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A New Temperature-Based Model for Estimating Global Solar Radiation in Port-Harcourt, South-South Nigeria.

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ABSTRACT

In this paper, multiple linear temperature-based regression models were developed to estimate the monthly mean daily global solar radiation on horizontal surfaces using maximum and minimum temperature parameters over a period of twenty one years (1990-2010) for Port-Harcourt, Nigeria (Latitude 04.51^{0}N, Longitude 07.01^{0}E and Altitude 19.5m above sea level). The values of the estimated global solar radiation by the models and that of the measured were tested using the Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE), t-test and the Nash-Sutcliffe equation (NSE) statistical techniques. The values of the correlation coefficient (R) and coefficient of determination (R^2) were also determined for each of the models. Based on the MPE results, good agreement $(MPE \leq \pm 10\%)$ was obtained between the estimated and measured global solar radiation by all the developed models which suggest that the models could be employed in estimating global solar radiation in the study site. The t-test also shows perfect model performance at 95% and 99% confidence level for all the developed models. The equation with the highest values of R, R^2 and NSE and least value of RMSE which is reported to be recommended is given as

$$\frac{H_p}{H_0} = -0.250 + 0.494\, ln(\Delta T) - 0.878\, ln(\tau_r)$$

The developed model can be used for estimating global solar radiation in Port-Harcourt and other regions with similar climatological information.

KEY WORDS: *Global Solar Radiation, Coefficient of determination, Temperature, Developed models and Port-Harcourt.*

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I. INTRODUCTION

The energy transferred from the sun in the form of radiant to the earth's surface is normally referred as the global solar radiation. Solar radiation is the most important parameter in the design and evaluation of solar energy devices. An accurate knowledge of solar radiation distribution at a particular geographical location is of vital importance for surveys in agronomy, hydrology, meteorology, soil physics science, ecology and sizing of the photovoltaic or thermal solar systems and estimates of their performances.The traditional way of knowing the amount of global solar radiation (GSR) in a particular region is to install global solar radiation measuring device (pyranometers) at as many locations as possible in this region thus requiring daily maintenance and data recording, which increases the cost of GSR data collection. Therefore, it is rather more economical to develop methods to estimate the GSR using climatological parameters (Kassem *et al*., 2009; Falayi *et al*., 2008; El-Sebaii and Trabea, 2005).

Obviously, the best and most reliable solar radiation information is that obtained from daily experimental measurements of the global and diffuse components of the solar insolation at the location in question. Unfortunately, there are few meteorological stations conducting such measurements in developing countries such as Nigeria, due to inability to afford the measuring equipment due to the cost or lack of trained personnel to handle the measurement. Therefore, it is rather important to develop models to estimate the solar radiation using the available weather parameters. 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), Augustine and Nnabuchi (2009), Majnooni-Heris et al. (2014), Ituen et al. (2012), Akpootu and Momoh (2014), Muzathik et al. (2011), Okonkwo and Nwokoye (2014), Ekwe et al. (2014), Mfon et al. (2013), El- sabaii et al. (2005), and Ugwu and Ugwuanyi (2011) to mention but a few.

Basically, models developed to estimate global solar radiation based on different available meteorological data are broadly categorized as cloud-based, sunshine duration-based (Angstrom, 1924, Prescott, 1940) and air temperature-based (Bristow and Campbell, 1984).

The main goal of this study was the development of temperature based models for estimation of the global solar radiation and selection of the best accurate model at Port-Harcourt station.

II. METHODOLOGY

The measured monthly average daily global solar radiation, maximum and minimum temperatures of the study area were obtained from Nigeria Meteorological Agency (NIMET), Oshodi, Lagos, Nigeria. The data covered a period of twenty one years (1990-2010) for Port-Harcourt located at Latitude 04.51^{0}N, Longitude 07.01^{0}E and Altitude 19.5m above sea level. Monthly averages over the twenty one years of the data in preparation for correlation are presented in **Table 1.**

Extraterrestrial radiation is the maximum amount of solar radiation available to the Earth at the top of the atmosphere. The monthly average daily extraterrestrial radiation on a horizontal surface (H_o) can be calculated for days giving average of each month (Iqbal, 1983; Zekai, 2008; Saidur *et al*., 2009) from the following equation (Iqbal, 1983; Zekai, 2008):

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

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 (Iqbal, 1983; Zekai, 2008):

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

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

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

$$S_o = \frac{2}{15} W_s \quad (4)$$

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)

$$K_T = \frac{H}{H_o} \quad (5)$$

In this study, H_o and S_o were computed for each month using equations (1) and (4) respectively.

Hargreaves and Samani (1982) developed an empirical model that took the form of a linear regression between the relative incoming solar radiation and the square root of the temperature difference as

$$\frac{H}{H_0} = a_1 + b_1 \Delta T^{0.5} \quad (6)$$

where H is the monthly average daily global solar radiation on a horizontal surface (MJ/m^2/day), ΔT is the difference between the monthly average daily maximum and minimum temperatures, i.e., $T_{max} - T_{min}$ and a_1 and b_1 are empirical coefficients to be determined by regression techniques.

The Garcia (1994) model is the only attempt made to estimate incoming solar radiation in Peru. The model is an adaptation of the Angstrom-Prescott model given as

$$\frac{H}{H_0} = a_2 + b_2\left(\frac{\Delta T}{S_0}\right) \quad (7)$$

The Hargreaves and Samani (1982) and the Garcia (1994) models are both temperature based models as they employ maximum and minimum temperatures (temperature range) as the required meteorological data.

The proposed models for this study in form of mathematical equations that relate the clearness index as the dependent variable with the maximum and minimum temperatures as the independent variables are

$$\frac{H}{H_0} = a_3 + b_3 \ln(\Delta T) \quad (8)$$

$$\frac{H}{H_0} = a_4 + b_4 \ln(\tau_r) \quad (9)$$

Where τ_r is the monthly average daily temperature ratio, and is given as

$$\tau_r = \frac{T_{max}}{T_{min}}$$

$$\frac{H}{H_0} = a_5 + b_5 \ln(T_m) \quad (10)$$

Where T_m is the mean temperature, and is given as

$$T_m = \frac{T_{max}+T_{min}}{2}$$

$$\frac{H}{H_0} = a_6 + b_6 \ln(\Delta T) + c_6 \ln(\tau_r) \quad (11)$$

$$\frac{H}{H_0} = a_7 + b_7 \ln(\Delta T) + c_7 \ln(T_m) \quad (12)$$

$$\frac{H}{H_0} = a_8 + b_8 \ln(\tau_r) + c_8 \ln(T_m) \quad (13)$$

where a_1, a_2………a_8, b_1, b_2………b_8 and c_6….c_8 are the regression coefficients and the other terms are the correlated parameters. In this study, equations (6)…….equation (13) are models (1)………..model (8), where equation (6) (model 1) and equation (7) (model 2) are the Hargreaves and Samani and Garcia models respectively, while the developed models are equations (8)-(13) which implies models (3)-(8)

SPSS 16.0 Software Program was used in evaluating the model parameters. The values of the regression coefficients obtained for Port-Harcourt were used to estimate the global solar radiation and compared with the measured global solar radiation.

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

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(H_{i,cal} - H_{i,mea}\right) \quad (14)$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(H_{i,cal} - H_{i,mea}\right)^2\right]^{\frac{1}{2}} \quad (15)$$

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{H_{i,mea}-H_{i,cal}}{H_{i,mea}}\right) * 100 \quad (16)$$

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.

$$t = \left[\frac{(n-1)(MBE)^2}{(RMSE)^2 - (MBE)^2}\right]^{\frac{1}{2}} \quad (17)$$

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

$$NSE = 1 - \frac{\sum_1^n \left(H_{i,meas}-H_{i,cal}\right)^2}{\sum_1^n \left(H_{i,meas}-\bar{H}_{i,meas}\right)^2} \quad (18)$$

From equations (14), (15), (16), (17) and (18) above $H_{i,mea}$, $H_{i,cal}$ and n are respectively the i^{th} measured and i^{th} calculated values of daily global solar radiation and the total number of observations, while $\bar{H}_{i,meas}$ is the mean measured global radiation. Iqbal (1983), Halouani et al. (1993), Almorox et al. (2005) and Che et al. (2004) have recommended that a zero value for MBE is ideal and a low RMSE is desirable. Furthermore, the smaller the value of the MBE and RMSE the better is the model's performance. The RMSE test provides information on the short-term performance of the studied model as it allows a term – by – term comparison of the actual deviation between the calculated values and the measured values. The MPE test gives long term performance of the examined regression equations, a positive MPE and MBE values provide the averages amount of overestimation in the calculated values, while the negative values gives underestimation. For a better model performance, a low value of MPE is desirable and the percentage error between -10% and $+10\%$ is considered acceptable (Merges *et al*., 2006). The smaller the value of t the better is the performance. To determine whether a model's estimates are statistically significant, one simply has to determine, from standard statistical tables, the critical t value, i.e., $t_{\alpha/2}$ at α level of significance and $(n-1)$ degrees of freedom. For the model's estimates to be judged statistically significant at the $(1-\alpha)$ confidence level, the computed t value must be less than the critical value. A model is more efficient when NSE is closer to 1 (Chen *et al*., 2004). Similarly, for better data modelling, the coefficient of correlation R and coefficient of determination R^2 should approach 1 as closely as possible.

III. RESULTS AND DISCUSSION

Table 1: Meteorological Data and Global Solar Radiation for Port-Harcourt, Nigeria (1990-2010)

Month	T_{max} (^{0}C)	T_{min} (^{0}C)	H_{mea}/H_o	S_o (hrs)
Jan	32.9667	21.1571	0.5502	11.7703
Feb	33.6476	22.8714	0.5787	11.8569
Mar	33.2333	23.8810	0.5394	11.9748
Apr	32.7381	23.5381	0.5180	12.1011
May	31.8143	23.1571	0.5385	12.2055
Jun	30.5143	22.9333	0.5138	12.2568
Jul	28.9095	22.5048	0.4419	12.2328
Aug	28.6571	22.6143	0.4042	12.1428
Sep	29.4381	22.6476	0.4621	12.0211
Oct	30.3238	22.5619	0.5259	11.8950
Nov	31.4619	22.6286	0.6054	11.7916
Dec	32.1524	21.4714	0.5939	11.7430

Model 1 : The correlation of coefficient of 0.827 exists between the clearness index and the square root of the monthly average daily temperature range also coefficient of determination of 0.684 which connotes 68.4% of clearness index can be accounted for using the square root of the monthly average daily temperature range. Therefore the monthly average daily global solar radiation on a horizontal surface for any month of the year in Port-Harcourt can be predicted using equation (6) as

$$\frac{H_p}{H_0} = 0.049 + 0.161\Delta T^{0.5} \qquad (19)$$

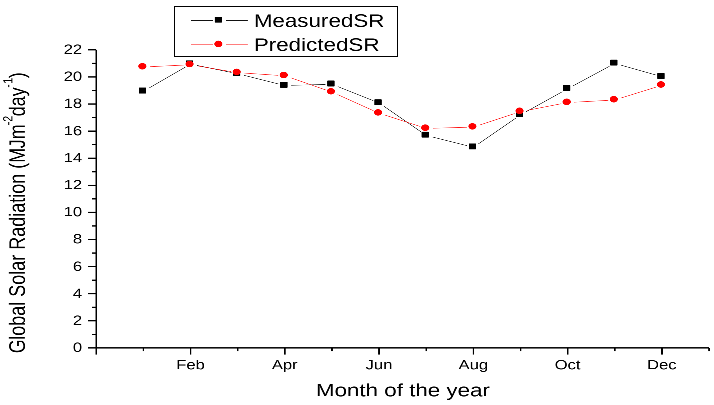

Figure 1: Comparison between the measured and predicted global solar radiation for model 1

Figure 1 shows the comparison between the measured and predicted global solar radiation using Hargreaves and Samani model. It is clear from the figure that a good correlation exists between the measured and predicted global solar radiation. However, the predicted global solar radiation overestimated the measured in the months of January, March, April, July, August and September and is underestimated in the months of February, May, June, October, November and December.

Model 2

The correlation of coefficient of 0.810 exists between the clearness index and the ratio of the monthly average daily temperature range and the monthly average day length, also coefficient of determination of 0.656 which connotes 65.6% of clearness index can be accounted for using the ratio of the monthly average daily temperature range and the monthly average day length. Therefore the monthly average daily global solar radiation on a horizontal surface for any month of the year in Port-Harcourt can be predicted using equation (7) as

$$\frac{H_p}{H_0} = 0.301 + 0.306\left(\frac{\Delta T}{S_0}\right) \qquad (20)$$

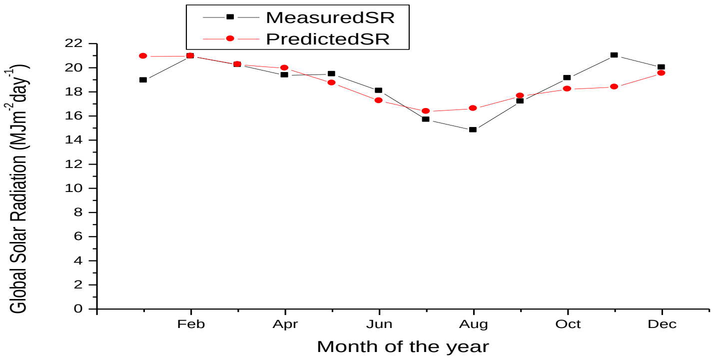

Figure 2: Comparison between the measured and predicted global solar radiation for model 2

Figure 2 shows the comparison between the measured and predicted global solar radiation using the Garcia model. It is clear from the figure that a good correlation exists between the measured and predicted global solar radiation. However, the predicted global solar radiation overestimated the measured in the months of January, February, March, April, July, August and September and is underestimated in the months of May, June, October, November and December.

Model 3 : The correlation of coefficient of 0.846 exists between the clearness index and the natural logarithm of the monthly average daily temperature range, also coefficient of determination of 0.716 which connotes 71.6% of clearness index can be accounted for using the natural logarithm of the monthly average daily temperature range .Therefore the monthly average daily global solar radiation on a horizontal surface for any month of the year in Port-Harcourt can be predicted using equation (8) as

$$\frac{H_p}{H_0} = 0.007 + 0.240 \ln(\Delta T) \qquad (21)$$

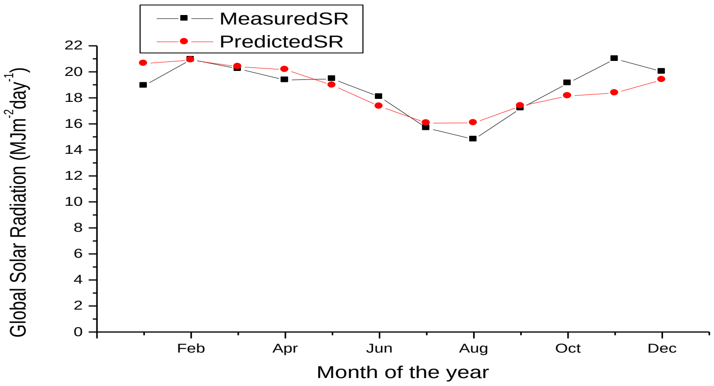

Figure 3: Comparison between the measured and predicted global solar radiation for model 3

Figure 3 shows the comparison between the measured and predicted global solar radiation using model 3. It is clear from the figure that a good correlation exists between the measured and predicted global solar radiation. However, the predicted global solar radiation overestimated the measured in the months of January, March, April, July, August and September and is underestimated in the months of February, May, June, October, November and December.

Model 4 : The correlation of coefficient of 0.785 exists between the clearness index and the natural logarithm of the monthly average daily temperature ratio, also coefficient of determination of 0.617 which connotes 61.7% of clearness index can be accounted for using the natural logarithm of the monthly average daily temperature ratio .Therefore the monthly average daily global solar radiation on a horizontal surface for any month of the year in Port-Harcourt can be predicted using equation (9) as

$$\frac{H_p}{H_0} = 0.278 + 0.758 \ln(\tau_r) \qquad (22)$$

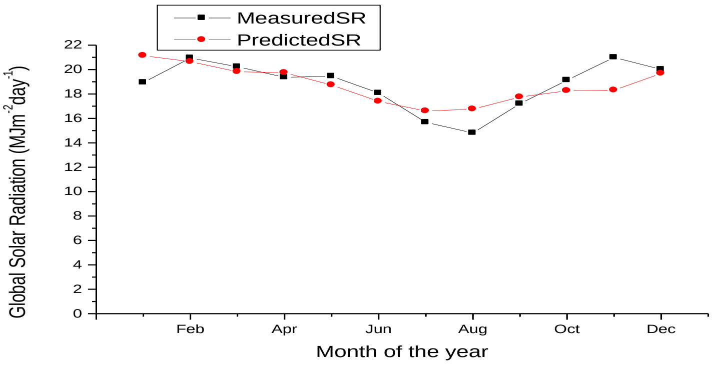

Figure 4: Comparison between the measured and predicted global solar radiation for model 4

Figure 4 shows the comparison between the measured and predicted global solar radiation using model 4. It is clear from the figure that a good correlation exists between the measured and predicted global solar radiation. However, the predicted global solar radiation overestimated the measured in the months of January, April, July, August and September and is underestimated in the months of February, March, May, June, October, November and December.

Model 5 : The correlation of coefficient of 0.648 exists between the clearness index and the natural logarithm of the mean temperature, also coefficient of determination of 0.420 which connotes 42.0% of clearness index can be accounted for using the natural logarithm of the mean temperature .Therefore the monthly average daily global solar radiation on a horizontal surface for any month of the year in Port-Harcourt can be predicted using equation (10) as

$$\frac{H_p}{H_0} = -3.090 + 1.096\ln(T_m) \quad (23)$$

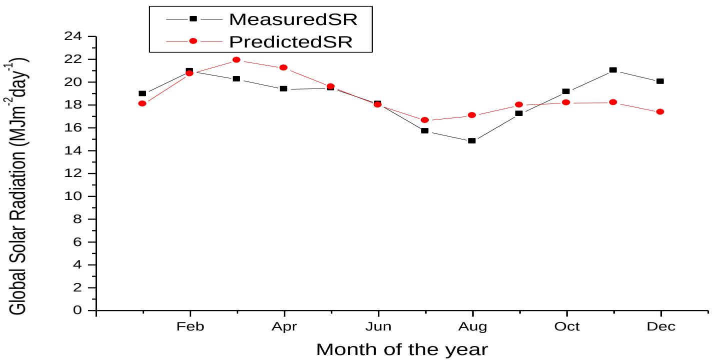

Figure 5: Comparison between the measured and predicted global solar radiation for model 5

Figure 5 shows the comparison between the measured and predicted global solar radiation using model 5. It is clear from the figure that a good correlation exists between the measured and predicted global solar radiation. However, the predicted global solar radiation overestimated the measured in the months of March, April, May, July, August and September and is underestimated in the months of January, February, June, October, November and December.

Model 6

The correlation of coefficient of 0.868 exists between the clearness index and the natural logarithm of the monthly average daily temperature range and the temperature ratio, also coefficient of determination of 0.753 which connotes 75.3% of clearness index can be accounted for using the natural logarithm of the monthly average daily temperature range and the temperature ratio .Therefore the monthly average daily global solar radiation on a horizontal surface for any month of the year in Port-Harcourt can be predicted using equation (11) as

$$\frac{H_p}{H_0} = -0.250 + 0.494\ln(\Delta T) - 0.878\ln(\tau_r) \quad (24)$$

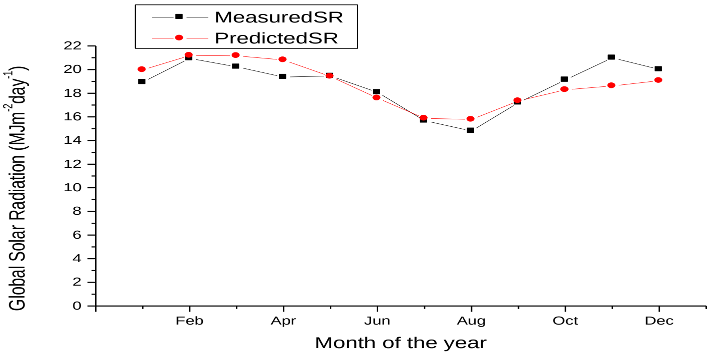

Figure 6: Comparison between the measured and predicted global solar radiation for model 6

Figure 6 shows the comparison between the measured and predicted global solar radiation using model 6. It is clear from the figure that a good correlation exists between the measured and predicted global solar radiation. However, the predicted global solar radiation overestimated the measured in the months of January, February, March, April, July, August and September and is underestimated in the months of May, June, October, November and December.

Model 7 : The correlation of coefficient of 0.847 exists between the clearness index and the natural logarithm of the monthly average daily temperature range and the temperature mean, also coefficient of determination of 0.718 which connotes 71.8% of clearness index can be accounted for using the natural logarithm of the monthly average daily temperature range and the temperature mean. Therefore the monthly average daily global solar radiation on a horizontal surface for any month of the year in Port-Harcourt can be predicted using equation (12) as

$$\frac{H_p}{H_0} = -0.329 + 0.227\ln(\Delta T) + 0.111\ln(T_m) \qquad (25)$$

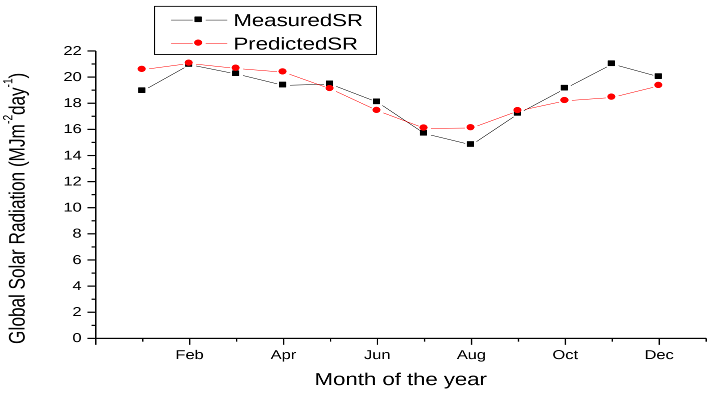

Figure 7: Comparison between the measured and predicted global solar radiation for model 7

Figure 7 shows the comparison between the measured and predicted global solar radiation using model 7. It is clear from the figure that a good correlation exists between the measured and predicted global solar radiation. However, the predicted global solar radiation overestimated the measured in the months of January, February, March, April, July, August and September and is underestimated in the months May, June, October, November and December.

Model 8 : The correlation of coefficient of 0.822 exists between the clearness index and the natural logarithm of the monthly average daily temperature ratio and the temperature mean, also coefficient of determination of 0.675 which connotes 67.5% of clearness index can be accounted for using the natural logarithm of the monthly average daily temperature ratio and the temperature mean. Therefore the monthly average daily global solar radiation on a horizontal surface for any month of the year in Port-Harcourt can be predicted using equation (13) as

$$\frac{H_p}{H_0} = -1.300 + 0.595\ln(\tau_r) + 0.495\ln(T_m) \qquad (26)$$

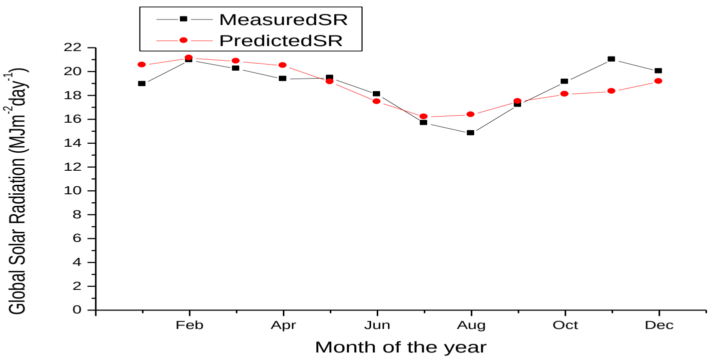

Figure 8: Comparison between the measured and predicted global solar radiation for model 8

Figure 8 shows the comparison between the measured and predicted global solar radiation using model 8. It is clear from the figure that a good correlation exists between the measured and predicted global solar radiation. However, the predicted global solar radiation overestimated the measured in the months of January, February, March, April, July, August and September and is underestimated in the months of May, June, October, November and December.

Equations (19) - (26) are the developed models and H_p are the predicted monthly average daily global solar radiation.

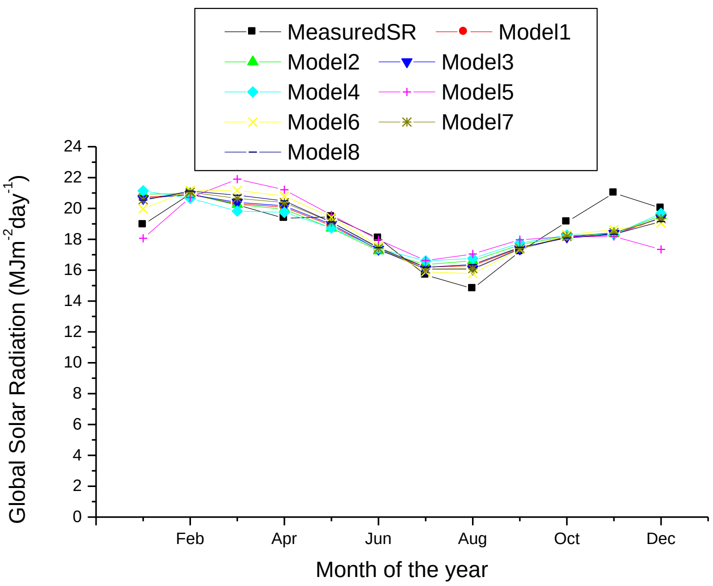

Figure 9: Comparison between the measured and predicted global solar radiation for models (1-8)

Figure 9 shows the comparison between the measured and predicted global solar radiation for the eight (8) models. The figure shows that all the predicted models underestimated the measured global solar radiation in the months of June, October, November and December. However, all the predicted models overestimated the measured in the months of July and August.

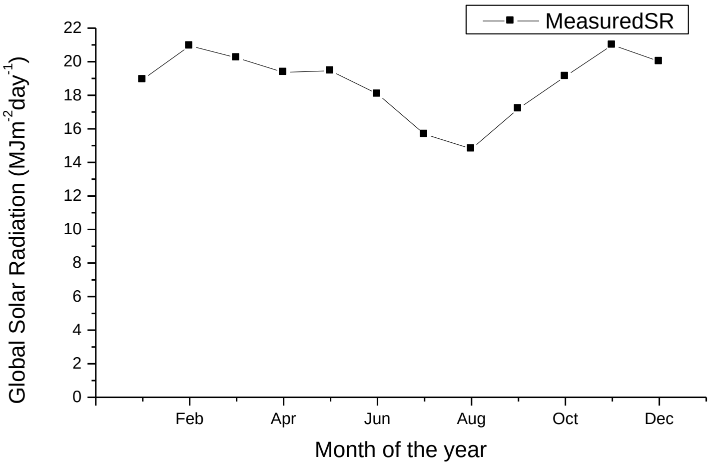

Figure 10: graph of computed values of the global solar radiation for Port-Harcourt (1990-2010)
Figure 10 shows that high values of global solar radiation for Port-Harcourt was recorded during the dry season and low values in the wet season. The highest amount of global solar radiation was obtained in the month of November and the least in August.

Table 2: Comparison of measured and estimated global solar radiation for the different models for Port-Harcourt (1990-2010)

Month	Measured SR	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Jan	18.9409	20.7332	20.9310	20.6390	21.1433	18.0643	19.9743	20.5700	20.5333
Feb	20.9434	20.8990	20.9566	20.9006	20.6498	20.7069	21.1861	21.0451	21.1231
Mar	20.2361	20.3103	20.2586	20.3923	19.8276	21.8982	21.1688	20.6549	20.8528
Apr	19.3635	20.0867	19.9485	20.1716	19.7406	21.2138	20.8075	20.3799	20.4920
May	19.4553	18.8842	18.7155	18.9674	18.7411	19.5731	19.4141	19.1031	19.1202
Jun	18.0775	17.3191	17.2478	17.3495	17.3964	17.9762	17.5870	17.4326	17.4596
Jul	15.6800	16.1979	16.3668	16.0644	16.6019	16.6239	15.8798	16.0732	16.1877
Aug	14.8074	16.2949	16.6066	16.0735	16.7615	17.0509	15.7799	16.0990	16.3648
Sep	17.2048	17.4455	17.6432	17.3778	17.7520	17.9718	17.3518	17.4124	17.4850
Oct	19.1338	18.1023	18.2160	18.1483	18.2685	18.1691	18.2904	18.1805	18.0838
Nov	20.9985	18.2980	18.3925	18.3792	18.3085	18.1789	18.6217	18.4383	18.3276
Dec	20.0157	19.3859	19.5258	19.3945	19.6851	17.3434	19.0604	19.3363	19.1514

Table 2 shows the comparison between the measured and estimated global solar radiation for the different models for Port-Harcourt during the years (1990-2010). It shows that there is a favorable agreement between them. Though, there are some underestimation and overestimation as depicted in figure 9.

Table 3: Validation of the models under different statistical tests.

Models	R	R^2	MBE($MJm^{-2}day^{-1}$)	RMSE($MJm^{-2}day^{-1}$)	MPE(%)	t	NSE
1	0.827	0.684	-0.07500	1.15241	0.03579	0.21631	0.62540
2	0.810	0.656	-0.00401	1.20117	-0.39449	0.01106	0.59303
3	0.846	0.716	-0.08324	1.09275	0.12916	0.25339	0.66318
4	0.785	0.617	0.00160	1.26760	-0.49894	0.00419	0.54676
5	0.648	0.420	-0.00721	1.56976	-0.48876	0.01523	0.30494
6	0.868	0.753	0.02205	1.02488	-0.32927	0.07137	0.70372
7	0.847	0.718	-0.01097	1.08796	-0.24127	0.03345	0.66612
8	0.822	0.675	0.02702	1.17121	-0.48818	0.07653	0.61307

A close examination of table 3 shows the statistical tests adopted in this study to test the performance of the models. It can seen from the table that the correlation coefficients, R is within the range of 0.648 and 0.868 which indicate that a good fit exists between the measured and estimated global solar radiation data.Based on the coefficient of correlation, $R,$ coefficient of determination, R^2 and NSE model 6 produces the highest value thereby reported the best correlation and model 5 the least. For the MBE models 1, 2, 3, 5 and 7 indicate underestimation in the estimated value and models 4 and 6 indicate overestimation in the estimated value. However, model 4 produces the least value of MBE and is reported the best while model 3 produces the lowest accuracy correlation model with slightly higher value of MBE.Based on RMSE, model 6 produces the least value and is reported the best correlation model while model 5 gives the highest RMSE thereby reported the lowest accuracy correlation model with slightly higher value of RMSE. Based on MPE models 2, 4, 5, 6, 7 and 8 indicate underestimation in the estimated value and model 1 and 3 indicate overestimated in the estimated value. However, all the models performs better as they are within the acceptable range of -10% and $+10\%$ with model 1 been the lowest and model 4 highest. The study site is statistically tested at the $(1-\alpha)$ confidence levels of significance of 95% and 99%. For the critical t-value, i.e., at α level of significance and degree of freedom, the calculated t-value must be less than the critical value $(t_{critical} = 2.20,\ df = 11, p < 0.05)$ for 95% and $(t_{critical} = 3.12, df = 11, p < 0.01)$ for 99%. It is shown that the $t_{cal} < t_{critical}$ values. The $t-$test shows that all models are significant at 95% and 99% confidence levels.

IV. CONCLUSION

Knowledge of global solar radiation is indispensable for the proper and effective design and prediction of the solar system performance. However, direct measuring is not available in many areas, therefore the need for empirical equations become effective alternatives to predict global solar radiation through observed data. In this study, eight temperature-based radiation prediction models were developed and evaluated for Port-Harcourt station during a period of twenty one years (1990-2010) using observed maximum and minimum temperature data. Based on the obtained results, model 6 was found the most accurate for the prediction of global solar radiation in Port-Harcourt when compared to other developed models including the well-known existing Hargreaves and Samani and Garcia models. Though, based on long time performance, model 4 and the Hargreaves and Samani (model 1) stands as the best performing models. In this study, good agreement $(MPE \leq \pm 10\%)$ was confirmed between measured and predicted values of global solar radiation for all the evaluated models. Similarly, all models shows high significant at 95% and 99% confidence level.Conclusively, a thorough inspection of the statistical test analysis, we can safely conclude that all the developed models give reasonably degree of good fitting and correlation between the measured and predicted global solar radiation, as such, can be use in predicting global solar radiation in Port-Harcourt. Though, slight differences were recorded starting with model 6 in terms of ranking the best performing model.

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REFERENCES

[1] Akpabio, L. E., Udo, S. O and Etuk, S. E. (2004). Empirical correlation of Global Solar Radiation with Meteorological Data for Onne, Nigeria. *Turkish Journal of Physics*, **28**, 222-227.

[2] Akpootu, D. O. and Momoh, M. (2014). Empirical Model for Estimating Global Solar Radiation in Makurdi, Benue State, North Central Nigeria. A paper presented at the 36th Annual Nigerian Institute of Physics, National Conference, held at the Department of Physics, University of Uyo, Nigeria on May 26-29, 2014.

[3] Almorox, J., Benito, M and Hontoria, C. (2005). Estimation of monthly Angstrom-Prescott Equation coefficients from measured daily data in Toledo, Spain. *Renewable Energy*., **30**, 931-936.

[4] Angstrom, A. (1924). Solar and terrestrial radiation. *Quarterly Journal of the Royal Meteorological society*., **50**, 121-125.

[5] Augustine, C and Nnabuchi, M. N. (2009). Empirical Models for the Correlation of Global Solar Radiation with Meteorological Data for Enugu, Nigeria. *The Pacific Journal of Science and Technology*., **10**(1), 693-700.

[6] Bevington, P. R. (1969). Data reduction and error analysis for the physical sciences, first ed. McGraw Hill Book Co., New York.

[7] Bristow, K and Cambell, G. (1984). On the relationship between incoming solar radiation and daily maximum and minimum temperature. *Agricultural and Forest Meteorology*., **31**, 159-166.

[8] Chen, R., Ersi, K., Yang, J., Lu, S and Zhao, W. (2004). Validation of five global radiation Models with measured daily data in China. *Energy Conversion and Management*., **45**, 1759-1769.

[9] Ekwe, M. C., Joshua, J. K and Igwe, J.E. (2014). Estimation of Daily Global Irradiation at Owerri, Imo State (Nigeria) from Hours of Sunshine, Minimum and Maximum Temperature and Relative Humidity. *International Journal of Applied Research and Studies*., **3**(3), 1-15.

[10] El-Sebaii, A and Trabea, A.(2005). Estimation of Global Solar Radiation on Horizontal Surfaces Over Egypt, *Egypt. J. Solids*, **28**(1), 163-175.

[11] Falayi, E., Adepitan, J. and Rabiu, A.B. (2008). Empirical models for the correlation of Global solar radiation with meteorological data for Iseyin, Nigeria, *Physical Sciences*, **3**(9) 210- 216.

[12] Falayi, E. O., Rabiu, A. B and Teliat, R. O. (2011). Correlations to estimate monthly mean of daily diffuse solar radiation in some selected cities in Nigeria, *Pelagia Research Library*., **2**(4): 480-490.

[13] Gana, N. N and Akpootu, D. O. (2013). Angstrom Type Empirical Correlation for Estimating Global Solar Radiation in North-Eastern Nigeria, *The international Journal of Engineering And Science*., **2**(11): 58-78.

[14] Garcia, J. V. (1994). Principios F'isicos de la Climatolog'ia. Ediciones UNALM (Universidad Nacional Agraria La Molina: Lima, Peru).

[15] Halouani, N., Nguyen, C. T and Vo-Ngoc, D. (1993). Calculation of monthly average solar radiation on horizontal surfaces using daily hours of bright sunshine. *Solar Energy*., **50**, 247-248.

[16] Hargreaves, G and Samani, Z. (1982). Estimating potential evapotranspiration. Journal *of Irrigation and Drainage Engineering. ASCE*., **108**, 225-230.

[17] Iqbal, M. (1983). An introduction to solar radiation, first ed. Academic Press, New York.

[18] Ituen, E. E., Esen, N. U., Nwokolo, S. C and Udo, E. G. (2012). Prediction of global solar Radiation using relative humidity, maximum temperature and sunshine hours in Uyo, in The Niger Delta Region, Nigeria. *Pelagia Research Library*., **3**(4), 1923-1937.

[19] Kassem, A., Aboukarima, A. and El Ashmawy, N. (2009).Development of Neural Network Model to Estimate Hourly Total and Diffuse Solar Radiation on Horizontal Surface at Alexandria City (Egypt), *Journal of Applied Sciences Research*, **5**(11), 2006-2015.

[20] Majnooni-Heris, A., Najafi, V., Bahadori, H and Sadraddini, A. A. (2014). Evaluation and Calibration of Sunshine based solar radiation models for Tabriz, Iran. *International Journal of Biosciences*., **4**(12), 27-34.

[21] Merges, H. O., Ertekin, C and Sonmete, M. H. (2006). Evaluation of global solar radiation Models for Konya, Turkey. *Energy Conversion and Management*., **47**, 3149-3173.

[22] Mfon D. U., Sunday, O. U and Ye-obong, N. U. (2013). Solar Radiation on Horizontal Surface Based on Sunshine Hours Over Owerri, Nigeria. *Asian Journal of Science and Technology*., **4**(10), 116-119.

[23] Muzathik, A. M., Nik, W. B. W., Ibrahim, M. Z., Samo, K. B., Sopian, K and Alghoul, M. A.(2011). Daily Global Solar Radiation Estimate Based on Sunshine Hours. *International Journal of Mechanical and Materials Engineering*., 6(1), 75-80.

[24] Okonkwo, G. N and Nwokoye, A. O. C. (2014). Estimating Global Solar Radiation from Temperature Data in Minna Location. *European Scientific Journal*., 10(15), 254-264.

[25] Prescott, J. A. (1940). Evaporation from water surface in relation to solar radiation, *Transactions of the Royal Society of Australia*, **46:** 114-118.

[26] Saidur, R., Masjuki, H. H and Hassanuzzaman, M. (2009). Performance of an Improved Solar car Ventilator,*International Journal of Mechanical and Materials Engineering*., **4**(1), 24-34.

[27] Ugwu, A. I and Ugwuanyi, J. U. (2011). Performance assessment of Hargreaves model in Estimating solar radiation in Abuja using minimum climatological data. *International Journal of the Physical Sciences*., **6**(31), 7285-7290.

[28] Zekai, S. (2008). Solar energy fundamentals and modeling techniques: atmosphere, Environment, climate change and renewable energy, first ed. Springer, London.