Performance of Temperature Base Models for Estimating Solar Radiation in Yola, Adamawa State, Nigeria

Ogbaka D.T[1], Yohanna E[2]

[1]Department of Pure and Applied Physics, Adamawa State University, Mubi, Adamawa State, Nigeria
[2]Department of Sciences, Federal Government Girls College, Jalingo, Taraba State. Nigeria

***Abstract:* - The performance of temperature models were evaluated for the estimation of global solar radiation for Yola, Nigeria. The variations of the mean monthly, annual temperatures and extraterrestrial solar radiation were estimated and the monthly global solar radiation was estimated over five (2011 – 2015). Meteorological data comprising of Gunn-Bellani radiation and maximum and minimum temperatures. It is very encouraging to observe a very fine agreement between measured and estimated values obtained from Hargreaves and Sammani model. The model performance of the three models was compared based on MBE, RMSE, and MPE as shown in table 7. Based on the RMSE, Hargreaves model and Sammani model produces the best coefficient of determination 8.46, while the Allen et al., model gives the worst with larger value of 14.89. It was observed that the lower the RMSE, the more accurate the equation used. For MBE, the result shows that the Hargreaves and Sammani model is the best with a value of 4.78, Allen et al., models is again the worst with a value of 18.34. With respect to MPE, Hargreaves and Sammani model offers best correlation of – 3.74, while the**

Allen et al., models model gives the worst. Hargreaves and Sammani model (Eq. 8) was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola, Adamawa State. The global solar radiation intensity produced by the recommended model can be utilized in design, analysis and performance estimation of solar energy conversion system, which is gaining significant attention in Adamawa State and Nigeria at large.

I. INTRODUCTION

The growing demand in urban and rural areas for energy has necessitated the finding of alternative sources of energy. With the change in the rural scenario and agricultural practices, and the advent of gadgets like televisions, mobile phones, and computers, the demand of energy has increased by a multitude (Yorukoglu and Celik, 2006). To overcome the dependency on conventional fuels, researchers and many organizations are working on alternative fuels, which should be commercially viable, easy to use, less pollutant, and must be abundant in nature (Campbell and Norman, 1998). In this direction, renewable energies, like Solar Energy, Tidal Energy, Wind Energy, Biofuels, and so forth, are suitable than conventional sources of energy. These nonconventional forms are not only renewable but also maintain ecology and environment as they are eco-friendly and do not contribute in global warming and production of green house gases, and so forth (Campbell and Norman, 1998).

Solar radiation is the largest energy source and is capable of affecting large quantities of events on the Earth's surface including climate, existence and so on. Research outcomes on studies of global solar radiation have facilitated improvement in Agronomy, power generation, environmental temperature controls, etc. Thus, the urgent requirement for daily weather data such as minimum (Tmin) and maximum (Tmax) air temperatures, rainfall, and global solar radiation (GSR) become neces-sary in order to effectively model the tools or mechanisms involved in management of phenomena employing these weather data, such as those mentioned previously (Jagtap and Jones, 2002).

The widely used correlations for estimating solar radiation are mainly based on sunshine duration and air temperature. In fact, the models estimating solar radiation from sunshine duration are generally more accurate than those involving other meteorological observations. However, sunshine duration is not as readily available as air temperature data at standard meteorological stations. So, it is meaningful to elaborate models that estimate solar radiation based on air temperature as an alternative.

In Nigeria, a number of other studies have been conducted on the measurement and estimation of solar radiation from other meteorological variables and these include: Ezekwe and Ezeilo (1981), Awachie and Okeke (1982), Bamiro (1983) and Okogbue and Adedokun (2002b). Ezekwe and Ezeilo (1981), presented empirical correlations for Nsukka a town located in the southeastern part of Nigeria. On the other hand, Bamiro (1983), presented some empirical correlations for predicting global insolation for Ibadan (Nigeria).

Temperature based models can be used to estimate the solar radiation of Yola. Many common approaches are used like (Hargreaces and Samani 1982; Bristow and Campphell, 1984). The two models can be applied monthly calculation (Allen, 1997). In this study a solar resources parameter ambient temperature has been analyse to deduce a two parameter based linear model for estimating the global solar radiation on horizontal surfaces like Yola city using five years' records of monthly mean daily maximum and minimum ambient temperature. Site map of study location is Yola Adamawa State - Nigeria.

II. MATERIALS AND METHODS

Yola has a tropical climate characterized by dry and wet seasons. Local variations originate from the peculiar meteorological and geographical influence of the area in question. The dominant features of the rainfall are its seasonal character, its variability from year to year and the intensity of the rainfall or the large energy content of the rainfall and ends later October, while the dry season lasts from November to March. There is one primary rainfall peak each year. This occurs between June and September when the mean monthly rainfall is 198mm. Daily minimum temperatures normally drop more rapidly than the maximum. Consequently, the diurnal range of temperature increases rapidly. Daily maximum screen temperatures in November may rise as high as 33Â°C and the minimum may fall as low as 11Â°C. The sky is mostly clear in November and this permits longer hours of sunshine.

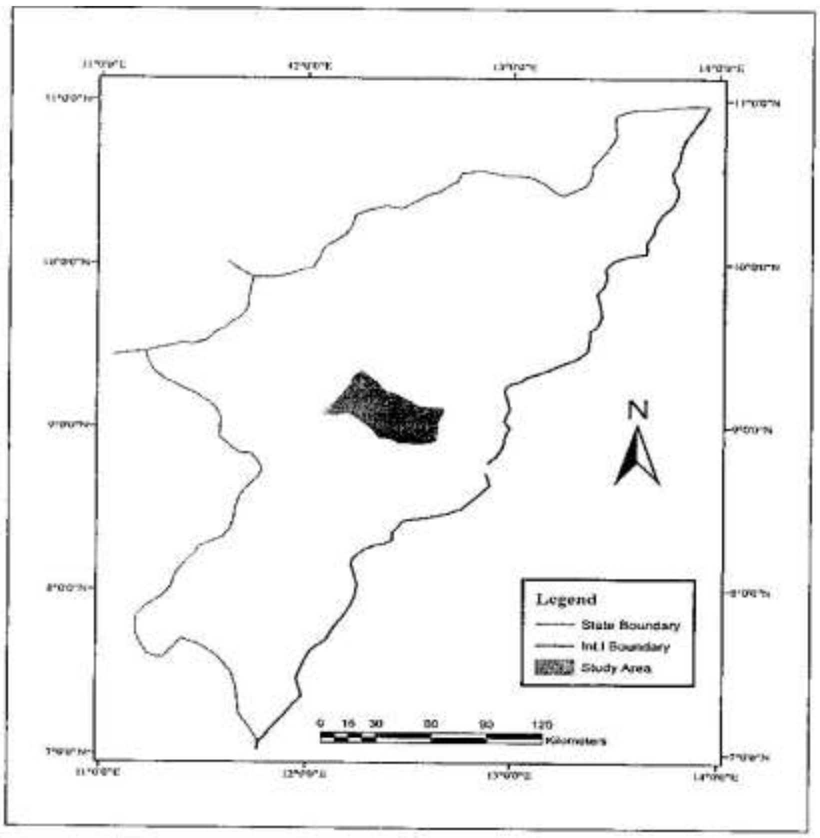

Fig. 1 Study area of Yola

Yola, the capital of Adamawa State, comprising of Yola North and Yola South Local Government Areas, is located between Longitudes 12^0 33'E of the prime meridian and between Latitudes 09^0 12'N, 09^0 19'N of the equator (Fig.1)

Meteorological data comprising of Gunn-Bellani radiation and maximum and minimum temperatures, measured in Yola for five years period (2011 – 2015) were obtained from Nigerian Meteorological Agency of the Federal Aviation Authority, Yola. The Gunn-Bellani radiation data in millimetres, which relate the` volume of liquid distilled by solar radiation to the amount of solar radiation reaching a horizontal surface, were first converted to solar radiation intensity unit of $MJm^{-2}day^{-1}$ using the conversion factor of 1.216 ($MJ^{-2}day^{-1}$) proposed by Ododo (1994).

Several empirical models exist to evaluate global solar radiation, using available meteorological and geographical parameters such as sunshine duration, difference between the maximum, T_{max}, and the minimum, T_{min} daily temperatures. Microsoft Office Excel software's will be used for the data analysis.

The Angstrom-Prescott regression model was given by Igbal (1983)

$$\frac{\bar{H}}{H_o} = a + b\frac{\bar{S}}{\bar{S}_0} \qquad 1$$

Where $\bar{H}$ is the monthly average global solar radiation ($MJm^{-2}day^{-1}$), $\bar{S}$ is the monthly average daily bright sunshine hour, $\bar{S}_0$ is the maximum possible monthly average daily sunshine hour or the day length, a and b are coefficients of Angstrom's formula.

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

$$H_o = \frac{24}{\pi} I_{sc} \left[1 + 0.033\cos 360n365 \cos\emptyset\cos\delta\sin\omega s + \pi 180 \omega s \sin\emptyset\sin\delta \right. \qquad 2$$

where is the solar constant ($1367\ Wm^{-2}$), φ is the latitude of the site, δ is the solar declination and ω_s is the mean sunrise hour angle for the given month and is the number of days of the year starting from 1st of January to of 31st December. The solar declination, and the mean sunrise hour angle, can be calculated using the following equation (Iqbal, 1983; Zekai, 2008):

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

And ω is the sunset hour angle as

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

The maximum possible sunshine duration $\bar{S}_0$ is given by

$$\bar{S}_0 = \left(\frac{2}{15}\right)\omega_s \qquad 5$$

Different models used different approaches for estimating the coefficient a and b (Rietveld, 1978; Neuwirth, 1980).

$$a = -0.110 + 0.235\cos\emptyset + 0.323\frac{\bar{S}}{\bar{S}_0} \qquad 6$$

$$b = 1.449 - 0.553\cos\emptyset - 0.694\frac{\bar{S}}{\bar{S}_0} \qquad 7$$

Hargreaves and Sammani (1985) were the first to suggest that global radiation could be evaluated from the difference between daily maximum and daily minimum temperature. The proposed the model below:

$$\frac{\bar{H}}{H_o} = a + (T_{max} - T_{max})^{0.5} + b \qquad 8$$

Allen et al., (1998) suggested self-calibrating model that is function of the daily extraterrestrial radiation, mean monthly maximum and minimum temperature as:

$$\frac{\bar{H}}{H_o} = a(T_{max} - T_{max})^{0.5} \qquad 9$$

Okonkwo and Nwokoye (2014) also proposed this model for Minna.

$$\frac{\bar{H}}{H_o} = a + b\,(T_{max}) \qquad 10$$

Statistical test

$$MPE = \frac{[\sum(H_{i,m} - H_{i,c})/H_{i,m}]100}{N} \qquad 11$$

Where $H_{i,m}$ is the ith measured value, $H_{i,c}$ is the ith 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:

$$RMSE = \left(\left[\frac{\sum\{H_{i,c} - H_{i,m}\}^2}{N}\right]\right)^{1/2} \qquad 12$$

Mean Bias Error: The mean bias error is defined as:

$$MBE = \frac{[\sum\{H_{i,c} - H_{i,m}\}]}{N} \qquad 13$$

RMSE provides information on short-term performance of the models. It is always positive. The demerit of this parameter is that a single value of high error leads to a higher value of RMSE. MPE test provides information on long-term performance of the examined regression equations. A positive and a negative value of MPE indicate the average amount of over estimation and under estimation in the calculated values, respectively. It is recommended that a zero value for MBE is ideal while a low RMSE and low MPE are desirable (Igbal, 1983; Akpabio and Etuk, 2003).

III. RESULTS AND DISCUSSION

In this paper, H_o and $\bar{S}_0$ were computed for each month of the year using equation (2) and (5) in table 2. The values of the sunshine hours ($\bar{S}$), Solar Radiation ($\bar{H}_m$) and the monthly mean (minimum and maximum) air temperature data for five years were obtained from the Archives of Nigeria Meteorological Agency, Yola Adamawa State.

Table 1: The imputed parameter used in this analysis for years

Months	T_{max} (^oC)	T_{min} (^oC)	$\bar{S}$ (hr)	$\bar{H}_m$ ($MJm^{-2}day^{-1}$)
Jan.	34.58	18.34	8.33	17.80
Feb.	38.54	22.42	7.32	19.26
March	40.54	22.58	7.66	20.20
April	40.22	26.52	8.44	20.54
May	39.12	26.28	7.47	21.34
June	34.16	24.84	7.46	17.58
July	31.94	23.94	6.29	15.40
Aug.	30.88	23.40	5.02	13.66
Sept.	31.16	23.40	6.10	16.04
Oct.	33.70	24.08	8.14	17.72
Nov.	36.64	21.12	7.39	19.14
Dec.	35.32	18.92	9.33	18.40

Table 2: Computed values used for the analysis for five years

Months	$\bar{H}_o$ ($MJm^{-2}day^{-1}$)	$\bar{S}_0$ (hr)	$\bar{S}$ (hr)	$\frac{\bar{S}}{\bar{S}_0}$
Jan.	34.25	12.35	8.33	0.67
Feb.	35.84	12.16	7.32	0.60
March	34.43	11.72	7.66	0.65
April	39.32	12.56	8.44	0.67
May	40.61	11.23	7.47	0.66
June	38.73	11.52	7.46	0.47
July	37.34	11.67	6.29	0.53
Aug.	38.96	12.33	5.02	0.40
Sept.	37.56	12.58	6.10	0.48
Oct.	36.02	12.14	8.10	0.66
Nov.	36.94	11.56	7.39	0.63
Dec.	35.72	11.70	9.33	0.79

Table 3: Imputed parameters for the estimation of Mean Monthly Global Solar Radiation for Yola Using Hargreaves and Sammani model

Months	T_{max} (^oC)	T_{min} (^oC)	$\bar{H}_m$ ($MJm^{-2}day^{-1}$	Hargreaves and Sammani Model $\bar{H}_e$ ($MJm^{-2}day^{-1}$)
Jan.	35.76	19.55	17.80	18.05
Feb.	38.54	22.87	19.26	18.61
March	39.22	21.98	20.20	19.79
April	41.89	25.81	20.54	20.26
May	38.29	25.36	21.34	20.69
June	34.74	24.66	17.58	16.52
July	29.72	22.86	15.40	14.49
Aug.	29.09	23.42	13.66	14.009
Sept.	31.57	23.27	16.04	15.18
Oct.	34.01	24.35	17.72	17.01
Nov.	35.37	21.45	19.14	19.22
Dec.	34.81	19.36	19.33	18.40

Table 4: Imputed parameters for the estimation of Mean Monthly Global Solar Radiation for Yola Using Allen et al., Model

Months	T_{max} (^oC)	T_{min} (^oC)	$\overline{H}_m$ ($MJm^{-2}day^{-1}$)	Allen et al., Model $\overline{H}_e$ ($MJm^{-2}day^{-1}$)
Jan.	34.48	18.25	17.80	19.54
Feb.	37.00	20.73	19.26	21.67
March	37.10	23.82	20.20	24.75
April	39.48	24.90	20.54	23.54
May	39.60	23.36	21.34	23.12
June	33.96	24.66	17.58	20.42
July	29.64	22.86	15.40	18.33
Aug.	28.95	21.66	13.66	17.47
Sept.	30.86	21.64	16.04	18.03
Oct.	31.27	21.55	17.72	20.44
Nov.	34.80	19.08	19.14	20.11
Dec.	35.83	17.86	19.33	21.63

Table 5: Imputed parameters for the estimation of Mean Monthly Global Solar Radiation for Yola Using Okonkwo and Nwokoye Model

Months	T_{max} (^oC)	T_{min} (^oC)	$\overline{H}_m$ ($MJm^{-2}day^{-1}$)	Okonkwo and Nwokoye Model $\overline{H}_e$ ($MJm^{-2}day^{-1}$)
Jan.	35.26	25.88	17.80	18.90
Feb.	37.10	24.92	19.26	20.73
March	36.24	24.11	20.20	20.82
April	35.46	23.90	20.54	23.91
May	34.12	20.21	21.34	24.33
June	30.27	23.18	17.58	24.98
July	30.49	19.11	15.40	18.09
Aug.	30.70	20.17	13.66	16.70
Sept.	31.57	20.99	16.04	23.18
Oct.	30.71	25.14	17.72	23.25
Nov.	36.19	28.30	19.14	19.46
Dec.	37.81	33.01	19.33	20.30

Table 6: Comparison for all the models used in the estimation of solar radiation for Yola and the measured values

Months	$\overline{H}_m$ ($MJm^{-2}day^{-1}$)	Hargreaves and Sammani Model	Allen et al., Model	Okonkwo and Nwokoye Model
Jan.	17.80	18.05	19.54	18.90
Feb.	19.26	18.61	21.67	20.73
March	20.20	19.79	24.75	20.82
April	20.54	20.26	23.54	23.91
May	21.34	20.69	23.12	24.33
June	17.58	16.52	20.42	24.98
July	15.40	14.49	18.33	18.09
Aug.	13.66	14.009	17.47	16.70
Sept.	16.04	15.18	18.03	23.18
Oct.	17.72	17.01	20.44	23.25
Nov.	19.14	19.22	20.11	19.46
Dec.	19.33	18.40	21.63	20.30

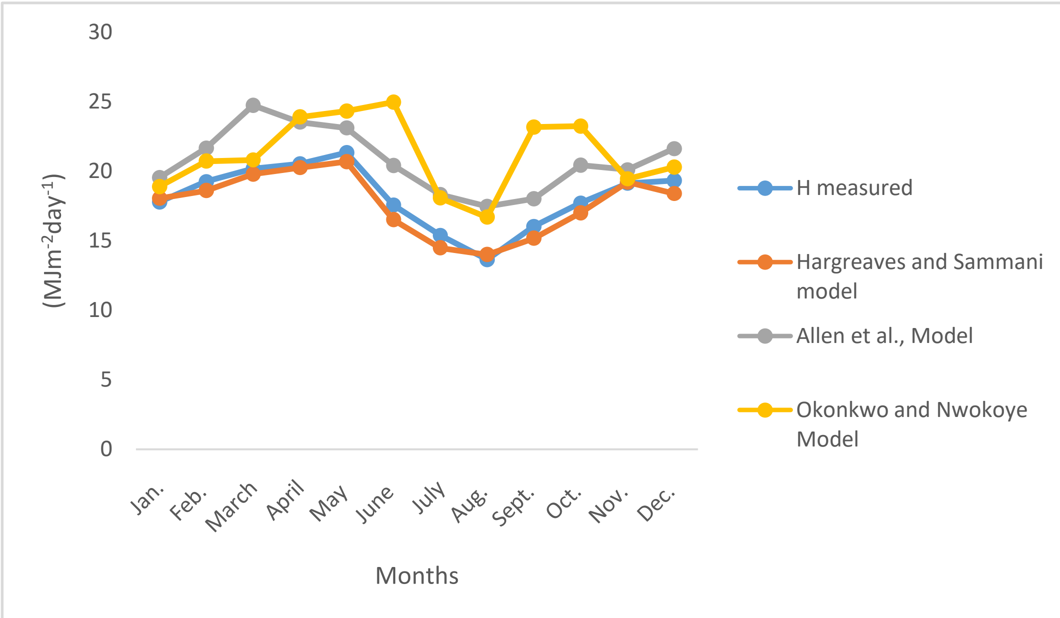

Figure 4.1: Mean monthly variation of the estimated global solar radiation using the three models.

Table 7: Statistical test results of models applied for Yola

Models	MPE	% RMSE	% MBE
Hargreaves and Sammani	- 3.74	8.46	4.78
Allen et al.,	1.03	14.89	18.34
Okonkwo and Nwokoye	0.95	11.95	13.82

IV. DISCUSSION

The extraterrestrial solar radiation, H_O (MJ/m^2/day), and the monthly day length, S_O (hr), were computed for each location using equations (2) and (5), the input parameters for the calculation of the mean monthly global solar radiation for Yola (2011 - 2015) are shown in the table 4.2. Using these parameters, the regression constants ‘a’ and ‘b’ evaluated as 0.283 and 0.570 respectively. Substituting these values into equations (8) – (10) to obtain the estimated values from each models.

The monthly average daily global solar radiation estimated through equations (8) and (10) for Yola are given in tables 3 – 4, along with the measured values and the estimated values from the models. It is very encouraging to observe a very fine agreement between measured and estimated values obtained from Hargreaves and Sammani model. The monthly average daily global solar radiation of the three models were compared with measured values in figure 2.

The model performance of the three models was compared based on MBE, RMSE, and MPE as shown in table 7. Based on the RMSE, Hargreaves model and Sammani model produces the best coefficient of determination 8.46, while the Allen et al., model gives the worst with larger value of 14.89. It was observed that the lower the RMSE, the more accurate the equation used. For MBE, the result shows that the Hargreaves and Sammani model is the best with a value of 4.78, Allen et al., models is again the worst with a value of 18.34. With respect to MPE, Hargreaves and Sammani model offers best correlation of – 3.74, while the

Allen et al., models model gives the worst.

V. CONCLUSION

From the monthly average solar radiation measurements, three empirical models have been used in estimating global solar radiation at Yola, Northeast Nigeria. The

The models require only the maximum and minimum temperatures and sunshine hours. The performance of the models was evaluated and analyzed using statistical indicators that is RMSE, MBE and MPE. Hargreaves and Sammani model was found to be more accurate and the best. Hence, the model could be employed in estimating global solar radiation of location that has the geographical location information as Yola. The study therefore recommends that the models presented in this study may be used reasonably well for estimating the solar radiation at a given location and possibly in elsewhere with similar climatic conditions. Hargreaves and Sammani model (Eq. 3.8) was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola, Adamawa State. The global solar radiation intensity produced by the recommended model can be utilized in design, analysis and performance estimation of solar energy conversion system, which is gaining significant attention in Adamawa State and Nigeria at large.

REFERENCES

[1] Allen R. "Self calibrating method for estimating solar radiation from air temperature". J Hydrol Eng 1997;2:56 - 67.

[2] Bamiro O.A. "Empirical relations for the determination of solar radiation in Ibadan, Nigeria". Solar energy,1983. vol. 31, No. 1. pp. 85-94.

[3] Bristow KL, Champbell GS. "On the relationship between incoming solar radiation and daily maximum and minimum temperature". Agric Forest Meteorol 1984;31:159 - 66.

[4] Ezekwe C.I. and Ezeilo C.C.O. "Measured solar radiation in a Nigerian Environment compared with predicted data". Solar energy, 1981. vol. 26, pp. 181-186.

[5] G. S. Campbell and J. M. Norman, "An Introduction to Environmental Biophysics," 2nd Edition, Springer-Verlag, New York, 1998. doi:10.1007/978-1-4612-1626-1.

[6] Hargreaves,G.,Hargreaves,G.,and Riley,J. "Irrigation water requirement for the Senegal River Basin". J Irrigat Drain Eng, ASCE 1985;111:265–75.

[7] Iqbal M. "An introduction to solar radiation" academic press. New York 1983. pp. 59- 67.

[8] Ododo JC, Sulaiman AT, Aidan J, Yuguda MM, Ogbu FA. "The importance of maximum air temperature in the parameterisation of solar radiation in Nigeria". Renew Energy 1995;6:751 - 63.

[9] Okogbue E.C. and Adedokun J.A. "Improving the estimation of global solar radiation over Ondo in southwestern Nigeria". Nig Jour of physics, 2003. Vol 15, No 1, pp. 20- 31.

[10] Okogbue E.C.and Adedokun J.A. "On the estimation of solar radiation at Ondo, Nigeria". Nig. Jour. 2002b. Physics, vol. 14, No 1, pp.

[11] Yorukoglu, M. and Celik, N., (2006), "A critical review on the estimation of daily global solar radiation from sunshine duration", Energy Conversion and Management, 47(15-16): 2441-2450.