Developing Empirical Models for Predicting Diffuse Solar Radiation over Yola, Adamawa State, North-Eastern, Nigeria

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Abstract - ***In this study, several regression empirical models were developed to estimate the diffuse solar radiation for Yola, North Eastern, Nigeria (Latitude 09.14^{0}N, Longitude 12.28^{0}E and altitude 186.1 m above sea level). The input parameters are the measured monthly average daily global solar radiation, sunshine duration, wind speed, maximum and minimum temperatures, rainfall, cloud cover and relative humidity during the period of thirty one years (1980 – 2010). The results of this work show that the addition of a single meteorological variable to the well-known Page model in developing a model gives better results in the estimation of diffuse solar radiation in the study area and its environs. The contribution of diffuse solar radiation is high during the months of July and August whereas sky conditions are clear during the dry season. The analyses of the monthly average of diffuse to global solar radiation reveals that Yola enjoys clear sky weather condition of at least 80% throughout the year. The accuracy of the developed models were statistical tested using Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t – test and coefficient of determination (R^2) from which the model (Eqn. 28) was recommended based on R^2, RMSE and MPE while the model (Eqn. 31) was recommended based on R^2, MBE and t – test.***

Key Words: *Diffuse solar radiation, clearness index, cloud cover, wind speed, clear sky weather condition.*

1. INTRODUCTION

With the rapid depletion of fossil fuel reserves, it is feared that the world will soon run out of its energy resources. This is a matter of concern for the developing countries whose economy heavily leans on its use of energy. Under these situations it is highly desirable that alternate energy resources should be utilized with maximum conversion efficiency to cope with the ever increasing energy demand. Among the non-conventional energy resources, solar energy, wind energy and biomass has emerged the most prospective option for the future. Detailed information about the availability of solar radiation on horizontal surface is essential for the optimum design and study of solar energy conversion system. For a country like Nigeria, the economical and efficient application of solar energy seems inevitable because of abundant sunshine available throughout the year. The global solar radiation is divided into two components; diffuse solar radiation, which results from scattering of solar radiation caused by gases in the Earth's atmosphere, dispersed water droplets and particulates while direct solar radiation, sometimes called beam radiation is used to describe solar radiation travelling on a straight line from the sun down to the surface of the Earth. That is, one that have not been scattered. Global solar radiations in Nigeria are measured at some stations while diffuse solar radiation is not observed experimentally in any meteorological station of the country. However, empirical correlations are usually used to extract diffuse and direct solar radiation from the global solar radiation obtained over a horizontal surface from the location under study. The monthly average daily diffuse solar radiation is usually estimated using an empirical formula developed by Page [16] which correlates the diffuse components of the solar radiation to the daily measured total radiation. [12] Proposed a model relating the ratio of diffuse to global solar radiation incident on a horizontal surface with the clearness index and developed by [11]. In another study, [4] proposed a fourth order polynomial relation using data from five stations in United States. Similarly, [3] proposed another fourth order polynomial relation using data from India. [15] Used measurements of global and diffuse solar radiations at the Earth's surface, in the city of Sao Paulo, Brazil to develop correlation models to estimate hourly, daily and monthly diffuse solar radiation on horizontal surfaces. [7] Presented that the correlations relating the diffuse fraction with clearness index, the relative sunshine duration, relative humidity and ratio of maximum to minimum daily temperature are more reliable for diffuse radiation predictions in the Nigeria environment than using each variable separately. Other related studies include that of [1], [8], [10], [13 – 14] and [18] to mention but a few.

The objective of this study is to find out the best performing models for estimating diffuse solar radiation based on the modification of the well-known existing page model and other developed regression empirical models using several meteorological variables.

2. METHODOLOGY

The measured monthly average daily global solar radiation, sunshine duration, wind speed, maximum and minimum temperatures, rainfall, cloud cover and relative humidity covering a period of thirty one years (1980-2010) for Yola, Adamawa State, North – Eastern, Nigeria was obtained from the Nigeria 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 monthly average daily extraterrestrial radiation on a horizontal surface (H_o) in $(MJm^{-2}day^{-1})$ can be calculated for days giving average of each month [9], [17] and [19] from the following equation [9] and [19]:

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

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 [9] and [19]:

$$\delta = 23.45sin\left\{360\left(\frac{284+n}{365}\right)\right\} \quad (2)$$

$$W_s = Cos^{-1}(-tan\varphi tan\delta) \quad (3)$$

[16] proposed a model for estimating diffuse solar radiation which is given by the relation

$$\frac{H_d}{H} = 1.00 - 1.13K_T \quad (4)$$

[12] Proposed a correlation which was developed by [11] and is given by the relation

$$\frac{H_d}{H} = 1.390 - 4.027K_T + 5.531{K_T}^2 - 3.108{K_T}^3 \quad (5)$$

From equations (4) and (5) H_d is the diffuse solar radiation$(MJm^{-2}day^{-1})$, H is the global solar radiation $(MJm^{-2}day^{-1})$ K_T is the clearness index. The clearness index (K_T) is calculated using [5] as

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

The global solar radiation (H) diffuse solar radiation (SR_{diff}) and direct solar radiation (SR_{dir}) are related by the equation:

$$H = SR_{diff} + SR_{dir} \quad (7)$$

where H, is the global solar radiation, SR_{diff} is the diffuse solar radiation and SR_{dir} is the direct solar radiation. H, SR_{diff} and SR_{dir} are measured in $(MJm^{-2}day^{-1})$. Equations (4) and (5) were applied to obtain the diffuse radiation due to [16] and [12] respectively, being the most popularly applied models for estimating the diffuse fraction of the global solar radiation. Subsequently, the average of the two values obtained from them was used to determine the diffuse solar radiation for Yola, Nigeria. Minitab 16 software program was used in evaluating the model parameters. The performance of each of the models was tested statistically 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 based on the modification of the [6] are stated according to the following equations.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(H_{d_{i,cal}} - H_{d_{i,meas}}\right) \quad (8)$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(H_{d_{i,cal}} - H_{d_{i,meas}}\right)^2\right]^{\frac{1}{2}} \quad (9)$$

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_{d_{i,meas}} - H_{d_{i,cal}}}{H_{d_{i,meas}}}\right) * 100 \quad (10)$$

The t-test defined by student [2] in one of the tests for mean values, the random variable t with n-1 degrees of freedom may be written as follows.

$$t = \left[\frac{(n-1)(MBE)^2}{(RMSE)^2 - (MBE)^2}\right]^{\frac{1}{2}} \quad (11)$$

From equations (8), (9) and (10) above $H_{d_{i,meas}}$, $H_{d_{i,cal}}$ and n are respectively the i^{th} measured and i^{th} calculated values of daily diffuse solar radiation and the total number of observations. Generally, a low RMSE and MBE are desirable while positive MBE shows overestimation while a negative MBE indicates underestimation. The MPE test gives long term performance of the examined regression equations, a positive MPE values provide the averages amount of the overestimation in the calculated values, while the negative values gives underestimation. For better data modelling, the coefficient of determination R^2 should approach 1 (100%) as closely as possible.

3. RESULTS AND DISCUSSION

Table 1: Input parameters for estimation of monthly average daily diffuse solar radiation for Yola (1980 – 2010)

Mth	S/S_0	WS	T_{mx}-T_{mn}	RF	CC	RH
Jan	0.64	3.25	16.83	0.04	6.25	23.68
Feb	0.60	3.82	15.79	4.25	6.46	20.19
Mar	0.56	4.48	14.81	6.12	6.74	32.23
Apr	0.58	4.71	12.95	53.13	6.80	43.94
May	0.64	4.43	10.97	98.22	6.89	61.90
Jun	0.60	4.25	10.04	132.45	6.94	68.65
Jul	0.52	4.05	8.87	194.23	6.99	72.55
Aug	0.51	3.88	7.95	194.68	6.92	76.55
Sep	0.56	3.39	8.36	153.07	6.95	76.55
Oct	0.67	3.13	11.45	50.51	6.82	62.13
Nov	0.77	3.22	17.07	0.44	6.53	38.71
Dec	0.73	3.21	17.39	0.00	6.34	32.90

The various meteorological parameters shown in Table 1 are all related to the diffuse 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 $\left(\frac{S}{S_0}, WS, T_{max}-T_{min}, RF, CC \text{ and } RH\right)$ with $\frac{H_d}{H_m}$ been the dependent variable was employed. Here, the six meteorological parameters represents the monthly average daily sunshine duration in hours, monthly average daily wind speed in ms^{-1}, monthly average daily temperature in ℃, monthly average daily rainfall in mm, monthly average daily cloud cover and monthly average daily relative humidity in %. The various linear regression analyses developed in this study for estimating diffuse solar radiation for Yola during the period of thirty one years are as follows:

$$\frac{H_d}{H_m} = a + b\left(\frac{H}{H_0}\right) + c\left(\frac{S}{S_0}\right) \quad (12)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{H}{H_0}\right) + cWS \quad (13)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{H}{H_0}\right) + c(T_{max} - T_{min}) \quad (14)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{H}{H_0}\right) + cRF \quad (15)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{H}{H_0}\right) + cCC \quad (16)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{H}{H_0}\right) + cRH \quad (17)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{S}{S_0}\right) + cRH \quad (18)$$

$$\frac{H_d}{H_m} = a + bRF + cRH \quad (19)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{S}{S_0}\right) + c(T_{max} - T_{min}) + dRH \quad (20)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{S}{S_0}\right) + cRF + dRH \quad (21)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{S}{S_0}\right) + c(T_{max} - T_{min}) + dRF + eRH \quad (22)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{S}{S_0}\right) + cWS + d(T_{max} - T_{min}) + eRH \quad (23)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{S}{S_0}\right) + c(T_{max} - T_{min}) + dRF + eCC + fRH \quad (24)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{S}{S_0}\right) + cWS + d(T_{max} - T_{min}) + eRF + eRH \quad (25)$$

$$\frac{H_d}{H_m} = a + b\left(\frac{S}{S_0}\right) + cWS + d(T_{max} - T_{min}) + eRF + fCC + gRH \quad (26)$$

The developed empirical regression equations based on equations (12 – 26) are

$$\frac{H_{dp}}{H_m} = 0.882 - 0.953\left(\frac{H}{H_0}\right) - 0.00565\left(\frac{S}{S_0}\right) \ (R^2 = 100\%) \quad (27)$$

$$\frac{H_{dp}}{H_m} = 0.878 - 0.955\left(\frac{H}{H_0}\right) + 0.000617WS \ (R^2 = 100\%) \quad (28)$$

$$\frac{H_{dp}}{H_m} = 0.878 - 0.945\left(\frac{H}{H_0}\right) - 0.000281(T_{max} - T_{min}) \ (R^2 = 100\%) \quad (29)$$

$$\frac{H_{dp}}{H_m} = 0.914 - 1.00\left(\frac{H}{H_0}\right) - 0.000049RF \ (R^2 = 100\%) \quad (30)$$

$$\frac{H_{dp}}{H_m} = 0.866 - 0.952\left(\frac{H}{H_0}\right) + 0.00186CC \ (R^2 = 100\%) \quad (31)$$

$$\frac{H_{dp}}{H_m} = 0.881 - 0.957\left(\frac{H}{H_0}\right) + 0.000RH \ (R^2 = 100\%) \quad (32)$$

$$\frac{H_{dp}}{H_m} = 0.398 - 0.417\left(\frac{S}{S_0}\right) + 0.00257RH \; (R^2 = 94.3\%) \quad (33)$$

$$\frac{H_{dp}}{H_m} = 0.212 + 0.00112RF - 0.000459RH \; (R^2 = 98.6\%) \quad (34)$$

$$\frac{H_{dp}}{H_m} = 0.219 - 0.676\left(\frac{S}{S_0}\right) + 0.0174(T_{max} - T_{min}) + 0.00488RH \; (R^2 = 95.4\%) \quad (35)$$

$$\frac{H_{dp}}{H_m} = 0.279 - 0.126\left(\frac{S}{S_0}\right) + 0.000892RF + 0.000085RH \; (R^2 = 99.2\%) \quad (36)$$

$$\frac{H_{dp}}{H_m} = 0.234 - 0.213\left(\frac{S}{S_0}\right) + 0.00491(T_{max} - T_{min}) + 0.000849RF + 0.00086RH \; (R^2 = 99.2\%) \quad (37)$$

$$\frac{H_{dp}}{H_m} = 0.209 - 0.673\left(\frac{S}{S_0}\right) + 0.0013WS + 0.0175(T_{max} - T_{min}) + 0.00491RH \; (R^2 = 95.4\%) \quad (38)$$

$$\frac{H_{dp}}{H_m} = 0.273 - 0.219\left(\frac{S}{S_0}\right) + 0.00474(T_{max} - T_{min}) + 0.000835RF - 0.0053CC + 0.00092RH \; (R^2 = 99.2\%) \quad (39)$$

$$\frac{H_{dp}}{H_m} = 0.191 - 0.191\left(\frac{S}{S_0}\right) + 0.00534WS + 0.00539(T_{max} - T_{min}) + 0.000865RF + 0.00090RH \; (R^2 = 99.3\%) \quad (40)$$

$$\frac{H_{dp}}{H_m} = 0.678 - 0.237\left(\frac{S}{S_0}\right) + 0.0175WS + 0.00395(T_{max} - T_{min}) + 0.000696RF - 0.0787CC + 0.00197RH \; (R^2 = 99.6\%) \quad (41)$$

Equations (27 – 32) are the modified fashion of the Page model by addition of the six meteorological variables separately. H_{dp} Implies predicted diffuse solar radiation and H_m is the measured global solar radiation.

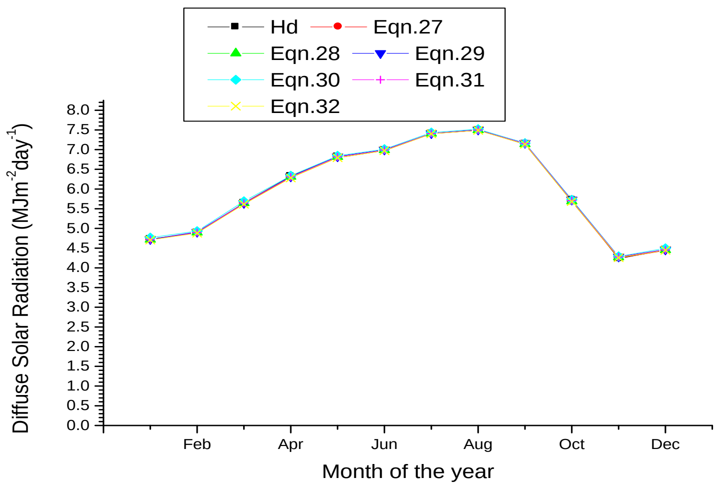

Figure 1: Comparison between the observed diffuse solar radiation (Page and Liu and Jordan Models) and the predicted diffuse solar radiation (Eqn. 27 – 32) for Yola (1980 – 2010)

Figure 1 shows the comparison between the observed diffuse solar radiation (Page and Liu and Jordan Models) and the predicted diffuse solar radiation (Eqn. 27 – 32) for Yola during the period of thirty one years. It is obvious from the figure that a perfect correlation exists between the observed and predicted diffuse solar radiation, this may be attributed to the fact that all the developed models has coefficient of correlation and coefficient of determination of 100%.

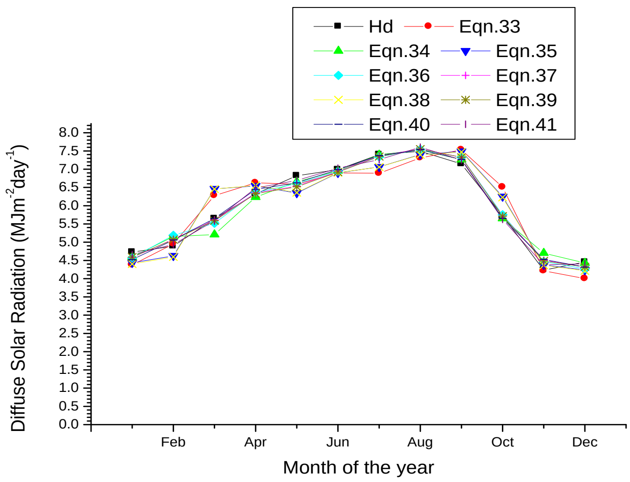

Figure 2: Comparison between the observed diffuse solar radiation (Page and Liu and Jordan Models) and the predicted diffuse solar radiation (Eqn. 33 – 41) for Yola (1980 – 2010)

Figure 2 shows the comparison between the observed diffuse solar radiation (Page and Liu and Jordan Models) and the predicted diffuse solar radiation (Eqn. 33 – 41) for Yola during the period of thirty one years. It is clear that a fairly good correlation exists between the observed and predicted diffuse solar radiation, showing some noticeable forms of underestimation and overestimation in the predicted values of the diffuse solar radiation.

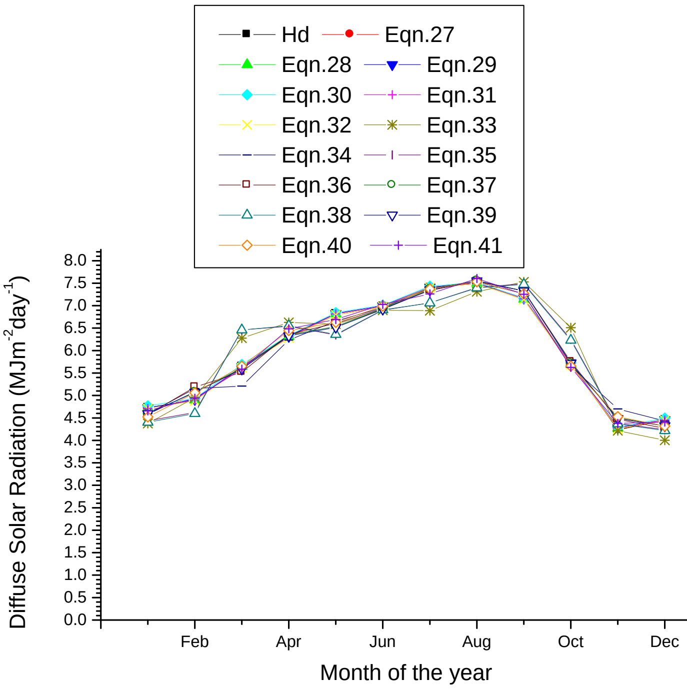

Figure 3: Comparison between the observed diffuse solar radiation (Page and Liu and Jordan Models) and the predicted diffuse solar radiation (Eqn. 27 – 41) for Yola (1980 – 2010)

Figure 3 shows the comparison between the observed diffuse solar radiation (Page and Liu and Jordan Models) and the predicted diffuse solar radiation (Eqn. 27 – 41) for Yola during the period of thirty one. It is clear that the models (Eqn. 27 – 32) shows excellent correlation with the observed diffuse solar radiation as compared with the other developed models (Eqn. 33 – 41).

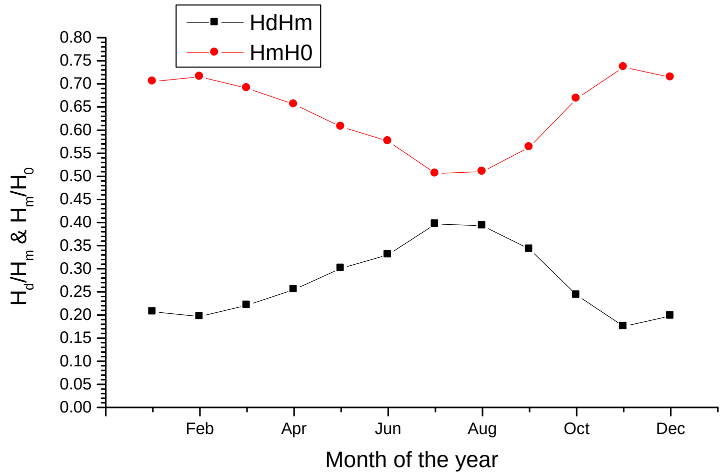

Figure 4: Variation of ratio of diffuse to global solar radiation and clearness index for Yola (1980 – 2010)

Figure 4 depicts the variation of ratio of diffuse to global solar radiation and clearness index for Yola during the period of thirty one years. The dip in the value of the clearness index in the months of July and August is in accordance with the high value of the ratio of diffuse to global solar radiation for the same months. During these period of the months, the study area is under heavy rainfall. In rainy season, it is observed that there are more cloud cover in the sky which in turn reduces the intensity of solar radiation reaching the earth's surface. From these analysis of variation of ratio of diffuse to global solar radiation and clearness index, it was observed that the maximum value of clearness index occurred during the dry season with the highest being in the month of November, this is favorable condition when solar radiation are utilized. High values of clearness index suggests immense availability of solar radiation during dry season as the cloud is free from sky condition like aerosol and water vapour, hence, the demand for solar radiation for utilization purposes.

Table 2: validation of the models under different statistical test for the developed models (Eqn. 27 – 32)

Models	R^2	MBE	RMSE	MPE	t
Eqn.27	100.0	-0.0135	0.0205	0.2229	2.9244
Eqn.28	100.0	-0.0007	0.0149	-0.0039	0.1563
Eqn.29	100.0	0.0093	0.0175	-0.1787	2.0720
Eqn.30	100.0	0.0297	0.0330	-0.5518	6.8557
Eqn.31	100.0	0.0004	0.0156	-0.0224	0.0887
Eqn.32	100.0	-0.0153	0.0230	0.2481	2.9411

Table 2 shows validation of the models under different statistical test for the developed models (Eqn. 27 – 32). Based on R^2 all the developed models produce 100%. Based on MBE the model (Eqn. 31) has the lowest value of MBE and was judged the best and the model (Eqn. 30) has the highest value. Based on RMSE the model (Eqn. 28) has the lowest value of RMSE and was judged the best and the model (Eqn. 30) has the highest value. Based on MPE the model (Eqn. 28) has the lowest value of MPE and was judged the best and the model (Eqn. 30) has the highest value. Based on t – test the model (Eqn. 31) has the lowest value of t – test and was judged the best and the model (Eqn. 30) has the highest value. It is important to note here that R^2 and MPE are in % while the MBE and RMSE are in $MJm^{-2}day^{-1}$.

Table 3: validation of the models under different statistical test for the developed models (Eqn. 33 – 41)

Models	R^2	MBE	RMSE	MPE	t
Eqn.33	94.3	0.0268	0.4029	-0.3486	0.2213
Eqn.34	98.6	-0.0069	0.2155	-0.1422	0.1059
Eqn.35	95.4	0.0232	0.3757	-0.3970	0.2049
Eqn.36	99.2	0.0023	0.1608	-0.1199	0.0477
Eqn.37	99.2	0.0027	0.1513	-0.1450	0.0592
Eqn.38	95.4	0.0142	0.3756	-0.2083	0.1256
Eqn.39	99.2	-0.0076	0.1506	0.0217	0.1666
Eqn.40	99.3	0.0096	0.1442	-0.2307	0.2217
Eqn.41	99.6	0.0053	0.1050	-0.1117	0.1684

Table 3 shows validation of the models under different statistical test for the developed models (Eqn. 33 – 41). Based on R^2 the model (Eqn. 41) has the highest value and was returned the best. Based on MBE the model (Eqn. 36) has the lowest value of MBE and was returned the best. Based on RMSE the model (Eqn. 41) has the lowest value of RMSE and was returned the best. Based on MPE the model (Eqn. 39) has the lowest value of MPE and was returned the best. Based on t – test the model (Eqn. 36) has the lowest value and was returned the best.

Table 4: Overall validation of the models under different statistical test for all the developed models (Eqn. 27 – 41)

Models	R^2	MBE	RMSE	MPE	t
Eqn.27	100.0	-0.0135	0.0205	0.2229	2.9244
Eqn.28	100.0	-0.0007	0.0149	-0.0039	0.1563
Eqn.29	100.0	0.0093	0.0175	-0.1787	2.0720
Eqn.30	100.0	0.0297	0.0330	-0.5518	6.8557
Eqn.31	100.0	0.0004	0.0156	-0.0224	0.0887
Eqn.32	100.0	-0.0153	0.0230	0.2481	2.9411
Eqn.33	94.3	0.0268	0.4029	-0.3486	0.2213
Eqn.34	98.6	-0.0069	0.2155	-0.1422	0.1059
Eqn.35	95.4	0.0232	0.3757	-0.3970	0.2049
Eqn.36	99.2	0.0023	0.1608	-0.1199	0.0477
Eqn.37	99.2	0.0027	0.1513	-0.1450	0.0592
Eqn.38	95.4	0.0142	0.3756	-0.2083	0.1256
Eqn.39	99.2	-0.0076	0.1506	0.0217	0.1666
Eqn.40	99.3	0.0096	0.1442	-0.2307	0.2217
Eqn.41	99.6	0.0053	0.1050	-0.1117	0.1684

Table 4 shows the overall validation of the models under different statistical test for all the developed models (Eqn. 27 – 41). Based and R^2 the models (Eqn. 27 – 32) were returned the best having the highest value of 100% each. Based on MBE the model (Eqn. 31) has the lowest value of MBE and was returned the best. Based on RMSE the model (Eqn. 28) has the lowest value of RMSE and was returned the best. Based on MPE the model (Eqn. 28) has the lowest value of MPE and was returned the best. Based on t – test the model (Eqn. 36) has the lowest value of t – test and was returned the best.

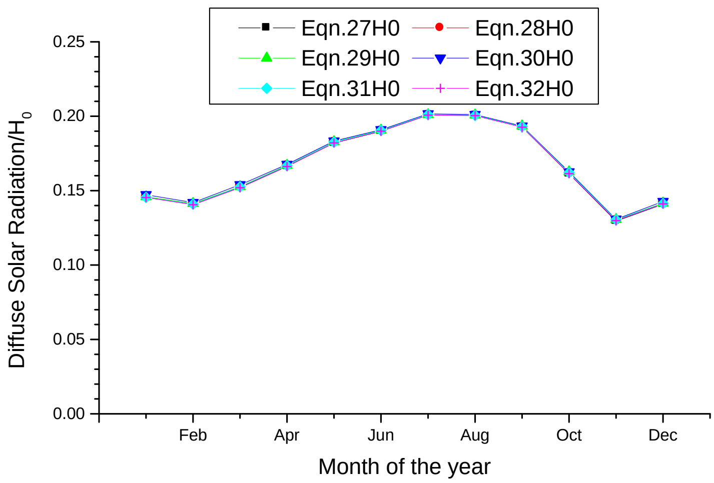

Figure 5: Monthly average daily ratio of diffuse to extra-terrestrial solar radiation for Yola (1980 – 2010).

Figure 5 shows the monthly average daily ratio of diffuse to extra-terrestrial solar radiation for Yola during the period of thirty one years. It is worthy to note that the contribution of the diffuse solar radiation does not exceed 20.20%, the highest being 20.16% during the month of July for the model (Eqn. 30) and the lowest as 12.95% during the month of November for the model (Eqn. 27). However, the best performing model based on RMSE and MPE is the model (Eqn. 28) having the highest value of 20.10% during the month of July and lowest value of 13.02% during the month of November. Based on MBE and t – test the model (Eqn. 31) appeared to be outstanding having the highest value of 20.10% during the month of July and lowest value of 13.04% in the month of November. It is clear that the maximum value of the ratio of the diffuse to extra-terrestrial solar radiation was recorded in the month of July and the minimum value in November.

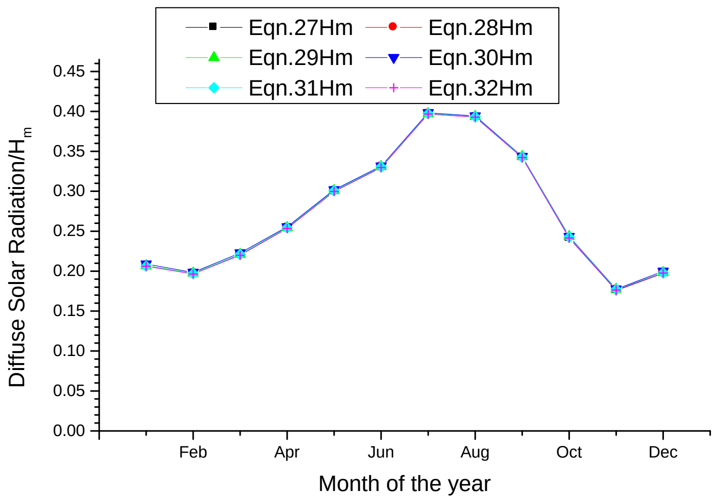

Figure 6: Monthly average of diffuse to global solar radiation for Yola (1980 – 2010).

Figure 6 shows the monthly average of diffuse to global solar radiation for Yola during the period of thirty one years. It is important to note here that the diffuse radiation has the highest value of 39.84% during the month of July for the model (Eqn. 30) and the lowest as 17.59% during the month of November for the model (Eqn. 27). Based on the model (Eqn. 28) the highest value of 39.72% was recorded in the month of July and the lowest value of 17.68% in the month of November. Based on the model (Eqn. 31) the highest value of 39.72% was recorded in the month of July and the lowest value of 17.71% in the month of November. This implies that the direct solar radiation for Yola will be between 60.28% (July) and 82.32% (November) based on the model (Eqn. 28) and between 60.28% (July) and 82.29% (November) based on the model (Eqn. 31). Hence, Yola enjoys clear sky weather conditions for at least 80% of the year.

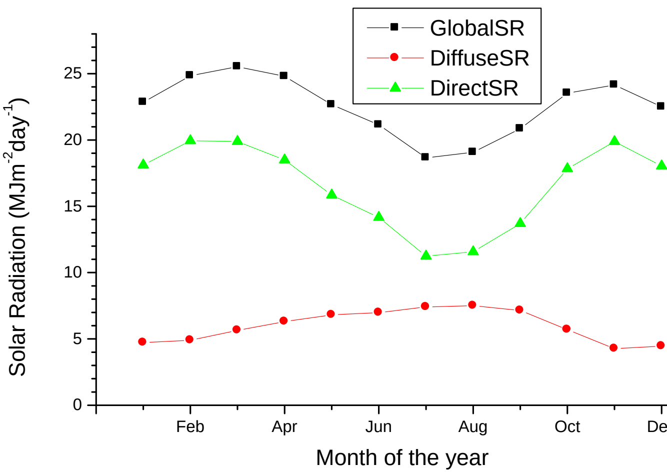

Figure 7: Variation of the global, diffuse and direct solar radiation for Yola (1980 – 2010).

Figure 7 shows the variation of the global, diffuse and direct solar radiation for Yola during the period of thirty one years. It is clear from the figure that the highest values of diffuse solar radiation was obtained in the months of July and August which corresponds to the lowest values of global and direct solar radiation in the same months of July and August. This reveals that solar radiation can be efficiently used to compensate for the energy deficit and implies high demand for solar radiation utilization purposes during the rainy season in the study area.

4. CONCLUSIONS

This paper examines the impact of several meteorological parameters in the estimation of diffuse solar radiation in Yola during the period of thirty one years. The results obtained in this study shows that the addition of wind speed to the Page model gives better estimate in the estimation of diffuse solar radiation based on R^2, RMSE and MPE while the addition of cloud cover to the Page model gives better estimate in the estimation of diffuse solar radiation based on R^2, MBE and t – test. Therefore, the models (Eqns. 28 and 31) based on modification of the Page model has been proposed for the estimation of diffuse solar radiation in Yola, Nigeria and its environs with similar climatic information. However, despite the value of R^2 for the model (Eqn. 30) our result shows that the rainfall data does not give a reasonable estimate for the prediction of diffuse solar radiation for Yola, this may be probably due to unreliability of measuring instrument or variability of atmospheric parameters in the months of January – March in some specific days of the year from the observed data as rainfall is not expected during this period, since weather condition for each day can only be forecasted. The results in this present study revealed that Yola enjoys clear sky weather condition of at least 80% throughout the year. Based on the overall results, we can safely conclude that Yola has very high global solar radiation and therefore possesses a strong potential for utilization of solar radiation.

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