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COMPARISON BETWEEN LINEAR AND QUADRATIC MODELS FOR ESTIMATING SOLAR RADIATION DATA IN YOLA, ADAMAWA STATE, NIGERIA

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ABSTRACT

An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for the development of many solar energy devices. In this study, the value of monthly average global solar radiation for Yola area have been estimated using different linear and Quadratic models. The values of monthly average global solar radiation were calculated using the regression constants in the models. The predictive efficiency was validated and compared based on mean percentage error (MPE), mean biased error (MBE) and root mean square error (RMSE). Each of the five tested models exhibited some degree of efficiency in the estimation of the global solar radiation In Yola. On comparison it was observed that the quadratic model (Ogelman et.al) was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola. The MBE and RMSE values were given as $0.211MJ^{2}$ and $0.818MJ^{2}$ which is low compare to what is obtained from other models, indicating that the quadratic model is more suitable for the simulation of global solar radiation in Yola and other locations with similar latitudinal variations.

KEY WORDS: *Global solar radiation, Regression constant, predictive efficiency, Global solar radiation, clearness index*

INTRODUCTION

Almost all the renewable energy sources originate entirely from the sun. The sun's rays that reach the outer atmosphere are subjected to absorption, scattering, reflection and transmission processes through the atmosphere, before reaching the earth's surface (Rensheng *et.al* , 2004; Hay 1979; Ahmad and Ulfat, 2004).

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 estimation of crop evapo-transpiration, as well as in the health sector, in research and in many fields of natural sciences (Akpabio and Etuk, 2003). 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 (Ulgen and Hepbasli, 2004).

Several empirical models have been developed to calculate global solar radiation using various climatic parameters. These parameters include extraterrestrial radiation, sunshine hours, mean temperature, maximum temperature, soil temperature, relative humidity, number of rainy days, altitude, latitude, total precipitation, cloudiness and evaporation. The most commonly used parameter for estimating global solar radiation is sunshine duration. Sunshine duration can be easily and reliably measured and data are widely available. Some authors have also developed polynomial models (Veeran and Kumar, 1993; Tiris et.al, 1996; Said et.al 1998; Ulgen et.al 2000).

It is pertinent to note that many researchers who have done similar work to estimate incoming solar radiation in Nigeria (Bamiro, 1983; Akpabio et.al., 2004;) in different locations concentrated on one or more models, either with artificial neural network or in most cases with linear models of different modeling. This study is aimed at comparing linear and quadratic models in estimating global solar radiation at Yola, Adamawa State.

MATERIALS AND METHOD

STUDY AREA

Yola, Nigeria is at 9°14'N, 12°28'E, 186 m (611 ft). Yola has a tropical wet and dry/ savanna climate with a pronounced dry season in the low-sun months, no cold season, wet season is in the high-sun months. According to the Holdridge life zones system of bioclimatic classification Yola is situated in or near the tropical dry forest biome. The annual average temperature is 28.1 degrees Celsius (82.5 degrees Fahrenheit). Average monthly temperatures vary by 7.2 °C (13°F). This indicates that the continentality type is hyperoceanic, subtype barely hyperoceanic. On average there are 2954 hours of sunshine per year.

The solar radiation data comprising of monthly mean daily global solar radiation and sunshine hours for Yola Adamawa State, Nigeria were obtained for the period of fifteen years (1999-2013) from the Nigeria Meteorological Agency, Federal Ministry of Aviation, Yola International Airport, Adamawa State.

MODELS

The most convenient and widely used correlation for predicting solar radiation was developed by Angstrom and later modified by Prescott. According to Duffie and Beckman (1994), the Angstrom formula is given by:

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

Where $\bar{H}$ is the monthly average global solar radiation ($MJm^{-2}day^{-1}$), $\bar{H}_o$ is the monthly average daily extraterrestrial radiation, $\bar{S}$ 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 the regression constant to be determined.

Different models use different approaches for estimating the coefficient a and b (Rietveld, 1978; Neuwirth, 1980). The monthly average daily extraterrestrial radiation on a horizontal surface (H_o) can be computed from the following equation Duffie and Beckman (1994):

$\bar{H}_o$, is the monthly average daily extraterrestrial radiation which can be expressed as:

$$H_o = \frac{24\times 360}{\pi} I_{sc}\left[1+0033\cos\left(360\frac{dn}{365}\right)\right]\left[\frac{2\pi\omega}{360}\right] Sin\,\emptyset\, Sin\,\delta\ \sin\omega + Cos\,\emptyset\, Cos\,\delta\ Sin\,\omega \quad (2)$$

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:

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

And ω is the sunset hour angle as

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

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

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

Model 1: Bahel *et.al.,* suggested the following relationship.

$$\frac{H}{H_o} = 0.175 + 0.552\frac{S}{S_o} \quad (6)$$

Model 2: **Page** has given a coefficient of the modified Angstrom-type model, which is believed to be applicable anywhere in the world, as the following:

$$\frac{H}{H_o} = 0.23 + 0.48\frac{S}{S_o} \tag{7}$$

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.

$$a = 0.37022 - 0.00313\emptyset \tag{8a}$$

$$b = 0.32029 - 0.00506\emptyset \tag{8b}$$

$$\frac{H}{H_o} = (0.34507 - 0.00301\emptyset) + (0.34572 + 0.00495\emptyset)\frac{S}{S_o}\ for\ January \tag{8c}$$

$$\frac{H}{H_o} = (0.33459 - 0.00255\emptyset) + (0.35533 + 0.00457\emptyset)\frac{S}{S_o} for\ February \tag{8d}$$

$$\frac{H}{H_o} = (0.36690 - 0.00303\emptyset) + (0.36377 + 0.00466\emptyset)\frac{S}{S_o} for\ March \tag{8e}$$

$$\frac{H}{H_o} = (0.38557 - 0.00334\emptyset) + (0.35802 + 0.00456\emptyset)\frac{S}{S_o} for\ April \tag{8f}$$

$$\frac{H}{H_o} = (0.35057 - 0.00245\emptyset) + (0.33550 + 0.00485\emptyset)\frac{S}{S_o} for\ May \tag{8g}$$

$$\frac{H}{H_o} = (0.39890 - 0.00327\emptyset) + (0.27292 + 0.00578\emptyset)\frac{S}{S_o} for\ June \tag{8h}$$

$$\frac{H}{H_o} = (0.41234 - 0.00369\emptyset) + (0.27004 + 0.00568\emptyset)\frac{S}{S_o} for\ July \tag{8i}$$

$$\frac{H}{H_o} = (0.36243 - 0.00269\emptyset) + (0.33162 + 0.00412\emptyset)\frac{S}{S_o} for\ August \tag{8j}$$

$$\frac{H}{H_o} = (0.3947 - 0.00338\emptyset) + (0.27125 + 0.00564\emptyset)\frac{S}{S_o} for\ September \tag{8k}$$

$$\frac{H}{H_o} = (0.36213 - 0.00317\emptyset) + (0.31790 + 0.00504\emptyset)\frac{S}{S_o} for\ October \tag{8l}$$

$$\frac{H}{H_o} = (0.36680 - 0.00350\emptyset) + (0.31467 + 0.00523\emptyset)\frac{S}{S_o} for\ November \tag{8m}$$

$$\frac{H}{H_o} = (0.36262 - 0.00350\emptyset) + (0.30675 + 0.00559\emptyset)\frac{S}{S_o} for\ December \tag{8n}$$

Model 4: Ogelman ***et.al*** have correlated $\frac{H}{H_o}$ with $\frac{\bar{n}}{N}$ in the form of a second order polynomial equation:

$$\frac{H}{H_o} = 0.195 + 0.676\frac{\bar{n}}{N} - 0.142\left(\frac{\bar{n}}{N}\right)^2 \tag{9}$$

Model 5: Akinoglu and Ecevit obtained the correlation between (H/H_o) and (S/S_o) in a second order polynomial equation for Turkey:

$$\frac{H}{H_o} = 0.145 + 0.845\frac{S}{S_o} - 0.280\left(\frac{S}{S_o}\right)^2 \tag{10}$$

DATA ANALYSIS

In this work, 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). The use of MBE and RMSE is not enough as statistical indicator for the evaluation of the model performance and we decided that MPE should be used in order to give more reliable results. MPE gives long term performance of the examined regression equations, a positive MPE values provides the averages amount of overestimation in the calculated values, while the negatives value gives underestimation. A low value of MPE is desirable. These tests are the ones that are applied most commonly in comparing the models of solar radiation estimations.

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

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:

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

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

$$MBE = \frac{\left[\sum \{H_{i,c} - H_{i,m}\}\right]}{N} \quad (13)$$

RESULTS AND DISCUSSIONS

The five models listed above were applied to the sunshine data at Yola. The calculated and measured valued of average daily global radiation on the horizontal surface were compared, to find the best correlation that will fit the measured global solar radiation. The results are shown in the tables and graphs below.

The regression constants have been generally computed using observations of sunshine hours and monthly average daily global radiation of the given location.

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

Month	$\bar{H}$ (MJm^{-2}day^{-1})	$\bar{H}_o$ (MJm^{-2}day^{-1})	$\bar{n}/\bar{N}$	$\bar{H}/\bar{H}o$
JAN	17.22	36.58	0.45	0.56
FEB	20.09	37.13	0.47	0.54
MAR	21.21	37.96	0.50	0.58
APR	22.02	39.14	0.55	0.62
MAY	23.68	39.78	0.52	0.59
JUN	17.29	38.49	0.43	0.45
JUL	18.38	39.29	0.37	0.46
AUG	14.31	37.76	0.29	0.37
SEP	16.42	37.88	0.38	0.43
OCT	18.84	38.74	0.39	0.49
NOV	20.38	39.59	0.53	0.51
DEC	19.22	36.96	0.51	0.52

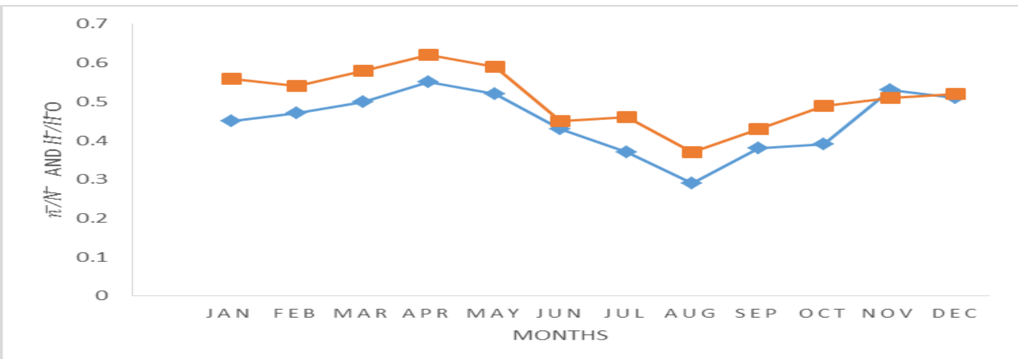

Figure 1. Variation of $\bar{n}/\bar{N}$ and $\bar{H}/\bar{H}o$ (The clearness index) for Yola

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

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

Month	$H_{measured}$	Model 1	Model 2	Model 3	Model 4	Model 5
JAN	17.22	16.48	16.31	11.78	17.21	17.14
FEB	20.09	16.13	16.91	11.74	20.16	19.73
MAR	21.21	17.12	17.84	13.07	21.89	19.78
APR	22.02	19.63	19.33	14.10	22.50	21.45
MAY	23.68	18.38	19.07	13.24	22.21	20.23
JUN	17.29	16.77	16.79	14.33	17.68	18.47
JUL	18.38	14.90	16.01	14.98	17.72	17.37
AUG	14.31	13.55	13.94	12.85	14.31	14.73
SEP	16.42	15.47	15.62	13.89	16.29	16.12
OCT	18.84	18.51	16.16	13.04	16.75	17.63
NOV	20.38	17.77	19.17	13.43	20.32	20.35
DEC	19.22	18.68	17.54	12.93	19.18	19.49

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

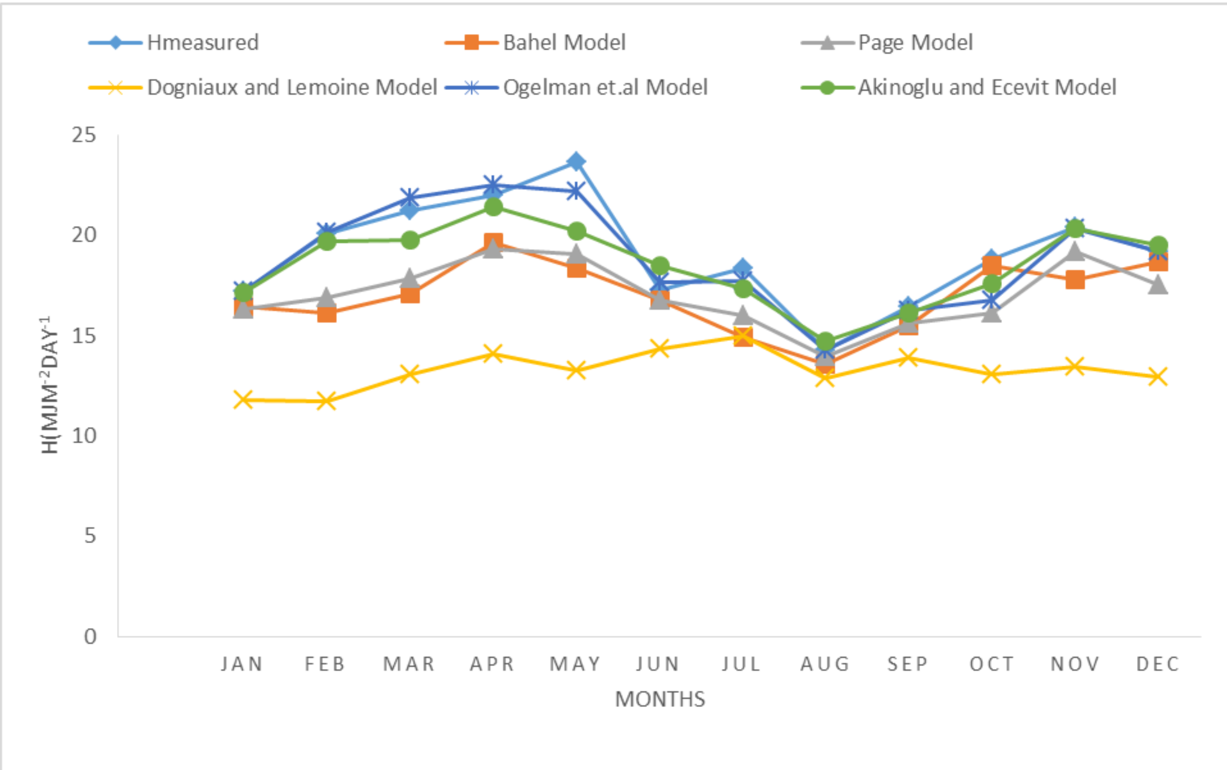

Figure 2: Estimated value of monthly average daily global solar radiation from equations (6) to (10) and comparison with measure data.

Table 3: Estimation of monthly average daily global solar radiation from Model 4 and Model 5 for Yola.

Month	$H_{measured}$	Model 4	Model 5
JAN	17.22	17.21	17.14
FEB	20.09	20.16	19.73
MAR	21.21	21.89	19.78
APR	22.02	22.50	21.45
MAY	23.68	22.21	20.23
JUN	17.29	17.68	18.47
JUL	18.38	17.72	17.37
AUG	14.31	14.31	14.73
SEP	16.42	16.29	16.12
OCT	18.84	16.75	17.63
NOV	20.38	20.32	20.35
DEC	19.22	19.18	19.49

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

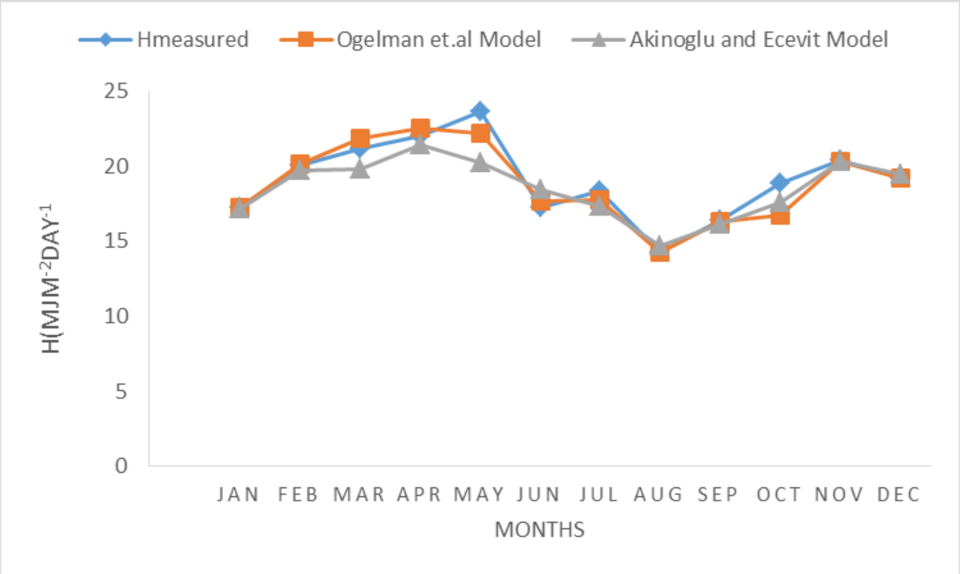

Figure 3: Estimated value of monthly average daily global solar radiation of Model 4, Model 5 and comparison with measure data.

The values of monthly mean daily global solar radiation intensity estimated using the proposed models were compared with the corresponding measured values. Comparing the models, it is realized that the performance of the Bahel, Page and Dogniaux and Lemoine Models are worst. However, the performance of Akinnoglu and Ecevit model is slightly better than the rest of the models, except Ogelman et.al (model 4). It is very encouraging to observe a very fine agreement between measured and estimated values obtained from model 4.

The statistical tests of MBE, MPE and RMSE were determined for the period of 1999 to 2013; the results are summarizes in Table 3.

Table 3: Validation of the models under different statistical tests.

Error terms	Model 1	Model 2	Model 3	Model 4	Model 5
MPE	0.747	0.712	2. 035	- 0.547	0.188
MBE	- 0.142	- 0.135	- 0.386	0.211	-0.036
RMSE	0.552	0.524	1. 497	0.818	0.139

The validation of these five models has been performed by using MPE, MBE, RMSE. According to the results in in table 3, Model 4, was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola. With respect to MPE, model 4 gives the best correlation while model 3 present the worst. On the whole, low MPE value is desirable. However, an over estimation of MPE may be cancelled by an under estimation. The MBE and RMSE values were given as $0.211MJ^{-2}$ and $0.818MJ^{-2}$ which is low compare to what is obtained from other models. A low value of MBE and RMSE is expected and acceptable.

CONCLUSION

Sunshine based models are employed for estimation global solar radiation for a location. 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 observed data. Most of solar radiation models given to estimate the monthly average daily global solar radiation are of the modified Angstrom-type equation. Yola is endowed appreciable with solar radiation and large rural dwellers lived in villages without proper infrastructure to develop an electricity grid, the use of photo voltaic (PV) is seen as attractive alternative because of its modular features, namely, its ability to generate electricity at the point of use, its low maintenance requirements and its non-polluting characteristics. 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, the Ogelman et.al model was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola.

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