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Estimation of Solar Radiation at Yola, Nigeria

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Abstract- Yola 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. The performance of 10 empirical models were used to estimate global solar radiation for the region. Model 4 model was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola. The MPE, RMSE and MBE were 0.0628, - 0.012 MJ/m^2 and 0.0464 MJ/m^2 respectively. This model can be described for Yola. After comparing the measured global radiation values with the predicted values at any particular month for validation of the established model, these values laid around the straight line. This means that the generalized model is valid for the geographical and meteorological data of Yola.

Indexed Terms- Global solar radiation, Regression constant, predictive efficiency, Global solar radiation, clearness index

I. INTRODUCTION

The amount of global solar radiation and its temporal distribution are the primary variable for the use of solar energy. The design and operation of any solar energy system requires a good knowledge of the solar radiation data in a location. This data finds application in agriculture, climatology, meteorology, etc. Since the solar radiation reaching the earth’s surface varies with climatic conditions of a place, a study of solar radiation under local climatic condition is essential. Measured values of solar radiation can be in the form of global solar radiation, diffused solar radiation or beam solar radiation. The average daily values of these three parameters are sought after (Falayi and Rabiu, 2005) for various applications. Unfortunately, these parameters are not measured or not reliably estimated in many parts of the world especially in the developing nations because of the lack of the measuring facilities. Solar radiation data for many parts of these countries are extrapolated

An alternative to a weather station is the use of solar radiation predicting models. This requires the correlation of some climatic and meteorological parameters with the global solar radiation. One advantage of this approach is that some of the meteorological parameters, for example, ambient temperature can easily be measured in most places. Many researchers across the globe have predicted global solar radiation with high accuracy using data from sunshine duration, relative humidity, cloud cover and ambient temperature (Glover and McCulloch, 1958; DeMiguel *et al.*, 1994; Ibrahim, 1985; Ahmad and Ulfat, 2004).

In the absence and scarcity of trustworthy solar radiation data, the need for an empirical model to predict and estimate global solar radiation seems inevitable. These models use climatological parameters of the location under study. However, the main objective of this study is to performance of empirical models for estimating global solar radiation over Yola, Adamawa State Nigeria.

II. METHODOLOGY

- Study Area

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. 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 are recorded. Then a distinct gradual decline is recorded from the onset of rains in April/May due to cloud effects.

- Model Application

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.

$$H_o = \frac{24\times 3{,}600}{\pi} I_{sc} E_o \left[\cos(\varphi)\cos(\delta)\sin(\omega_s) + \frac{\pi\omega_s}{180}\sin(\varphi)\sin(\delta)\right] \qquad (2)$$

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

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:

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

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

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

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

The regression models used in this work are given below:

Mode1 1: Page has given a coefficient of the modified Angstrom-type model, which is believed to be applicable anywhere in the world, as the following:

$$\frac{H}{H_o} = 0.23 + 0.48\frac{S}{S_o} \qquad (8)$$

Model 2: Rietveld examined several published values of a and b from the following equations,

$$\frac{\bar{H}}{\bar{H}_o} = 0.18 + 0.62\frac{\bar{S}}{\bar{S}_0} \qquad (9)$$

Model 3: Dogniaux and Lemoine have also proposed the following equation, where the regression coefficients a and b seem to be as a function of $\emptyset$ in average and on the monthly base in these equations respectively.

$$a = 0.37022 - 0.00313\emptyset \qquad (10a)$$

$$b = 0.32029 - 0.005060\emptyset \qquad (10b)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.34507 - 0.00301\emptyset) + (0.34572 + 0.00495\emptyset)\frac{S}{\bar{S}_0}\ for\ January \quad (10c)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.33459 - 0.00255\emptyset) + (0.35533 + 0.00457\emptyset)\frac{S}{\bar{S}_0} for\ February \quad (10d)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.36690 - 0.00303\emptyset) + (0.36377 + 0.00466\emptyset)\frac{S}{\bar{S}_0} for\ March (10e)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.38557 - 0.00334\emptyset) + (0.35802 + 0.00456\emptyset)\frac{S}{\bar{S}_0} for\ April \quad (10f)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.35057 - 0.00245\emptyset) + (0.33550 + 0.00485\emptyset)\frac{S}{\bar{S}_0} for\ May \qquad (10g)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.39890 - 0.00327\emptyset) + (0.27292 + 0.00578\emptyset)\frac{S}{\bar{S}_0} for\ June \qquad (10h)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.41234 - 0.00369\emptyset) + (0.27004 + 0.00568\emptyset)\frac{S}{\bar{S}_0} for\ July \qquad (10i)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.36243 - 0.00269\emptyset) + (0.33162 + 0.00412\emptyset)\frac{S}{\bar{S}_0} for\ August (10j)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.3947 - 0.00338\emptyset) + (0.27125 + 0.00564\emptyset)\frac{S}{\bar{S}_0} for\ September \qquad (10k)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.36213 - 0.00317\emptyset) + (0.31790 + 0.00504\emptyset)\frac{S}{\bar{S}_0} for\ October (10l)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.36680 - 0.00350\emptyset) + (0.31467 + 0.00523\emptyset)\frac{S}{\bar{S}_0} for\ November \quad (10m)$$

$$\frac{\bar{H}}{\bar{H}_o} = (0.36262 - 0.00350\emptyset) + (0.30675 + 0.00559\emptyset)\frac{S}{\bar{S}_0} for\ December \quad (10n)$$

Model 4: Jain fitted the Angstrom equation using the least square method of the monthly average daily global solar radiation and sunshine hour duration data of 31 Italian locations. The equation using the mean values of these locations is given as follow:

$$\frac{H}{H_o} = 0.177 + 0.692\frac{S}{S_o} \quad (11)$$

Model 5: Glover and McCulloch attempted to introduce latitude dependency to one of the Angstrom-Prescott coefficients and presented the following:

$$\frac{\bar{H}}{\bar{H}_o}\ 0.29\cos\emptyset\ + 0.52\ \frac{\bar{S}}{\bar{S}_0} \quad (12)$$

Model 6: Ogelman *et.al.,* have correlated $\frac{\bar{H}}{\bar{H}_o}$ with $\frac{\bar{S}}{\bar{S}_0}$ in the form of a second order polynomial equation:

$$\frac{\bar{H}}{\bar{H}_o} = 0.195 + 0.676\frac{\bar{S}}{\bar{S}_0} - 0.142\ (\frac{\bar{S}}{\bar{S}_0})^2 (13)$$

Model 7: Gopinathan proposed a and b are related to three parameters, the latitude, the elevation and the sunshine hours.

$$\frac{\bar{H}}{\bar{H}_o} = \left[-0.309 + 0.539\ \cos\emptyset - 0.0693Z + 0.290\frac{\bar{S}}{\bar{S}_0}\right] + \left[\ 1.527 - 1.027\cos\emptyset + 0.0926Z - 0.359\frac{\bar{S}}{\bar{S}_0}\right]\frac{\bar{S}}{\bar{S}_0}\ (14)$$

Where Z is the altitude in kilometers.

$$\frac{\bar{H}}{\bar{H}_o} = 0.32 + 0.42\frac{\bar{S}}{\bar{S}_0} \quad (15)$$

Model 8: Bahel *et.al.,* suggested the following relationship.

$$\frac{\bar{H}}{\bar{H}_o} = 0.175 + 0.552\frac{\bar{S}}{\bar{S}_0} \quad (16)$$

Model 9: Ahmad *et.al.,* have suggested to first order polynomial equations developed for Karachi of Pakistan:

$$\frac{\bar{H}}{\bar{H}_o} = 0.324 + 0.405\frac{\bar{n}}{\bar{N}} \quad (17)$$

Model 10: Akinoglu and Ecevit obtained the correlation between (H/H_o) and (S/S_o) in a second order polynomial equation for Turkey:

$$\frac{\bar{H}}{\bar{H}_o} = 0.145 + 0.845\frac{\bar{S}}{\bar{S}_0} - 0.280\ (\frac{\bar{S}}{\bar{S}_0})^2 \quad (18)$$

III. STATISTICAL TEST

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). A positive and a negative value of MBE indicate the average amount of over estimation and under estimation in the calculated values, respectively. One drawback of this test is that over estimation in one observation is cancelled by under estimation in another observation. 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.

Mean percentage error: The Mean percentage error is defined as:

$$MPE = \frac{[\Sigma(H_{i,m} - H_{i,c})/H_{i,m}]100}{N} \quad (19)$$

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:

$$RMSE = \left(\left[\frac{\Sigma\{H_{i,c} - H_{i,m}\}^2}{N}\right]\right)^{1/2} \quad (20)$$

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

$$MBE = \frac{[\Sigma\{H_{i,c} - H_{i,m}\}]}{N} \quad (21)$$

IV. RESULTS AND DISCUSSION

Table 1: Impute parameters for the estimation of monthly average daily global solar at Yola for the period of fifteen years.

Months	$\bar{H}$ (MJm^{-2}day^{-1})	$\bar{H}_o$ (MJm^{-2}day^{-1})	$\bar{S}$ (hr)	$\bar{S}_o$ (hr)	$\bar{S}/\bar{S}_o$	$\bar{H}/\bar{H}o$
JAN	17.22	36.58	5.67	12.56	0.45	0.56
FEB	20.09	37.13	5.46	11.46	0.47	0.54
MAR	21.21	37.96	5.80	11.55	0.50	0.58
APR	22.02	39.14	6.48	11.75	0.55	0.62
MAY	23.68	39.78	6.52	12.65	0.52	0.59
JUN	17.29	38.49	5.46	12.46	0.43	0.45
JUL	18.38	39.29	4.68	12.54	0.37	0.46
AUG	14.31	37.76	3.66	12.56	0.29	0.37
SEP	16.42	37.88	4.48	11.65	0.38	0.43
OCT	18.84	38.74	4.84	12.45	0.39	0.49
NOV	20.38	39.59	6.37	11.50	0.53	0.51
DEC	19.22	36.96	6.34	12.55	0.51	0.52

Table 2: Estimation of monthly average daily global solar radiation from various models for Yola.

Month	H_m	Model 4	Model 5	Model 6	Model 7	Model 9	Model 10
JAN	17.22	17.86	19.03	17.21	18.62	18.51	17.14
FEB	20.09	19.54	19.44	20.16	19.39	20.55	19.73
MAR	21.21	20.75	20.07	21.89	21.56	20.59	19.78
APR	22.02	22.72	22.39	22.5	21.78	21.39	21.45
MAY	23.68	21.35	22.14	22.21	23.06	23.26	20.23
JUN	17.29	18.26	19.62	17.68	17.26	19.17	18.47
JUL	18.38	17.01	18.8	17.72	18.67	18.61	17.37
AUG	14.31	14.26	16.5	14.31	15.68	16.66	14.73
SEP	16.42	16.66	18.32	16.29	18.16	18.1	16.12
OCT	18.84	17.31	19.04	16.75	18.83	18.76	17.63
NOV	20.38	21.52	21.24	20.32	20.48	21.32	20.35
DEC	19.22	19.58	20.38	19.18	19.24	19.61	19.49

All numerical values are in units of MJm^{-2}day^{-1}

Table 3: Statistical test results for the estimated monthly average daily global solar radiation from different models.

Error terms	Rietveld Model	Glover and McCulloch Model	Ahmad et.al Model	Gopinathan Model	Ogelman et.al Model
MPE	1.244	- 0.600	- 0.568	0.624	- 0.547
MBE	2.717	1.614	0.464	1.036	0.211
RMSE	10.524	6.251	5.990	7.073	0.818

Table 4: Statistical test results for the estimated monthly average daily global solar radiation from different models.

Error terms	Jain Model	Bahel Model	Page Model	Dogniaux and Lemoine Model	Akinoglu and Ecevit Model
MPE	0.0628	0.747	0.712	2. 035	0.188
MBE	- 0.012	- 0.142	- 0.135	- 0.386	-0.036
RMSE	0.0464	0.552	0.524	1. 497	0.139

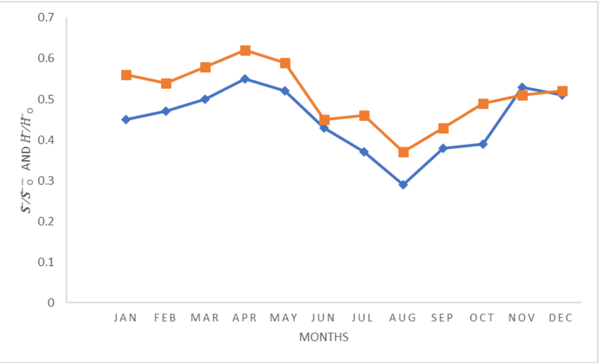

Figure 1. Variation of $\bar{S}/\bar{S}_o$ and $\bar{H}/\bar{H}o$ (The clearness index)

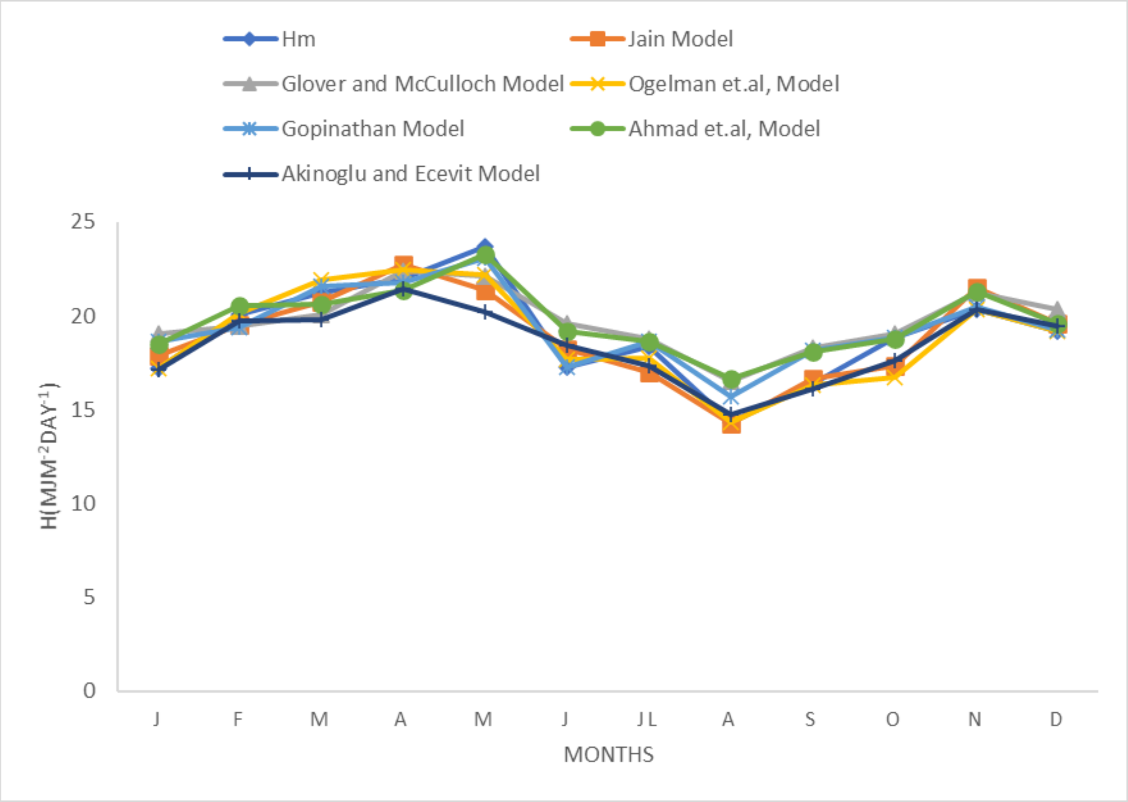

Figure 2: Comparison of the estimated value of monthly average daily global solar radiation from various models, with the measured data.

Figure 1 shows the variation of $\bar{S}/\bar{S}_o$ and $\bar{H}/\bar{H}o$, the clearness index for Yola. The dip in the months of June-August indicates poor sky conditions where $\bar{S}/\bar{S}_o$ goes as low as 0.29 and K_T values reaches minimum i.e 0.37 (for August) and 0.43 (for September).

The monthly average daily global solar radiation was estimated through equations (1) to (18) for Yola from the ten models used in the study are given in Table 2, along with the measured values, are also plotted with the measured data in Figure 4.2. It is very encouraging to observe a very fine agreement between the measured and estimated values shown in table 4.12, it is seen that the Jain model, Ogelman *et.al* model, Glover and McCulloch model, Gopinathan model, Ahmad *et.al* model, Akinnoglu and Ecevit model show more accuracy when compared with the measured values. But it can also be seen that Ogelman *et.al* model show greater accuracy

The validation of these ten models was performed by using MPE, MBE, RMSE. With respect to MPE, Ogelman *et.al* model gives the best correlation followed by Ahmad *et.al* model, Glover and McCulloch model, Dogniaux and Lemoine model present the worst. Since the test of MPE gives information on the long-term performance of the examined regression equation, a positive MPE value provides the average amount of over estimation in the calculated values, while a negative MPE value gives under estimation. On the whole, low MPE value is desirable.

The MBE values obtained from the models are positive in some cases and negative in others, which show that these models vary between under and over estimation of the clearness index K_T. However, values of MBE from, Rietveld model, Glover and McCulloch, Gopinathan model indicate high over-estimation. While those from Akinoglu and Ecevit, Bahel model, Page model, Dogniaux and Lemoine models gives little over estimation, but Jain model has a very little under estimation.

It was observed that the lower the Root Mean Square Errors (RMSE), the more accurate the equation used. The RMSE values, which are a measure of the accuracy of estimation, have been found to be low for Jain model, Page model, Akinoglu and Ecevit model, but the lowest is found to be Jain model which the most acceptable, Rietveld model gives the highest value.

According to the results, Model 4, the Jain model was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola. The MPE, RMSE and MBE were 0.0628, - 0.012 MJ/m^2 and 0.0464 MJ/m^2 respectively. This model can be described for Yola. After comparing the measured global radiation values with the predicted values at any particular month for validation of the established model, these values laid around the straight line. This means that the generalized model is valid for the geographical and meteorological data of Yola.

CONCLUSION

Solar radiation data are essential in the design and study of solar energy conservation devices. In this regard, empirical correlations are developed to estimate the monthly average daily global radiation on a horizontal surface. The correlation equations given in this study will enable the solar energy researcher to use the estimated data with trust because of its fine agreement with the measured data.

It may be concluded 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. Model 4 was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola and can also be extended for other locations which have the same values of the maximum clearness index.

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