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Research Article

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The Use of Sunshine Based Models to Estimate Global Solar Radiation in Yola, Nigeria.

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Abstract In this paper with the help of different empirical models we have estimated the value of monthly average global solar irradiation for Yola, Nigeria (9°14'N, 12°28'E). The solar radiation data comprising of monthly mean daily global solar radiation and sunshine hours for Yola was obtained for the period of fifteen years (1999-2013). The performance of the models were 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. From the results, Jain model was found as the most precise model for the prediction of global solar radiation on a horizontal surface for Yola. The values of the correlation coefficient, R, determination coefficient R2 , MPE, RMSE and MBE were 0.992, 0.984, 0.0628, - 0.012 MJ/m2 and 0.0464 MJ/m2 respectively. This model can be recommended for Yola and elsewhere with similar climatic conditions.

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

Introduction

Solar energy technologies offer a clean, renewable and domestic energy source and are essential components of a sustainable energy future. The amount of global solar radiation and its temporal distribution are the primary variable for the use of solar energy [1, 2]. Development of a solar energy research program must always start with a study of solar radiation data at a site or region of interest [3]. Unfortunately, the measurement of these parameters is made only in a few meteorological stations, especially in developing countries, for both historical and economical reasons. For places where it is not directly measured, solar radiation can be estimated by using models and empirical correlations. Therefore, there have been numerous research on the Examination of the relationship between global radiation and sunshine duration for which data are available in a greater number of meteorological stations [4].

However, the computational complexity, associated time and input data requirements discourage many researchers and users from basing their calculations of energy, irradiation on models which have strong links to the fundamental radiative equations rather they are encouraged by simplicity and expediency of calculations using empirically based methods [5]. It was observed that the meteorological stations measuring solar radiation data in the developing countries are few. This situation can be solved by using empirical models, which estimate global solar radiation based on the relationships with frequently measured climatic variables [6].

The objective of this study was to validate several Regression Models for the prediction of monthly average global solar radiation on a horizontal surface from sunshine duration in Yola and to select the most adequate model.

Materials and Method

Yola, Nigeria is at 9°14'N, 12°28'E, 190.5m (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).

The solar radiation data comprising of monthly mean daily global solar radiation and sunshine hours for Yola was obtained for the period of fifteen years (1999-2013) from the Nigeria Meteorological Agency, FederalMinistry of Aviation, Yola.

Methodology

Various climatic parameters have been used in developing empirical models for predicting the monthly average global solar radiation. Among the existing correlation, the following relation is the generally accepted modified form of Angstrom-type regression equation, relating monthly average daily global radiation to average daily sunshine hours [7].

$$\frac{\bar{H}}{\bar{H}_o} = a + b\frac{\bar{S}}{\bar{S}_0} \quad (1)$$

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.

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

$$H_o = \frac{24}{\pi} I_{sc}\left[1 + 0.033\cos\frac{360n}{365}\right]\left[\cos\emptyset\cos\delta\sin\omega_s + \frac{\pi}{180}\omega_s\sin\emptyset\sin\delta\right] \quad (2)$$

Where n is the Julian day number, I_{sc} = 1367Wm^{-2} is the solar constant, $\emptyset$ is the latitude of the location, $\delta$is the declination angle [7] given as:

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

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

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

Basically, this work have explored various models that can be used to predict global solar radiation in Adamawa State. The regression models proposed in the literature based on sunshine hour based models are listed in Table 1.

Table 1: Regression models proposed in the literature

Model No.	Regression equation	Source
1	$\frac{H}{H_o} = 0.23 + 0.48\frac{S}{S_o}$	Page model[8]
2	$\frac{\bar{H}}{\bar{H}_o} = 0.18 + 0.62\frac{\bar{S}}{\bar{S}_0}$	Rietveld model[9]
3	$\frac{H}{H_o} = 0.177 + 0.692\frac{S}{S_o}$	Jain model [10, 11]
4	$\frac{\bar{H}}{\bar{H}_o}$ $0.29\cos\emptyset + 0.52\frac{\bar{S}}{\bar{S}_0}$	Glover and McCulloch model [12]
5	$\frac{H}{H_o} = 0.32 + 0.42\frac{S}{S_o}$	Gopinathan model [1]
6	$\frac{\bar{H}}{\bar{H}_o} = 0.175 + 0.552\frac{\bar{S}}{\bar{S}_0}$	Bahel et.al, model [12]

Comparison Techniques

There are numerous works which deal with the assessment and comparison of monthly mean daily solar radiation estimation models. The most popular statistical parameters are the mean bias error (MBE) and the root mean square error (RMSE). In this study, to evaluate the accuracy of the estimated data, from the models described above, the following statistical tests were used, MBE, RMSE and coefficient of correlation (r), to test the linear relationship between predicted and measured values. For better data modeling, these statistics should be closer to zero, but coefficient of correlation, r, should approach to 1 as closely as possible.

The Mean percentage error is defined as:

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

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.

The root mean square error is defined as:

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

The RMSE is always positive, a zero value is ideal. This test will provide information on the short-term performance of the models by allowing a term by term comparison of the actual deviation between the calculated value and the measured value.

The mean bias error is defined as:

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

This test will provide information on the long-term performance. A low MBE is expected. Ideally a zero value of MBE should be obtained. A positive value gives the average amount of over-estimation in the calculated value and vice versa. One drawback of this test is that over-estimation of an individual observation will cancel under-estimation in a separate observation.

The correlation coefficient R between estimated and measured radiation values was defined by:

$$R = \frac{\Sigma(\bar{H}_{estimate\ d} - \bar{H}_e)(\bar{H}_{measured} - \bar{H}_m)}{\sqrt{(\Sigma(\bar{H}_{estimated} - \bar{H}_e)^2)(\Sigma(\bar{H}_{measured} - \bar{H}_m)^2)}} \quad (9)$$

Where $\bar{H}_e$ is the arithmetic mean value of the estimated value of the global solar radiation, $\bar{H}_m$ is the arithmetic mean value of the measured values of the global solar radiation.

R^2 denotes the multiple coefficient of determination, which is a measure of how well the regression equation fits the sample data. A perfect fit would result in $R^2 = 1$. A very good fit results in a value near 1. A very poor fit results in a value of R^2 close to 0. The R^2 has serious flaws however; this is because, as more variables are included R^2 increases. This is not supposed to be so. Consequently, it is better to use the adjusted R^2 when comparing different model equations.

Results and Discussion

Table 2: Impute parameters for the estimation of monthly average daily global solar at Yola for the period of fifteen years (1999-2013)

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

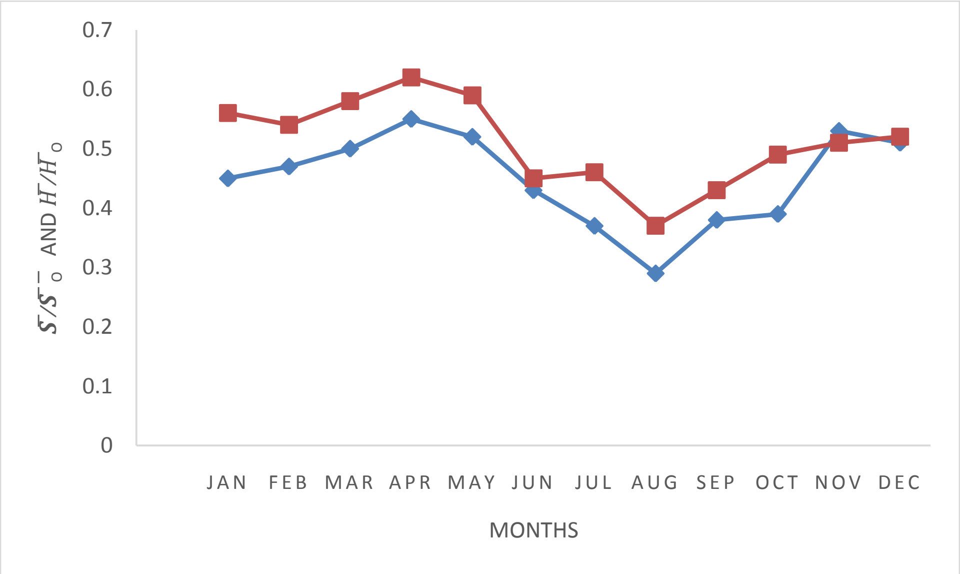

Figure 1: Variation of $\bar{S}/\bar{S}_o$ and $\bar{H}/\bar{H}o$ (The clearness index) for Yola

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).

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

Months	H_m	$\bar{H}_o$	Page Model	Rietveld Model	Jain Model	Glover and McCulloch Model	Gopinathan Model	Bahel Model
JAN	17.22	36.58	16.31	16.46	17.86	19.03	18.62	16.48
FEB	20.09	37.13	16.91	18.44	19.54	19.44	19.39	16.13
MAR	21.21	37.96	17.84	19.50	20.75	20.07	21.56	17.12
APR	22.02	39.14	19.33	20.02	22.72	22.39	21.78	19.63
MAY	23.68	39.78	19.07	19.89	21.35	22.14	23.06	18.38
JUN	17.29	38.49	16.79	18.83	18.26	19.62	17.26	16.77
JUL	18.38	39.29	16.01	15.28	17.01	18.80	18.67	14.90
AUG	14.31	37.76	13.94	13.21	14.26	16.50	15.68	13.55
SEP	16.42	37.88	15.62	15.53	16.66	18.32	18.16	15.47
OCT	18.84	38.74	16.16	16.35	17.31	19.04	18.83	18.51
NOV	20.38	39.59	19.17	19.79	21.52	21.24	20.48	17.77
DEC	19.22	36.96	17.54	18.12	19.58	20.38	19.24	18.68

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

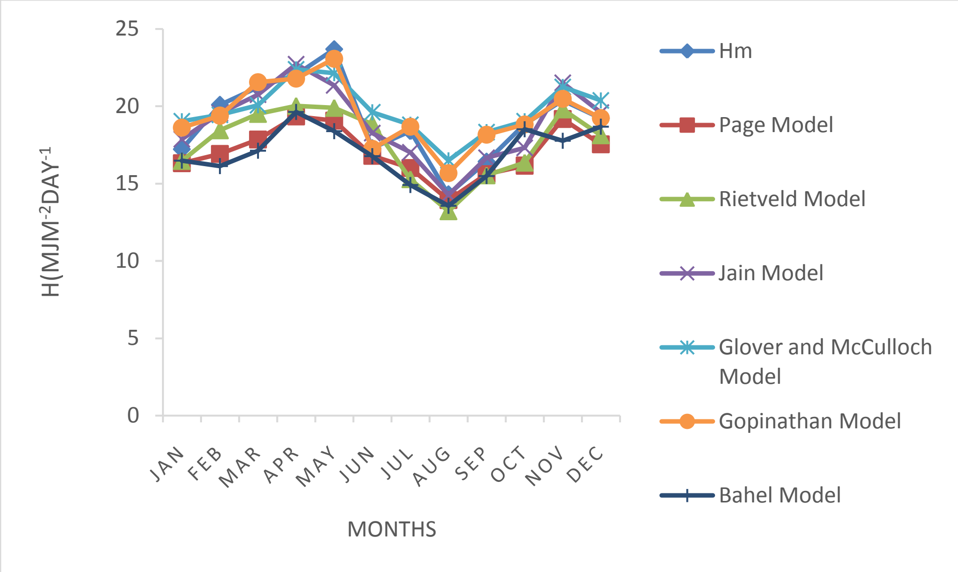

Figure 2: Estimated value of monthly average daily global solar radiation from model 1 – 6 and comparison with measure data.

Table 3: Statistical test results of models applied for Yola.

Models	MPE	MBE	RMSE	R	R^2
Rietveld Model	1.244	2.717	10.524	0.973	0.952
Glover and McCulloch Model	-0.600	1.614	6.251	0.982	0.964
Gopinathan Model	0.624	1.036	7.073	0.989	0.978
Jain Model	0.0628	-0.012	0.0464	0.992	0.984
Bahel Model	0.747	-0.142	0.552	0.987	0.974
Page Model	0.712	-0.135	0.524	0.963	0.936

From table 2 and figure 2 above, it is very encouraging to observe a very fine agreement between measured and estimated values obtained from Jain model. The validation of these ten models were performed by using MPE, MBE, RMSE, R and R^2. From Table 3 above, MBE values obtained from the models are positive in some cases and negative in others, which shows these models vary under and over estimate of global solar radiation. However, values of MBE from most of the models Rietveld (1.244), Glover and McCulloh (1.614) and Gopinathan with (1.036) indicates an over estimation, while other models indicates an under estimation. Lower MBE indicates how efficient the is the model, Jain model with (-0.012) has the lowest MBE

It was observed that the lower the Root Mean Square Errors (RMSE), the more precise 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, Gopinathanmodel, but the lowest is found to be Jain model (0.0464) which the most acceptable, while Rietveld model (10.524) gave the highest value.
From the results, Jain model was found as the most precise model for the prediction of global solar radiation on a horizontal surface for Yola. The values of the correlation coefficient, R, determination coefficient R^2, MPE, RMSE and MBE were 0.992, 0.984, 0.0628, - 0.012 MJ/m^2 and 0.0464 MJ/m^2 respectively.

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. 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. Comparison of the predictive efficiency of these models showed that the Jain model performed better than all the other models. Looking at statistical analysis of the models, we also observed that despite overestimation and underestimation of the models, there are fairly good level of significance at confidence level, but the Jain model was the best.

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