Estimation of Global Solar Radiation Using Angstrom Type Empirical Correlation

OGBAKA, D. T[1], NUHU RICHARD[2]
[1, 2] *Faculty of Science, Department of Pure and Applied Physics. Adamawa State, Nigeria.*

Abstract- Solar radiation measurement for particular location plays vital role for solar system design. The measurement of solar radiation at every location is not available in Nigeria so that estimation of global solar radiation for particular location is an important factor in the solar energy field. For the estimation of solar radiation, the models are used in this paper. The calculated global solar radiation is in excellent agreement with the sunshine based model. The study explains the Angstrom - Prescott model is used to calculate the monthly average global solar irradiance. The calculated Angstrom constants a = 0.206 and b = 0.415 are found for this location. The statistical test results obtained are MPE = 0.472, MBE = 5.605 and RMSE = 7.930 was obtained. Results suggest that the model can be used for any location in the Northern hemisphere and can be utilized in the design and performance estimation of solar energy systems, which is gaining significant attention in Nigerian particular and the world at large.

Indexed Terms- Global solar radiation, Angstrom, Clearness Index, Correlation, Solar Energy.

I. INTRODUCTION

Solar energy is the most important energy resource to man and indeed it is essential factor for human life. Solar energy is the clean, abundant, renewable and sustainable energy resource from the sun which reaches the earth in form of light and heat. Solar energy occupies one of the most important places among the various possible alternative energy sources for both urban and rural areas. An accurate knowledge of the solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices and for estimates of their performance (Chegaar and Chibani, 2000).

Solar radiation at the earth's surface is the principal and fundamental energy for many physical, chemical and biological processes. Solar radiation data at ground level are important for a wide range of applications in meteorology, engineering, agricultural sciences (particularly for soil physics, agricultural hydrology, crop modeling and estimating crop evapo-transpiration), in health sector and in research of many fields of natural sciences. A few examples showing the diversity of applications may include: architecture and building design (e. g. air conditioning and cooling systems); solar heating system design and use; solar power generation and solar powered car races; weather and climate prediction models; evaporation and irrigation; calculation of water requirements for crops; monitoring plant growth and disease control and skin cancer research (Badescu, 2008; Duffie and Beckman, 1991; Muneer, 2004; Hunt, Kucharb, and Swanton, 1998).

So far, a number of formulas and methods have been developed to estimate daily or monthly global radiation at different places in the world. The availability of meteorological parameters, which are used as the input of radiation models, is the important key to choose the proper radiation models at any location. Among all such meteorological parameters, cloud cover and bright sunshine hours are the most widely and commonly used ones to predict daily global solar radiation and its components at any location of interest (Sabziparvar, 2008). Most of these models estimate monthly average daily global solar radiation and are based on the modified Angstrom-type equation.

Makurdi, having an area of about 33.16 km^2 is located at latitude $7^o.41'$ N and longitude $8^o.37'$E. It is the capital of Benue State, Nigeria, having a population of as about 297, 398 people. Makurdi is noted for its hotness during the dry season with an average air temperature of about 33°C. This high temperature is attributed to the presence of River Benue (the second largest river in Nigeria) which cuts across the middle of the city, and serves a heat reservoir. This work will help in utilizing the solar energy potential to solve the energy problems in the state. The global solar radiation and sunshine hour data used in this research was obtained from the Gunn - Bellani radiation integrator, Air force Base Makurdi, Nigeria located at an altitude of about 106.4 m.

II. METHODOLOGY

The Angstrom type regression equation is related with the monthly average daily radiation to the clear day radiation at the location and the average fraction of possible sunshine hours (Angstrom 1924). Page (1961) and others have modified the method using the values of extraterrestrial radiation on a horizontal surface rather than that of clear day radiation (Duffie and Beckman, 1991).

$$\frac{\bar{H}}{H_o} = a + b\frac{S}{S_o} \quad (1)$$

Where $\bar{H}$ is the monthly average global solar radiation (MJm^{-2}day^{-1}), S is the monthly average daily bright sunshine hour, S_o is the maximum possible monthly average daily sunshine hour or the day length, and b are coefficients of Angstrom's formula.

H_o, is the monthly average daily extraterrestrial radiation which can be expressed as:

$$H_o = \frac{24\times360}{\pi} I_{sc}\left(1+0.033\cos\left(360\frac{\bar{D}}{365)}\right)\right)\cos\emptyset\cos\delta\ \sin\omega + \omega\sin\emptyset\sin\delta \quad (2)$$

Where $\bar{D}$ 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:

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

And ω is the sunset hour angle as

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

The maximum possible sunshine duration S_o is given by

$$S_o = \left(\frac{2}{15}\right)\omega \quad (5)$$

Also, the values of H_o and S_o were computed for each month by using Equation (2) and (5), respectively, $\bar{H}$ was also obtained using equation (1).

Tiwari and Sangeeta (1997), computed regression coefficient *a* and *b* from the calculated monthly average global solar radiation has been obtained from the relationship given as:

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

$$b = 1.449 - 0.553\cos\varphi - 0.694\left(\frac{\bar{S}}{\bar{S}_o}\right) \quad (7)$$

For the clearness index, the monthly average of daily global radiation (H_{cal}) was stabilized by dividing with monthly average of daily extraterrestrial radiation (H_o). We can define clearness index (K_T) as the ratio of the measured horizontal solar radiation (H_{cal}), to the calculated extraterrestrial solar radiation (H_o).

$$K_T \frac{H_{cal}}{H_o} \quad (8)$$

The performance of the models was evaluated on the basis of the following statistical error tests: The Mean Percentage Error (MPE), Root Mean Square Error (RMSE) and Mean Bias Error (MBE). These tests are the ones that are applied most commonly in comparing the models of solar radiation estimations. MPE, MBE and RMSE are defined as below: Mean Percentage Error: The Mean percentage error is defined as

$$\mathrm{MPE} = \frac{[\sum(\mathrm{H_{i,m}}-\mathrm{H_{i,c}})/\mathrm{H_{i,m}}]100}{\mathrm{N}} \quad (9)$$

Where $H_{i,m}$ is the measured value, $H_{i,c}$ is the calculated value of solar radiation and N is the total number of observations.

Root Mean Square Error: The root mean square error is defined as:

$$\mathrm{RMSE} = \left(\left[\frac{\sum\{\mathrm{H_{i,c}}-\mathrm{H_{i,m}}\}^2}{\mathrm{N}}\right]\right)^{1/2} \quad (11)$$

The RMSE is always positive, a zero value is ideal. This test will provide information on the short-term performance of the models by allowing a term by term comparison of the actual deviation between the calculated value and the measured value. Mean Bias Error: The mean bias error is defined as:

$$MBE = \frac{[\sum\{H_{i,c}-H_{i,m}\}]}{N} \quad (12)$$

III. RESULTS AND DISCUSSIONS

Estimation of solar radiation from the measured meteorological variables offers an important alternative in the absence of measured solar radiation. The monthly averaged daily solar radiation (H_m), fraction of sunshine hour $\left(\frac{S}{S_o}\right)$, clearness index $\left(\frac{H_{cal}}{H_o}\right)$ for Makurdi is presented in Table 1 - 3.

Table 1: Calculated monthly average global solar irradiance and monthly average parameters.

Months	H_{cal}	H_o	S	S_o	$\frac{S}{S_o}$	$\frac{H_{cal}}{H_o}$
Jan.	25.93	28.48	5.78	12.55	0.46	0.91
Feb.	27.27	29.16	5.62	7.01	0.80	0.93
Mar.	30.46	34.78	6.75	13.55	0.59	0.87
Apr.	32.88	35.61	4.41	12.54	0.35	0.92
May	34.90	35.46	4.68	12.52	0.37	0.98
Jun.	35.04	36.74	5.11	12.54	0.40	0.95
Jul.	32.79	35.28	4.74	12.54	0.37	0.92
Aug.	31.47	30.67	4.79	12.51	0.38	0.91
Sept.	29.95	30.89	4.71	12.54	0.37	0.96
Oct.	28.37	30.39	5.25	12.57	0.41	0.93
Nov.	27.59	26.67	5.52	12.54	0.44	0.90
Dec.	24.79	24.98	5.09	12.50	0.40	0.99

Table 2: Correlation between calculated and measured global solar irradiance with extra-terrestrial solar irradiance.

Months	H_{cal}	H_m	H_0	$\frac{H_m}{H_0}$	$\frac{H_{cal}}{H_0}$
Jan.	25.93	28.48	29.44	0.96	0.91
Feb.	27.27	29.16	28.43	1.02	0.93
Mar.	30.46	34.78	39.94	0.87	0.87
Apr.	32.88	35.61	35.84	0.99	0.92
May	34.90	35.46	34.34	1.03	0.98
Jun.	35.24	36.74	37.85	0.97	0.95
Jul.	32.79	35.28	39.34	0.89	0.92
Aug.	31.47	30.67	37.34	0.82	1.02
Sept.	29.95	30.89	33.84	0.91	0.96
Oct.	28.37	30.39	36.86	0.82	0.93
Nov.	27.59	26.67	33.84	0.78	1.03
Dec.	24.79	24.98	36.37	0.68	0.99

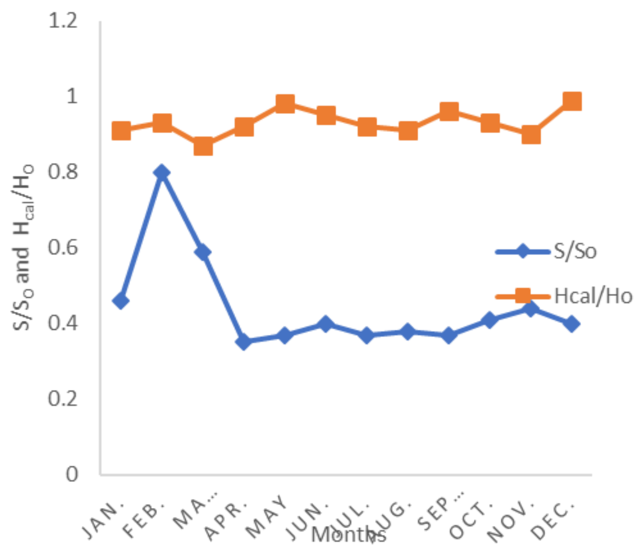

Figure 4.1: Correlation of monthly variation of S/S_o and H_{cal}/H_o

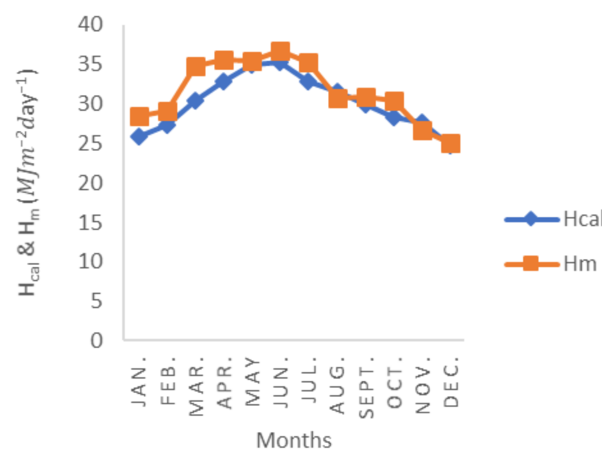

Figure 2: Comparison between measured and calculated value of global solar irradiance

Table 3: RMSE, MPE and MBE computed in the comparison between measured and calculated monthly average daily solar radiation.

a	b	RMSE	MPE	MBE
0.206	0.415	7.930	0.472	5.605

The extraterrestrial global solar irradiance (H_o) ($MJm^{-2}day^{-1}$) is calculated using equation 2 for that declination angle, sunshine hour angle and maximum sunshine duration are calculated using equations 3, 4, 5 respectively. Monthly average global solar irradiance is calculated using equation 1 by substituting the values of Angstrom constant ' a ' and ' b '. Where the regression constant values of a = 0.206 and b = 0.415 are calculated (see table 3) using Rietveld model using equations 6 and 7 respectively. From the measured data the lowest clearness index is observed in the months of July, August and September. The results from the table - 01 the calculated maximum global solar irradiance is 35.24 $MJm^{-2}day^{-1}$. The data are tested with result MPE = 0.472, MBE = 5.605 and RMSE = 7.930. The positive value of MBE = 5.605 indicates the calculated results are over estimated.

CONCLUSION

The estimation of global solar irradiance is performed for the location having an area of about 33.16 km^2 is located at latitude 7°.41' N and longitude 8°.37'E. It is the capital of Benue State. The minimum and maximum value of global solar irradiance for this location is 24.79 $MJm^{-2}day^{-1}$ to 35.24 $MJm^{-2}day^{-1}$ respectively. The calculated Angstrom constants a = 0.206 and b = 0.415 are found for this location. The statistical test results obtained are MPE = 0.472, MBE = 5.605 and RMSE = 7.930. The results were concluded that the Angstrom - Prescott model is the perfect estimation of horizontal surface of the station which is highly useful to predict the global solar irradiance at any location having same climate condition. The maximum value of monthly average global solar irradiance (= 35.24 $MJm^{-2}day^{-1}$) indicates the strong potential for utilization of solar energy for the tested location.

REFERENCES

[1] Angstrom A., (1924). Solar and terrestrial radiation. Quarterly Journal of Royal Meteorological Society. 50:121–125.

[2] Badescu V., (2008). Modeling Solar Radiation at the Earth's Surface: Recent Advances; Berlin Heidelberg, Springer-Verlag.

[3] Chegaar, M. and Chibani, A. (2000). 'A Simple Method for Computing Global Solar Radiation', Rev. Energ. Ren: Chemss, pp 111–115.

[4] Duffie J.A. and Beckman W.A. (1991). Solar engineering of thermal processes. New York: Wiley.

[5] Hunt L. A., Kucharb L., Swanton C. J., (1998). Estimation of solar radiation for use in crop modeling. Agricultural and Forest Meteorology; 91: 293–300.

[6] Muneer T., (2004). Solar Radiation and Daylight Models, 2nd ed., Elsevier Butterworth-Heinemann.

[7] Prescott J.A., (1940). Evaporation from water surface in relation to solar radiation. Transactions of the Royal Society of Australia; 46:114–8.

[8] Rietveld M.R., (1978). A new method for estimating the regression coefficients in the formula relating solar radiation to sunshine. Agricultural Meteorology, 19, 243–252.

[9] Sabziparvar A. A., (2008), 'A Simple Formula for Estimating Global Solar Radiation in Central Deserts of Iran' Renewable Energy, Volume33, pp 1002-1010.