Empirical Model for the Estimation of Global Solar Radiation in Yola, Nigeria

Ogbaka, D.T[1*], Vandi, T[2].

[1, 2]*Department of Pure and Applied Physics, Faculty of Science, Adamawa State University, Mubi, Adamawa State, Nigeria*
**Corresponding Author*

Abstract: **Solar radiation measurement for particular location plays vital role for solar system design. This work proposes the coefficients for Angstrom - Prescott type of model for the estimation of global solar radiation in Yola, Nigeria using relative sunshine duration alongside the measured global solar radiation data (2014 - 2018). The model constants a and b obtained in this investigation for Yola are 0.267 and 0.461 respectively. The correlation coefficient of 85% (P=0.00) between the clear sky index and relative sunshine duration, as well as the coefficient of determination, R^2 of 87.9 obtained shows that this model fits the data very well. Consequently, the developed model in this work can be used with confidence for Yola and other locations with similar climate conditions.**

***Keywords*: Global solar radiation; Angstrom – Prescott model; Clearness Index**

I.INTRODUCTION

For the improvement of quality of life of human being as well as economic and social development, energy is an essential factor. Solar energy reaches to the earth for the every year is 160 times the world's proven fossil fuel reserves, it is expected that the recent worldwide research and development on solar energy will help to reduce the energy crisis of the world [9], [10]. Solar radiation data are fundamental input for solar energy utilization such as photovoltaic and solar thermal system design. For optimization and performance evaluation of solar technology for any particular location, the solar radiation data should be easily and readily available[8].

Solar radiation at the earth's surface is essential for the development and utilization of solar energy. It is needed for designing collectors for solar heaters and other photovoltaic equipment that depend on solar energy. Incoming solar radiation has a significant role in hydrological and crop growth modelling. For instance, it is a key input for estimating potential evapotranspiration which play a major role in the design of water supply storage reservoirs and irrigation systems. In spite of the importance of global solar radiation data, its measurements are not frequently available especially in developing countries [3].

[2] Observed that the meteorological stations measuring solar radiation data in the developing countries are few. This situation can be solved by using empirical models, which estimate global solar radiation based on the relationships with frequently measured climatic variables. Solar energy occupies one of the most important places among the various possible alternative energy sources. An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices. Unfortunately, for many developing countries solar radiation measurements are not easily available due to the shortage of measurement equipment's [12]. It is therefore important to consider methods of estimating the solar radiation based on the readily available meteorological parameters [11].

Many studies have been calculated to estimate incoming solar radiation in Nigeria [5], [2]. [4] was the first scientist known to suggest a simple linear relationship to estimate global solar radiation, later on modified by [14].

Yola, the capital of Adamawa State, comprising of Yola North and Yola South Local Government Areas, is located between Longitudes 12° 12'E, 12° 33'E of the Prime Meridian and between Latitudes 09° 12'N, 09° 19'N of the Equator. It is situated in the Benue Valley area of the state with a mean elevation 186 m.a.s.l. The area falls within the Tropical Wet and Dry/ West African Savanna Climate zone of Nigeria, with pronounced dry season in the low-sun months and wet season in the high-sun months. It is characterized by an average range of sunshine hours of 5.5 hours per day in August to 9.7 hours per day from the months of January through March. On balance, there are 2,954 sunshine hours annually and approximately 8.1 sunlight hours per day [15]. Its Temperature characteristic is high all year round due to high solar radiation effect. However, seasonal changes usually occur such that there is a gradual increase in temperature from January to April when the seasonal maxima is recorded. Then a distinct gradual decline is recorded from the onset of rains in April/May due to cloud effects. This temperature characteristic continuous until October when a slight increase is experienced at the cessation of rains before the arrival of cold dry continental winds (harmattan) conditions (Adebayo, 1999). Thus, the study area is characterized by a mean temperature of 27.9 °C with a mean monthly range of 6.5 °C. The warmest mean maximum/ high temperature of the area is 39 °C in March & April, while the coolest mean minimum/ low temperature is 16 °C in December [15].

II. METHODOLOGY

The Angstrom- Prescott regression equation which has been used to estimate the monthly average daily solar radiation on a horizontal surface in Nigeria or other places is given as:

$$\frac{H_m}{H_o} = \left[a + b\frac{S}{S_o}\right] \qquad (1)$$

H_m is daily mean values of global radiation ($MJm^{-2}day^{-1}$), S_o the daily average value of day length, and 'a' and 'b' values are known as Angstrom constants and they are empirical. H_o is daily mean values of extraterrestrial radiation ($MJm^{-2}day^{-1}$), calculated using equation (2) as described by [14].

$$H_o = \frac{24\times3{,}600}{\pi} I_{sc} E_o \left[\cos(\varphi)\cos(\delta)\sin(\omega_s) + \frac{\pi\omega_s}{180}\sin(\varphi)\sin(\delta)\right] \qquad (2)$$

$$I_{sc} = \frac{1{,}367\times3{,}600}{1{,}000{,}000} MJm^{-2}day^{-1} \qquad (3)$$

I_s the solar constant, The units in $kWhm^{-2}day^{-1}$

E_o represents the eccentricity correction, and described using Eq. (3.4) in Eq. 3.2

$$E_o = 1 + 0.033\cos\frac{360 n_d}{365} \qquad (4)$$

n_d is the day number of the year /Julian day (1 Jan, n_d = 1 and 31st December, n_d = 365), φ is the latitude of the site, δ the solar declination and, ω_s, the mean sunset hour angle for the given month. The solar declination (δ) and the mean sunset hour angle (ω_s) can be calculated as suggested by [7]:

$$\delta = 23.45\sin 360\frac{284 + n_d}{265} \qquad (5)$$

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \qquad (6)$$

For a given day, the maximum possible sunshine duration (monthly values of day length, (S_o) can be computed by using Cooper's formula [6]:

$$S_o = \frac{2}{15}\cos^{-1}(-\tan\varphi\tan\delta) \qquad (7)$$

In this work, and were computed for each month using equations (1) and (2). The values of

the monthly average daily global solar radiation, and were obtained from daily measurements coveringa period of five (5) years. The SPSS computer software was applied to obtain the regression constants a and b. Mean Bias Error (MBE) was also obtained to assess the validity of estimation made through equation (1).

III. RESULTS AND DISCUSSIONS

The declination angle and sunset hour angle were calculated using equation (4), (5), (6) and (7) respectively.

Table 1: Meteorological Data and Global Solar Radiation for Yola

MONTH	S	S_o	S/S_o	H_m	H_o	H_m/H_o
JAN	4.72	11.74	0.40	18.5	34.2	0.54
FEB	4.80	11.65	0.41	20.1	36.4	0.55
MAR	4.61	11.34	0.40	21.1	38.5	0.54
APR	4.92	11.24	0.43	19.8	39.0	0.50
MAY	4.89	12.34	0.39	18.2	38.2	0.47
JUN	3.86	12.86	0.30	17.2	36.5	0.47
JUL	2.27	11.32	0.24	15.4	37.9	0.40
AUG	2.31	11.42	0.22	14.2	34.2	0.41
SEPT	2.57	11.23	0.29	16.5	38.3	0.43
OCT	4.15	11.21	0.37	18.9	36.0	0.52
NOV	5.23	11.43	0.49	20.4	31.6	0.64
DEC	5.66	11.26	0.46	19.0	30.4	0.63

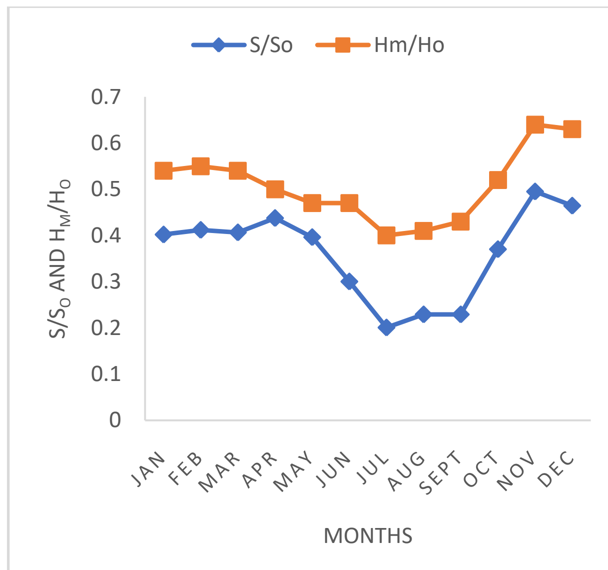

Figure 1: Relationship between the clearness index and relative sunshine duration

The model constants, a and b obtained in this investigation were 0.267 and 0.461 respectively. Hence the first order polynomial developed for Yola is:

$$\frac{H_m}{H_o} = 0.267 + 0.461\frac{S}{S_o} \qquad (8)$$

The coefficient of determination, R^2 of 87.9 obtained for this analysis shows that this model fits the data very well. The relationship between the relative sunshine duration ($\frac{S}{S_o}$), and clearsky index (K_T) or($\frac{H_m}{H_o}$) for Yola are presented in Figure 1 above. The value of K_T (=0.41) corresponding to the lowest value of $\frac{S}{S_o}$(=0.22) and H_m(=14.2 $MJm^{-2}day^{-1}$) in the month of August indicate poor sky conditions. These conditions correspond to the wet or rainy season (June - September) observed in Nigeria during which there is much cloud cover. Hence, the correlation coefficient between K_T and is as high as85% (p=0.00).

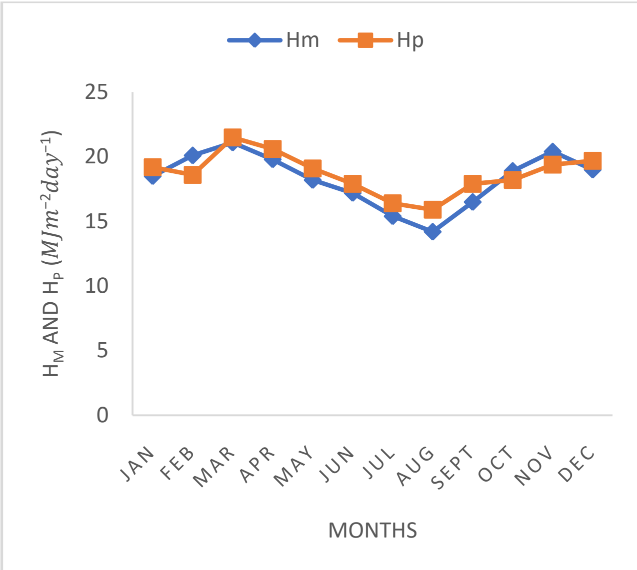

Figure 2: Relationship between the measured and predicted global solarradiation.

Observation from Fig. 2 above shows that both the estimated and the measured vary correspondingly except in February, May and April, where they respectively exhibit under estimation and over estimation of the predicted values. This could be due to variability in atmospheric parameters during the measurement. However, the estimated value of the global solar radiation correlates well with the measured, hence, theMeans Standard Error (MSE) between the measured and the estimated global solar radiation is as 0.043. This shows a good agreement between the measured and estimated values.

Figure 2 also shows that the maximum solar radiation in Yola, were obtained for the period 2014 - 2018 in (February - March) and (October- November). In the rainy season, the lowest solar radiation was obtained in August (probably due to rain bearing clouds which pervaded the sky), where as in the dry season, the highest was measured in November and the lowest in December and January (probably due to hamartan dust which scattered the solar radiation at that time. Under clear perfect sky condition, the transmission of the atmosphere for global; solar radiation is given as the sum of the regression coefficients a + b, where as the transmissivity of an over cast atmosphere is interpreted as the intercept a. Finally, our model fits adequately with the radiation data presented in Table 1. Consequently, equation (6) can be used with confidence for Yola, and other locations with similar climate conditions.

IV.CONCLUSION

In the absence and scarcity of trust worthy solar radiation data, the need for empirical model to predict and estimate solar radiation seems inevitable. In this paper, the results clearly indicates the significance of using empirical models for estimating global radiation on horizontal surfaces reaching the earth for a particular geographical location. The Angstrom model used in this study can also be applied to other cities to predict global solar radiation. The global solar radiation intensity predicted in this study can also be utilized in design, analysis and performance estimation of solar energy systems, which is gaining significant attention in Nigeria and Mubi North in particular and the world at large.

REFERENCE

[1]. Ad ebayo, A. A. (1999). Climate I: Sunshine Temperature, Evaporation and Relative Humidity. In A. A. Adebayo, and A. L. Tukur, (eds). Adamawa State in Maps. Yola; Paraclete Publishers.

[2]. Akpabio, L.E., UDO, S.O., Etuk, S.E., (2004). Empirical correlations of global solar radiation with meteorological data for Onne, Nigeria. Turk. J. Physics 28, 205 – 212.

[3]. Allen, R.G., (1997). Self-calibrating method for estimating solar radiation from air temperature. ASCE J. Hydrol. Eng. 2, 56 – 57.

[4]. Angstrom, A., (1924). Solar and terrestrial radiation. Quart. Jour. Roy. Meteorol. Soc. 50, 121 – 125.

[5]. Bamiro, O.A., (1983). Empirical relations for the determination of solar radiation in Ibadan. Nigeria Sol. Energy 31, 85 – 94.

[6]. Cooper, P.I (1969). “The Absorption of Radiation on Solar Stills”, Solar Energy, vol. 12, no. 3, pp 333 – 346.

[7]. Duffie, J. A. and Beckman, W. A., (1991). Solar Engineering of Thermal Processes, 2nd edition, New York: Wiley.

[8]. Gana N.N, Jitendra K.R, and Musa M. (2014). Angstrom Constants for Estimatiing Solar Radiation in Sokoto, North Western, Nigeria, International journal of scientific &Engineering Research, Volume 5, Issue 1.

[9]. Kartini S., Sufiyan A.H., Jedol D., Mohamad Z.H.M and Mohd S.S, (2015). Measurement of Global Solar Radiation in Kota Kinabalu Malasiya, ARPN Journal of Engineerig and Applied Sciences, Vol.10, No.15.

[10]. Medugu D.W, Adisa A.B, Burari F.W, and Abdul Azeez M.A, (2013). Solar Radiation: correlation between measured and predicted values in mubi, Nigeria, International Journal of Science and Technology Education Research, Vol 4(1), pp. 11-17.

[11]. MusaB., Zangina U.and Aminu M., (2012). Estimation of global solar radiation in Maiduguri, Nigeria using angstrom model. ARPN journal of Engineering and Applied Science. Vol. 12 No. 7.

[12]. 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 Sciences, Engineering and Technology. 2(8): 805-812.

[13]. Neuwirth, F., (1980). The estimation of global and sky radiation in Austria. Sol. Energy 24, 421 – 426.

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

[15]. Yola Climate Report 2012. Retrieved March 12, 2012 from http://www.climatemps.com