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A Comparative Study of some Meteorological Parameters for Predicting Global Solar Radiation in Kano, Nigeria Based on Three Variable Correlations

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Abstract
In this present study, twenty empirical regression equations based on three variable correlations were developed and used to estimate the monthly average daily global solar radiation on a horizontal surface using measured monthly average daily global solar radiation, sunshine duration, wind speed, maximum and minimum temperatures, rainfall, cloud cover and relative humidity parameters during the period of thirty one years (1980 – 2010) for Kano, Nigeria (Latitude 12.03^{0}N, Longitude 08.12^{0}E and altitude 472.5 m above sea level). The comparative performance of the developed models has been evaluated on the basis of statistical parameters using Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t – test and Nash – Sutcliffe Equation (NSE). The values of the correlation coefficient (R) and coefficient of determination (R^2) were also obtained for each of the developed models. The MPE values for all the developed models lie within the acceptable range ($MPE \leq \pm 10\%$). The t – test produces perfect model performance at 95% and 99% confidence level for all the developed models. Three equations were recommended from this study, firstly, the model (Eqn. 20) with the highest value of R and R^2, secondly, the model (Eqn. 24) with the least value of RMSE and the highest value of NSE and thirdly, the model (Eqn. 31) with the least values of MPE and t – test. These developed models can be used for estimating monthly average daily global solar radiation for Kano, North – Western, Nigeria and other locations with similar weather conditions where the solar radiation data is unavailable.
Keywords: global solar radiation, Kano, variable correlation, Mean Bias Error (MBE) and coefficient of determination.

1. Introduction

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 (Ahmed and Ulfat, 2004)

Obviously, the best way of knowing the amount of global solar radiation at the site of interest is to install pyranometer at many locations in the given region and look after their day-to-day maintenance and recording which is a very expensive venture to embark on.

The alternative approach could be to predict the global solar radiation by means of some models incorporating the easily available meteorological parameters as input. The resulting correlation developed may then be used for locations of similar meteorological characteristics (Amitabh *et al*., 2014).

Developing empirical models for estimating the monthly average daily global solar radiation using easily available parameters such as sunshine duration, wind speed, maximum and minimum temperatures, rainfall, cloud cover, relative humidity etc., is an essential assignment for developing countries like Nigeria where solar radiation data are not available at most of the places. Several empirical models have been developed to estimate the global solar radiation using various meteorological parameters. Such models include that of Akpabio et al. (2004), Gana and Akpootu (2013), Akpootu and Sanusi (2015), Ituen et al. (2012), Akpootu and Momoh (2014), Muzathik et al. (2011), Okonkwo and Nwokoye (2014), Mfon et al. (2013), Amitabh et al. (2014), Falayi (2013), Muhammad and Darma (2014) and Habbib (2011) to mention but a few.

The aim of this paper is to develop empirical models by combining all the six meteorological parameters based on three variable correlations. The twenty models developed in this study were statistically tested to ascertain the best performing model to be recommended for the estimation of global solar radiation for Kano and its environs.

2. Methodology

The measured monthly average daily global solar radiation, sunshine hour, wind speed, maximum and minimum temperatures, rainfall, cloud cover and relative humidity covering a period of thirty one years (1980-2010) for Kano, North – Western, Nigeria was obtained from the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos, Nigeria. Monthly averages over the thirty one years of the data in preparation for correlation are presented in **Table 1.**

The first correlation proposed for estimating the monthly average global solar radiation is based on the method of

Angstrom (1924). The original Angstrom- Prescott type regression equation-related monthly average daily radiation to clear day radiation in a given location and average fraction of possible sunshine hours is given by the equation:

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

where H is the monthly average daily global solar radiation on a horizontal surface (MJ/m^2/day), H_o is the monthly average daily extraterrestrial radiation on a horizontal surface (MJ/m^2/day), S is the monthly average daily hours of bright sunshine, S_o is the monthly average day length and a and b values are the Angstrom empirical constants. The monthly average daily extraterrestrial radiation on a horizontal surface (H_o) can be calculated for days giving average of each month (Iqbal, 1983; Zekai, 2008; Saidur et al., 2009) from the following equation (Iqbal, 1983; Zekai, 2008):

$$H_o = \left(\frac{24}{\pi}\right) I_{sc}\left[1 + 0.033Cos\left(\frac{360n}{365}\right)\right]\left[Cos\varphi Cos\delta Sin W_s + \left(\frac{2\pi W_s}{360}\right) Sin\varphi Sin\delta\right] \quad (2)$$

where I_{sc} is the solar constant (=1367 Wm^{-2}), φ is the latitude of the site, δ is the solar declination and W_s is the mean sunrise hour angle for the given month and n is the number of days of the year starting from 1^{st} of January to 31^{st} of December.

The solar declination, δ and the mean sunrise hour angle, W_s can be calculated using the following equation (Iqbal, 1983; Zekai, 2008):

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

$$W_s = Cos^{-1}(-tan\varphi tan\delta) \quad (4)$$

For a given month, the maximum possible sunshine duration (monthly average day length (S_o)) can be computed (Iqbal, 1983; Zekai, 2008) by

$$S_o = \frac{2}{15} W_s \quad (5)$$

The clearness index (K_T) is defined as the ratio of the observed/measured horizontal terrestrial solar radiation H, to the calculated/predicted/estimated horizontal extraterrestrial solar radiation H_o. The clearness index (K_T) gives the percentage deflection by the sky of the incoming global solar radiation and therefore indicates both level of availability of solar radiation and changes in atmospheric conditions in a given locality (Falayi *et al*., 2011)

$$K_T = \frac{H}{H_o} \quad (6)$$

In this study, H_o and S_o were computed for each month using equations (2) and (5) respectively. The mean temperature T_a was obtained by taken the average of the maximum and minimum temperatures. Multiple linear regression equation for estimating the global solar radiation with the clearness index been the dependent variable and the six independent meteorological variables for the three variable correlations is given as

$$\frac{H}{H_0} = a + bx_1 + cx_2 + dx_3 + ex_4 + fx_5 + gx_6 \quad (7)$$

where $a \dots\dots g$ are the regression coefficients and $x_1 \dots\dots x_6$ are the correlated parameters. The estimated values of the global solar radiation were compared to that of the measured values in each regression equation through coefficient of determination R^2 and standard error of estimate σ. In this study, the number of ways of combining the meteorological variables was obtained using the equation

$$n_{C_r} = \frac{n!}{(n-r)!r!} (8)$$

where n is the total number of meteorological variables under study and r is the number of the three meteorological variables to be combined. Minitab 16 software program was used in evaluating the model parameters. In this study, all the twenty developed regression equations were used for the statistical analysis.

The accuracy of the estimated values was tested by computing the Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t-test and the Nash-Sutcliffe equation (NSE). The expressions for the MBE, RMSE and MPE as stated according to El-Sebaii and Trabea (2005) and are given as follows.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(H_{i,cal} - H_{i,mea}\right) \quad (9)$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(H_{i,cal} - H_{i,mea}\right)^2\right]^{\frac{1}{2}} \quad (10)$$

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_{i,mea} - H_{i,cal}}{H_{i,mea}}\right) * 100 \quad (11)$$

The t-test defined by student (Bevington, 1969) in one of the tests for mean values, the random variable t with n-1 degrees of freedom may be written as follows.

$$t = \left[\frac{(n-1)(MBE)^2}{(RMSE)^2 - (MBE)^2}\right]^{\frac{1}{2}} \quad (12)$$

The Nash-Sutcliffe equation (NSE) is given by the expression

$$NSE = 1 - \frac{\sum_1^n (H_{i,meas} - H_{i,cal})^2}{\sum_1^n (H_{i,meas} - \bar{H}_{i,meas})^2} \quad (13)$$

From equations (9), (10), (11) (12) and (13) above $H_{i,mea}$, $H_{i,cal}$ and n are respectively the i^{th} measured and i^{th} calculated values of daily global solar radiation and the total number of observations, while $\bar{H}_{i,meas}$ is the mean measured global radiation. Iqbal (1983), Halouani et al. (1993), Almorox et al. (2005) and Chen et al. (2004) have recommended that a zero value for MBE is ideal and a low RMSE is desirable. Furthermore, the smaller the value of the MBE and RMSE the better is the model's performance. The RMSE test 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 values and the measured values. The MPE test gives long term performance of the examined regression equations, a positive MPE and MBE values provide the averages amount of overestimation in the calculated values, while the negative values gives underestimation. For a better model performance, a low value of MPE is desirable and the percentage error between -10% and $+10\%$ is considered acceptable (Merges *et al*., 2006). The smaller the value of t the better is the performance. To determine whether a model's estimates are statistically significant, one simply has to determine, from standard statistical tables, the critical t value, i.e., $t_{\alpha/2}$ at α level of significance and $(n-1)$ degrees of freedom. For the model's estimates to be judged statistically significant at the $(1-\alpha)$ confidence level, the computed t value must be less than the critical value. A model is more efficient when NSE is closer to 1 (Chen *et al*., 2004). Similarly, for better data modelling, the coefficient of correlation R and coefficient of determination R^2 should approach 1 (100%) as closely as possible.

3. Results and Discussion

Table 1: Relevant meteorological data for Kano

Month	S/So	WS (ms^{-1})	T_a (^{0}C)	RF (mm)	CC	RH (%)
Jan	0.6359	8.1903	21.4323	0.0000	4.7968	24.8710
Feb	0.6494	8.6323	24.0032	0.2613	4.8194	20.2903
Mar	0.5856	8.1742	28.5242	0.8387	5.1903	22.4516
Apr	0.6035	8.5968	31.6871	33.6129	5.4968	36.0323
May	0.5899	9.1742	31.0839	69.1839	6.0484	53.0000
Jun	0.6416	9.5645	29.2726	151.3742	6.0710	65.0968
Jul	0.5711	8.4645	26.7919	269.6742	6.4032	75.8710
Aug	0.5902	7.3097	27.4129	319.2419	6.5710	79.3226
Sep	0.6301	7.0032	26.8855	149.5774	6.2710	71.1613
Oct	0.6506	6.5355	27.4290	13.8355	5.5516	48.7097
Nov	0.7063	6.8613	25.0032	0.0226	5.1097	26.6129
Dec	0.6552	7.8613	21.8323	0.0000	4.9516	26.2258

The various meteorological parameters shown in Table 1 are all related to the measured global solar radiation in varying degrees. In order not to overlook any particular parameter or group of parameters, multiple linear regression of the six meteorological parameters $\left(\frac{S}{S_0}, WS, T_a, RF, CC \text{ and } RH\right)$ with $\frac{H}{H_0}$ been the dependent variable was employed. Here, the six meteorological parameters represents the monthly average daily sunshine duration, monthly average daily wind speed, monthly average daily temperature, monthly average daily rainfall, monthly average daily cloud cover and monthly average daily relative humidity. The various models based on three variable correlation linear regression analyses developed in this study are as follows:

Model 1:

A correlation coefficient of 67.7% exists between the clearness index, the monthly average daily sunshine duration, monthly average daily wind speed and monthly average daily temperature. Similarly, the coefficient of determination of 45.9% of the clearness index can be accounted for using the monthly average daily sunshine duration, monthly average daily wind speed and monthly average daily temperature. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = -0.042 + 0.985\frac{S}{S_0} + 0.0125\,WS - 0.00073\,T_a \quad (R^2 = 45.9\%) \quad (14)$$

Model 2

A correlation coefficient of 97.3% exists between the clearness index, the monthly average daily sunshine duration, monthly average daily wind speed and monthly average daily rainfall. Similarly, the coefficient of determination of 94.6% of the clearness index can be accounted for using the monthly average daily sunshine duration, monthly average daily wind speed and monthly average daily rainfall. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.0493 + 0.285\frac{S}{S_0} + 0.00213\,WS - 0.000403\,RF \quad (R^2 = 94.6\%) \quad (15)$$

Model 3

A correlation coefficient of 94.2% exists between the clearness index, the monthly average daily sunshine duration, monthly average daily wind speed and monthly average daily cloud cover. Similarly, the coefficient of determination of 88.8% of the clearness index can be accounted for using the monthly average daily sunshine duration, monthly average daily wind speed and monthly average daily cloud cover. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.830 + 0.297\frac{S}{S_0} + 0.00219\,WS - 0.0677\,CC \quad (R^2 = 88.8\%) \qquad (16)$$

Model 4

A correlation coefficient of 97.7% exists between the clearness index, the monthly average daily sunshine duration, monthly average daily wind speed and monthly average daily relative humidity. Similarly, the coefficient of determination of 95.5% of the clearness index can be accounted for using the monthly average daily sunshine duration, monthly average daily wind speed and monthly average daily relative humidity. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.494 + 0.388\frac{S}{S_0} + 0.00093\,WS - 0.0019573\,RH \quad (R^2 = 95.5\%) \qquad (17)$$

Model 5

A correlation coefficient of 97.2% exists between the clearness index, the monthly average daily sunshine duration, monthly average daily temperature and monthly average daily rainfall. Similarly, the coefficient of determination of 94.5% of the clearness index can be accounted for using the monthly average daily sunshine duration, monthly average daily temperature and monthly average daily rainfall. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.548 + 0.241\frac{S}{S_0} - 0.00037\,T_a - 0.000408\,RF \quad (R^2 = 94.5\%) \qquad (18)$$

Model 6

A correlation coefficient of 98.4% exists between the clearness index, the monthly average daily sunshine duration, monthly average daily temperature and monthly average daily cloud cover. Similarly, the coefficient of determination of 96.9% of the clearness index can be accounted for using the monthly average daily sunshine duration, monthly average daily temperature and monthly average daily cloud cover. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.690 + 0.412\frac{S}{S_0} + 0.000601\,T_a - 0.0810\,CC \quad (R^2 = 96.9\%) \qquad (19)$$

Model 7

A correlation coefficient of 99.1% exists between the clearness index, the monthly average daily sunshine duration, monthly average daily temperature and monthly average daily relative humidity. Similarly, the coefficient of determination of 98.2% of the clearness index can be accounted for using the monthly average daily sunshine duration, monthly average daily temperature and monthly average daily relative humidity. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.357 + 0.488\frac{S}{S_0} + 0.00324\,T_a - 0.00207\,RH \quad (R^2 = 98.2\%) \qquad (20)$$

Model 8

A correlation coefficient of 98.0% exists between the clearness index, the monthly average daily sunshine duration, monthly average daily rainfall and monthly average daily cloud cover. Similarly, the coefficient of determination of 96.1% of the clearness index can be accounted for using the monthly average daily sunshine duration, monthly average daily rainfall and monthly average daily cloud cover. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.680 + 0.216\frac{S}{S_0} - 0.000292\,RF - 0.0243\,CC \quad (R^2 = 96.1\%) \qquad (21)$$

Model 9

A correlation coefficient of 99.0% exists between the clearness index, the monthly average daily sunshine duration, monthly average daily rainfall and monthly average daily relative humidity. Similarly, the coefficient of determination of 98.0% of the clearness index can be accounted for using the monthly average daily sunshine duration, monthly average daily rainfall and monthly average daily relative humidity. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.542 + 0.289\frac{S}{S_0} - 0.000199\,RF - 0.00112\,RH \quad (R^2 = 98.0\%) \qquad (22)$$

Model 10

A correlation coefficient of 98.5% exists between the clearness index, the monthly average daily sunshine duration, monthly average daily cloud cover and monthly average daily relative humidity. Similarly, the coefficient of determination of 97.0% of the clearness index can be accounted for using the monthly average daily sunshine duration, monthly average daily cloud cover and monthly average daily relative humidity. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.201 + 0.496\frac{S}{S_0} + 0.0527\,CC - 0.00333\,RH \quad (R^2 = 97.0\%) \qquad (23)$$

Model 11

A correlation coefficient of 96.3% exists between the clearness index, the monthly average daily wind speed, monthly average daily temperature and monthly average daily rainfall. Similarly, the coefficient of determination of 92.8% of the clearness index can be accounted for using the monthly average daily wind speed, monthly average daily temperature and monthly average daily rainfall. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.736 - 0.00071\,WS - 0.00144\,T_a - 0.000444\,RF \quad (R^2 = 92.8\%) \quad (24)$$

Model 12

A correlation coefficient of 96.4% exists between the clearness index, the monthly average daily wind speed, monthly average daily temperature and monthly average daily cloud cover. Similarly, the coefficient of determination of 93.0% of the clearness index can be accounted for using the monthly average daily wind speed, monthly average daily temperature and monthly average daily cloud cover. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 1.09 - 0.00810\,WS + 0.00561\,T_a - 0.0932\,CC \quad (R^2 = 93.0\%) \quad (25)$$

Model 13

A correlation coefficient of 95.7% exists between the clearness index, the monthly average daily wind speed, monthly average daily temperature and monthly average daily relative humidity. Similarly, the coefficient of determination of 91.5% of the clearness index can be accounted for using the monthly average daily wind speed, monthly average daily temperature and monthly average daily relative humidity. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.775 - 0.0756\,WS - 0.00183\,T_a - 0.00237\,RH \quad (R^2 = 91.5\%) \quad (26)$$

Model 14

A correlation coefficient of 97.3% exists between the clearness index, the monthly average daily wind speed, monthly average daily rainfall and monthly average daily cloud cover. Similarly, the coefficient of determination of 94.6% of the clearness index can be accounted for using the monthly average daily wind speed, monthly average daily rainfall and monthly average daily cloud cover. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.861 - 0.00219\,WS - 0.000307\,RF - 0.0290\,CC \quad (R^2 = 94.6\%) \quad (27)$$

Model 15

A correlation coefficient of 97.7% exists between the clearness index, the monthly average daily wind speed, monthly average daily rainfall and monthly average daily relative humidity. Similarly, the coefficient of determination of 95.4% of the clearness index can be accounted for using the monthly average daily wind speed, monthly average daily rainfall and monthly average daily relative humidity. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.755 - 0.00369\,WS - 0.000260\,RF - 0.00107\,RH \quad (R^2 = 95.4\%) \quad (28)$$

Model 16

A correlation coefficient of 95.2% exists between the clearness index, the monthly average daily wind speed, monthly average daily cloud cover and monthly average daily relative humidity. Similarly, the coefficient of determination of 90.6% of the clearness index can be accounted for using the monthly average daily wind speed, monthly average daily cloud cover and monthly average daily relative humidity. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.804 - 0.00550\,WS - 0.0004\,CC - 0.00225\,RH \quad (R^2 = 90.6\%) \quad (29)$$

Model 17

A correlation coefficient of 97.3% exists between the clearness index, the monthly average daily temperature, monthly average daily rainfall and monthly average daily cloud cover. Similarly, the coefficient of determination of 94.7% of the clearness index can be accounted for using the monthly average daily temperature, monthly average daily rainfall and monthly average daily cloud cover. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.866 + 0.00131\, T_a - 0.000262\, RF - 0.0400\, CC \quad (R^2 = 94.7\%) \quad (30)$$

Model 18

A correlation coefficient of 97.5% exists between the clearness index, the monthly average daily temperature, monthly average daily rainfall and monthly average daily relative humidity. Similarly, the coefficient of determination of 95.0% of the clearness index can be accounted for using the monthly average daily temperature, monthly average daily rainfall and monthly average relative humidity. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.730 - 0.00030\, T_a - 0.000277\, RF - 0.000967\, RH \quad (R^2 = 95.0\%) \quad (31)$$

Model 19

A correlation coefficient of 95.6% exists between the clearness index, the monthly average daily temperature, monthly average daily cloud cover and monthly average daily relative humidity. Similarly, the coefficient of determination of 91.3% of the clearness index can be accounted for using the monthly average daily temperature, monthly average daily cloud cover and monthly average daily relative humidity. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.984 + 0.00396\, T_a - 0.0742\, CC - 0.00043\, RH \quad (R^2 = 91.3\%) \quad (32)$$

Model 20

A correlation coefficient of 97.5% exists between the clearness index, the monthly average daily rainfall, monthly average daily cloud cover and monthly average daily relative humidity. Similarly, the coefficient of determination of 95.0% of the clearness index can be accounted for using the monthly average daily rainfall, monthly average daily cloud cover and monthly average daily relative humidity. Therefore, the monthly average daily global solar radiation on a horizontal surface for any month of the year in Kano can be calculated using the regression equation

$$\frac{H_{cal}}{H_0} = 0.749 - 0.000270\, RF - 0.0059\, CC - 0.000850\, RH \quad (R^2 = 95.0\%) \quad (33)$$

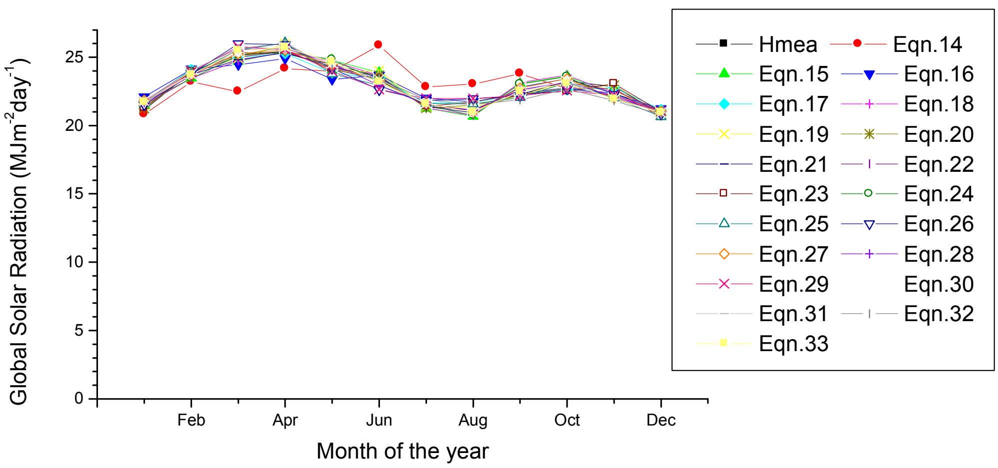

Figure 1: Comparison between the measured and the estimated global solar radiation for the developed models (Eqn.14-33)

Figure 1 shows the comparison between the measured and the estimated global solar radiation for the developed models (Eqn. 14 – 33). The figure depicts that a good correlation exists between the measured and the estimated global solar radiation. However, it is obvious from the figure that model 1 (Eqn. 14) underestimated the measured including other estimated global solar radiation in the months of January – April and overestimated the measured and other estimated global solar radiation in the months of June – September. This effect could be due to variability in the atmospheric parameters during measurement. More so, it was observed that model 1 (Eqn. 14) has the least value of coefficient of correlation and coefficient of determination over the other developed models

(Eqn. 15 – 33).

Table 2: Overall validation of the models under different statistical test for all the variable correlations

Models	R(%)	R^2(%)	MBE($MJm^{-2}day^{-1}$)	RMSE($MJm^{-2}day^{-1}$)	MPE (%)	t	NSE
Eqn.14	67.7	45.9	0.0521	1.3994	-0.4567	0.1237	0.1814
Eqn.15	97.3	94.6	0.0044	0.4231	-0.0337	0.0349	0.9252
Eqn.16	94.2	88.8	-0.0398	0.6044	0.0304	0.2191	0.8473
Eqn.17	97.7	95.5	0.0030	0.3800	-0.0934	0.0259	0.9397
Eqn.18	97.2	94.5	0.0032	0.4224	-0.0395	0.0254	0.9254
Eqn.19	98.4	96.9	0.0040	0.3311	-0.0273	0.0400	0.9542
Eqn.20	99.1	98.2	-0.0074	0.2537	0.0240	0.0964	0.9731
Eqn.21	98.0	96.1	-0.0120	0.3404	0.0044	0.1168	0.9516
Eqn.22	99.0	98.0	0.0025	0.2395	-0.0517	0.0341	0.9760
Eqn.23	98.5	97.0	-0.0124	0.3165	0.0109	0.1300	0.9581
Eqn.24	96.3	92.8	-0.0005	0.4653	-0.0208	0.0038	0.9095
Eqn.25	96.4	93.0	-0.0612	0.4825	0.2507	0.4239	0.9027
Eqn.26	95.7	91.5	0.0147	0.5438	-0.0870	0.0899	0.8764
Eqn.27	97.3	94.6	0.0158	0.3926	-0.1029	0.1337	0.9356
Eqn.28	97.7	95.4	0.0010	0.3750	-0.0192	0.0088	0.9412
Eqn.29	95.2	90.6	-0.0006	0.5615	-0.0615	0.0033	0.8682
Eqn.30	97.3	94.7	0.0133	0.3873	-0.0664	0.1140	0.9373
Eqn.31	97.5	95.0	-0.0008	0.3818	-0.0042	0.0070	0.9391
Eqn.32	95.6	91.3	0.0016	0.5166	-0.0200	0.0101	0.8884
Eqn.33	97.5	95.0	-0.0039	0.3809	0.0103	0.0344	0.9394

Table 2 shows summary of the statistical test based on the three variable correlations. The values of the correlation coefficient, R and coefficient of determination, R^2 for all the proposed models were observed to vary between (94.2 – 99.1)% and (88.8 – 98.2)% indicating statistical significant between the estimated and measured global solar radiation except for the model (Eqn. 14) with 67.7% and 45.9%. Based on R and R^2 the model (Eqn. 20) has the highest values and was judged the best performing model while the model (Eqn. 14) with the lowest values was judged to be the worst. Based on MBE, it was observed that there is some slight underestimation and overestimation in the estimated values, the model (Eqn. 24) has the lowest value of MBE as compared with all the proposed models and was considered as the best performing model while the model (Eqn. 14) has the highest MBE value and was considered the weakest performing model. Based on RMSE, all the developed models show overestimation in the estimated value. However, the model (Eqn. 22) has the lowest value of RMSE and was considered the best performing model while the model (Eqn. 14) has the highest value and considered the weakest performing model. Based on MPE, despite the observed overestimation and underestimation exhibited by some of the developed models they are fall within the acceptable range ($MPE \leq \pm 10\%$) with model (Eqn. 31) been the lowest and model (Eqn. 14) the highest. The study site is statistically tested at the $(1-\alpha)$ confidence levels of significance of 95% and 99%. For the critical t-value, i.e., at α level of significance and degree of freedom, the calculated t-value must be less than the critical value ($t_{critical} = 2.20,\ df = 11, p < 0.05$) for 95% and ($t_{critical} = 3.12, df = 11, p < 0.01$) for 99%. It is shown that the $t_{cal} < t_{critical}$ values. The $t -$ test shows that all models are significant at 95% and 99% confidence levels.

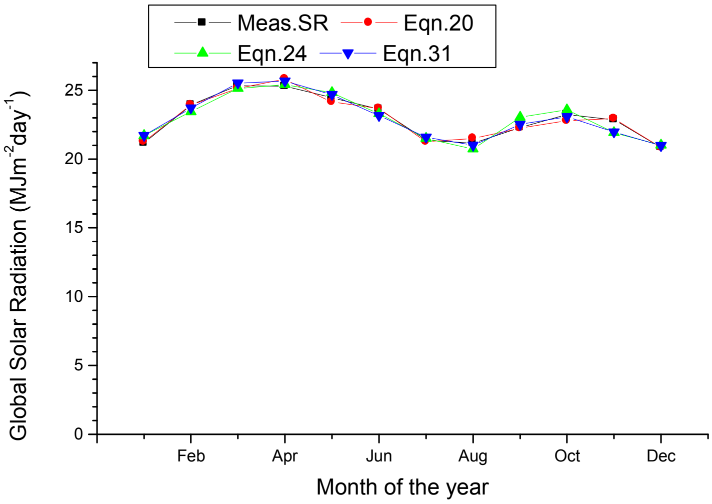

Figure 2: Comparison between the measured and the recommended estimated global solar radiation

Figure 2 shows that a good relationship exists between the measured and the recommended estimated global solar radiation.

4. Conclusion

The monthly average daily global solar radiation, sunshine duration, wind speed, maximum and minimum temperatures, rainfall, cloud cover and relative humidity parameters during the period of thirty one years (1980 – 2010) for Kano, Nigeria (Latitude 12.03^{0}N, Longitude 08.12^{0}E and altitude 472.5 m above sea level) have been employed in this study to develop twenty empirical regression correlation equations. Three equations with three different meteorological variables has been developed and recommended for the estimation of global solar radiation in Kano, North – Western, Nigeria and locations with similar climatic information where any of the three meteorological variables of the recommended models are available. The model (Eqn. 20) with the highest value of R and R^2, the model (Eqn. 24) with the least value of RMSE and the highest value of NSE, the model (Eqn. 31) with the least values of MPE and t – test are recommended for the estimation of global solar radiation in Kano and its environs. It was observed from figure 2 that a good correlation exist between the measured and estimated global solar radiation except for the model (Eqn. 14) which gives a noticeable underestimation in the estimated value in the months of January – April and overestimation in the months of June – September, this could be attributed to the weak performance in the correlation coefficient (R) and coefficient of determination (R^2) exhibited by the model and/or variability in the atmospheric parameters during measurement.

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