Empirical Models for the Correlation of Global Solar Radiation with Meteorological Data for Iseyin, Nigeria.

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ABSTRACT

A number of multilinear regression equations were developed to predict the relationship between global solar radiations with one or more combinations of the following weather parameters: clearness index, mean of daily temperature, ratio of maximum and minimum daily temperature, relative humidity and relative sunshine duration for Iseyin Nigeria for five years (1995-1999). Using the Angstrom model as the base, other regression equations were developed by modifying the Angstrom equation. The value of correlation coefficient (r) and value of Root Mean Square Error (RMSE), Mean Bias Error (MBE), and Mean Percentage Error (MPE) were determined for each equation. The equation with the highest value of r and least value of RMSE, MPE, and MBE is given as:

$$\frac{H}{H_o} = 1.3467 + 0.5305\left(S/S_{\max} \right) - 1.567\,(\theta) + 0.0033\,(RH) - 0.00806\,(T),$$

where H/H_o is the cleanness index, R is the relative humidity, S/S_{max} is the relative sunshine duration, θ is ratio of minimum and maximum daily temperature, and T is the monthly average daily temperature. The developed model can be used for estimating global solar radiation on horizontal surfaces.

(Keywords: solar global solar radiation, relative humidity, temperature, relative sunshine duration)

INTRODUCTION

Global solar radiation is of economic importance as a renewable energy alternative. More recently global solar radiation has being studied due to its importance in providing energy for Earth's climate system. The solar radiation reaching the Earth's surface depends upon climatic conditions of a location, which is essential to the prediction, and design of a solar energy system by Burari and Sambo (2001). Several researchers have determined the applicability of the Angstrom type regression model for estimating global solar irradiance (Akpabio et al., 2004; Ahmad and Ulfat, 2004; Sambo, 1985; Sayigh 1993; Fagbenle, 1990; Akinbode, 1992; Udo, 2002; Awachie and Okeke, 1990; El – Sebaii and Trabea; 2005, Falayi and Rabiu, 2005; Serm and Korntip, 2004; Zhou Jin et al., 2004 and Skeiker, 2006). Recently, Akpabio and Etuk (2002) have developed a multiple linear regression model with ten variables to estimate the monthly average daily global solar radiation for Onne, Nigeria, Okogbue and Adedokun (2002) developed modified models for estimating global solar radiation with metrological data from 24 stations in Nigeria and also Chandel et al. (2007) developed a new correlation incorporating the latitude and altitude of a site to estimate the monthly average global solar radiation on horizontal surfaces using the sunshine hour and temperature data at six Indian stations with different geographical locations. Accurate modeling depends on the quality and quantity of the measured data used and is a better tool for estimating the global solar radiation of location where measurements are not available.

The objective of the present study is to develop an equation that correlates monthly daily global solar radiation on horizontal surface for Iseyin, southwest, Nigeria.

METHODOLOGY

The monthly average daily solar radiations, sunshine duration, temperature, and relative humidity, were obtained from the Archives of Nigeria Meteorological Agency Oshodi, Lagos. The data obtained, covered a period of 5 years (1995-1999) for Iseyin located at latitude 7.98^{0}N and longitude 3.6^{0}E. The monthly averages data processed in preparation for the correlations are presented in Table 1.

To develop the model, the hourly global solar radiation which were obtained using Gun Bellani distillate were converted and standardized after Folayan (1988), using the conversion factor calculated from the following equations

$$H = (1.35 \pm 0.176) H_{GB} \text{ MJ/m}^2 \quad \textbf{(1)}$$

where H is the hourly global solar radiation in MJ/m^2, H_{GB} is the raw data obtained using Gun-Bellani distillate.

The linear regression model used in correlating the measured global solar radiation data (H) data with relative sunshine duration (S/S_{max}) is given after Angstrom (1924) and later modified by Page (1964):

$$H = Ho\left(a + b\left(\frac{S}{S_{max}}\right)\right) \quad \textbf{(2)}$$

where:
H is the monthly mean horizontal daily total terrestrial solar radiation.

Ho is the monthly mean horizontal daily total extraterrestrial solar radiation.

$$H_0 = \frac{24 \times 3600}{\pi} Gsc \left(1 + 0.033 \, Cos \, \frac{360 \, n}{365}\right) \cdot \left(Cos \, \phi Cos \, \delta Sin Ws + \frac{2\pi Ws}{360} Sin \, \phi Sin \, \delta\right) \quad \textbf{(3)}$$

where:

Ho = monthly mean daily extraterrestrial radiation MJ/m^2

Gsc= solar constant = 1367 W/m^2

δ = declination angle

ϕ = latitude of the station

Ws= sunset hour angle for the typical day n of each month in degrees =$\cos^{-1}$ (-tan ϕ tan δ)

n= mean day of each months.

S is the monthly mean of daily hours sunshine duration was divided by the number of hour's of insolation (S_{max}). The values of S_{max} were computed from the following equations:

$$S_{max} = \frac{2}{15}\cos^{-1}(-\tan\phi\tan\delta) \quad \textbf{(4)}$$

S_{max} is the number of hour of insolation, δ is the declination angle and ϕ is the latitude of the station.

Then the monthly average of daily global radiation H was normalized by dividing with the monthly average of daily extraterrestrial radiation H_o. Therefore, Clearness index K_T is defined as the ratio of the observed/measured horizontal terrestrial solar radiation (H), to the calculated/predicted horizontal extraterrestrial solar radiation (H_0).

Table 1: Meteorology Data and Global Solar Radiation for Iseyin.

Monthly	**K_T=H/H_0**	**T ^{0}C**	**Θ**	**RH %**	**S/S_{max}**
Jan.	0.5793	27.72	0.6088	62.0	0.4375
Feb.	0.6516	28.95	0.6126	59.8	0.5635
Mar.	0.6184	28.79	0.6670	74.2	0.5461
Apr.	0.5867	28.16	0.6943	78.2	0.5326
May	0.5541	27.06	0.7183	81.8	0.5454
Jun.	0.5028	25.93	0.7370	85.2	0.4832
Jul.	0.4027	24.69	0.7510	89.0	0.2672
Aug.	0.3652	23.61	0.7690	86.0	0.1925
Sep.	0.4318	24.86	0.7450	89.0	0.2901
Oct.	0.5167	25.96	0.7230	86.0	0.4559
Nov.	0.6926	27.29	0.6570	75.4	0.6328
Dec.	0.7064	27.69	0.6270	69.6	0.5769

The value of extraterrestrial solar radiation H_0 and maximum number of hours of insolation S/S_{max} are computed by, Duffie and Beckman (1994) and Sodha et al. (1988) with a multiple regression equation for estimating H/H_O with five parameters.

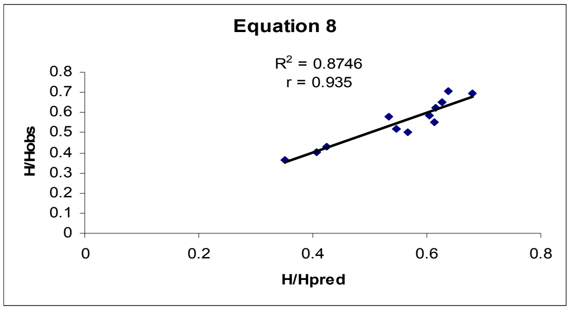
DATA ANALYSIS

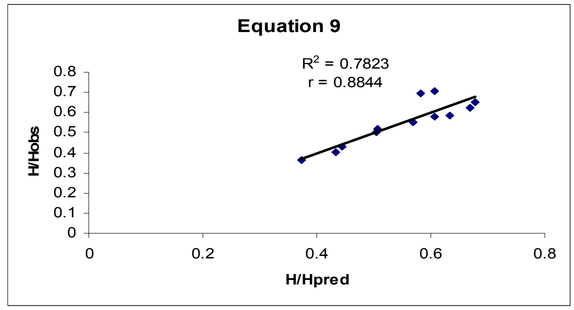
The various meteorological data are related to global solar radiation. Multiple linear repression analysis of five parameters was employed to estimate the prediction of global solar radiation (H/H_0, S/S_{max}, RH, θ, and T) where H/H_0 is the clearness index, S/S_{max} is the relative sunshine duration, RH is the relative humidity, θ is the ratio of minimum to maximum daily temperature and T is the monthly average daily temperature. The linear regressions are expressed in Table 2 below.

Regression and correlation analyses was carried out between the clearness index, relative sunshine duration, relative humidity, ratio of maximum to minimum temperature, monthly average daily temperature. The regression values and correlation coefficients are reported on Table 2. Figure 1 further illustrates the comparison between observed and predicted values of the correlation equation. Microsoft Excel® software was used in evaluating model parameters by writing computer programs for the appropriate formulae.

Table 2: Equations with Regression and Statistical Indicators.

Equations	r	R^2	MBE	RMSE	MPE
H/Ho=0.20765 +0.7475(S/Smax)	0.9350	0.8746	-0.000189	0.03765	-0.03216
H/Ho=-0.97877+0.05722(T)	0.8828	0.7794	-0.004610	0.04961	0.06931
H/Ho=1.197363- 0.00829(RH)	0.7529	0.5669	-0.000199	0.06996	0.12284
H/Ho=1.7217-1.691(Θ)	0.8629	0.7447	-0.000201	0.05373	0.13299
H/Ho=0.5475+0.5987(S/Smax) -0.0035(RH)	0.97023	0.9414	-0.000205	0.02574	-0.09159
H/Ho=0.8758+0.5168(S/Smax) +0.0194(Θ)	0.9822	0.9646	-0.000260	0.020013	-0.0521
H/Ho= -0.2144+0.541(S/Smax) +0.0194(T)	0.9473	0.8984	-0.000197	0.03389	-0.20838
H/Ho=1.1203+0.4690(S/Smax) -1.5956(Θ)+0.0041(RH)	0.9864	0.9728	-0.000204	0.017526	0.029567
H/Ho=0.8559+0.6758(S/Smax)-0.01049(T) -0.0043(RH)	0.9718	0.9445	-0.000204	0.025164	-0.09963
H/Ho=1.3098+0.601005(S/Smax)-0.99902(Θ)-0.01287(T)	0.9849	0.9701	-0.000211	0.018631	-0.0823
H/Ho=0.7162+0.0106(RH)-2.684(Θ)+0.0324(T)	0.9464	0.8957	-0.000196	0.034115	-0.27861
H/Ho=1.3467+0.5305(S/Smax)-1.567(Θ)+0.0033(RH)-0.00806(T)	0.9870	0.9748	-0.000197	0.017059	0.02125


Equation 8
R² = 0.8746
r = 0.935
H/Hobs
H/Hpred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r = 0.8844
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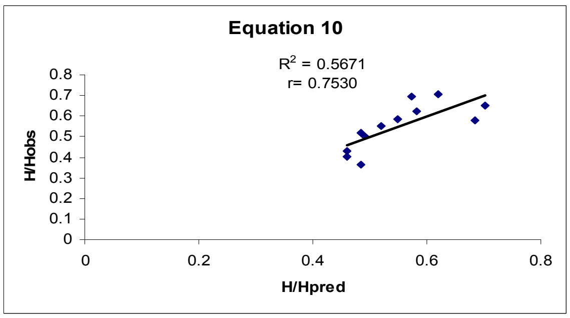
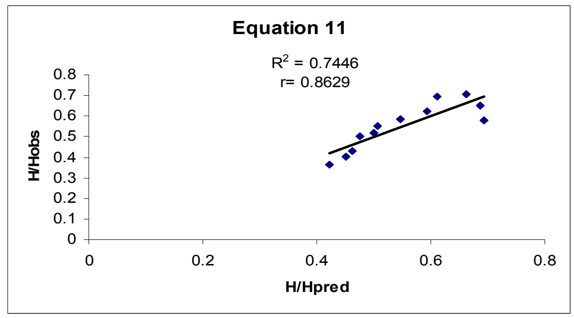
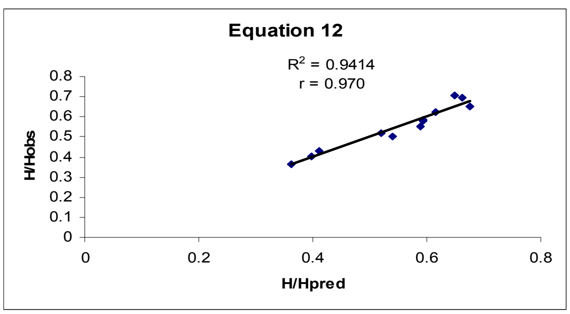
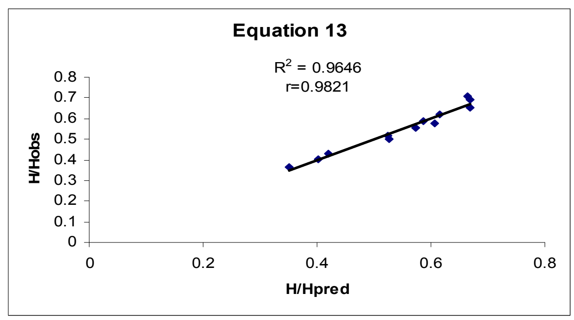
H/Hpred


Equation 10
R² = 0.5671
r= 0.7530
H/Hobs
H/Hpred


Equation 11
R² = 0.7446
r= 0.8629
H/Hobs
H/Hpred


Equation 12
R² = 0.9414
r = 0.970
H/Hobs
H/Hpred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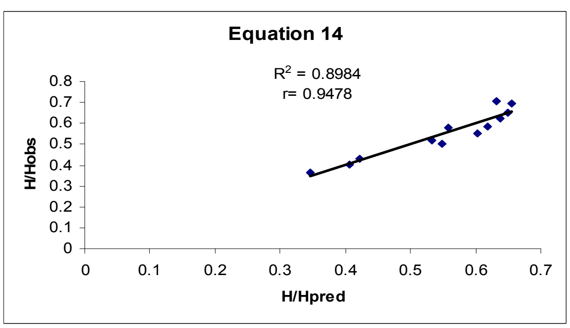
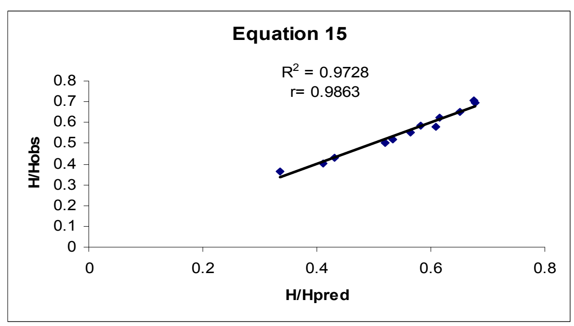
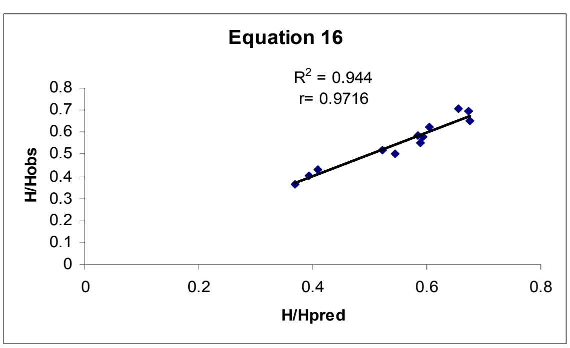
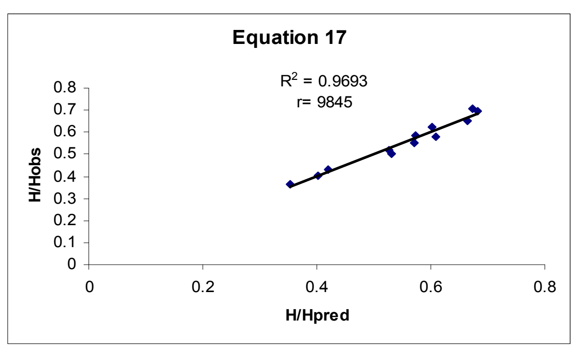
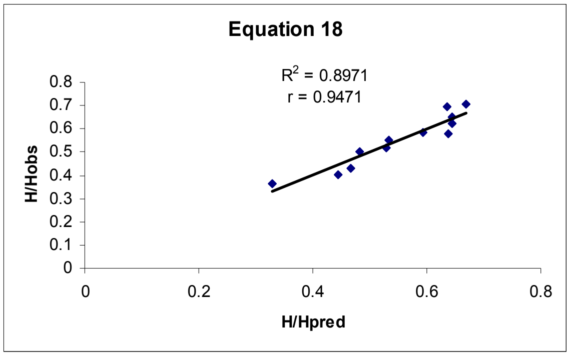
R² = 0.9646
r=0.9821
H/Hobs
H/Hpred


Equation 14
R² = 0.8984
r= 0.9478
H/Hobs
H/Hpred


Equation 15
R² = 0.9728
r= 0.9863
H/Hobs
H/Hpred


Equation 16
R² = 0.944
r= 0.9716
H/Hobs
H/Hpred


Equation 17
R² = 0.9693
r= 9845
H/Hobs
H/Hpred



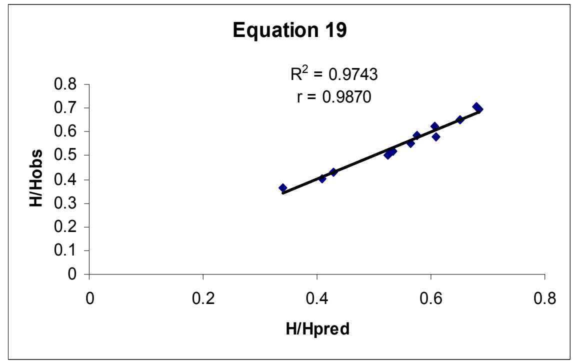


Figure 1: Comparison Between Observed and Predicted Values of the Correlation Equation.

The accuracy of the estimated values was tested by calculating the RMSE (Root Mean square Error), MBE (Mean Bias Error), and MPE (Mean Percentage Error). The RMSE (MJ/m^2), MBE (MJ/m^2), and MPE (%) for the four variables.

$$RMSE = \left\{\left[\sum \left(H_{pred} - H_{obs}\right)^2\right]/n\right\}^{1/2} \quad \textbf{(5)}$$

$$MBE = \left[\sum \left(H_{pred} - H_{obs}\right)\right]/n \quad \textbf{(6)}$$

$$\text{MPE}=\left[\sum\left(\frac{H_{obs} - H_{pred}}{H_{obs}} \times 100\right)\right]/n \quad \textbf{(7)}$$

RMSE and MBE statistical indicators are commonly used in comparing the models of solar radiation predictions. Low values of RMSE are desirable, but few errors in the sum can produce a significant increase in the indicator. Low values of MBE are desirable, but overestimation of an individual data element will cancel underestimation in a separate observation. It is also possible to have large RMSE values at the same time a small MBE or vice versa.

The use of RMSE and MBE statistical indicator is not adequate for the evaluation of models performance and we concluded that MPE is used in addition to RMSE and MBE to give more reliable result.

MPE gives long performance on the 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.

RESULTS AND DISCUSSION

Table 2 contains summaries of various liner regression analyses, obtained from the application of Equation (1) to the monthly mean value for the four variables under study. It is clear that the correlation coefficient r, correlation of determination R^2, MBE (MJ/m^2), RMSE (MJ/m^2) and MPE (%) vary from one variable to another variable.

Generally, correlation coefficients (0.935-0.987) are high for all the variables. This implies that, there are statistically significant relationships between the clearness index, relative sunshine duration, the relative humidity, the ratio of minimum to maximum daily temperature and the monthly average daily temperature. This is further demonstrated by high values of coefficient of determination R^2 (0.874-0.974) across the variables.

<u>One Variable correlation</u>:

The correlation of coefficient of 0.935 exists between the clearness index and relative sunshine duration also coefficient of determination of 0.8746 implies 87.46% of clearness index can be accounted using relative sunshine duration.

$$H/H_o=0.20765 +0.7475(S/S_{max}) \quad \textbf{(8)}$$

The correlation of coefficient of 0.883 exists between the clearness index and monthly average daily temperature also coefficient of determination of 0.7794 implies 77.94% of clearness index can be accounted using monthly average daily temperature.

$$H/Ho=-0.9787+0.0572\ (T) \quad \textbf{(9)}$$

The correlation of coefficient of 0.753 exists between the clearness index and relative humidity also coefficient of determination of 0.5669 implies 56.69% of clearness index can be accounted using relative humidity.

$$H/Ho=1.1974-0.00829\ (RH) \quad \textbf{(10)}$$

The correlation of coefficient of 0.863 exists between the clearness index and relative humidity also coefficient of determination of 0.7447 implies 77.94% of clearness index can be accounted using ratio of minimum to maximum daily temperature.

$$H/Ho=1.7217-1.691\ (\Theta) \quad \textbf{(11)}$$

Two Variables Correlations:

The correlation of coefficient of 0.970 exists between the clearness index, relative sunshine duration and relative humidity, also coefficient of determination of 0.941 implies 94.1% of clearness index can be accounted using relative sunshine duration and relative humidity.

$$H/Ho=0.5475+0.5987(S/S_{max})\ -0.0035(RH) \quad \textbf{(12)}$$

The correlation of coefficient of 0.982 exists between the clearness index, relative sunshine duration and ratio of minimum to maximum daily temperature, the coefficient of determination of 0.9646 implies 96.46% of clearness index can be accounted by relative sunshine duration and ratio of minimum to maximum daily temperature.

$$H/Ho=0.8758+0.5168(S/S_{max})\ +0.0194(\Theta) \quad \textbf{(13)}$$

The correlation of coefficient of 0.947 exists between the clearness index, relative sunshine duration and monthly average daily temperature, the coefficient of determination of 0.8984 implies 89.84% of clearness index can be accounted by relative sunshine duration and monthly average daily temperature.

$$H/Ho= -0.2144+0.541(S/S_{max})\ +0.0194(T) \quad \textbf{(14)}$$

Three Variables Correlations:

Equations (10) - (11) can be modified by incorporating extra parameters to the set of correlation equations for two variables.

The correlation of coefficient of 0.986 exists between the clearness index, relative sunshine duration, ratio of minimum to maximum daily temperature and relative humidity, the coefficient of determination of 0.9728 implies 97.28% of clearness index can be accounted by relative sunshine duration, ratio of minimum to maximum daily temperature and relative humidity.

$$H/Ho=1.1203+0.4690(S/Smax)\ -1.5956(\Theta)\ +0.0041(RH) \quad \textbf{(15)}$$

The correlation of coefficient of 0.9718 exists between the clearness index, relative sunshine duration, relative humidity and the monthly average daily temperature, the coefficient of determination of 0.9445 implies 94.45% of clearness index can be accounted by relative sunshine duration, monthly average of daily temperature and relative humidity.

$$H/Ho=0.8559+0.6758(S/Smax)-0.0043(RH)\ -0.01049(T) \quad \textbf{(16)}$$

The correlation of coefficient of 0.985 exists between the clearness index, relative sunshine duration, the monthly average daily temperature and ratio of minimum to maximum daily temperature. The coefficient of determination of 0.9700 implies 97.00% of clearness index can be accounted by relative sunshine duration, ratio of minimum to maximum daily temperature and monthly average of daily temperature.

$$H/Ho=1.3098+0.601005(S/S_{max})\ -0.99902(\Theta)\ -0.01287(T) \quad \textbf{(17)}$$

The correlation of coefficient of 0.946 exists between the clearness index, relative humidity, ratio of minimum to maximum daily temperature and the monthly average daily temperature. The coefficient of determination of 0.8957 implies 89.57% of clearness index can be accounted by relative sunshine duration, ratio of minimum to maximum daily temperature and monthly average of daily temperature.

$$H/Ho=0.7162+0.0106\,(RH)-2.684(\Theta)+0.0324(T) \quad \textbf{(18)}$$

Four Variables Correlation:

The Equations (12) - (15) can be modified by incorporating extra parameters to the set of correlation equations for two variables.

The correlation of coefficient of 0.987 exists between the clearness index, relative sunshine duration, ratio of minimum to maximum daily temperature, relative humidity, and the monthly average daily temperature. The coefficient of determination of 0.9748 implies 97.48% of clearness index can be accounted by relative sunshine duration, ratio of minimum to maximum daily temperature, relative humidity and monthly average of daily temperature.

$$H/Ho=1.3467+0.5305(S/Smax)-1.567(\Theta)+0.0033(RH)-0.00806(T) \quad \textbf{(19)}$$

For better analysis the developed correlation will be considered that has high value of correlation r and correlation of determination R^2: Equations (8), (9), (10), (11), (12), (13), (14), (15), (16), (17), (18) and (19). Equation (12), (13), (15), (16), (17) and (19) has the highest value of correlation coefficient and correlation of determination, while the others have low values of correlation coefficient. Furthermore there is a remarkable agreement between the observed and predicted values of global solar radiation for five years from our correlation.

From Table 2, based on the RMSE, Equation (19) produces the best correlation, while Equation (10) give the weakest correlation with high values of RMSE. For MBE, the result shows that Equation (8) also has good correlation while Equation (9) has weak correlation of MBE. For MPE, it was observed that Equation (19) has the best value while Equation (11) has the weak value of MPE.

The test RMSE provides information on the short-term performance of the studied model as it allows a term-by-term Comparison of the actual deviation between the calculated value and the measured value. Igbal (1993), Halouani (1993), Almorox (2005) and Che et al. (2007) have recommended that a Zero value for MBE is ideal and low RMSE is desirable. MPE value provides information on under estimation since it is negative while if it s positive it is overestimation in the calculated value. A low value of MPE is desirable by Akpabio et al. (2004).

CONCLUSION

The monthly global solar radiation, relative sunshine duration, means temperature, ratio of minimum to maximum temperature and relative humidity have been employed in this study to develop several correlation equations. Four variables have been developed with different types of equations obtained. It was observed that Equation (19) has the highest value of correlation coefficient and correlation of determination, which gives good results when considering statistical indicators i.e. RMSE, MBE, and MPE.

The equation could be employed in estimation of global solar radiation of location that has the same geographical location information as Iseyin in the South- west, Nigeria. The correlating equation with the smallest value of the RMSE is

$$H/Ho=1.3467+0.5305(S/Smax)-1.567(\Theta)+0.0033(RH)-0.00806(T)$$

The global solar radiation intensity values produced by this approach can be used in the designed and estimation of performance of solar applications system which is gaining attention in Nigeria.

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