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Research Article

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Performance of Empirical Models for Estimating Global Solar Radiation in Yola, Nigeria

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Abstract The study examined the performance of the empirical models for estimating mean monthly global solar radiation in Yola, Adamawa State. Solar radiation data are required by solar engineers, architects, agriculturists and hydrologists for many applications. In the past, several empirical correlations have been developed in order to estimate the solar radiation around the world and the measured values, which is encouraging. The RMSE values, which are is the measure of accuracy of a particular model or correlation use. For the present analysis, it was found to be lowest for Model 1 was 6.25 kWhm^{-2}day^{-1}. 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 estimate of global solar radiation. However, model has the lowest under estimation with a value of -0.011, which is expected and acceptable. A low value of MPE is expected, model 1 was observed to have an MPE value of - 0.063.

Keywords Empirical Models, Global Solar Radiation

Introduction

Energy plays a vital role in the current societies, accelerate economics development and has been thought to be one of the critical issues in the last decades [1]. Renewable energy is consider as the key source for the future as it is the vital and essential ingredients for all human transactions and without them human activities of all kind will not be progressive at all [2]. According to the World Energy Council (2017), the potential of solar energy that could be used by humans differs from the amount of solar energy present near the surface of the planets because factors such as geography, time variation, cloud cover and the land available to humans limit the amount of solar energy that we can acquire. Measurements of solar radiation are important because of the increasing number of solar heating and cooling applications and the need for accurate solar irradiation data to predict performance. Experimental determination of the energy transferred to a surface by solar radiation required instrument which will measure the heating effect of direct solar radiation and diffuse solar radiation [4]. Solar radiation is a major contributor for stability in the weather-system and climate-atmosphere mechanism. Keeping a tab on its variability therefore helps in understanding the weather and climate conditions of an environment and ultimately at a global scale [4]. The design of a solar energy conversion system requires precise knowledge regarding the availability of global solar radiation and its components at the location of interest. Since the solar radiation reaching the earth’s surface depends upon climatic conditions of the place, a study of solar radiation under local climatic conditions is essential [5]. Since sunshine hour is measured routinely at numerous meteorological stations in Nigeria and across the globe, researchers often use this parameter first proposed by Angstrom [6] and modified by Prescott [7] as mentioned earlier for global solar radiation estimation worldwide. Over the years, previous studies [8] reported that Angstrom-Prescott sunshine based model yielded the best correlation on one variable basis with the clearness index. Thus, it has been the most accepted model worldwide for estimating global solar radiation on one variable basis [9]. Without the sun's radiant energy, the earth would gradually cool, in time becoming ice. Chukwu and Nwachukwu, [10] observed that the network of stations measuring solar radiation data is sparse in many countries. In Nigeria, only few stations have been measuring the daily solar radiation consistently. It is therefore, necessary to appreciate radiation from commonly available climate parameter such as sunshine hours, relative humidity, maximum and minimum temperature, cloud cover and geographical locations.

This study therefore assesses the performance of empirical models for estimating mean monthly global solar radiation in Yola. The aim of the study is to assess the performance of empirical models for estimating mean monthly global solar radiation in Yola, Adamawa State.

Methodology

Most empirical models used to predict global solar radiation are based on the Angstrom-Prescott model [7]. Empirical models by Falayi [11] and Maduekwe and Garba [12] was used for the study. Prescott [7] reconsidered this model in order to make it possible to calculate monthly average of the daily global solar radiation on a horizontal surface from monthly average daily total insolation on an extraterrestrial horizontal surface. This equation has been found to be very convenient to a large number of locations and the most widely used correlation. The Angstrom-type regression equations were obtained by correlating the measured global solar radiation data with the meteorological data. The accuracy of the estimated values was tested by calculating the Mean Bias Error (MBE), Root Mean Square Error (RMSE), and Mean Percentage Error (MPE).

Yola, the capital of Adamawa state, comprising of Yola North and Yola South local Government Areas, is located between longitude 12°.12 E of the prime meridian and between latitudes 09°.12 Nof the equator. It is situated in the Benue Valley area of the state with a mean elevation 186ft.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 west 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 Characteristics 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. Thus, the study area is characterized by a mean temperature of 27.9^{o}C with a mean monthly range 6.5^{o}C. The warmest mean maximum/high temperature of an area is 39^{o}C in March and April; the coolest mean minimum/low temperature is 16^{o}C in December (Yola Climate and Temperature, 2012).

The measured monthly average daily global solar radiation, sunshine hour, maximum and minimum temperatures, rainfall, wind speed and relative humidity covering a period of five years (2012 - 2017) for Yola, North – Eastern, Nigeria was obtained from the Nigerian Meteorological Agency (NIMET), Yola International Airport, Adamawa State. The station is a standardized weather station in which climatic data are measured primarily for the purpose of aviation and also used for research purpose.

Data Analysis

The first model used sunshine duration to estimate daily mean values of solar radiation on a horizontal surface can be described using Eqn. (1) as (Prescott [7]):

$$\frac{H_m}{H_o} = \left[a + b\frac{n}{N}\right] \quad (1)$$

H_m is daily mean values of global radiation (MJ/m^{2}day), N 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 (MJ/m^{2}day), calculated using Eq. (2) as described by (Prescott [7]).

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

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

I_s the solar constant, The units in KWh m^{-2} day^{-1} .

E_o represents the eccentricity correction, and described using Eq. (4) in Eq. (2)

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

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, 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 Duffie and Beckman [13]:

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

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

For a given day, the maximum possible sunshine duration (monthly values of day length, (N) can be computed by using (Duffie and Beckman [13]):

$$N = \frac{2}{15}\omega \quad (7)$$

Falayi *et al.,* [11] developed the empirical models for Yola is given by:

$$\frac{H}{H_0} = 0.642 + 0.85\left(\frac{\bar{n}}{\bar{N}}\right) - 0.0214\left(\frac{S}{S_0}\right) + 0.1117\left(\frac{T_{max}}{T_{min}}\right) + 0.001\,(RH) \quad (8)$$

For Maiduguri is also given by:

$$\frac{H}{H_0} = 1.055 + 0.815\left(\frac{\bar{n}}{\bar{N}}\right) - 0.0353\left(\frac{S}{S_0}\right) + 0.142\left(\frac{T_{max}}{T_{min}}\right) + 0.00078\,(RH) \quad (9)$$

Maduekwe and Garba [12], developed the empirical model for Zaria as:

$$\frac{H}{H_0} = 0.973 - 0.546\left(\frac{S}{S_0}\right) - 0.00283\,(h) \quad (10)$$

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:

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

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:

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

the regression coefficient *a* and *b* can be obtain from the relationship given by Medugu and Yakubu [2], regression coefficient *a* and *b* from the calculated monthly average global solar radiation has been obtained from the relationship given as:

$$a = -0.110 + 0.235\cos\varphi + 0.323\ nN \quad (14)$$

$$b = 1.449 - 0.553\cos\varphi - 0.694\ nN \quad (15)$$

Results and Discussions

Table 1: The predicted monthly average solar radiation (2014 – 2018)

Months	$H_m(MJm^{-2}day^{-1})$	Model 1 $(MJm^{-2}day^{-1})$	Model 2 $(MJm^{-2}day^{-1})$	Model 3 $(MJm^{-2}day^{-1})$
Jan.	23.8	22.6	19.5	17.7
Feb.	23.2	21.7	20.9	19.10
Mar.	24.4	24.8	23.9	22.8
Apri.	22.3	23.7	25.11	24.9
May	21.5	22.3	27.7	26.3
Jun.	20.6	20.1	24.10	23.6
Jul	18.7	19.9	20.4	18.8
Aug.	17.5	18.1	19.8	18.3
Sept.	19.9	20.2	21.9	20.7
Oct.	21.3	21.5	22.5	21.5
Nov.	22.4	22.7	19.6	18.6
Dec.	22.3	22.8	17.9	17.3

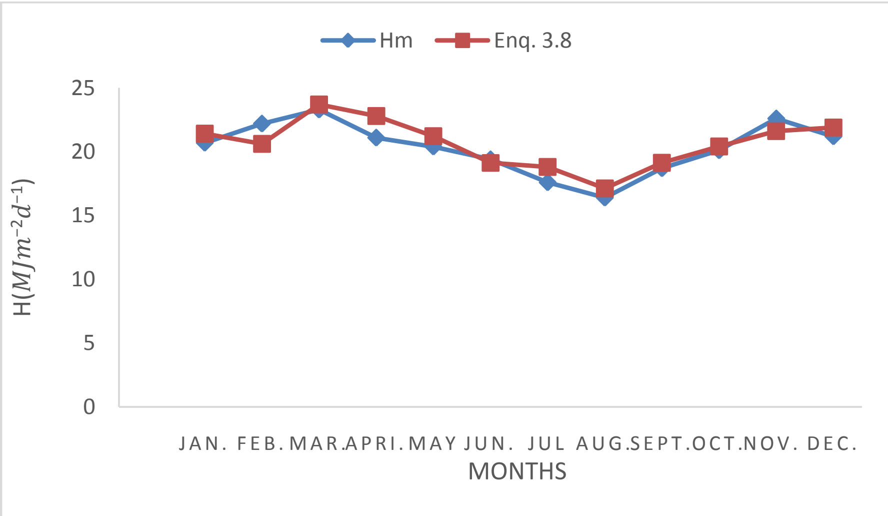

Figure 1: The figure above presents the chart of monthly average daily solar radiation for Mode1 and measured values

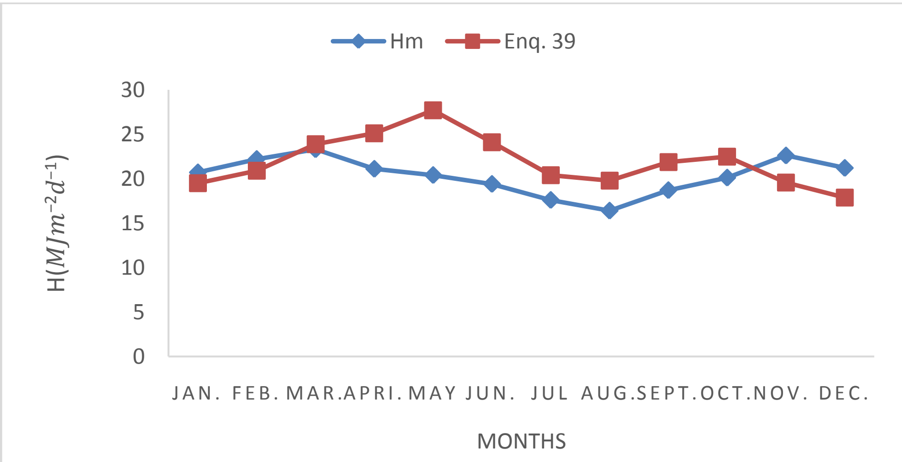

Figure 2: The figure above presents the chart of monthly average daily solar radiation for Model 2 and measured values

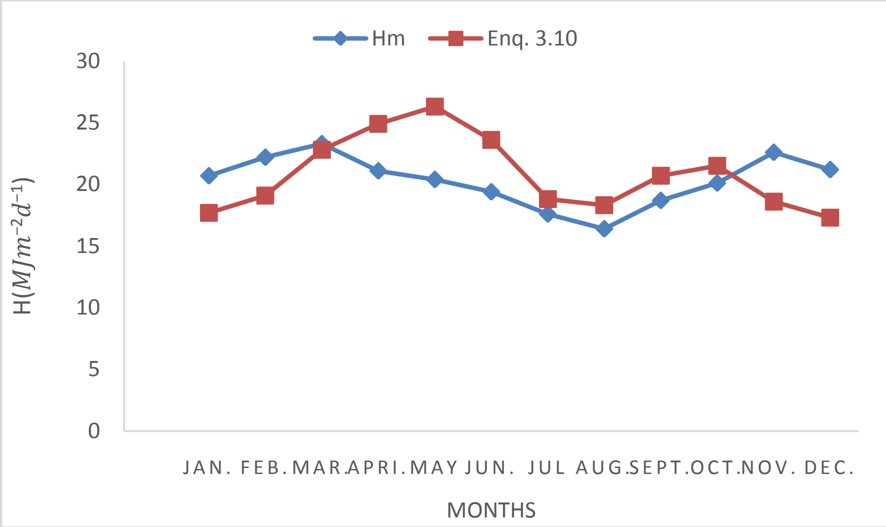

Figure 3: The figure above presents the chart of monthly average daily solar radiation for Model 3 and measured values

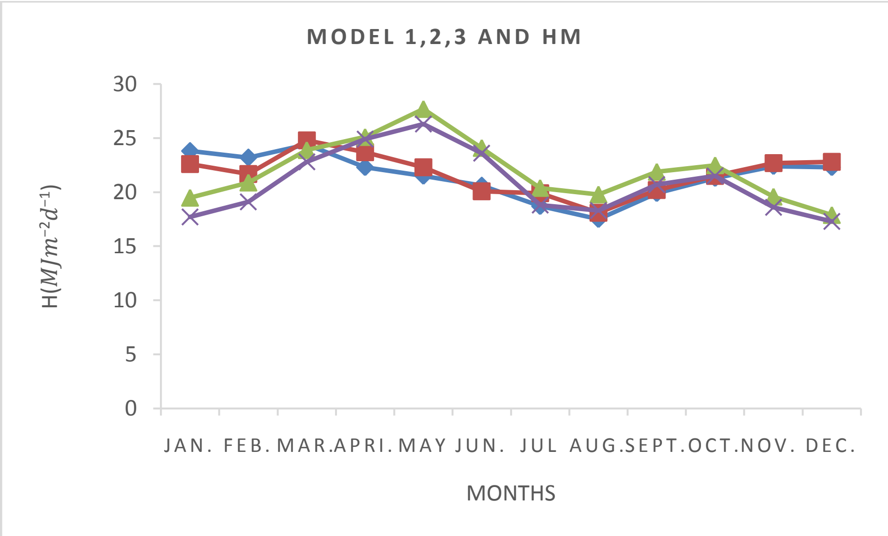

Figure 4: The figure above presents the chart of monthly average daily solar radiation for Enq. 8,9 and 10 and measured values

Table 2: The table describes the statistical test results of models applied for Yola for the period of eight years.

Statistical Test	Model 1	Model 2	Model 3
RMSE	6.25	11.56	7.34
MBE	-0.011	0.16	1.65
MPE (%)	-0.063	0.162	-12.1

The predicted monthly average solar radiation for the five years (2014 – 2018) under study using the equations are shown in the Table 1, while Table 2 describes the statistical test results of models applied for Yola for the period of five Years. The various meteorological parameters shown in Table 1 are all related to the measured global solar radiation in varying degrees. Table 2 presents the Statistical test results of models applied for Yola. These tests are the ones that are applied most commonly in comparing the models of solar radiation estimations. MBE provides information on the long-term performance of models. A close examination of Table 1 shows that the monthly average daily solar radiation estimated through Model 1 and Model 3 applied for Yola, along with the measured values. Observing a very fine agreement between the model and the measured values is very encouraging. Figure 4 indicates that Model 1 is the most suitable for the estimation of monthly average daily global solar radiation for Yola.

Also from the statistical test results presented in Table 2. The RMSE values, which are is the measure of accuracy of a particular model or correlation use. For the present analysis, it was found to be lowest for Model value (6.25) as shown in Table 2. 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 estimate of global solar radiation. However, model has the lowest under estimation with a value of (-0.011), which is expected and acceptable. A low value of MPE is expected, Model was observed to have an MPE value of (-0.063) which is within the acceptable prediction error range [14].

Conclusion

In view of the worldwide concern about the economic importance of global solar radiation as an alternative renewable energy, the monthly global solar radiation using relative humidity, sunshine hour and maximum temperature have been employed in this study to develop correlation equations. Three variables have been developed with different types of equations obtained. Statistical indices show that all models produce reasonably good estimates of diffuse solar radiation. The lowest values of -0.063%, 6.25 $kWhm^{-2}day^{-1}$ and -0.011 $kWhm^{-2} day^{-1}$ for MPE, RMSE, and MBE respectively are obtained for model 1 by Falayi *et al* [11].

This equation can be employed in the prediction of global solar radiation of location with similar latitude and other geographical information. The correlation with the smallest value of RMSE is given by model 1. The global solar radiation intensity values produced by this approach can be used in the designed and prediction of performance of solar applications system which is gaining attention in Nigeria**.** It is recommended that Government, nongovernmental organizations and individuals should step up their effort in harnessing this renewable energy form in order to boost the economy and standard of living in the country.

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