy in the rural areas is renew-able energy type, particularly fuel wood, agricultural and animal wastes, wind energy and solar energy; which are mainly used for cooking, cottage industrial applications, winnowing and open-to-sun drying process.

In Nigeria, a number of correlations involving global solar radiation and sunshine duration for different locations have been studied by different researchers. For example, Okogbue and Adedokun (2002), estimated the global solar radiation of Ondo, Nigeria; Okundamiya and Nzeako (2010), developed empirical model for estimating global solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria; Agbo *et al,* (2010) developed empirical models for the correlation of monthly average global solar radiation with sunshine hours at Minna, Nigeria; Medugu and Yakubu (2011), used angstrom model to estimate mean monthly global solar radiation in Yola, Nigeria; 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; Akpabio and Etuk (2008) developed a relationship between global solar radiation and sunshine duration for Onne, with regression coefficients a = 0.23 and b = 0.38. All these earliest researchers developed their models based on correlation of global solar radiation with sunshine hours for some selected cities in Nigeria. Based on the available literatures, there is little or no study carried out on global and diffuse radiations in Nigeria cities. This is partly due to the fact that, information is scarce on the distribution of diffuse radiation in the country.

The key objective of this research was to examining the selected model for estimating the mean monthly global and diffuse solar radiations of Potiskum in Nigeria, and to establish regression coefficients using sunshine hour's data.

2. Materials and Method

The daily global solar radiation and sunshine hour, used for this study, were obtained from the Archives of the Nigerian Meteorological Agency, National Weather Forecasting and Climate Research Centre Abuja for the period of eight years (2010 - 2018). The city of Potiskum being studied, lie on lat. 11.42 ^{0}N, long. 11.02 ^{0}E.

2.1. Data analysis

The solar radiation outside the atmosphere incident on a horizontal surface (Extraterrestrial Radiation on a horizontal Surface) is given by the following expression.

$$H_0 = \frac{24}{\pi} I_{sc} \left[1 + 0.33\cos\left(\frac{360d}{365}\right)\right]\left[cos\varphi cos\delta sinw_s + \left(\frac{2\pi w_s}{360} sin\varphi sin\delta\right)\right] \quad (1)$$

where H_0 is the extraterrestrial insolation on horizontal surface;

I_{sc} is the solar constants having the recommended value of 1367 Wm^{-2} (Klein, 1977),

φ is the latitude,

δ is the solar declination,

and w_s is the sunset hour angle (Duffie & Beckman, 1994).

$$S_{max} = \frac{2}{15} ws \quad (2)$$

With S_{max} being the day length (Duffie & Beckman, 1994).

According to Cooper (1969), the declination angle, δ is calculated as:

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

And the sunshine hour angle, according to Duffie & Beckman (1994) as:

$$\cos w_S = -\tan\Phi \tan\delta \quad (4)$$

Equation (1) gives the estimate of the extraterrestrial radiation (i.e, radiation that is nearly parallel falling on top of the earth). Equation (2) gives the estimate of the possible bright sunshine hour, equation (3) gives the value of the latitude of the location under study and equation (4) gives sunset hour angle.

2.2. Global radiation at horizontal surface

Angstrom (1924) was the first scientist known to suggest a simple linear relationship to estimate global solar radiation. Prescott (1940) put the correlation in a convenient form as;

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_{max}}\right) \quad (5)$$

Where H is the monthly average daily global solar radiation falling on a horizontal surface at a particular location,

H_0 the monthly mean daily radiation on a horizontal surface in the absence of atmosphere; S the monthly mean daily number of observed sunshine hours; S_{max} the monthly mean value of day length at a particular location; and "a", "b" the climatologically determined regression constants.

Tiwari, & Sangeeta, (1997) gave the expression for determining "a", "b" as

$$a = 0.110 + 0.235\cos\Phi + 0.323\left(\frac{S}{S_{max}}\right) \quad (6)$$

$$b = 1.449 - 0.553\cos\Phi - 0.694\left(\frac{S}{S_{max}}\right) \quad (7)$$

In equation (5) S/S_{max} is often called the percentage of possible sunshine hour (Black *et al,* 1954).

2.3. Model evaluation

The models are evaluated in terms of mean bias error (MBE) and root mean square error (RMSE). These error terms are calculated using the following statistical tests equations:

$$MBE = \frac{1}{n}\left[\sum\left(H_{prd} - H_{obs}\right)\right] \quad (8)$$

$$RMSE = \left\{\frac{1}{n}\sum\left(H_{Pred} - H_{Obs}\right)^2\right\}^{1/2} \quad (9)$$

The root mean square error (RMSE) and mean bias error (MBE) were used to evaluate the accuracy of the predicted global radiation. Using the MBE and RMSE, models were tested under various meteorological and climatic conditions (Togrul *et al,* 2000). The lower the RMSE, the more accurate is the estimate. A positive value of MBE shows an over-estimate while a negative value shows an under estimate by the model according to Iqbal (1983), a draw-back with this method is that an over-estimation of an individual observation will cancel an underestimation in a separate observation. The values of the MBE represent the systematics error or bias, while the RMSE is a non-systematic error (Onier, 1994).

2.4. Prediction of diffuse solar radiation

The diffuse solar radiation H_d can be estimated by an empirical formula which correlates the diffuse solar radiation component H_d to the daily radiation H_O. the following correlation equations were widely used and was developed by Page (1964) and Liu and Jordan (1961) were widely used.

$$\frac{H_d}{H_O} = 1.00 - 1.13K_T \quad (10)$$

$$\frac{H_d}{H_O} = 1.390 - 4.027K_T + 5.531\,(K_T)^2 - 3.108\,(K_T)^3 \quad (11)$$

Where H_d is the monthly mean of the daily diffuse solar radiation,

H_g is the monthly average daily global solar radiation,

H_O is the daily total solar radiation,

and K_T is the clearness index. (Duffie and Beckman 1994).

$$K_T = \frac{H_g}{H_o} \quad (12)$$

3. Results and Discussion

The monthly mean solar radiation data for Potiskum is shown in table 1 above. The sunshine duration of Potiskum range from 55% to 85%, throughout a year. The regression constants 'a' and 'b' were evaluated to be "0.43" and "0.75" respectively. From the calculated result it appears that the contribution of diffuse solar radiation is very low throughout the year in Potiskum. From the observation of clearness index and ratio of diffuse to global, concluded that the presence of clouds in monsoon months. This is the favorable condition for solar energy utilization. The extraterrestrial radiations (H_o) were computed from equation (1) having known the latitude of the location under studies. These were obtained when the declination angle and the sunset angle were obtained for each location using equation (3) and (4) respectively. Equation (5) was used is computing the predicted global solar radiation (H_{pred}) when the regression constant "a" and "b" were obtained by series of regression analysis and also using

Table 1: Average Solar Radiaton Data (2010-2018) for Potiskum

Months	Sunshine (hours)	Day Length Smax (hour)	Percentage Sunshine Hour,S/ Smax	H_g (MJ/m^2 /day)	H_o (MJ/m^2 /day)	K_T	H_d (MJ/m^2 /day)
Jan.	6.90	11.51	0.59	18.30	32.32	0.57	6.60
Feb.	8.80	11.76	0.75	22.40	32.71	0.68	6.05
Mar.	8.00	10.09	0.66	24.10	36.99	0.65	4.17
Apr.	6.80	12.28	0.55	23.10	37.91	0.61	5.74
May	8.30	12.61	0.66	23.90	37.37	0.64	4.47
Jun.	8.80	12.55	0.70	24.00	36.74	0.65	5.20
Jul.	6.60	12.51	0.53	21.80	36.89	0.59	5.95
Aug.	6.50	12.21	0.53	21.90	37.46	0.58	7.23
Sep.	7.10	11.89	0.51	21.80	37.15	0.65	6.84
Oct.	7.80	11.48	0.68	22.90	35.35	0.65	3.35
Nov.	9.40	11.41	0.82	21.40	32.79	0.65	5.57
Dec.	10.10	11.37	0.89	21.90	31.47	0.70	6.04

H_g is the global radiation in MJ/m^2 /day

H_o is the total daily observed radiation in MJ/m^2 /day

H_d is the daily diffuse radiation in MJ/m^2 /day

K_T is the clearness index

Table 2: Comparison of the Observed and Predicted Values of the Global Radiation for Potiskum

Months	H_{obs} (MJ/m²/ Day)	H_o (MJ/m² / day)	Percentage Sunshine Hour,S/Smax	H_{pred}((MJ/m²/ day)	MBE (MJ/m²/day)	RMSE ((MJ/m² /day)
Jan.	18.3	32.32	0.59	19.25	0.95	0.95
Feb.	22.4	34.71	0.75	23.17	0.77	0.77
Mar.	24.1	63.99	0.66	23.19	-0.91	0.91
Apr.	23.1	37.91	0.55	21.89	-1.21	1.21
May	23.9	37.37	0.66	23.43	-0.47	0.47
Jun.	24.0	36.74	0.70	23.61	-0.39	0.39
Jul.	21.8	36.89	0.53	20.97	-0.83	0.83
Aug.	21.9	37.46	0.53	21.21	-0.69	0.69
Sep.	21.8	37.15	0.51	20.79	-1.01	1.01
Oct.	22.9	35.35	0.68	22.48	-0.42	0.42
Nov.	21.4	32.79	0.82	22.92	1.52	1.52
Dec.	19.5	31.42	0.89	21.95	2.45	2.45

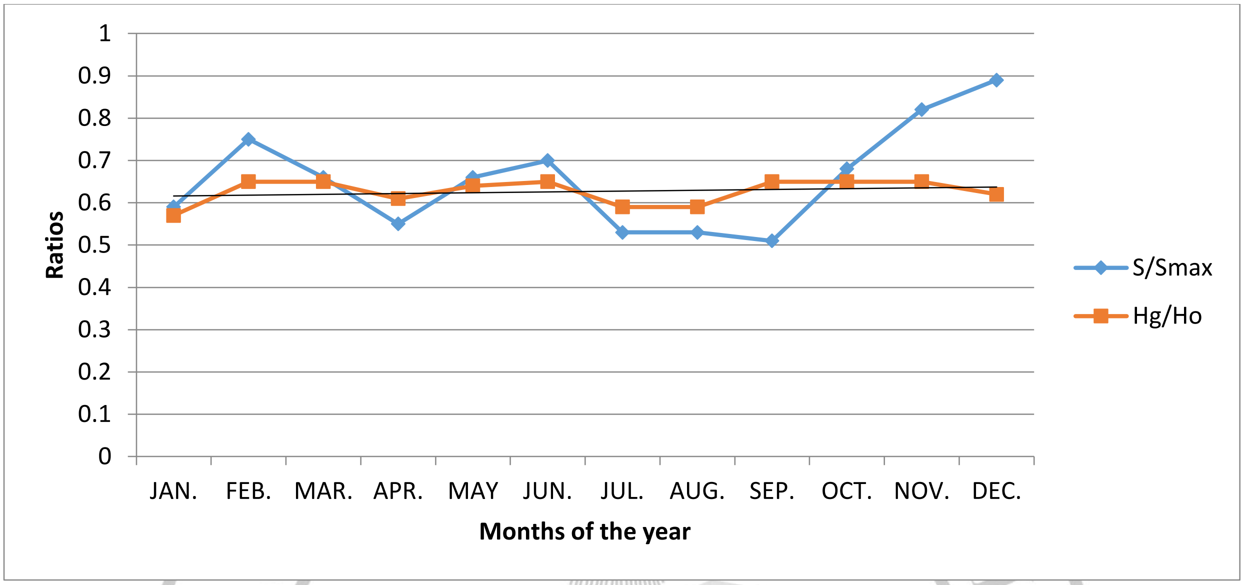

Fig. 1. Variation of S/S_{max} and H_g/H_o (the clearness index) for Potiskum, Nigeria.

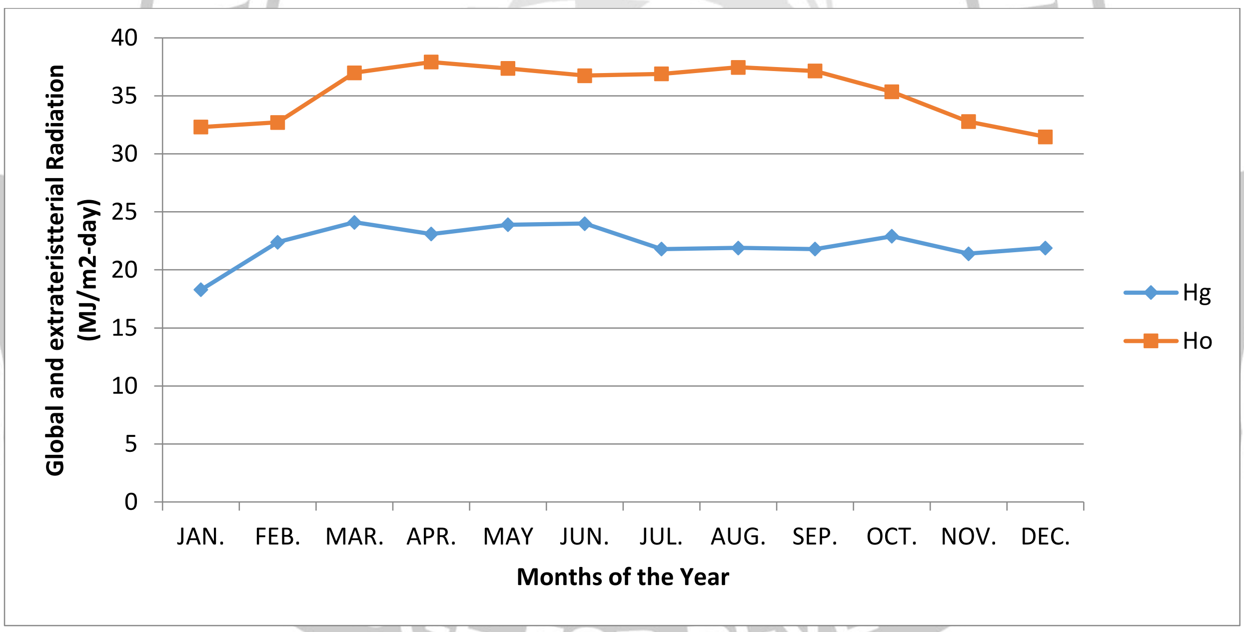

Fig. 2. Monthly variation of Global (Hg) and Extraterrestrial (Ho) radiation for Potiskum, Nigeria

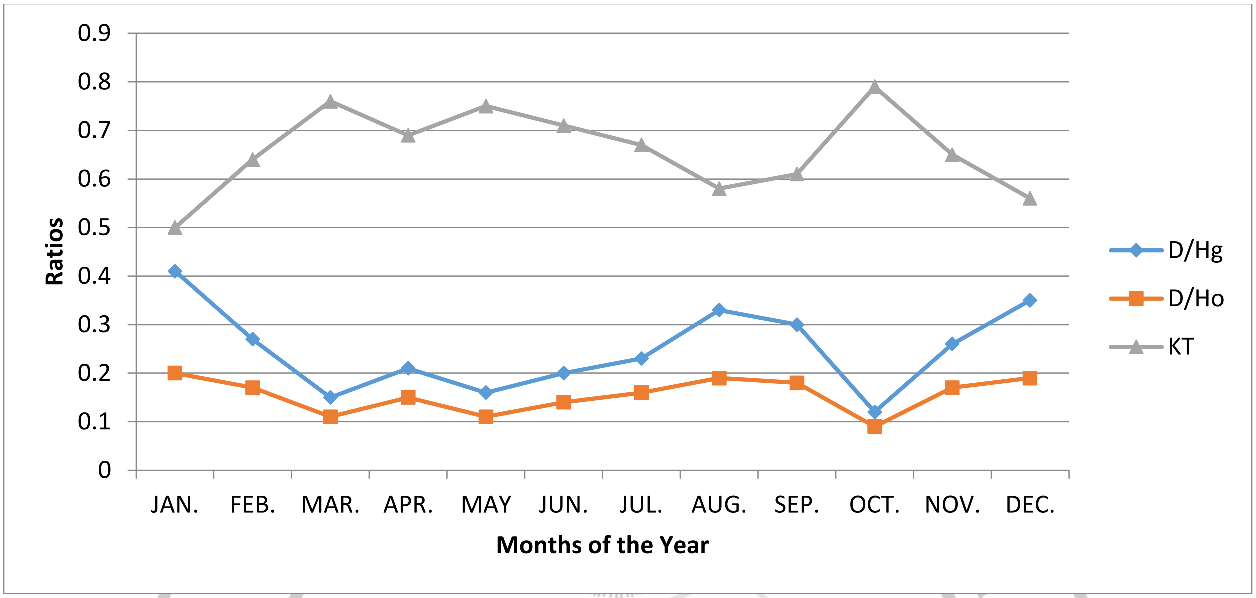

Fig. 3. Behavior of the cloudness index K_T, D/H_g and D/H_o during a year for Potiskum, Nigeria.

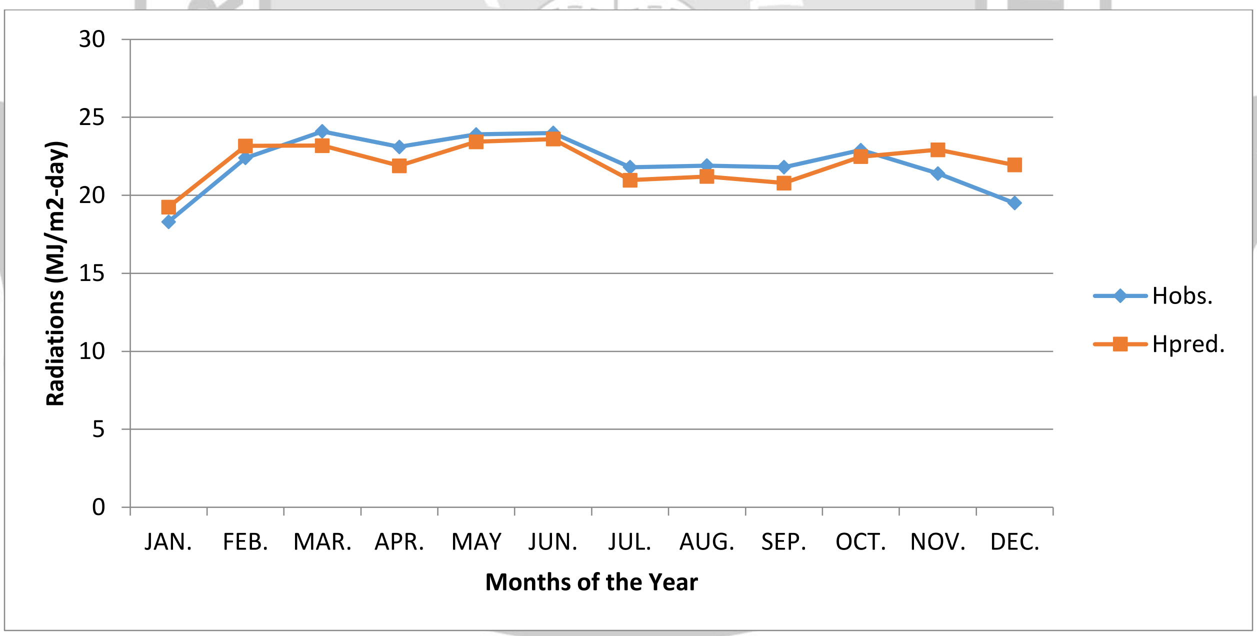

Fig.4. Comparative plot of the observed and predicted global radiation for Potiskum.

equation (6) and (7) respectively. The correlation MBE (MJm^2-day) and RMSE (MJ/m^2-day) varies from one station to another station. The RMSE is a measure of the variation of predicted values around the measured values while MBE is an indication of the average deviation of the predicted values from the measured values. The low MBE values exhibited by the model imply that it has a good long-term representation of the physical problem. The RMSE values lie in the range of 0.03 (MJ/m^2-day) to 2.45

(MJ/m^2-day) which indicates a good agreement between observed and predicted values of monthly mean of daily global solar radiation. In this research 8 years period (2010 - 2018) was assumed to be sufficient to eliminate the possible effects due to change in atmospheric transparency as a result of change in air pollution. Different values of the clearness index at different stations may be as a result of different atmospheric contents of water vapor and aerosols.

4. Conclusion

The result obtained indicates that the solar energy utilization has bright prospects in this area. The estimated values of global and diffuse radiation can be very efficiently used to compensate for energy deficits. For the estimation of diffuse radiation Lieu and Jordan (1961) and Page (1964) methods were in good agreement. The global and diffuse solar radiation was carried out using sunshine hour data. The result obtained shows the variation of direct and diffuse component of solar radiation in summer and winter months. In this area the diffuse radiations is maximum during the month of July and August and minimum during the months of November, December and January. The cloudiness index K_T values indicated the clear sky in the month of June to September, but high solar energy during October to February. From this study it has been observed that with the exception of monsoon months August and September solar energy can be utilized throughout the year in Potiskum.

Acknowledgement

We acknowledge the Nigerian Meteorological Agency, Abuja office for providing solar radiation data for this work.

REFERENCES

Ahmad, F. & Intikhab, U. (2004). Empirical model for the correlation of Monthly Average Daily Global solar Radiation with hours of sunshine on a horizontal surface at Karachi, Pakistan, *Turkish Journal of Physic. 28:301-307.*

Agbo G.A, Baba, A and Obiekezie, T.N (2010),'Empirical models for the correlation of monthly average global solar radiation with sunshine hours at Minna, Niger State, Nigeria', *Journal of Basic Physical Research, Vol.1 No1, pp 41-47*

Akpabio, L.E. & Etuk, S.E., (2008). Empirical correlations of global solar radiation with Meteorological data for Onne, Nigeria. *Turk. J. Physics 28, (2004), 205 – 212.*

Akhlaque, M. Ahmed, F. & Wasim, M. Akhtar, (2011), Total Global and Diffuse Solar Radiation For Upper Sindh, Pakistan, *Journal of Basic and Applied science 7 (2), 147 – 150*

Angstrom, A. (1924). Solar and terrestrial radiation. Q.J.R Met. Soc. 50: 121 – 126.

Augustine, C. and Nnabuchi, M. N. (2010), ' Analysis of Some Meteorological Data for Some Selected Cities in The Eastern and Southern Zone of Nigeria', *African Journal of Environmental Science and Technology, Vol.4 (2), pp 92–99*

Black, J.N Bonython, C.W & Presentt, J.A. (1954). Solar radiation and duration of sunshine, *Q.J.R Metero. Soc. 80: 231 – 235*

Burari, F.W., Abdul'Azeez, M. A., & Medugu, D.W. (2001), 'Estimation of Global Solar Radiation in Bauchi'. *Advances in Applied Science Research, 1 (1), 80 – 88*

Cooper, P.I, (1969): Model relationship for calculating Solar declination angle. *Solar Energy 12,333*

Duffie, J.A & Beckman, W.A (1994): Solar Engineering of Thermal processes. *John Willey, New York, U.S.A , 234 – 367*

Falayi, E.O., Rabiu, A. B. &Teliat, R.O., (2011): Correlations to estimate monthly mean of daily diffuse solar radiation in some selected cities in Nigeria. *Advances in Applies science Research, 2 (4): 480 – 490.*

FOS (1996). Annual Abstract of Statistics.

Iqbal, M. (1983): An introduction to solar Radiation Academic press, *New York, 15 – 280.*

Klien, S.A. (1977): Calculation of monthly average insolation on tilted surface, *Solar Energy 9:325.*

Liu, B. & Jordan, R.C (1961). Daily Insolation on surfaces Tilted Toward the Equator Trans. *ASHRAE, 67, 526.*

Prescott, J.A., (1940) Evaporation from a water surface in relation to solar radiation. *Trans R. Sco. Sci. Australia 64, 114 – 125.*

Medugu, D.W. and Yakubu, D. (2011), 'Estimation of mean monthly global solar radiation in Yola, Nigeria, Using Angstrom Model', *Advances in Applied Science Research, 2(2): 414–421.*

Offiong, A. (2003), 'Assessing the economic and environmental prospect of Stan-by solar powered systems in Nigeria, *Journal of Applied Science and environmental management, 7(1): 37-42.*

Okundamiya, M. S. and Nzeako, A.N. (2010), 'Empirical model for estimating global solar radiation on horizontal surfaces for selected cities in the six geopolitical zones in Nigeria', *Research Journal of Applied Science, Engineering and Technology, 2(8): 805–812*

Okogbue, E.C. and Adedokun, J.A. (2002), 'On the estimation of solar radiation at Ondo, Ni-geria, *J. Phys. 14: 97–99*

Onier, A. M. (1994), Renewable Energy: *4(2) 227 – 233*

Page, J. K. (1964), The estimation of monthly values of daily short wave radiation on vertical and inclined surface from sunshine records of latitude 40 degree N to 40 degree S. *Proc. of UN-Conf. on new Sources of Energy. 1:4 paper s/98.378.*

Tiwari, R.F. and Sangeeta, T.H. (1997), Solar Thermal Engineering System, *Narosa Publishing House, New Delhi, India.*

Togrul, I., Togrull. T. & Evin H. (2000): *Renewble Energy, 19:587-595.*