COMPARISON OF EMPIRICAL MODELS FOR ESTIMATING SOLAR RADIATION DATA IN YOLA REGION, ADAMAWA STATE, NIGERIA

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ABSTRACT

In this paper, the value of monthly average global solar radiation for Yola area has been estimated using different empirical models. The values of monthly average global solar radiation were calculated using the regression constants in the models (both linear and quadratic). The predictive efficiency was validated and compared based on mean percentage error (MPE), mean biased error (MBE) and root mean square error (RMSE). On comparison it was observed that the quadratic model is overall more accurate for calculating the Global Solar Radiation for Yola region, because of the fine agreement found between the estimated and the measured values and may be used reasonably well for estimating the solar radiation at a given location and possibly in elsewhere with similar climatic conditions.

KEYWORDS: Global solar radiation, Empirical model, Regression constant, predictive efficiency, climatic condition

INTRODUCTION

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 modeling. 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 (Ibrahim, 1985). In spite of the importance of global solar radiation data, its measurements are not frequently available especially in developing countries (Allen, 1997).

Meteorological stations measuring solar radiation data in the developing countries are few (Akpabio, *et. al*., 2004). This situation can be addressed by using empirical models, which estimate global solar radiation based on relationships among some 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 (Okundamiya, *et.al*, 2010). It is therefore important to consider methods of estimating the solar radiation based on the readily available meteorological parameters (Musa *et.al*, 2012) 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 model, either with artificial neural network or in most cases with empirical model of different modeling.

The main objective of this work is to use different models for estimating global solar radiations in Yola, Adamawa State and continue in the effort to compare different models for predicting solar radiation for as many regions as possible to provide a basis for future (sub-saharan) iso-radiation maps.

Theoretical Background

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:

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

Where $\overline{H}$ is the monthly average global solar radiation ($MJm^{-2}day^{-1}$), $\overline{H}_o$ is the monthly average daily extraterrestrial radiation, $\overline{S}$ is the monthly average daily bright sunshine hour, $\overline{S}_o$ 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): $\overline{H}_o$ is the monthly average daily extraterrestrial radiation which can be expressed as:

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

Where $\overline{D}$ is the Julian day number, I_{sc} = 1367Wm^{-2} is the solar constant, ø is the latitude of the location, δ is the declination angle given as:

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

And ω is the sunset hour angle as:

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

The maximum possible sunshine duration $\overline{S}_o$ is given by

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

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 (Fig 1). It is situated in the Benue Valley area of the state with a mean elevation 186 m.a.s.l.

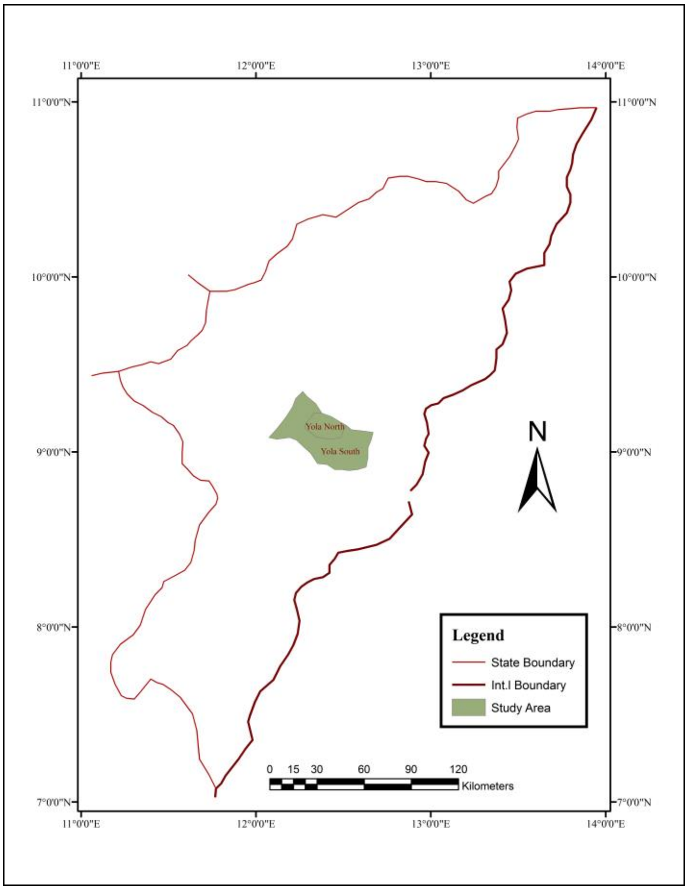

Figure 1: Adamawa State Showing the Study Area

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 (Yola Climate and Temperature, 2012). 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 (Yola Climate and Temperature, 2012).

MATERIALS AND METHODS

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). These tests are the ones that are applied most commonly in comparing the models of solar radiation estimations.

$$MPE = \frac{\left[\sum \left(H_{i,m} - H_{i,c}\right)/H_{i,m}\right]100}{N} \quad (6)$$

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

$$RMSE = \left(\left[\frac{\sum \left(H_{i,c} - H_{i,m}\right)^2}{N}\right]\right)^{1/2} \quad (7)$$

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

$$MBE = \frac{\left[\sum \left(H_{i,c} - H_{i,m}\right)\right]}{N} \quad (8)$$

Models

Model 1: Rietveld (1978) examined several published values of *a* and *b* from following equations, respectively:

$$a = 0.10 + 0.24\overline{n}/\overline{N} \quad (9)$$

$$b = 0.38 + 0.08\overline{n}/\overline{N} \quad (10)$$

$$\overline{H}/\overline{H_o} = 0.18 + 0.62\overline{n}/\overline{N} \quad (11)$$

Model 2: Glover and McCulloch, (1958) included latitude effect and presented the correlation as:

$$\overline{H}/\overline{H_o} = 0.29Cos\phi + 0.52\overline{n}/\overline{N} \quad (12)$$

Model 3: Ahmad and Ulfat (2004) have suggested to first order polynomial equations developed for Karachi of Pakistan:

$$\overline{H}/\overline{H_o} = 0.324 + 0.405\overline{n}/\overline{N} \quad (13)$$

Model 4: Gonipnathan (1988) proposed *a* and *b* are related to three parameters, the latitude, the elevation and sunshine hours.

$$a = -0.309 + 0.539\cos\phi - 0.0693h + 0.290\bar{n}/\bar{N} \qquad (14)$$

$$b = 1.527 - 1.027\cos\phi + 0.0926h + 0.359\bar{n}/\bar{N} \qquad (15)$$

$$\bar{H}/\bar{H}_o = 0.32 + 0.42\bar{n}/\bar{N} \qquad (16)$$

Model 5: Ogelman *et.al* (1984) has correlated $\bar{H}/\bar{H}_o$ with $\bar{n}/\bar{N}$ in the form of a second order polynomial equation:

$$\bar{H}/\bar{H}_o = 0.195 + 0.676\bar{n}/\bar{N} - 0.142\left(\bar{n}/\bar{N}\right)^2 \quad (17)$$

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

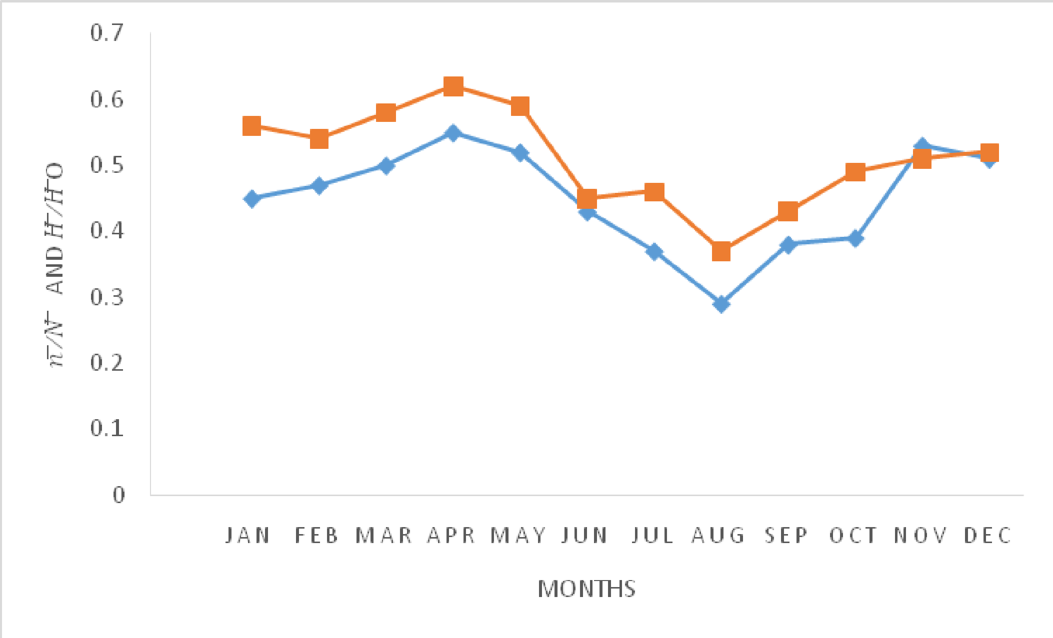

Figure 2. Variation of $\bar{n}/\bar{N}$ and $\bar{H}/\bar{H}o$ (The clearness index) for Yola

Figure 2 shows the variation of $\overline{n}/\overline{N}$ and $\overline{H}/\overline{H}_o$, the clearness index for Yola. The dip in the months of June-August indicates poor sky conditions where $\overline{n}/\overline{N}$ 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	$H_{measured}$	Rietveld	Glover and McCulloch	Ahmad *et.al*	Gopinathan	Ogelman *et.al*
JAN	17.22	16.46	19.03	18.51	18.62	17.21
FEB	20.09	18.44	19.44	20.55	19.39	20.16
MAR	21.21	19.50	20.07	20.59	21.56	21.89
APR	22.02	20.02	22.39	21.39	21.78	22.50
MAY	23.68	19.89	22.14	23.26	23.06	22.21
JUN	17.29	18.83	19.62	19.17	17.26	17.68
JUL	18.38	15.28	18.80	18.61	18.67	17.72
AUG	14.31	13.21	16.50	16.66	15.68	14.31
SEP	16.42	15.53	18.32	18.10	18.16	16.29
OCT	18.84	16.35	19.04	18.76	18.83	16.75
NOV	20.38	19.79	21.24	21.32	20.48	20.32
DEC	19.22	18.12	20.38	19.61	19.24	19.18

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

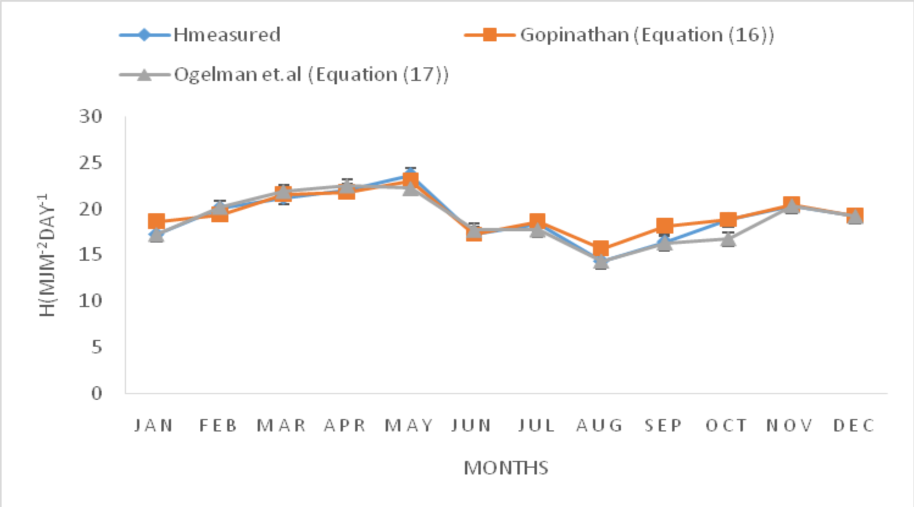

Figure 3: Estimated value of monthly average daily global solar radiation from equations (16) and (17) and comparison with measure data.

Comparing the models (Fig. 3), it is realized that the performance of the Glover and McCulloch model (equation 12) is worst, while models of Rietveld (1978), Ahmad *et.al* (2004) are poorer. However, the performance of Gopinathan (1988) is slightly better than the rest of the models, except Ogelman *et.al* (1984) Equation (17).It is very encouraging to observe a very fine agreement between measured and estimated values obtained.

Table 3: Comparison of Error values (MJm^{-2}) for the estimated monthly average daily global solar radiation from different models.

Error terms	Rietveld	Glover and McCulloch	Ahmad *et.al*	Gopinathan	Ogelman *et.al*
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

The validation of these five models has been performed by using MPE, MBE, RMSE. According to the results in Table 3, Model 5 of Ogelman *et.al* (1984) was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola. With respect to MPE, (Equation 17) gives the best correlation while Equation (11) presents 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.

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 5, the Ogelman et.al model (Eq. (17)) was found as the most accurate model for the prediction of global solar radiation on a horizontal surface for Yola.

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