

Modified And Multivariate Models for Estimation of Diffuse Solar Radiation in Ogoja, Cross River State, Nigeria

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ABSTRACT

This research utilized a 22-year dataset (2001-2022) of monthly average climatic data for Ogoja, Nigeria. The dataset includes global solar radiation, all-sky surface shortwave diffuse irradiance, mean temperatures, wind speed, relative humidity, and surface pressure, obtained from NASA. The data were analyzed using multiple linear regression, with atmospheric pressure, relative humidity, mean temperature, and wind speed as independent variables. Nineteen models were developed and categorized into modified Page, Liu and Jordan models, clearness index and single variable models, two-variable models, three-variable models, and four-variable models. The effectiveness of each model was evaluated using statistical indices: Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t-test, and coefficient of determination (R^2). Among the models, the quadratic regression expression model (equation 28b) was found most suitable in the modified Page, Liu, and Jordan models category. In the clearness index and single variable models category, the model relating diffuse solar radiation with clearness index and mean temperature (equation 28h) was the best. For the two-variable models category, the model relating diffuse solar radiation with wind speed and mean temperature (equation 28j) was the most found best. In the three-variable models, the model relating diffuse solar radiation with wind speed, relative humidity, and mean temperature (equation 28o) performed best. Overall, the model relating diffuse solar radiation with clearness index and temperature (equation 28h) was found to be the most effective for estimating diffuse solar radiation in Ogoja, which indicates that this model can be used for accurate estimation of diffuse solar radiation in this climatic location via simple temperature measurements, without the use of advanced instruments like pyrhemometers, which makes it a reliable method for estimating diffuse solar radiation, beneficial for solar energy planning and climate studies in similar regions.

Keywords: Clearness index, Diffuse solar radiation, Models, Ogoja, Statistical indices

1.0 INTRODUCTION

Since the early 19th century, the use of conventional fuels has significantly contributed to industrialization and the modern lifestyle. However, this has led to numerous health risks, environmental pollution, ecosystem disruptions including reduced crop and animal diversity, and an increase in global warming, all of which threaten the planet's future. Consequently, there is an urgent need for a sustainable energy source that is abundant and can be utilized without significantly contributing to atmospheric pollution and the greenhouse effect (Nwokolo and Otse, 2019).

Renewable energy also known as clean energy is simply a type of energy that is derived from natural sources or processes that are constantly replenished, these natural resources are sunlight, wind, or tides, etc (Zohuri *et al.*, 2022). It is expected that renewable energy will become the main solution addressing climate change. Due to their minimal or zero impact on the environment and ecosystems, which results in no health hazards to humans and animals,

renewable energies like solar, wind, hydro power, tidal energy, and biofuels are more suitable than fossil fuels. These energies are generated from natural processes such as sunlight, wind, rain, and various forms of biomass, making them eco-friendly and non-contributory to global warming and greenhouse gas production (Nwokolo, 2017; Peng *et al.*, 2019). These smart energy sources not only are renewable but also have the capacity to sustain ecological balance and environmental health. The solar radiation reaching the Earth's surface annually surpasses the world's proven fossil fuel reserves by 160 times (Yoshida *et al.*, 2013). Nigeria, in particular, enjoys a plentiful supply of sunshine, with approximately 3000 hours of sunlight annually (Sa'id *et al.*, 2019), with a solar reserve of between the range of 3.5 to 7.0 $\text{KWhm}^{-2}\text{day}^{-1}$ (Elehinafe *et al.*, 2021). Solar radiation measurements employ a device known as a Pyrhemometer, but as Olatona (2018) notes, its installation is costly and requires delicate handling. Consequently, these installations are infrequent and widely dispersed across Nigeria. Due to the costs, maintenance requirements, and expertise needed for ground and satellite-derived

techniques of measuring solar radiation data—particularly in rural and developing countries—alternative methods must be developed to derive solar radiation data using commonly monitored meteorological parameters in areas lacking dedicated solar radiation measuring instruments (Osinowo *et al.*, 2015; Nwokolo and Otse, 2019). To address these challenges, modeling techniques have been employed to assess global solar radiation using more readily available meteorological data. Consequently, many researchers have developed empirical models to forecast diffuse irradiance in the sky using various input parameters, with the clearness index (K_T) being among the most significant (Akpootu and Mustapha, 2015; Fan *et al.*, 2019; Peng *et al.*, 2019; Wang *et al.*, 2019; Zang *et al.*, 2019; Zhou *et al.*, 2019; Berrizbeitia *et al.*, 2020; Salhi *et al.*, 2020; Song *et al.*, 2020; Li *et al.*, 2020; Chabane, 2020; Emeksiz, 2020; Kurniawan and Shintaku, 2020; Hussain and Khan, 2021; Arslanoglu, 2021; Tahir *et al.*, 2021; Shrestha *et al.*, 2022; Jia *et al.*, 2022; Mustafa *et al.*, 2022; Nwokolo *et al.*, 2022; Salhi *et al.*, 2023; Lu *et al.*, 2023; Ilyas *et al.*, 2023; Yu *et al.*, 2023; Soneye-Arogundade and Rappenglück, 2023).

Liu and Jordan were among the first researchers to develop a model for estimating diffuse solar radiation, their model established a correlation between the diffuse fraction (H_d/H) and the clearness index (K_T), where the diffuse fraction is the ratio of diffuse radiation to global radiation, and the clearness index is the ratio of global radiation to extraterrestrial radiation (Iqbal, 1983 and Zatulala *et al.*, 2021). Subsequent studies across various regions and climates have refined and validated models for estimating daily and monthly mean diffuse solar radiation, which are crucial for improving solar energy system designs. Most recent are the works of Akpootu and Salifu (2024); Akpootu *et al.*, 2024; Salifu *et al.*, 2024a where they developed models within the coastal region of Nigeria with 22 years data obtained from NASA making use of statistical indices of RMSE, MPE, MBE, R^2 (Coefficient of determination) and t-test to validate/test

According to Iqbal, 1983 H_o measured in $MJm^{-2}day^{-1}$ is the mean daily extraterrestrial radiation on a horizontal surface and can be estimated for each day of a month by averaging the daily values over that month. Also, based on the equations presented by Zekai (2008):

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

where $I_{sc} = 1367Wm^{-2}$

Symbolically, the site latitude, solar constant, mean sunrise hour angle and solar declination are respectively denoted by φ , I_{sc} , ω_s and δ are utilized (in equation 1) to determine H_o likewise, n , (i.e the total days in a year from January 1st to December 31st) is also incorporated into the calculation. The mean sunrise hour angle and solar declination are determined using the methods presented by Iqbal (1983) and Zekai (2008) as reported by Sa'id *et al.*, 2019; Akpootu and Abdullahi (2022) and Salifu *et al.*, 2024a as shown in the below equations:

the accuracies of the developed models. The study aims to: (i) determine the most effective models for estimating diffuse solar radiation in Ogoja using the Page, Liu, and Jordan models, (ii) create correlation models by integrating two to four variables for estimating diffuse solar radiation, (iii) rank these models to identify the most precise one, and (iv) evaluate the relationships between estimated and measured values, offering a thorough assessment of models performance.

2.0 MATERIALS AND METHODS

2.1 Study Area

Ogoja is a town located in Cross River State, Nigeria, positioned at a latitude of 6.67°N and a longitude of 8.80°E. Nestled at an elevation of 117 meters above sea level, Ogoja enjoys a tropical climate. This town is part of the southeastern region of Nigeria, bordered by lush rainforests and intersected by numerous rivers.



Figure 1: Map of Nigeria, showing the study area

2.2 Data collection

A 22 years (2001-2022) monthly average climatic data for Ogoja, Nigeria (6.67°N, 8.80°E, 117 m above sea level) was utilized. These data are global solar radiation, all-sky surface shortwave diffuse irradiance, mean temperatures, wind speed, relative humidity and surface pressure, sourced from the NASA website. The data output file was in CSV.

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

$$\omega_s = \cos^{-1}(-\tan \varphi \tan \delta) \quad (3)$$

The clearness index, K_T , is the ratio of the global solar radiation to the extraterrestrial solar radiation (Iqbal, 1983). It do provide valuable information about the availability of solar radiation at any specific location. When K_T outcome is one (1), then the sky is completely clear indicating that maximum amount of solar radiation is reaching the Earth's surface and when a value of zero (0), it denotes a complete overcast of the sky, which means the solar radiation is not reaching the Earth's surface. Clearness index typically ranges between 0.2 and 0.8, whereby the higher values denotes clearer skies and more available solar radiation (Iqbal, 1983). The clearness index as reported by Akpootu *et al.*, 2023; Akpootu and Salifu (2024); Salifu *et al.*, 2024a is expressed as:

$$K_T = \frac{H_m}{H_o} \quad (4)$$

H_m , is global solar radiation in $MJm^{-2}day^{-1}$

2.3 Data Processing

The diffuse solar radiation and global solar radiation data were obtained from the NASA website in $Kwhm^{-2}day^{-1}$ which was converted to $MJm^{-2}day^{-1}$ according to the conversion factor: $1 Kwhm^{-2}day^{-1} = 3.6 MJm^{-2}day^{-1}$ (Akpootu and Rabiu, 2019; Salifu *et al.*, 2024b).

The surface pressure in kPa was multiplied with 10 converting it to hPa. The wind speed is in ms^{-1} , mean temperature in ($^{\circ}C$) and relative humidity in (%). The Minitab software (version 21.2) package was employed to obtain the empirical constants, while the Origin Pro software version 2018 was employed for plotting of the graphs.

2.4 Regression Analysis

The proposed models based on the modified Page; Liu and Jordan models are:

$$\frac{H_d}{H_m} = a + bK_T \quad (5)$$

$$\frac{H_d}{H_m} = a + bK_T + cK_T^2 \quad (6)$$

$$\frac{H_d}{H_m} = a + bK_T + cK_T^2 + dK_T^3 \quad (7)$$

$$\frac{H_d}{H_m} = a + bK_T + cK_T^2 + dK_T^3 + eK_T^4 \quad (8)$$

The multiple linear regression approach was employed, using as independent variables the four meteorological parameters of (WS, T_{mean}, RH, PS) and the

dependent variable been $\frac{H_d}{H_m}$. Where PS monthly

average daily atmospheric pressure (hPa); RH

monthly average daily relative humidity (%); T_{mean}

monthly average mean temperature ($^{\circ}C$); WS

denotes the monthly average daily wind speed (ms^{-1}).

The other proposed models developed in this study, involves correlations of the linear Page model with meteorological parameters as follows:

$$\frac{H_d}{H_m} = a + b \frac{H}{H_o} + cWS \quad (9)$$

$$\frac{H_d}{H_m} = a + b \frac{H}{H_o} + cRH \quad (10)$$

$$\frac{H_d}{H_m} = a + b \frac{H}{H_o} + cPS \quad (11)$$

$$\frac{H_d}{H_m} = a + b \frac{H}{H_o} + cT_{mean} \quad (12)$$

The proposed 2 variables models are:

$$H_d = a + bWS + cRH \quad (13)$$

$$H_d = a + bWS + cT_{mean} \quad (14)$$

$$H_d = a + bWS + cPS \quad (15)$$

$$H_d = a + bRH + cT_{mean} \quad (16)$$

$$H_d = a + bRH + cPS \quad (17)$$

$$H_d = a + bT_{mean} + cPS \quad (18)$$

The proposed 3 variables correlation models are:

$$H_d = a + bWS + cRH + dT_{mean} \quad (19)$$

$$H_d = a + bWS + cT_{mean} + dPS \quad (20)$$

$$H_d = a + bWS + cPS + dRH \quad (21)$$

$$H_d = a + bRH + cT_{mean} + dPS \quad (22)$$

The proposed 4 variables correlations model is:

$$H_d = a + bWS + cRH + dT_{mean} + ePS \quad (23)$$

The algebras a, b, c, d , and e above (in Eqn 5 to Eqn 23) are referred to as empirical coefficients or constants.

2.5 Accuracy of the Models

The statistical indices of Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error

(MPE), and t-test were employed to test the effectiveness of each of the models. The formulae used in obtaining MBE, RMSE, and MPE, based on modifications to the method proposed by El-Sebaei and Trabea, (2005) and reported by Akpootu *et al.*, (2015) are presented as follows:

$$MBE = \frac{1}{n} \sum_{i=1}^n (H_{d_{i,cal}} - H_{d_{i,meas}}) \quad (24)$$

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^n (H_{d_{i,cal}} - H_{d_{i,meas}})^2 \right]^{\frac{1}{2}} \quad (25)$$

$$MPE = \frac{1}{n} \sum_{i=1}^n \left(\frac{H_{d_{i,meas}} - H_{d_{i,cal}}}{H_{d_{i,meas}}} \right) \times 100 \quad (26)$$

According to Bevington (1969), the t-test, is amongst the statistical methods used to evaluate mean values, utilizes a random variable denoted as t , possessing $n-1$ degrees of freedom. It is a non-dimensional parameter according to (Akpootu *et al.*, 2019c, d; Akpootu *et al.*, 2023) and it is mathematically written as:

$$t = \left[\frac{(n-1)(MBE)^2}{(RMSE)^2 - (MBE)^2} \right]^{\frac{1}{2}} \quad (27)$$

3.0 RESULTS AND DISCUSSION

The results below were obtained from the approach and procedures stated in the methodology (2.3 and 2.4 respectively). The same procedures were employed for each of the categories of the proposed models and yielded the following:

$$\frac{H_d}{H_m} = 1.1220 - 1.145K_T \quad (28a)$$

$$\frac{H_d}{H_m} = 0.190 + 2.71K_T - 3.91K_T^2 \quad (28b)$$

$$\frac{H_d}{H_m} = 3.16 - 15.9K_T + 34.4K_T^2 - 26.0K_T^3 \quad (28c)$$

$$\frac{H_d}{H_m} = 14.3 - 109K_T + 324K_T^2 - 424K_T^3 + 204K_T^4 \quad (28d)$$

$$\frac{H_d}{H_m} = 1.021 - 1.059 \frac{H}{H_o} + 0.0354WS \quad (28e)$$

$$\frac{H_d}{H_m} = 1.207 - 1.213 \frac{H}{H_o} - 0.00062RH \quad (28f)$$

$$\frac{H_d}{H_m} = 21.7 - 1.42 \frac{H}{H_o} - 0.02052PS \quad (28g)$$

$$\frac{H_d}{H_m} = 0.603 - 1.1810 \frac{H}{H_o} + 0.0209\pi_{mean} \quad (28h)$$

$$H_d = 5.30 + 0.9IWS + 0.0347RH \quad (28i)$$

As seen in eqns (24), (25), and (26), $H_{d_{i,meas}}$ and $H_{d_{i,cal}}$ denotes i^{th} measured and i^{th} calculated values of daily diffuse solar radiation, while n represents the total number of observations. Lower values of RMSE, t-test, MPE, and MBE denotes superior model performance. These statistical tools are used to test the accuracy of a model's predictions compared to actual observed values. According to Akpootu *et al.*, 2023, positive values of MPE and MBE quantify the average degree of overestimation in a model's prediction, while negative values denotes underestimation. In addition, Merges *et al.* (2006), Akpootu and Sulu (2015), and Olomiyesan *et al.* (2021), when a model exhibits a low Mean Percentage Error (MPE), and errors are within the range of -10 % to +10 % , then the model is deemed to perform best. Additionally, Akpootu *et al.*, 2024 and Salifu *et al.*, 2024a, opined that a model would be an ideal model when the model have a Mean Bias Error (MBE) value close to zero, and a low Root Mean Square Error (RMSE) value that is desirable. A more reliable and accurate data modeling outcome will be achieved if the coefficient of determination (R^2) approaches a value of 1 i.e. 100% (Akpootu and Iliyasu 2015a, b; Akpootu *et al.*, 2019a, b), indicating a robust correlation between estimated and observed values, which reflects a well-fitting model.

$$H_d = -14.58 + 1.653WS + 0.841T_{mean} \quad (28j)$$

$$H_d = 397 + 2.11WS - 0.392PS \quad (28k)$$

$$H_d = -12.43 + 0.0375RH + 0.743T_{mean} \quad (28l)$$

$$H_d = 506 + 0.0839RH - 0.505PS \quad (28m)$$

$$H_d = -428 + 1.18T_{mean} + 4.08PS \quad (28n)$$

$$H_d = -15.73 + 1.423WS + 0.0262RH + 0.817T_{mean} \quad (28o)$$

$$H_d = -230 + 1.268WS + 1.043T_{mean} + 0.211PS \quad (28p)$$

$$H_d = 725 + 2.191WS - 0.728PS + 0.0860RH \quad (28q)$$

$$H_d = -399 + 0.0033RH + 1.156T_{mean} + 0.380PS \quad (28r)$$

$$H_d = 245 + 1.709WS + 0.047RH + 0.552T_{mean} + 0.257PS \quad (28s)$$

3.1 Modified Page, Liu and Jordan Models

Below are the statistical analysis summary of the models Equation 28a to Equation 28d.

Table 1: Modified Page, Liu and Jordan Models Statistical Error indicators

Models	R ²	MBE	RMSE	MPE	t
Eqn 28a	91.25%	-0.0085	0.4261	-0.2884	0.0662
Eqn 28b	95.67%	0.0305	0.3026	-0.4722	0.3359
Eqn 28c	96.11%	-0.1340	0.3209	1.2713	1.5234
Eqn 28d	96.21%	-0.2954	0.4173	2.8980	3.3243

Table 1 is a summary of the statistical validation tests conducted on the developed models for this category. Among these models, equation 28d stands out with the highest R² value at 96.21 %. While, eqn 28a has the lowest MBE, MPE and t-test values with underestimation of 0.0085 MJm⁻²day⁻¹, 0.2884 % in its estimated value and 0.0662 respectively. Also, eqn 28b has the lowest RSME value of 0.3026 MJm⁻²day⁻¹. The MPE values for all developed models are within the acceptable range of ± 10%. Additionally, the t-test values of the models are statistically significant at both 95% and 99%.

Table 2: Ranks obtained from the estimated modified Page, Liu and Jordan Models for Ogoja

Models	R ²	MBE	RMSE	MPE	T	Rank
Eqn 28a	4	1	4	1	1	11
Eqn 28b	3	2	1	2	2	10
Eqn 28c	2	3	2	3	3	13
Eqn 28d	1	4	3	4	4	16

Table 2 is the summary of the ranks deduced from the estimated modified Page, Liu and Jordan models for Ogoja. According the procedures stated in 2.5 (i.e Accuracy of models), the ranks achieved by each model range from 10 to 16. Notably, it is the quadratic regression model, as defined in equation 28b that proves to be best in estimating diffuse solar radiation in Ogoja when compared to the other three models.

These procedures of obtaining the models that performs best via the ranking above are applied to all other categories of models in this study.

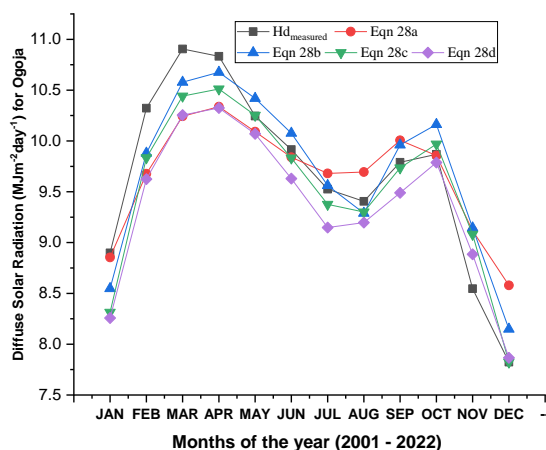


Figure 2: Comparison Between the Measured Diffused Solar Radiation and Estimated Modified Page, Liu and Jordan Models for Ogoja.

Figure 2 shows the comparison between the measured diffuse solar radiation and estimated models based on the modified Page, Liu and Jordan models for Ogoja. As evidently seen, the developed fourth degree polynomial model equation 28d underestimated the measured diffuse solar radiation and other developed models from the month June to October. While the quadratic model Eqn 28b followed similar pattern of variation with the measured diffuse solar radiation and making it the most suitable model for estimating diffuse solar radiation in Ogoja based on this category of models as compared to other estimated models in this category.

3.2 Clearness Index and One Variable Correlation Models

Below are the statistical analysis summary of the models Eqn 28e to Eqn 28h

Table 3: Clearness Index and One Variable Models Statistical Error indicators for Ogoja

Models	R ²	MBE	RMSE	MPE	t
Eqn 28e	92.03%	-0.0099	0.4028	-0.2603	0.0814
Eqn 28f	91.37%	-0.0067	0.4198	-0.3103	0.0532
Eqn 28g	96.31%	-0.0500	0.2762	0.3878	0.6100
Eqn 28h	96.33%	-0.0087	0.2835	-0.0354	0.1021

Table 3 is the summary of the statistical validation tests conducted on the Clearness index and a single variable model in this study. The model equation 28h possesses the highest R² value at 96.33 % and lowest MPE value with underestimation of 0.0354 % in its estimated value; while equation 28g, has the lowest RMSE of 0.2762 MJm⁻²day⁻¹. While equation 28f exhibits the lowest for both MBE and t-test values, recording an underestimation of 0.0067 MJm⁻²day⁻¹ in its estimated value and 0.0532 respectively. The MPE values for all developed models are within the acceptable range of ± 10% and all models have t-test values that are statistically significant at both 95% and 99%.

Table 4: Ranks obtained from the estimated Clearness Index and One Variable Correlation Models for Ogoja

Models	R ²	MBE	RMSE	MPE	t	Rank
Eqn 28e	3	3	3	2	2	13
Eqn 28f	4	1	4	3	1	13
Eqn 28g	2	4	1	4	4	15
Eqn 28h	1	2	2	1	3	9

Table 4 presents a summary of the ranks obtained from the estimated Clearness index and one variable models for Ogoja. As seen, the ranks attained by each model are within 9 to 15. In conclusion, to estimate diffuse solar radiation in Ogoja, the model equation 28h shows greater accuracy and performance compared to the other three models.

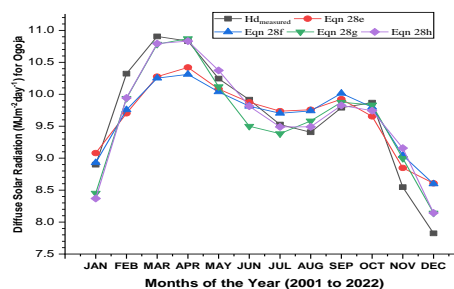


Figure 3: Comparison Between the Measured Diffused Solar Radiation and Estimated Clearness Index and a Single Variable Models for Ogoja.

Figure 3 represents the comparison between the measured diffuse solar radiation and estimated models based on the clearness index and a single variable models for Ogoja. From the figure the developed

model equation 28g underestimated the measured diffuse solar radiation and other developed models from the month of June to July. The model Eqn 28h has similar pattern of variation with the measured diffuse solar radiation and was reported to be the most suitable model for estimating diffuse solar radiation in Ogoja based on this category.

3.3 Two Variables Correlation Models

Below are the statistical analysis summary of the models Eqn 28i to Eqn 28n

Table 5: Two variables Models Statistical Error indicators for Ogoja

Models	R ²	MBE	RMSE	MPE	t
Eqn 28i	21.81%	0.0034	0.7702	-0.6965	0.0146
Eqn 28j	76.28%	-0.0161	0.4245	-0.0623	0.1261
Eqn 28k	34.84%	-0.1403	0.7170	0.8758	0.6620
Eqn 28l	66.89%	0.0014	0.5012	-0.3199	0.0093
Eqn 28m	49.22%	-0.3785	0.7270	3.4910	2.0224
Eqn 28n	70.07%	-0.4088	0.6278	3.9888	2.8453

Table 5 represents the statistical validation tests done on the two variable models in this study for Ogoja. The model equation 28j possesses the highest R², lowest RMSE and MPE with values 76.28 %, 0.4245 MJm⁻²day⁻¹ and with an underestimation of 0.0623 % in its estimated value respectively while equation 28l has the lowest MBE and t-test values with an overestimation of 0.0014 MJm⁻²day⁻¹ and 0.0093 respectively. The results also indicates that the MPE values of developed models are within the acceptable range of ± 10%. Additionally, all models t-test values are statistically significant at both 95% and 99%.

Table 6: Ranks obtained from the estimated Two Variables Correlation Models for Ogoja

Models	R ²	MBE	RMSE	MPE	t	Rank
Eqn 28i	6	2	6	3	2	19
Eqn 28j	1	3	1	1	3	9
Eqn 28k	5	4	4	4	4	21
Eqn 28l	3	1	2	2	1	9
Eqn 28m	4	5	5	5	5	24
Eqn 28n	2	6	3	6	6	23

Table 6 above provides a summary of the ranks derived from the estimated two variables models for Ogoja. It is evident from the table that the ranks achieved by each model range from 9 to 24. The comprehensive findings indicate that the model equations 28j and 28l, proves to be more accurate in estimating diffuse solar radiation in Ogoja when compared to the other four models in terms of the two variable correlation models above. Further comparison between model equations 28j and 28l.

Table 7: Statistical Error indicators 28j and 28l

Models	R ²	MBE	RMSE	MPE	t
Eqn 28j	76.28%	-0.0161	0.4245	-0.0623	0.1261
Eqn 28l	66.89%	0.0014	0.5012	-0.3199	0.0093

Table 8: Ranks obtained for table 7

Models	R ²	MBE	RMSE	MPE	t	Rank
Eqn 28j	1	2	1	1	2	7
Eqn 28l	2	1	2	2	1	8

Overall, the model equation 28j is most appropriate for the estimating diffuse solar radiation based on the two variables correlation models for Ogoja as seen in table 8.

Figure 4: Comparison between the Measured Diffused Solar Radiation and estimated Two Variable Models for Ogoja.

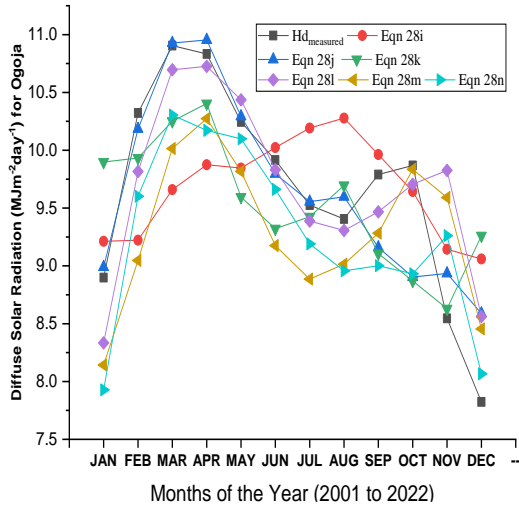


Figure 4 shows the comparison between the measured diffuse solar radiation and estimated models based on the two variable models for Ogoja. From the figure, the developed model equation 28m underestimated the measured diffuse solar radiation and other developed models from the month June to July. Also, 28i overestimated the measured diffuse solar radiation and other developed models from the month of June to September. The model equation 28j and the measured diffuse solar radiation has similar pattern of variations making it most suitable for estimating diffuse solar radiation in Ogoja based on this category.

3.4 Three Variables Models

Below are the statistical analysis summary of the models Eqn 28o to Eqn 28r

Table 9: Three Variable Models Statistical Error indicators for Ogoja

Models	R ²	MBE	RMSE	MPE	t
Eqn 28o	81.97%	0.0094	0.3700	-0.2690	0.0840
Eqn 28p	79.29%	-0.4701	0.6149	4.7057	3.9334
Eqn 28q	79.54%	0.0109	0.3941	-0.3097	0.0921
Eqn 28r	70.09%	0.1464	0.4983	-1.8011	1.0197

Table 9 shows a summarized statistical validation test done for this model category in this study. The model equation 28o, has the highest R² value of 81.99 %; lowest MBE, RMSE, MPE and t-test values with an overestimation of 0.0094 MJm⁻²day⁻¹ in its estimated value, 0.3700 MJm⁻²day⁻¹, an underestimation of 0.2690 % in its estimated value and 0.0840 respectively. The MPE values for all the developed models equation are within the acceptable range of ± 10 %. The t-test values for the models are significant at 95% and 99% except for model equation 28p.

Table 10: Ranks obtained from the estimated Three Variables Correlation Models for Ogoja

Models	R ²	MBE	RMSE	MPE	t	Rank
Eqn 28o	1	1	1	1	1	5
Eqn 28p	3	4	4	4	4	19
Eqn 28q	2	2	2	2	2	10
Eqn 28r	4	3	3	3	2	15

Table 10 provides a summary of the ranks derived for this category. As seen above, the ranks achieved by each model are from 5 to 19. In conclusion, the model equations 28o, proves to be the most accurate in estimating diffuse solar radiation in Ogoja when compared to the other four models in terms of the three variable correlation models above.

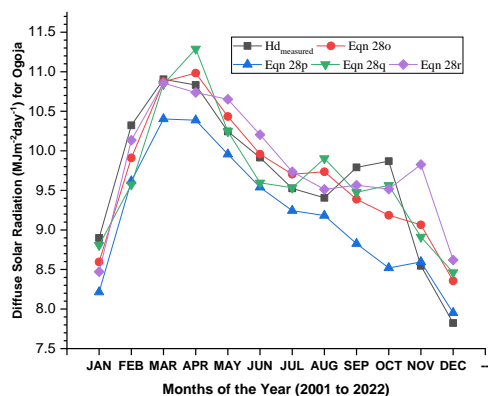


Figure 5: Comparison between the Measured Diffused Solar Radiation and estimated Three Variables Models for Ogoja.

Figure 5 shows the comparison between the measured diffuse solar radiation and estimated models based on the three variable models for Ogoja. From the figure, developed model equation 28p underestimated the measured diffuse solar radiation and other developed models in the month of January and also from the month of March to October. The model equation 28r overestimated the measured diffuse solar radiation and other developed models from May to June and November to December respectively. The model Eqn 28o and the measured diffuse solar radiation followed similar pattern of variation, making it most suitable model for estimating diffuse solar radiation in Ogoja based this category.

3.5 Four Variables Model

Below are the statistical analysis summary of the models Eqn 28s

Table 11: Four Variable Model Statistical Error indicators for Ogoja

Model	R ²	MBE	RMSE	MPE	t
Eqn 28s	82.83%	-0.1480	0.3901	1.3780	1.3603

The above table indicates that the four variables model (Eqn 28s) has an overestimation of 1.3780 % and underestimation of 0.1480 MJm⁻²day⁻¹ in its estimated value.

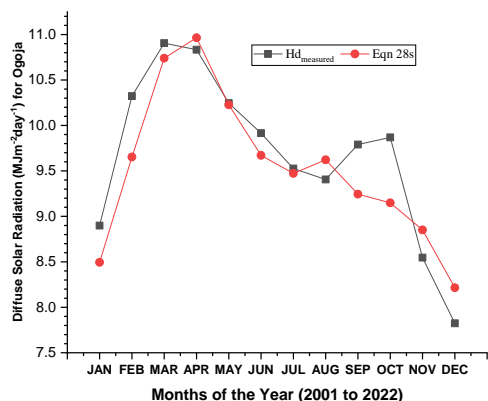


Figure 6: Comparison between the Measured Diffused Solar Radiation and estimated Four Variable model for Ogoja.

Table 12: Statistical summary of better performed models across each category for Ogoja

Models	R ²	MBE	RMSE	MPE	t
Eqn 28b	95.67%	0.0305	0.3026	-0.4722	0.3359
Eqn 28h	96.33%	-0.0087	0.2835	-0.0354	0.1021
Eqn 28j	76.28%	-0.0161	0.4245	-0.0623	0.1261
Eqn 28o	81.97%	0.0094	0.3700	-0.2690	0.0840
Eqn 28s	82.83%	-0.1480	0.3901	1.3780	1.3603

Table 13: Ranks obtained for the performed models across each category for Ogoja

Models	R ²	MBE	RMSE	MPE	t	Rank
Eqn 28b	2	4	2	4	4	16
Eqn 28h	1	1	1	1	2	6
Eqn 28j	5	3	5	2	3	18
Eqn 28o	4	2	3	3	1	13
Eqn 28s	3	5	4	5	5	22

Figure 6 shows that the four variable model underestimated the measured diffuse solar radiation from the month of January to March, in June and from the month of September to October. The overestimation occurred in the months of April, August and from November to December.

perform best in estimating diffuse solar radiation for Ogoja.

From table 13, equation 28h of the clearness index and one variable model category was found to

4.0 CONCLUSION

This research utilized a dataset spanning twenty-two years (2001 to 2022) that includes measured monthly average daily diffuse solar radiation, global solar radiation, atmospheric pressure, relative humidity, mean temperature and wind speed to develop new models for estimating diffuse solar radiation. Nineteen models developed and categorized into: modified Page, Liu and Jordan models; clearness index and single variable models; two variable models; three variable models; and four variable models. These models were tested using the statistical indices of: MBE, RMSE, MPE, t-test, and R^2 . The results after the successful ranking for each categories, indicated that among the modified Page, Liu and Jordan models, it was the quadratic regression expression model i.e equation 28b that was the most suitable; for the clearness index and single variable models category, it was model that relates the diffuse solar radiation with the clearness index and mean temperature i.e equation 28h that was found to be the best; for the two variable models category, it was the model that relates the diffuse solar radiation with the wind speed and mean temperature i.e equation 28j was found to be the most appropriate; and for the three variable models category, it was the model

that relates the diffuse solar radiation with the wind speed, relative humidity and mean temperature i.e equation 28o that performed best. When all these performed developed models from each categories were compared, further tested and ranked, it was the model that relates the diffuse solar radiation with clearness index and temperature (Eqn.28h) that performed best for estimation of diffuse solar radiation for Ogoja, indicating that for this location (or locations with similar climatic conditions) with a mere thermometer measurements of either of hourly, daily and monthly mean temperatures, one can easily calculate or obtain the diffuse solar radiation for the given duration (or period) which have helped greatly in the estimation the diffuse solar radiation without the aid of a pyrheliometer.

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