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The Impact of some Meteorological Variables on the Estimation of Global Solar Radiation in Kano, North Western, Nigeria

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Abstract
This study examines the impact of measured monthly average daily global solar radiation, sunshine duration, wind speed, maximum and minimum temperatures, rainfall, cloud cover and relative humidity parameters on the estimation of global solar radiation 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) using different selected proposed empirical models. The accuracy of the proposed models are tested using statistical indicator; Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t – test, correlation coefficient (R) and coefficient of determination (R^2). The developed models are based on one variable correlation, two variable correlations, three variable correlations, four variable correlations, five variable correlations and six variable correlations, in each case one or two empirical models has been recommended based on their outstanding performance in line with the statistical test subjected to. The model (Eqn. 36) with the highest values of R and R^2 and lowest values of MBE, RMSE, MPE and t – test as compared with other developed model is considered the best performing model. It was observed that the newly recommended developed models (Eqns. 13, 17, 21, 26, 27, 31, 35 and 36) can be used for estimating daily values of global solar radiation with higher accuracy and has good adaptability to highly changing climatic conditions for Kano and regions of similar climatic information.
Keywords: global solar radiation, sunshine duration, wind speed, rainfall and coefficient of determination.

1. Introduction

In the recent scenario of increasing depletion of various energy sources, solar energy proves to be an excellent alternative energy source (Ekwe *et al*., 2014). Solar radiation affects the earth's weather processes which determine the natural environment. Solar energy is the clean, abundant, renewable and sustainable energy resource from the sun which reaches the earth inform of light and heat (Nwokoye, 2006; Okonkwo and Nwokoye, 2011). Its presence at the earth's surface is necessary for the provision of food for mankind.

According to Galiwala et al. (2013), solar radiation and sunshine duration are two of the most important variables in the energy budget on the earth and play an important role in the performance evaluation of renewable energy systems and in many other applications like health, agriculture, construction etc.

The solar radiation has temporal and spatial variations. To collect this information, a network of solar monitoring stations equipped with pyranometers and data acquisition systems are generally established in the targeted locations of interest. Unfortunately, the number of such stations in the network is usually not sufficient to provide solar radiation data of the desired areas, especially in developing countries. This is mainly because high cost is involved with the measuring equipment and techniques. Therefore, it is necessary to develop methods to estimate the solar radiation on the basis of the more readily available meteorology data (Husaein, 2012). 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), Amitabh et al. (2014), Augustine and Nnabuchi (2009), Majnooni-Heris et al. (2014), Falayi (2013), Akpootu and Momoh (2014), Akpootu and Sanusi (2015), Muzathik et al. (2011), Ekwe et al. (2014) and Ugwu and Ugwuanyi (2011) to mention but a few.

The aim of this paper is to develop different sets of variable correlation models capable of estimating global solar radiation for Kano and its environs using the measured monthly average daily global solar radiation, sunshine duration, wind speed, maximum and minimum temperatures, rainfall, cloud cover and relative humidity parameters. The essence of developing different models is to identify the most appropriate models for estimating global solar radiation.

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):

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

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):

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

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

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_0 and S_0 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 is given as

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

where a……g are the regression coefficients and x_1......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

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

where n is the total number of meteorological variables under study and r is the number of meteorological variables to be combined. Minitab 16 software program was used in evaluating the model parameters. In this study, the best two and worst two regression equations based on coefficient of determination was selected for 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) and t-test. The expressions for the MBE, RMSE and MPE as stated according to El-Sebaii and Trabea (2005) 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.

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

From equations (9), (10) (11) and (12) 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. 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, RMSE and MPE 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 a level of significance and (n-1) degrees of freedom. For the model's estimates to be judged statistically significant at the(1-a) confidence level, the computed t value must be less than the critical value. 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 (^0C)	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 linear regression analyses developed in this study are as follows:

One variable correlation: This correlation gives the highest values of R^2 as 92.0% and 89.6% for RF and RH and the lowest values of R^2 as 0.6% and 11.4% for WS and T_a with their corresponding σ as

$$\frac{H_{cal}}{H_0} = 0.693 - 0.000455\, RF\ (R^2 = 92.0\%\ and\ \sigma = 0.01591) \quad (13)$$

$$\frac{H_{cal}}{H_0} = 0.758 - 0.00226\, RH\ (R^2 = 89.6\%\ and\ \sigma = 0.01815) \quad (14)$$

$$\frac{H_{cal}}{H_0} = 0.689 - 0.0042\, WS\ (R^2 = 0.6\%\ and\ \sigma = 0.05623) \quad (15)$$

$$\frac{H_{cal}}{H_0} = 0.804 - 0.00558\, T_a\ (R^2 = 11.4\%\ and\ \sigma = 0.05306) \quad (16)$$

Two variable correlations: The incorporation of one extra parameter to the sets of correlation equation for one variable yield the highest values of R^2 (95.5%) for $\frac{S}{S_0}$ and RH, $R^2(95.0\%)$ for RF and RH and the lowest values of $R^2(11.6\%)$ for WS and T_a, $R^2(41.9\%)$ for $\frac{S}{S_0}$ and T_a with their corresponding σ as

$$\frac{H_{cal}}{H_0} = 0.509 + 0.377\frac{S}{S_0} - 0.00196\, RH\ \ (R^2 = 95.5\%\ and\ \sigma = 0.01262) \quad (17)$$

$$\frac{H_{cal}}{H_0} = 0.724 - 0.000271 RF - 0.00101\, RH\ \ (R^2 = 95.0\%\ and\ \sigma = 0.01332) \quad (18)$$

$$\frac{H_{cal}}{H_0} = 0.793 + 0.0020\, WS - 0.00577\, T_a\ \ (R^2 = 11.6\%\ and\ \sigma = 0.05589) \quad (19)$$

$$\frac{H_{cal}}{H_0} = 0.102 + 0.890\, \frac{S}{S_0} - 0.00017\, T_a\ \ (R^2 = 41.9\%\ and\ \sigma = 0.04530) \quad (20)$$

Three variable correlations: in the three variable equations the highest values of R^2 (98.2%) was found for $\frac{S}{S_0}$, T_a and RH also R^2 (98.0%) for $\frac{S}{S_0}$, RF and RH while the lowest values of R^2 (45.9%) for $\frac{S}{S_0}$, WS and T_a also R^2 (88.8%) for $\frac{S}{S_0}$, WS and CC with their corresponding σ as

$$\frac{H_{cal}}{H_0} = 0.357 + 0.488\, \frac{S}{S_0} + 0.00324\, T_a - 0.00207 RH (R^2 = 98.2\%\ and\ \sigma = 0.00850) \quad (21)$$

$$\frac{H_{cal}}{H_0} = 0.542 + 0.289\, \frac{S}{S_0} + 0.000199 RF - 0.00112 RH (R^2 = 98.0\%\ and\ \sigma = 0.00827) \quad (22)$$

$$\frac{H_{cal}}{H_0} = -0.042 + 0.985\, \frac{S}{S_0} + 0.0125\, WS - 0.00073 T_a (R^2 = 45.9\%\ and\ \sigma = 0.04638) \quad (23)$$

$$\frac{H_{cal}}{H_0} = 0.830 + 0.297\, \frac{S}{S_0} + 0.00219\, WS - 0.0677\, CC\ (R^2 = 88.8\%\ and\ \sigma = 0.02113) \quad (24)$$

Four variable correlations: in the four variable equations the highest values of R^2 (99.0%) was found for $\frac{S}{S_0}$, T_a, RF and RH, R^2 (99.0%) for $\frac{S}{S_0}, RF, CC$ and RH also R^2 (98.2%) for $\frac{S}{S_0}$, WS, T_a and RH, R^2 (98.2%) for $\frac{S}{S_0}, T_a, CC$ and RH while the lowest values of R^2 (93.1%) for WS, T_a, CC and RH also R^2 (94.7%) for $\frac{S}{S_0}$, WS, T_a and RF with their corresponding σ as

$$\frac{H_{cal}}{H_0} = 0.426 + 0.396\frac{S}{S_0} + 0.00222T_a - 0.000129RF - 0.00149RH (R^2 = 99.0\% \; and \; \sigma = 0.00679) \quad (25)$$

$$\frac{H_{cal}}{H_0} = 0.292 + 0.394\frac{S}{S_0} + 0.000178\,RF + 0.0421CC - 0.00230RH (R^2 = 99.0\% \; and \; \sigma = 0.00686) \quad (26)$$

$$\frac{H_{cal}}{H_0} = 0.375 + 0.474\frac{S}{S_0} - 0.00138\,WS + 0.00333T_a - 0.00208RH (R^2 = 98.2\% \; and \; \sigma = 0.00898) \quad (27)$$

$$\frac{H_{cal}}{H_0} = 0.378 + 0.483\frac{S}{S_0} + 0.00341T_a - 0.0049CC - 0.00195RH (R^2 = 98.2\% \; and \; \sigma = 0.00907) \quad (28)$$

$$\frac{H_{cal}}{H_0} = 1.04 - 0.00805WS + 0.00508\,T_a - 0.0794CC - 0.00036RH (R^2 = 93.10\% \; and \; \sigma = 0.01773) \quad (29)$$

$$\frac{H_{cal}}{H_0} = 0.515 + 0.267\frac{S}{S_0} + 0.00236\,WS - 0.00048T_a - 0.000403RF (R^2 = 94.7\% \; and \; \sigma = 0.01557) \quad (30)$$

Five variable correlations: in the five variable equations the highest values of R^2 (99.1%) was found for $\frac{S}{S_0}$, T_a, RF, CC and RH also R^2 (99.0%) for $\frac{S}{S_0}$, WS, T_a RF and RH, R^2 (99.0%) for $\frac{S}{S_0}$, WS, RF, CC and RH while the lowest values of R^2 (95.4%) for WS, T_a, RF, CC and RH also R^2 (97.8%) for $\frac{S}{S_0}$, WS, T_a, RF and CC with their corresponding σ as

$$\frac{H_{cal}}{H_0} = 0.343 + 0.406\frac{S}{S_0} + 0.00129T_a - 0.000147RF + 0.0222CC - 0.00196RH (R^2 = 99.1\% \; and \; \sigma = 0.00700) \quad (31)$$

$$\frac{H_{cal}}{H_0} = 0.435 + 0.390\frac{S}{S_0} + 0.00070WS + 0.00228T_a - 0.000127RF - 0.00150RH (R^2 = 99.0\% \; and \; \sigma = 0.00729) \quad (32)$$

$$\frac{H_{cal}}{H_0} = 0.281 + 0.403\frac{S}{S_0} + 0.00075WS - 0.000178RF + 0.0420CC - 0.00229RH (R^2 = 99.0\% \; and \; \sigma = 0.00736) \quad (33)$$

$$\frac{H_{cal}}{H_0} = 0.808 - 0.00437WS + 0.00102T_a - 0.000236RF - 0.0159CC - 0.00079RH (R^2 = 95.4\% \; and \; \sigma = 0.01553) \quad (34)$$

$$\frac{H_{cal}}{H_0} = 0.685 + 0.323\frac{S}{S_0} - 0.00161WS + 0.00419T_a - 0.000137RF - 0.0571CC (R^2 = 97.8\% \; and \; \sigma = 0.01074) \quad (35)$$

Six variable correlations: The equation involves all the six variables and has R^2(99.1%) and its σ is as follows

$$\frac{H_{cal}}{H_0} = 0.345 + 0.406\frac{S}{S_0} - 0.00009WS + 0.00131T_a - 0.000147RF + 0.0219CC - 0.00195RH \quad (R^2 = 99.1\% \; and \; \sigma = 0.00767) \quad (36)$$

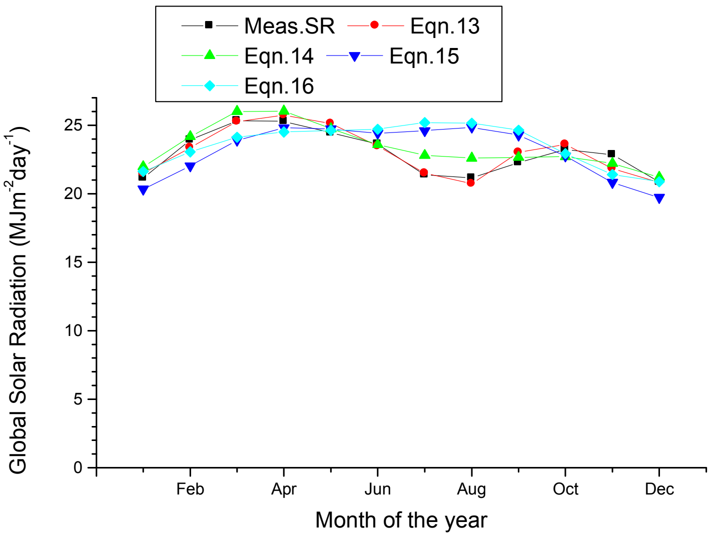

Figure 1: Comparison between the measured and the estimated global solar radiation for one variable correlation

Figure 1 shows the Comparison between the measured and the estimated global solar radiation for one variable correlation. It can be seen from the figure that a perfect correlation does not exist between the measured and the estimated global solar radiation. This effect is attributed to the selection of the two worst results (Eqn. 15 and 16) based on the coefficient of determination of 0.6% and 11.4% which will also be consider for the statistical analysis for comparison. However, Eqn.s 13 and 14 gives a good correlation with the measured values.

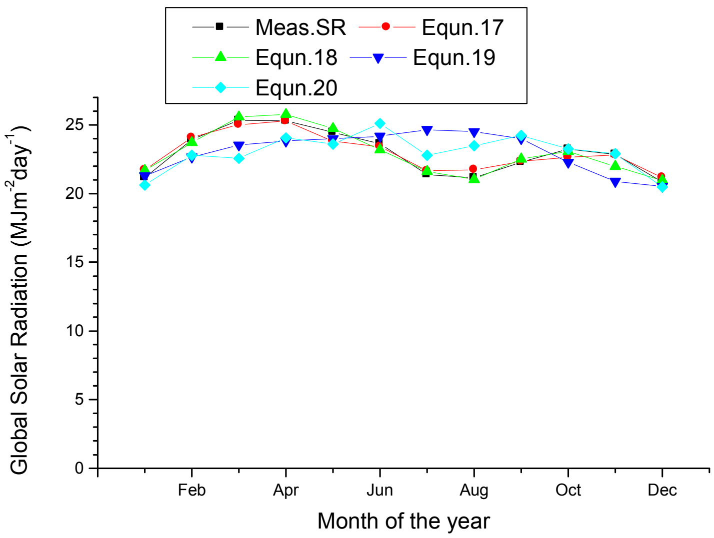

Figure 2: Comparison between the measured and the estimated global solar radiation for two variable correlations

Figure 2 shows the Comparison between the measured and the estimated global solar radiation for two variable correlations. It can be seen from the figure that a perfect correlation does not exist between the measured and the estimated global solar radiation. This effect is attributed to the selection of the two worst results (Eqn. 19 and 20) based on the coefficient of determination of 11.6% and 41.9% which will also be consider for the statistical analysis for comparison. However, Eqns.17 and 18 gives a good correlation with the measured values.

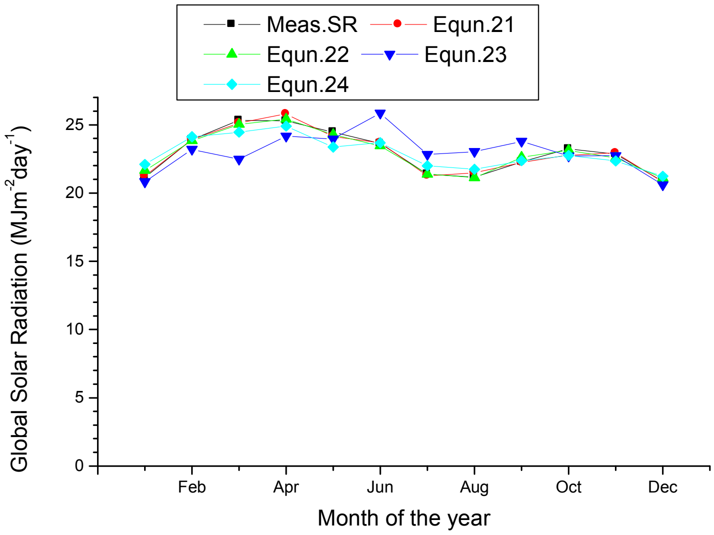

Figure 3: Comparison between the measured and the estimated global solar radiation for three variable correlations

Figure 3 shows the Comparison between the measured and the estimated global solar radiation for three variable correlations. The figure shows that a good correlation exists between the measured and estimated global solar radiation except for Eqn. 23 which shows a noticeable underestimation of the measured and other estimated values in the months of January – April and overestimation of the measured and other estimated values in the months of June – September. This effect is due to Eqn. 23 having the least coefficient of determination of 45.9%.

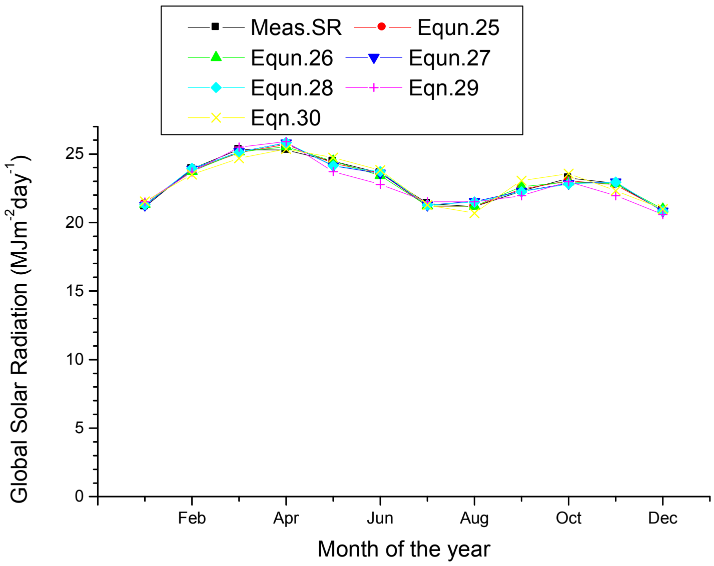

Figure 4: Comparison between the measured and the estimated global solar radiation for four variable correlations

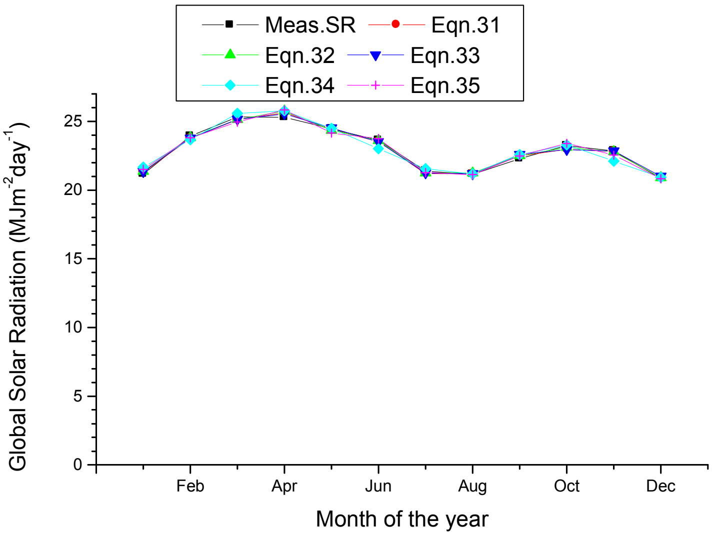

Figure 5: Comparison between the measured and the estimated global solar radiation for five variable correlations

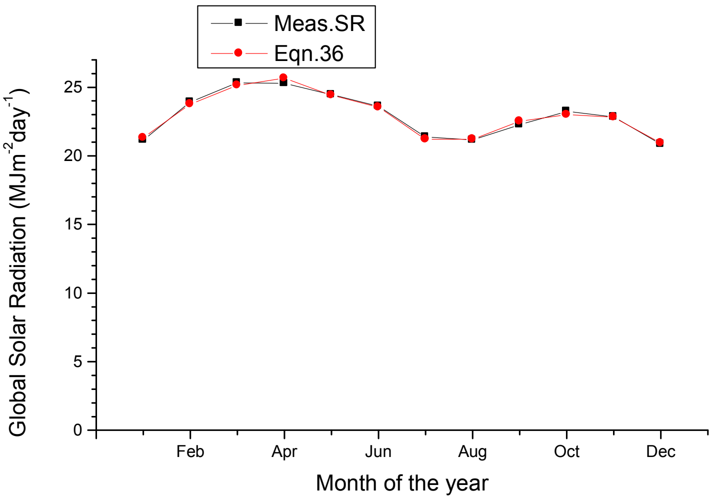

Figure 6: Comparison between the measured and the estimated global solar radiation for six variable correlations

Figure 4, 5 and 6 shows the Comparison between the measured and the estimated global solar radiation for the four, five and six variable correlations. It can be seen from the figures that a nearly perfect correlation exists between the measured and estimated global solar radiation. Though, there are some few slightly underestimation and overestimation of the estimated values. The good correlation that existed is attributed to the fact that all the developed models give a reasonable high coefficient of correlation and coefficient of determination$(> 93\%)$.

Table 2: Validation of the models under different statistical test for one variable correlation

Models	R (%)	R^2 (%)	MBE ($MJm^{-2}day^{-1}$)	RMSE ($MJm^{-2}day^{-1}$)	MPE (%)	t
Eqn.13	95.9	92.0	0.0370	0.4995	-0.1477	0.2462
Eqn.14	94.7	89.6	0.4334	0.7598	-1.9561	2.3035
Eqn.15	7.7	0.6	0.1427	1.8448	-0.8541	0.2572
Eqn.16	33.8	11.4	0.6086	1.8832	-2.9822	1.1326

Table 2 shows the summary of the various statistical tests performed on the one variable correlation to ascertain the accuracies of the proposed models. Based on the coefficient of correlation, *R* and coefficient of determination, R^2. The model (Eqn. 13) has the highest values and is judged as the best model while the model (Eqn. 15) has the lowest values and is judged to be the worst. Based on MBE it was observed that all the models (Eqn. 13 – 16) indicate overestimation in the estimated values. However, the model (Eqn. 13) has the lowest MBE value as compared with all the developed models and was returned as the best performing model while the model (Eqn. 16) has the highest MBE value and was returned as the weakest performing model. Based on RMSE, it was observed that all the developed models exhibit overestimation in the estimated values. However, the model (Eqn. 13) has the lowest value as compared to all the developed models and was returned as the best performing model while the model (Eqn. 16) has the highest RMSE value and was returned the weakest performing model. Based on MPE, all the models indicate underestimation in estimated values and perform better as they are all within the acceptable range of -10% and +10% with the model (Eqn. 13) the lowest and model (Eqn. 16) the highest. The study site is statistically tested at the (1-a) 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, except for Eqn. 14 that is only significant at 99% confidence level.

Table 3: Validation of the models under different statistical test for two variable correlations

Models	R (%)	R^2 (%)	MBE ($MJm^{-2}day^{-1}$)	RMSE ($MJm^{-2}day^{-1}$)	MPE (%)	t
Eqn.17	97.7	95.5	0.0093	0.3824	-0.1228	0.0803
Eqn.18	97.5	95.0	0.0209	0.3858	-0.0922	0.1799
Eqn.19	34.1	11.6	0.0562	1.7622	-0.5813	0.1059
Eqn.20	64.7	41.9	0.0231	1.4435	-0.3571	0.0530

Table 3 shows the summary of the various statistical tests performed on the two variable correlations to ascertain the accuracies of the proposed models. Based on the coefficient of correlation, R and coefficient of determination, R^2. The model (Eqn. 17) has the highest values and is judged as the best model while the model (Eqn. 19) has the lowest values and is judged to be the worst. Based on MBE it was observed that all the models (Eqn. 17 – 20) indicate overestimation in the estimated values. However, the model (Eqn. 17) has the lowest MBE value as compared with all the developed models and was returned as the best performing model while the model (Eqn. 19) has the highest MBE value and was returned as the weakest performing model. Based on RMSE, it was observed that all the developed models exhibit overestimation in the estimated values. However, the model (Eqn. 17) has the lowest value as compared to all the developed models and was returned as the best performing model while the model (Eqn. 19) has the highest RMSE value and was returned the weakest performing model. Based on MPE, all the models indicate underestimation in estimated values and perform better as they are all within the acceptable range of -10% and +10% with the model (Eqn. 18) the lowest and model (Eqn. 19) the highest. The study site is statistically tested at the (1-a) 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, 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.

Table 4: Validation of the models under different statistical test for three variable correlations

Models	R (%)	R^2 (%)	MBE ($MJm^{-2}day^{-1}$)	RMSE ($MJm^{-2}day^{-1}$)	MPE (%)	t
Eqn.21	99.1	98.2	-0.0074	0.2537	0.0240	0.0964
Eqn.22	99.0	98.0	0.0025	0.2395	-0.0517	0.0341
Eqn.23	67.7	45.9	0.0521	1.3994	-0.4567	0.1237
Eqn.24	94.2	88.8	-0.0398	0.6044	0.0304	0.2191

Table 4 shows the summary of the various statistical tests performed on the three variable correlations to ascertain the accuracies of the proposed models. Based on the coefficient of correlation, R and coefficient of determination, R^2. The model (Eqn. 21) has the highest values and is judged as the best model while the model (Eqn. 23) has the lowest values and is judged to be the worst. Based on MBE it was observed that the models (Eqns. 21 and 24) indicate underestimation and the models (Eqns. 22 and 23) indicate overestimation in the estimated values. However, the model (Eqn. 22) has the lowest MBE value as compared with all the developed models and was returned as the best performing model while the model (Eqn. 23) has the highest MBE value and was returned as the weakest performing model. Based on RMSE, it was observed that all the developed models exhibit overestimation in the estimated values. However, the model (Eqn. 22) has the lowest value as compared to all the developed models and was returned as the best performing model while the model (Eqn. 23) has the highest RMSE value and was returned the weakest performing model. Based on MPE, the models (Eqns. 21 and 24) indicate overestimation and the models (Eqns. 22 and 23) indicate underestimation in estimated values and perform better as they are all within the acceptable range of -10% and +10% with the model (Eqn. 21) the lowest and model (Eqn. 23) the highest. The study site is statistically tested at the (1-a) 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<0.01) 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.

Table 5: Validation of the models under different statistical test for four variable correlations

Models	R (%)	R^2 (%)	MBE ($MJm^{-2}day^{-1}$)	RMSE ($MJm^{-2}day^{-1}$)	MPE (%)	t
Eqn.25	99.5	99.0	-0.0140	0.1878	0.0562	0.2472
Eqn.26	99.5	99.0	-0.0113	0.1857	0.0348	0.2014
Eqn.27	99.1	98.2	-0.0034	0.2523	0.0052	0.0450
Eqn.28	99.1	98.2	0.0083	0.2540	-0.0440	0.1082
Eqn.29	96.5	93.1	-0.1635	0.5050	0.6978	1.1353
Eqn.30	97.3	94.7	-0.0072	0.4174	0.0083	0.0574

Table 5 shows the summary of the various statistical tests performed on the four variable correlations to ascertain the accuracies of the proposed models. Based on the coefficient of correlation, *R* and coefficient of determination,R^2 . The model (Eqn. 25 and 26) has the highest values and are judged as the best models while the model (Eqn. 29) has the lowest values and is judged to be the worst. Based on MBE it was observed that all the models indicate underestimation in the estimated values, except the model (Eqn. 28) which indicate overestimation in the estimated value. However, the model (Eqn. 27) has the lowest MBE value as compared with all the developed models and was returned as the best performing model while the model (Eqn. 29) has the highest MBE value and was returned as the weakest performing model. Based on RMSE, it was observed that all the developed models exhibit overestimation in the estimated values. However, the model (Eqn. 26) has the lowest value as compared to all the developed models and was returned as the best performing model while the model (Eqn. 29) has the highest RMSE value and was returned the weakest performing model. Based on MPE, all the models indicate overestimation in estimated values, except the model (Eqn. 28) that indicate underestimation in the estimated value. However, all the models perform better as they are all within the acceptable range of -10% and +10% with the model (Eqn. 27) the lowest and model (Eqn. 29) the highest. The study site is statistically tested at the (1-a) 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.

Table 6: Validation of the models under different statistical test for five variable correlations

Models	R (%)	R^2 (%)	MBE ($MJm^{-2}day^{-1}$)	RMSE ($MJm^{-2}day^{-1}$)	MPE (%)	t
Eqn.31	99.5	99.1	-0.0218	0.1795	0.0894	0.4056
Eqn.32	99.5	99.0	-0.0218	0.1795	0.0894	0.4056
Eqn.33	99.5	99.0	0.0085	0.1835	-0.0497	0.1533
Eqn.34	97.7	95.4	0.0218	0.3737	-0.1054	0.1935
Eqn.35	98.9	97.8	0.0071	0.2691	-0.0397	0.0878

Table 6 shows the summary of the various statistical tests performed on the five variable correlations to ascertain the accuracies of the proposed models. Based on the coefficient of correlation,R and coefficient of determination, R^2. The model (Eqn. 31) has the highest values and is judged as the best model while the model (Eqn. 34) has the lowest values and is judged to be the worst. Based on MBE it was observed that the models (Eqn. 31 and 32) indicate underestimation in the estimated values and the models (Eqns. 33 – 35) indicate overestimation in the estimated value. However, the model (Eqn. 35) has the lowest MBE value as compared with all the developed models and was returned as the best performing model while the models (Eqns. 31, 32 and 34) has the highest MBE value and was returned as the weakest performing model. Based on RMSE, it was observed that all the developed models exhibit overestimation in the estimated values. However, the models (Eqns. 31 and 32) has the lowest value as compared to all the developed models and was returned as the best performing model while the model (Eqn. 34) has the highest RMSE value and was returned the weakest performing model. Based on MPE, the models (Eqns. 31 and 32) indicate overestimation in estimated values and the models (Eqns. 33 – 35) indicate underestimation in the estimated values. The developed models perform better as they are all within the acceptable range of-10% and +10% with the model (Eqn. 35) the lowest and model (Eqn. 34) the highest. The study site is statistically tested at the (1-a) 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.

Table 7: Validation of the models under different statistical test for six variable correlations

Models	R (%)	R^2 (%)	MBE ($MJm^{-2}day^{-1}$)	RMSE ($MJm^{-2}day^{-1}$)	MPE (%)	t
Eqn.36	99.5	99.1	-0.0010	0.1784	-0.0018	0.0181

All the statistical test analysis for the six variable correlations shown on Table 7 shows high statistical significant relationship between the estimated and measured global solar radiation based on the six meteorological variables used in the study site.

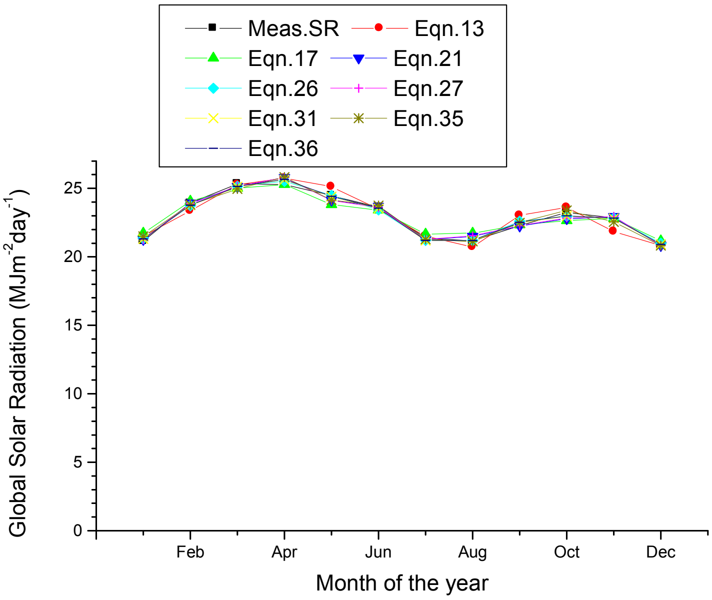

Figure 7: Comparison between the measured and the recommended estimated global solar radiation

Figure 7 shows that a good correlation exists between the measured and the recommended estimated global solar radiation.

Table 8: 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
Eqn.13	95.9	92.0	0.0370	0.4995	-0.1477	0.2462
Eqn.14	94.7	89.6	0.4334	0.7598	-1.9561	2.3035
Eqn.15	7.7	0.6	0.1427	1.8448	-0.8541	0.2572
Eqn.16	33.8	11.4	0.6086	1.8832	-2.9822	1.1326
Eqn.17	97.7	95.5	0.0093	0.3824	-0.1228	0.0803
Eqn.18	97.5	95.0	0.0209	0.3858	-0.0922	0.1799
Eqn.19	34.1	11.6	0.0562	1.7622	-0.5813	0.1059
Eqn.20	64.7	41.9	0.0231	1.4435	-0.3571	0.0530
Eqn.21	99.1	98.2	-0.0074	0.2537	0.0240	0.0964
Eqn.22	99.0	98.0	0.0025	0.2395	-0.0517	0.0341
Eqn.23	67.7	45.9	0.0521	1.3994	-0.4567	0.1237
Eqn.24	94.2	88.8	-0.0398	0.6044	0.0304	0.2191
Eqn.25	99.5	99.0	-0.0140	0.1878	0.0562	0.2472
Eqn.26	99.5	99.0	-0.0113	0.1857	0.0348	0.2014
Eqn.27	99.1	98.2	-0.0034	0.2523	0.0052	0.0450
Eqn.28	99.1	98.2	0.0083	0.2540	-0.0440	0.1082
Eqn.29	96.5	93.1	-0.1635	0.5050	0.6978	1.1353
Eqn.30	97.3	94.7	-0.0072	0.4174	0.0083	0.0574
Eqn.31	99.5	99.1	-0.0218	0.1795	0.0894	0.4056
Eqn.32	99.5	99.0	-0.0218	0.1795	0.0894	0.4056
Eqn.33	99.5	99.0	0.0085	0.1835	-0.0497	0.1533
Eqn.34	97.7	95.4	0.0218	0.3737	-0.1054	0.1935
Eqn.35	98.9	97.8	0.0071	0.2691	-0.0397	0.0878
Eqn.36	99.5	99.1	-0.0010	0.1784	-0.0018	0.0181

Table 8 shows the overall statistical test for all the variable correlation for Kano, North- Western, Nigeria based on thirty one years (1980-2010) meteorological data. From the results obtained the model (Eqn. 36) exhibits the minimum value of MBE (-0.0010), RMSE (0.1784), MPE (-0.0018) and t-test (0.0181) which is desirable and also shows maximum values of correlation coefficient, R (99.5%) and coefficient of determination, R^2 (99.1%). Therefore, the model (Eqn. 36) is reported to be best suitable for the estimation of monthly average daily global solar radiation on a horizontal surface for Kano for cases where all the six meteorological parameters are available.

4. Conclusion

In this study, multiple linear regression equations based on one variable correlation, two variable correlations, three variable correlations, four variable correlations, five variable correlations and six two variable correlations were developed and used to estimate the global solar radiation in Kano with clearness index been the dependent variable and the six meteorological variables as the independent variables. The best performing models from each of the variable correlations has been recommended, for one variable correlation (Eqn. 13), two variable correlations (Eqn. 17), three variable correlations (Eqns. 21), four variable correlations (Eqns. 26 and 27), five variable correlations (Eqns. 31 and 35) and six variable correlations (Eqn. 36). Even though up to six variable correlations has been developed, it was observed that the model (Eqn. 36) with the highest values of R and R^2 and lowest values of MBE, RMSE, MPE and t – test as compared with other developed model is considered the best performing model. Our study further revealed that a good correlation or fitting between the estimated and measured global solar radiation requires a high correlation coefficient (R) and coefficient of determination (R^2).

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