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PERFORMANCE OF SOME PARAMETRIC MODELS FOR GLOBAL SOLAR RADIATION ESTIMATION IN NIGERIA

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ABSTRACT: Energy forecast and engineering designs within the atmosphere requires some essential measurable parameters connected to solar radiations. Global solar radiation accounts for the influx of solar radiation received at the ground level. The study presents twelve empirical models using sunshine duration, relative humidity, and temperature as basic parameters, from 25 years observatory data obtained from some stations. The annual and seasonal performance of the models was validated using statistical measure, i.e. Mean Bias Error (MBE), Root Mean Square Error (RMSE), Mean Percentage Error (MPE) and Pearsons correlation coefficient. The proposed models show the lowest MBE, RMSE, and MPE for the temperature based models in Sokoto and Ilorin while all models performed favorably for Port -Harcourt. Similar trends were observed in both wet and dry seasons with improved in the estimated of global solar radiation. The study recommends some of the models for future prediction of solar radiation.

KEYWORDS: Global Solar Radiation; Empirical Models; Seasonal; Sunshine Duration; Temperature.

1. INTRODUCTION

The projected world population growth and the corresponding energy demand pose future challenges to the environment, economy, and food security. The impact of environmental challenges such as the depletion of the ozone layer and greenhouse effect, instability in the price of crude oil and climate change can be minimized by effective optimization and utilization of solar radiation. Solar radiation is promising and sustainable form of renewable energy received on the earth surface. The application of global solar radiation data spans various fields such as engineering, agriculture, and meteorology for engineering designs and agro-metrological calculations particularly in estimating water budget for irrigation or crop growth forecast respectively ([KM12]). The solar radiation components are generally measured using pyranometer; however the costs of maintenance and their availability inhibited the spread to every location for measurement, especially in developing countries. Consequently, the estimation of solar radiation at the earth's surface using parametric models is essential. There are number of reviews on models (see [GS97]; [EM00]; [YC06]; [T+05]; [Chin08]; [L+09]; [Ogo10]; [DA12]) that have developed to estimate Global Solar Radiation base on cheaper meteorological parameters or artificial neural network ([MB08]). The model base on Sunshine hour proposed by Angstrom and Prescott ([Pre40]) established the foundation for estimating global solar radiation for a long time using linear relationship with sunshine hour, and later modified to the quadratic and cubic form referred to as the first, second order and third order Angstrom-Prescott models respectively. Mubiru and Banda ([MB08]) formulated the relationship between global solar radiation and maximum temperature, while Togrul and co ([TO99], [TO00] combined relative sunshine duration and the ratio of the minimum to maximum air temperature. The model was used to estimate monthly mean of global solar radiation of various cities in Turkey. Hargreaves and Samani ([HS82]) model shows the relationship between global solar radiation and the root of the mean temperature. Garcia ([Gar94]) formulated temperature based empirical model in the form of Angstrom-Prescott model to estimate global solar radiation in Peru, while Newland ([New89]) combines both sunshine and temperature based models. This study aims to estimate global solar radiation on a horizontal surface in Sokoto, Ilorin and Port Harcourt using twelve (12) parametric models in the literature for solar radiation prediction. The performance of the models is validated and compared with the observed global solar radiation. Furthermore, statistical errors, such as root mean square error (RMSE), mean bias error (MBE), mean percentage error (MPE) and Pearson's correlation coefficient (P), were employed to evaluate the efficacy of these models. Based on the validation with the observed data, the models with the best estimations are identified. The study is divided into four sections; introduction, methodology, result and discussion, and conclusion.

2. METHODOLOGY

Twelve parametric models related to the sunshine hour, relative humidity, and temperature parameters were estimated and their predictive ability was evaluated by employing the test-train approach for the cross-validation and error analysis. Monthly minimum and maximum temperature; mean hourly solar radiation, sunshine hour, and relative humidity data for a long period, 25 years obtained from observatory station in Nigeria Meteorology Agency, Oshodi, Lagos Nigeria were used in this study. 20 years of data (1980-2000) was used to train the model while 5 years of data (2001-2005) was used for testing the performance of the models. Model 1 shows the original linear sunshine hour based model proposed by Angstrom and Prescott ([Ang24]; [Pre40]) Models 2 and 3 are the quadratic and polynomial form of the latter respectively. Models 4-7 shows the proposed exponential and logarithmic form of the sunshine hour parameter by Ampratwum, Togrul and others ([AD99]; [TT02]), while Models 7-10 are the linear temperature-based models proposed by Hargreaves and Samani, Garcia and others ([HS82]; [Gar40]). We presented the multiple regression models, which involves the combination of the climatic variable are presented in Models 11 and 12. The extraterrestrial solar radiation (R_0) was obtained using the site-specific input such as latitude (φ) and sunset hour angle (w_s) of the location of study. The extraterrestrial daily solar radiation ($MJm^{-2}\ day^{-1}$) is determined by the sets of equations given below.

$$R_0 = \frac{24(60)}{\pi} G_{SC} d_r [\omega_s sin\varphi sin\delta + cos\varphi cos\delta sin\omega_s] \quad (1)$$

$$d_r = 1 + 0.033 cos\left(\frac{2\pi J}{365}\right) \quad (2)$$

$$\delta = 0.409 \sin\left(\frac{2\pi J}{365} - 1.39\right) \quad (3)$$

$$\omega_s = cos^{-1}(-tan\varphi tan\delta) \quad (4)$$

Where R_0 is the extraterrestrial radiation in ($MJm^{-2}day^{-1}$), G_{SC} is the solar constant = 0.082 ($MJm^{-2}day^{-1}$), d_r is the inverse relative Earth-Sun distance, δ is the solar declination in radian, J is the number of the days in the calendar year. The daylight hours N (hours) is also calculated using the equation given below.

$$N = \frac{24}{\pi}\omega_s \quad (5)$$

2.1 Location description, data measurement and calibration

Nigeria is situated between Latitudes 4^0 and 14^0 North of the equator and between longitudes 3^0 and 15^0 East of the meridian ([Ilo65]). The sites Sokoto, Ilorin, and Port-Harcourt spread across the vegetation zones of Nigeria. Sokoto and Port Harcourt are located in the extreme North and Southern part of Nigeria, respectively, while Ilorin is located in the transition zone between the tropical forest of the South and the Savannah of the North ([UA99]). Sokoto has an annual average temperature of 28.3 degrees, with maximum average daytime temperatures of 40 degrees. Ilorin has a tropical climate with an annual average rainfall of 1217 mm; the least amount of rainfall occurs in January with an average rainfall of 10 mm, most of the precipitation falls in September averaging 232 mm. The average annual temperature is 26.5 degree. The temperatures are highest on average in March at around 29.0 August is the coldest month, with temperatures averaging 24.5. Port-Harcourt has a tropical climate with lengthy and heavy rainy seasons and very short dry seasons. Its heaviest precipitation occurs during the month of September with an average of 367 mm of rain with average temperatures between 25℃ and 28℃. The global solar radiation data obtained from the Nigerian meteorological agency is measured using Gunn Bellani radiometer calibrated in Gunn Bellani (GB) and the procedure described by Kolebaje and his colleagues ([KM12]; [KIA16]). The conversion factor given by Folayan ([Fol88]) was used.

$$1ml_{GB} = 1.357(\pm 0.176)MJm^{-2}$$

2.2 Performance evaluation

The study evaluated the deviation between the estimated and measured values using the following statistical parameters,

- Mean Bias Error (MBE):

$$MBE = \frac{\sum_1^n (R_{obs} - R_{est})}{n} \ ^\circ C \quad (6)$$

- Root Mean Square Error (RMSE):

$$RMSE = \sqrt{\frac{\sum_1^n (R_{obs} - R_{est})^2}{n}} \quad (7)$$

- Mean Percentage Error (MPE):

$$MPE = \frac{\sum_1^n \left(\frac{R_{obs} - R_{est}}{R_{obs}} \times 100\right)}{n} \quad (8)$$

Where R_{obs} and R_{est} data from observatory and estimated (models) global solar radiation respectively, and n is the number of observations used. Generally, low the MBE, MPE, and RMSE are projected for a good model. A positive and negative MBE or MPE value is measure of overestimation and underestimation respectively. The MBE and MPE is the long term performance prediction of the model while the RMSE measure the short term performance, meanwhile low values of RMSE are desirable, but few errors in the sum can produce a significant increase in the indicator. Low values of MBE are desirable, but overestimation of an individual data element will cancel underestimation in a separate observation. It is also possible to have large RMSE and small MBE values at the same time or vice versa. The Pearson correlation coefficient (P) between the observed and estimated values was obtained. The value of the correlation ranges between -1 and +1, which indicates negative or positive trends between the observed and estimated values. The closer the correlation coefficient is to the positive unity, the better is the correlation between the estimated and the observed solar radiation.

3. RESULTS AND DISCUSSION

20 years average monthly values of sunshine hour, global solar radiation and temperature dataset obtained from NIMET were used to develop the models presented as regression equation in Tables I, III and V for a whole year and seasonal; dry and wet seasons for three cities in Nigeria. January – December monthly average dataset were used to develop the models for whole year, while November – May and June – October monthly mean were used for Dry and Wet Seasons respectively. The models were validated by using 5 - year dataset for each location. The calculated values of the monthly global solar radiation obtained from the models were compared to the measured values collected from the sites. MBE, RMSE, MPE, and P value were used as a performance indicator of the developed models. The calculated MBE, RMSE, MPE and P of these models are presented in Table II, IV and VI for the whole year, Dry and Wet Seasons respectively. The best models were identified by the performance indicators in each model. With respect to that, Models 8, 9 and 10 showed good Pearson correlation values of 0.68, 0.84 and 0.75 respectively among the models studied. Model 9 was shown to have highest P value of 0.84, least RMSE of 1.087 MJ/m^2 and acceptable -0.189% value of MPE for Sokoto, thus, showing the best performance for estimation of global solar radiation in Sokoto than other models used in this study. The worst performance was displayed by the sunshine hour based Models 1-7 and 11-12 for Sokoto. Meanwhile, small Pearson's correlation and fairly large RMSE reveal that their estimated global solar radiations deviate considerably from the observed solar radiation. This implies that those models are unsuitable for estimating monthly daily global solar radiation, and can be excluded because of their poor performance, despite low values of MPE and MBE. Performance indicators of the models studied in Ilorin reveal models 7, 9 and 10 as having a better agreement between estimated and observed global solar radiation than other models studied. Model 7 exhibit the best performance with the highest P value of 0.70, followed by 0.65 and 0.61 in Models 9 and 10. The performance indicators; RMSE, MBE, MPE values of 2.117 MJ/m^2, -0.345 MJ/m^2 and 0.756% in model 7 agreed closely with 2.114 MJ/m^2, -0.304 MJ/m^2 and 0.825% in model 9 successively. Our results show both (Models 7 and 9) slightly underestimated the global solar radiation value relative the actual value. It is worthy to mention that temperature based models 7-10 performed generally better than sunshine hours based models 1-6 for both Sokoto and Ilorin. For Port Harcourt, high positive correlation was observed between the estimated and the measured solar radiation values were observed indicating a measure of reliability. Some of the models developed in this study underestimated measured solar radiation for Port Harcourt, due to negative MBE and MPE values. Model 7 gave the least RMSE and highest P values of 1.058 and 0.84, respectively. The models gave t-value that is less than the critical value, showing the estimated global solar radiations are statistically significant. All the models are recommended for estimating global solar radiation in Port Harcourt with Model 7 showing the best result. The trends of estimated average monthly global solar radiation for the models considered and the observed values for Sokoto, Ilorin and Port Harcourt within Jan – Dec is shown in figures 1, 2 and 3 provided. In summary, lower values of MBE and MPE obtained in all the models indicated their suitability for long term prediction; the large RMSE and low Pearson's coefficient which showed significant deviation between the estimated and observed global solar radiation are unacceptable.

The dry and wet season's model presented in Tables III and V also reveals good performance was not seen in the short term for prediction by the fairly large RMSE value obtained in some of the models, but relatively good results were seen in the long term for predictions. In Sokoto, Model 5 showed the best results with 0.91 and 0.889MJ/m^2 Pearson's coefficient and RMSE value in the dry season. On the contrary, all the models performed poorly for short term prediction in Sokoto during the wet season shown in Fig. 7. Results from the performance of the models in Ilorin are fairly satisfactory in the wet seasons than the dry season. Only Models 1, 2 and 4 in the dry season as wells as model 3, 7, 9, 10 and 11 in the wet seasons are statistically significant and satisfactory with high Pearson's coefficient and fairly low RMSE value.

Table I: Twelve Formulated Models for Sokoto, Ilorin and Port Harcourt

MODEL #	SOKOTO	ILORIN	PORT HARCOURT
1	$\frac{R_s}{R_0} = 0.13 + 0.82\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = 0.17 + 0.67\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = 0.13 + 0.84\left(\frac{n}{N}\right)$
2	$\frac{R_s}{R_0} = 1.48 - 3.23\left(\frac{n}{N}\right) + 3.03\left(\frac{n}{N}\right)^2$	$\frac{R_s}{R_0} = 1.54\left(\frac{n}{N}\right) - 0.82\left(\frac{n}{N}\right)^2$	$\frac{R_s}{R_0} = 1.69\left(\frac{n}{N}\right) - 1.35\left(\frac{n}{N}\right)^2$
3	$\frac{R_s}{R_0} = 15.96 - 70.78\left(\frac{n}{N}\right) + 106.78\left(\frac{n}{N}\right)^2 - 52.50\left(\frac{n}{N}\right)^3$	$\frac{R_s}{R_0} = 0.06 + 1.71\left(\frac{n}{N}\right) - 3.09\left(\frac{n}{N}\right)^2 + 2.71\left(\frac{n}{N}\right)^3$	$\frac{R_s}{R_0} = 0.27 - 0.65\left(\frac{n}{N}\right) + 4.72\left(\frac{n}{N}\right)^2 - 4.83\left(\frac{n}{N}\right)^3$
4	$\frac{R_s}{R_0} = 0.93\left(\frac{n}{N}\right)^{0.84}$	$\frac{R_s}{R_0} = 0.79\left(\frac{n}{N}\right)^{0.54}$	$\frac{R_s}{R_0} = 0.84\left(\frac{n}{N}\right)^{0.57}$
5	$\frac{R_s}{R_0} = 0.47\exp\left[0.87\left(\frac{n}{N}\right)\right]$	$\frac{R_s}{R_0} = 0.39\exp\left[0.83\left(\frac{n}{N}\right)\right]$	$\frac{R_s}{R_0} = 0.28\exp\left[1.22\left(\frac{n}{N}\right)\right]$
6	$\frac{R_s}{R_0} = -3.5 + 4.71\left(\frac{n}{N}\right) - 5.96\log\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = -0.37 + 1.33\left(\frac{n}{N}\right) - 0.67\log\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = 0.05 + 0.99\left(\frac{n}{N}\right) + -0.09\log\left(\frac{n}{N}\right)$
7	$\frac{R_s}{R_0} = 0.73 - 0.14\left(\frac{T_{max}}{65}\right)$	$\frac{R_s}{R_0} = -0.39 + 1.91\left(\frac{T_{max}}{65}\right)$	$\frac{R_s}{R_0} = -0.61 + 2.03\left(\frac{T_{max}}{65}\right)$
8	$\frac{R_s}{R_0} = 1.17 - 0.819\,(\theta)$	$\frac{R_s}{R_0} = 0.76 - 0.30\,(\theta)$	$\frac{R_s}{R_0} = 1.91 - 2.10(\theta)$
9	$\frac{R_s}{R_0} = 0.10 + 0.15\Delta T^{0.5}$	$\frac{R_s}{R_0} = -0.08 + 0.20\Delta T^{0.5}$	$\frac{R_s}{R_0} = -0.15 + 0.18\Delta T^{0.5}$
10	$\frac{R_s}{R_0} = 0.37 + 0.25\frac{\Delta T}{N}$	$\frac{R_s}{R_0} = 0.27 + 0.33\frac{\Delta T}{N}$	$\frac{R_s}{R_0} = 0.12 + 0.34\frac{\Delta T}{N}$
11	$\frac{R_s}{R_0} = 0.26 - 0.01\left(\frac{n}{N}\right) + 0.68\left(\frac{Tmax}{65}\right)$	$\frac{R_s}{R_0} = 0.07 + 0.60\left(\frac{n}{N}\right) + 0.29\left(\frac{Tmax}{65}\right)$	$\frac{R_s}{R_0} = -0.04 + 0.70\left(\frac{n}{N}\right) + 0.43\left(\frac{Tmax}{65}\right)$
12	$\frac{R_s}{R_0} = 0.93 + 0.34\left(\frac{n}{N}\right) - 0.83(\theta) + 0.0008\overline{RH}$	$\frac{R_s}{R_0} = 0.25 + 0.62\left(\frac{n}{N}\right) - 0.09(\theta) + 0.0002\overline{RH}$	$\frac{R_s}{R_0} = 0.38 + 0.70\left(\frac{n}{N}\right) - 0.24(\theta) - 0.0004\overline{RH}$

Table II: P, MBE, RMSE and MPE values for Sokoto, Ilorin and Port Harcourt

	SOKOTO				ILORIN				PORT HARCOURT			
Model #	**P**	**MBE MJ/m^2**	**RMSE MJ/m^2**	**MPE %**	**P**	**MBE MJ/m^2**	**RMSE MJ/m^2**	**MPE %**	**P**	**MBE MJ/m^2**	**RMSE MJ/m^2**	**MPE %**
1	0.34	-0.057	1.982	-0.360	0.23	-0.369	2.622	0.200	0.70**	-0.366	1.657	0.711
2	0.34	-0.122	1.973	-0.082	0.19	-0.522	2.674	0.930	0.74**	-0.122	1.708	-0.420
3	0.50	-0.245	1.767	0.560	0.29	-0.492	2.670	0.960	0.67*	-0.053	1.575	-0.470
4	0.35	-0.026	1.975	-0.490	0.21	-0.311	2.622	-0.110	0.72**	-0.379	1.659	0.985
5	0.38	-0.025	2.069	-0.445	-0.02	-0.519	2.796	0.313	0.68*	-0.360	1.462	-0.557
6	0.35	-0.246	0.246	0.120	0.23	-0.403	2.655	0.400	0.70**	-0.149	1.704	-0.910
7	0.27	-0.009	2.506	-0.543	0.70**	-0.345	2.117	0.756	0.84**	-0.163	1.058	-0.800
8	0.68*	-0.040	1.511	-0.361	0.04	-0.641	2.783	0.900	0.74**	-0.240	1.868	1.966
9	0.84**	-0.019	1.087	-0.189	0.65*	-0.304	2.114	0.825	0.75**	-0.195	1.455	1.141
10	0.75**	-0.070	1.312	-0.059	0.61*	-0.273	2.180	0.551	0.71**	-0.242	1.572	0.141
11	0.12	-0.022	2.225	-0.631	0.41	-0.307	2.402	0.090	0.79**	-0.136	1.306	-0.823
12	0.41	-0.108	2.404	-0.480	0.26	-0.240	3.014	-0.800	0.76**	-0.154	2.915	-0.710

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

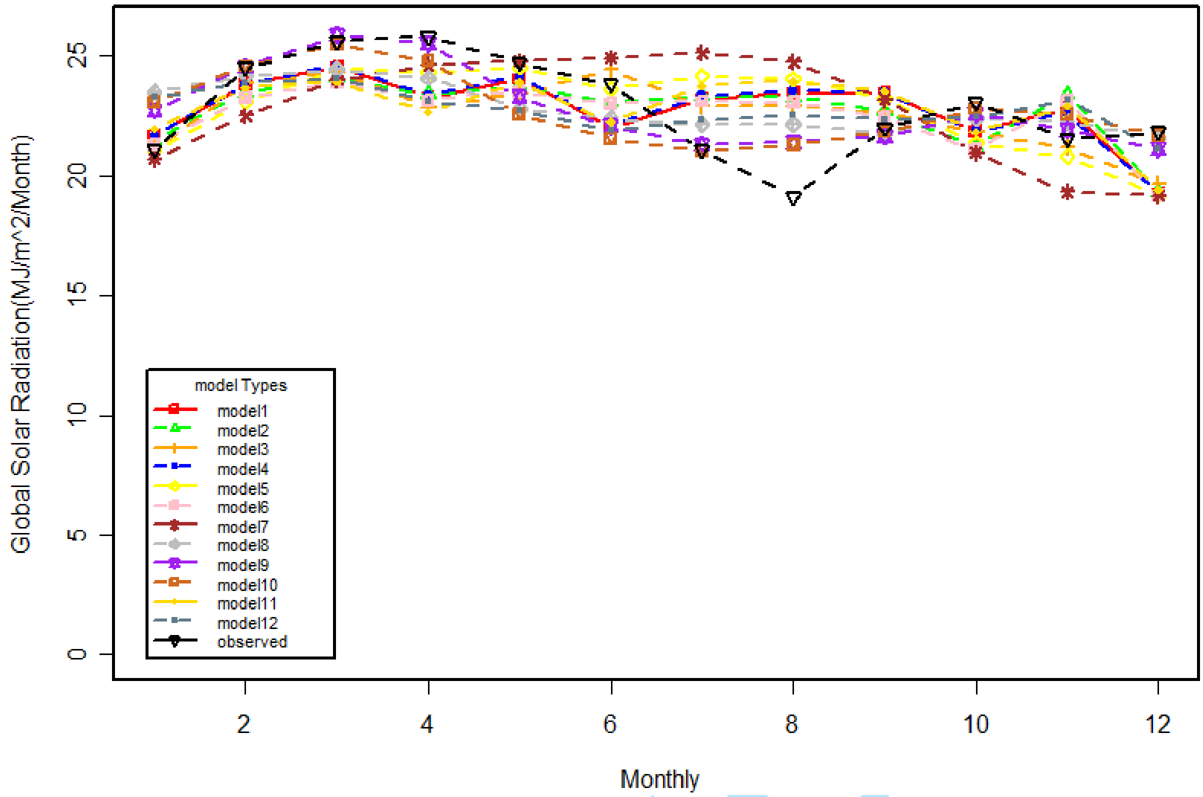

Figure 1: Trend of monthly estimate of global solar radiation compared with observed for Sokoto (Jan-Dec)

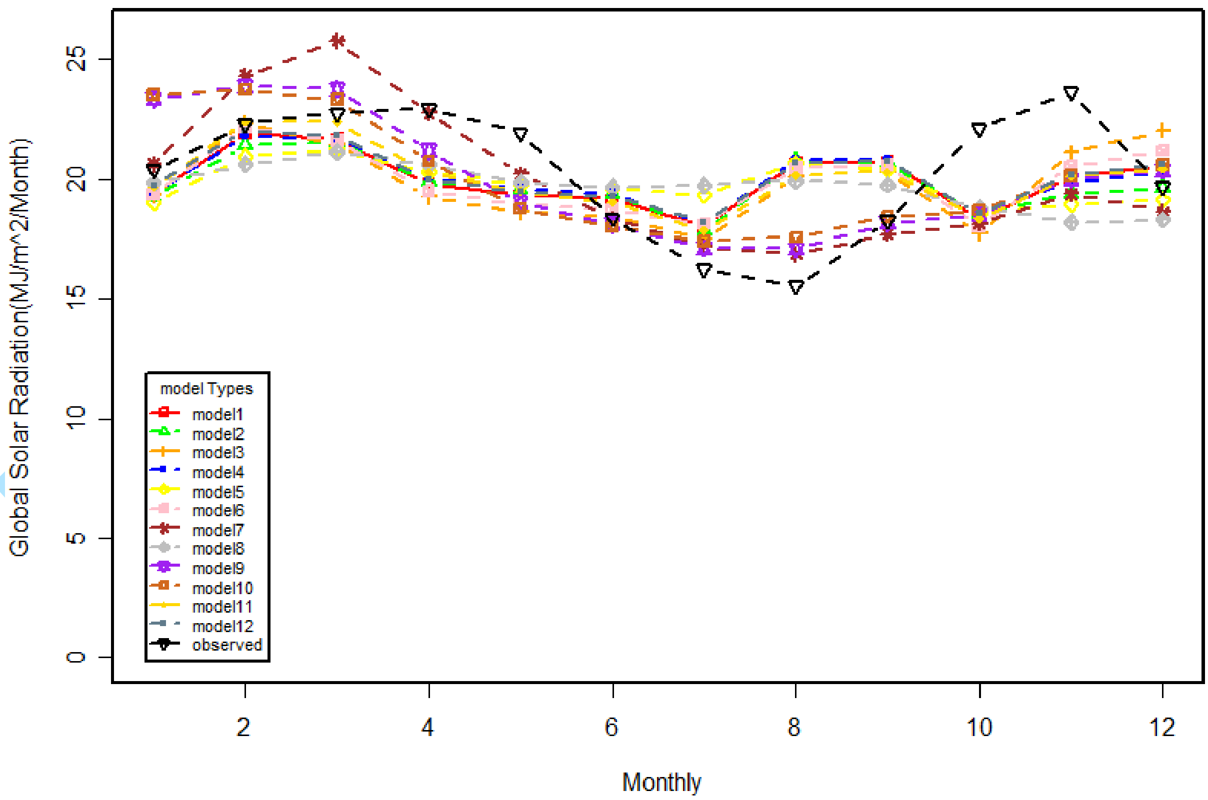

Figure 2: Trend of monthly estimate of global solar radiation compared with observed for Ilorin (Jan-Dec)

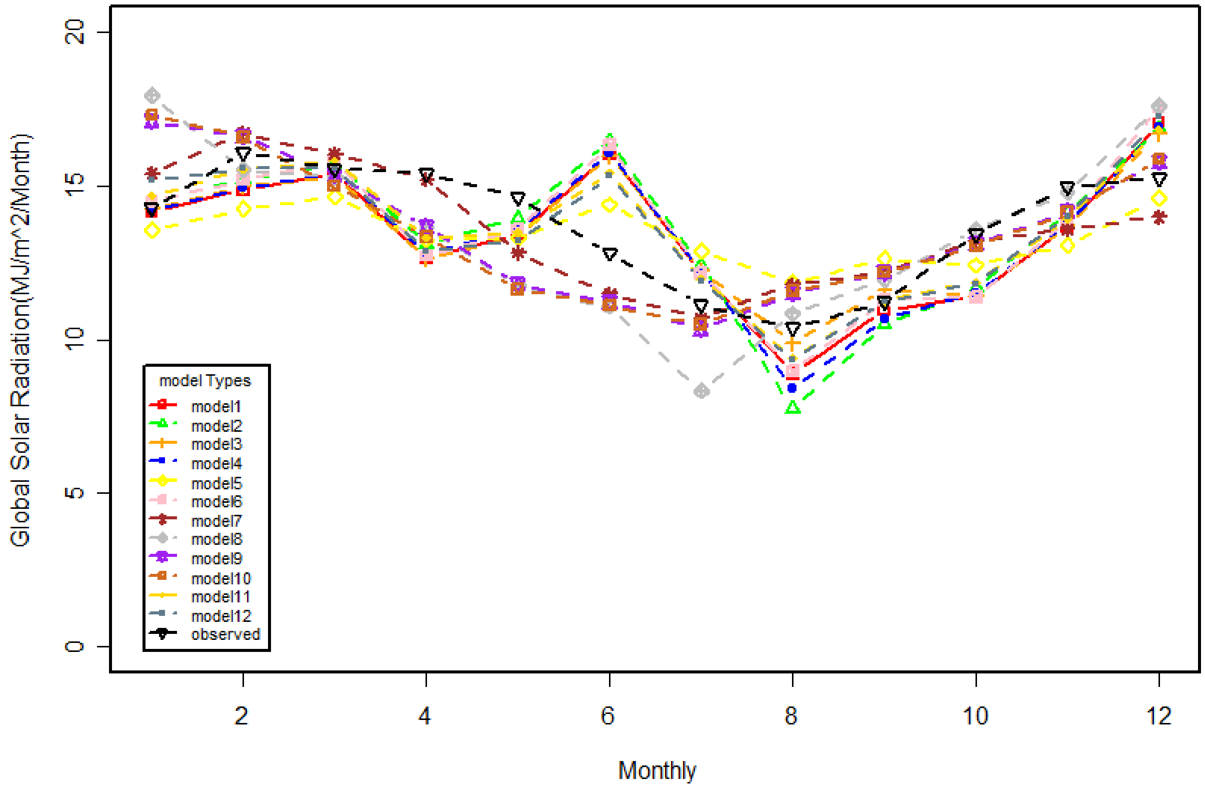

Figure 3: Trend of monthly estimate of global solar radiation compared with observed for Port Harcourt (Jan-Dec)

Table III: Twelve Formulated Models for Sokoto, Ilorin and Port Harcourt (Dry Season)

MODEL #	SOKOTO	ILORIN	PORT HARCOURT
1	$\frac{R_s}{R_0} = 0.105 + 0.913\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = 0.036 + 0.970\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = 0.169 + 0.687\left(\frac{n}{N}\right)$
2	$\frac{R_s}{R_0} = 1.216\left(\frac{n}{N}\right) - 0.219\left(\frac{n}{N}\right)^2$	$\frac{R_s}{R_0} = 1.084\left(\frac{n}{N}\right) - 0.090\left(\frac{n}{N}\right)^2$	$\frac{R_s}{R_0} = 1.615\left(\frac{n}{N}\right) - 1.157\left(\frac{n}{N}\right)^2$
3	$\frac{R_s}{R_0} = 41.57 - 176.80\left(\frac{n}{N}\right) + 252.74\left(\frac{n}{N}\right)^2 - 119\left(\frac{n}{N}\right)^3$	$\frac{R_s}{R_0} = 7.83 - 31.86\left(\frac{n}{N}\right) + 42.76\left(\frac{n}{N}\right)^2 - 16\left(\frac{n}{N}\right)^3$	$\frac{R_s}{R_0} = 4.08 - 29.18\left(\frac{n}{N}\right) + 74.41\left(\frac{n}{N}\right)^2 - 61\left(\frac{n}{N}\right)^3$
4	$\frac{R_s}{R_0} = 1.014\left(\frac{n}{N}\right)^{1.001}$	$\frac{R_s}{R_0} = 0.992\left(\frac{n}{N}\right)^{0.865}$	$\frac{R_s}{R_0} = 0.776\left(\frac{n}{N}\right)^{0.503}$
5	$\frac{R_s}{R_0} = 0.485 \exp\left[0.928\left(\frac{n}{N}\right)\right]$	$\frac{R_s}{R_0} = 0.406 \exp\left[1.11\left(\frac{n}{N}\right)\right]$	$\frac{R_s}{R_0} = 0.328 \exp\left[0.787\left(\frac{n}{N}\right)\right]$
6	$\frac{R_s}{R_0} = 7.852 - 7.082\left(\frac{n}{N}\right) + 13.292\, log\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = -13.569 + 15.960\left(\frac{n}{N}\right) - 20.342\, log\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = 1.867 + 3.297\left(\frac{n}{N}\right) - 2.370\, log\left(\frac{n}{N}\right)$
7	$\frac{R_s}{R_0} = 1.245 - 962\left(\frac{T_{max}}{65}\right)$	$\frac{R_s}{R_0} = 0.226 + 0.754\left(\frac{T_{max}}{65}\right)$	$\frac{R_s}{R_0} = 0.503 - 0.167\left(\frac{T_{max}}{65}\right)$
8	$\frac{R_s}{R_0} = 1.182 - 0.822\,(\theta)$	$\frac{R_s}{R_0} = 0.994 - 0.579\,(\theta)$	$\frac{R_s}{R_0} = 0.678 - 0.377(\theta)$
9	$\frac{R_s}{R_0} = -0.214 + 0.235\Delta T^{0.5}$	$\frac{R_s}{R_0} = 0.217 + 0.122\Delta T^{0.5}$	$\frac{R_s}{R_0} = 0.233 + 0.059\Delta T^{0.5}$
10	$\frac{R_s}{R_0} = 0.320 + 0.294\frac{\Delta T}{N}$	$\frac{R_s}{R_0} = 0.439 + 0.180\frac{\Delta T}{N}$	$\frac{R_s}{R_0} = 0.327 + 0.112\frac{\Delta T}{N}$
11	$\frac{R_s}{R_0} = 0.91 - 0.28\left(\frac{n}{N}\right) - 0.71\left(\frac{Tmax}{65}\right)$	$\frac{R_s}{R_0} = -0.36 + 0.96\left(\frac{n}{N}\right) + 0.76\left(\frac{Tmax}{65}\right)$	$\frac{R_s}{R_0} = 0.63 + 0.74\left(\frac{n}{N}\right) - 0.24\left(\frac{Tmax}{65}\right)$
12	$\frac{R_s}{R_0} = 2.83 + 0.56\left(\frac{n}{N}\right) - 2.15(\theta) + 0.001\overline{RH}$	$\frac{R_s}{R_0} = 0.23 - 0.82\left(\frac{n}{N}\right) - 0.26(\theta) + 0.0008\overline{RH}$	$\frac{R_s}{R_0} = 0.37 - 0.82\left(\frac{n}{N}\right) + 0.72\,(\theta) - 0.009\overline{RH}$

Table IV: P, MBE, RMSE and MPE values for Sokoto, Ilorin and Port Harcourt (Dry Season)

	SOKOTO				ILORIN				PORT HARCOURT			
Model #	**P**	**MBE MJ/m²**	**RMSE MJ/m²**	**MPE %**	**P**	**MBE MJ/m²**	**RMSE MJ/m²**	**MPE %**	**P**	**MBE MJ/m²**	**RMSE MJ/m²**	**MPE %**
1	-0.04	0.094	1.473	-0.650	0.81**	0.036	1.984	-0.540	-0.11	-0.167	1.527	0.934
2	-0.05	0.036	1.485	-0.411	0.80**	0.027	1.997	-0.490	-0.18	-0.099	1.697	0.464
3	-0.17	0.089	3.854	0.178	0.03	0.034	2.429	0.600	0.08	-0.349	3.396	0.220
4	-0.03	0.027	1.499	-0.376	0.81**	-0.003	1.963	-0.356	-0.13	-0.143	1.568	0.774
5	0.91**	-0.272	0.889	-0.110	0.39	-0.148	1.291	0.410	0.38	-0.110	0.538	0.620
6	0.21	0.058	2.727	-0.709	-0.09	-0.135	2.485	0.173	0.21	-0.081	0.930	0.453
7	0.73*	0.036	1.336	-0.362	0.47	0.041	1.631	-0.313	0.46	-0.203	0.634	0.127
8	0.61	-0.235	1.425	0.587	0.11	-0.159	1.647	0.398	0.39	-0.266	0.744	1.686
9	0.61	-0.305	1.575	0.976	0.17	0.640	1.887	-3.222	0.47	-0.153	0.675	0.954
10	0.58	-0.264	1.571	0.725	0.15	0.010	1.695	-0.359	0.44	-0.111	0.694	0.676
11	0.75*	-0.099	1.249	0.175	0.11	0.036	2.313	-0.486	0.02	0.513	0.976	-3.521
12	0.67	0.345	1.423	0.128	0.03	0.321	2.054	-0.512	0.28	0.623	1.422	-5.891

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

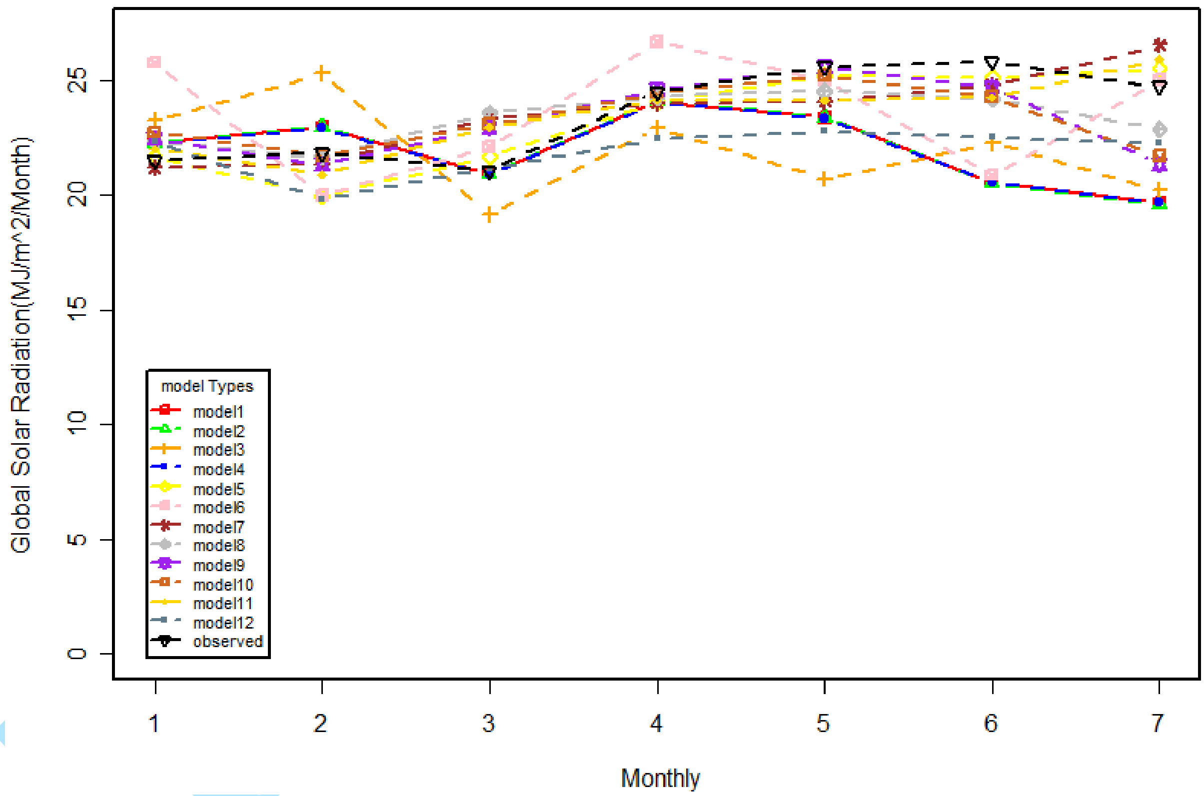

Figure 4: Trend of monthly estimate of global solar radiation compared with observed for Sokoto (Dry Season)

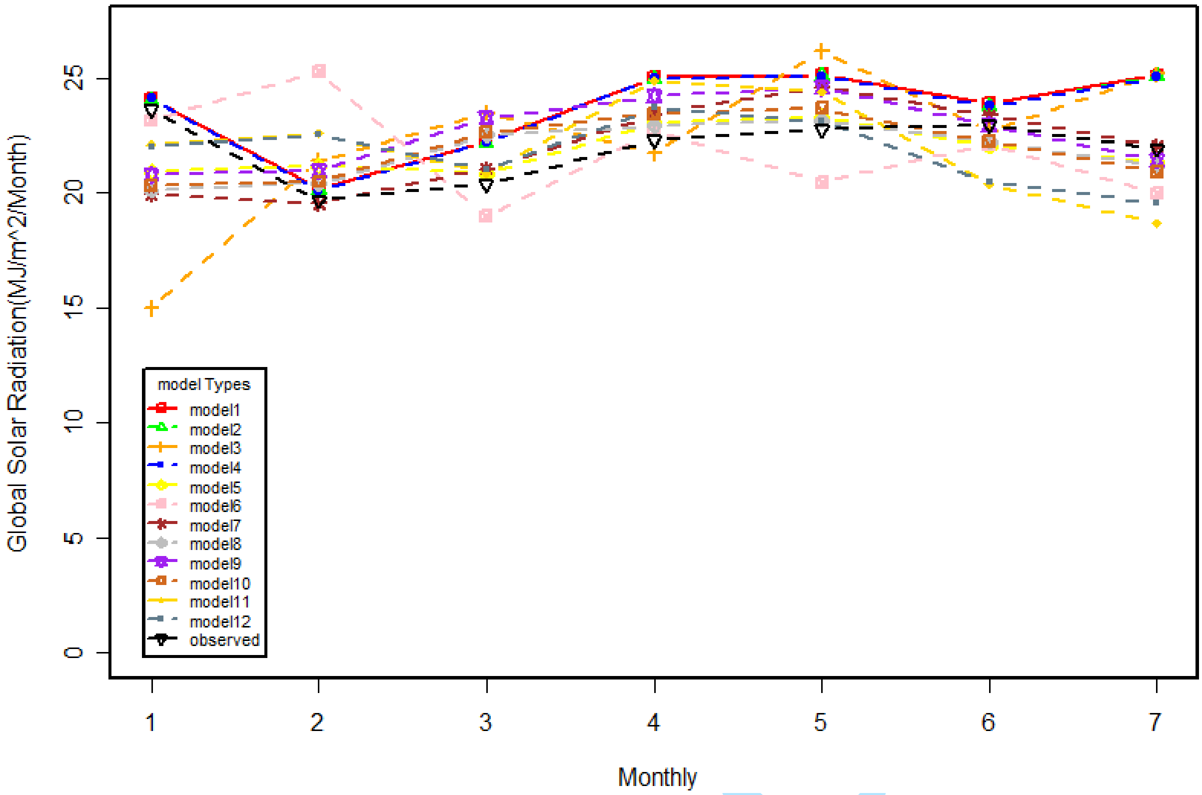

Figure 5: Trend of monthly estimate of global solar radiation compared with observed for Ilorin (Dry Season)

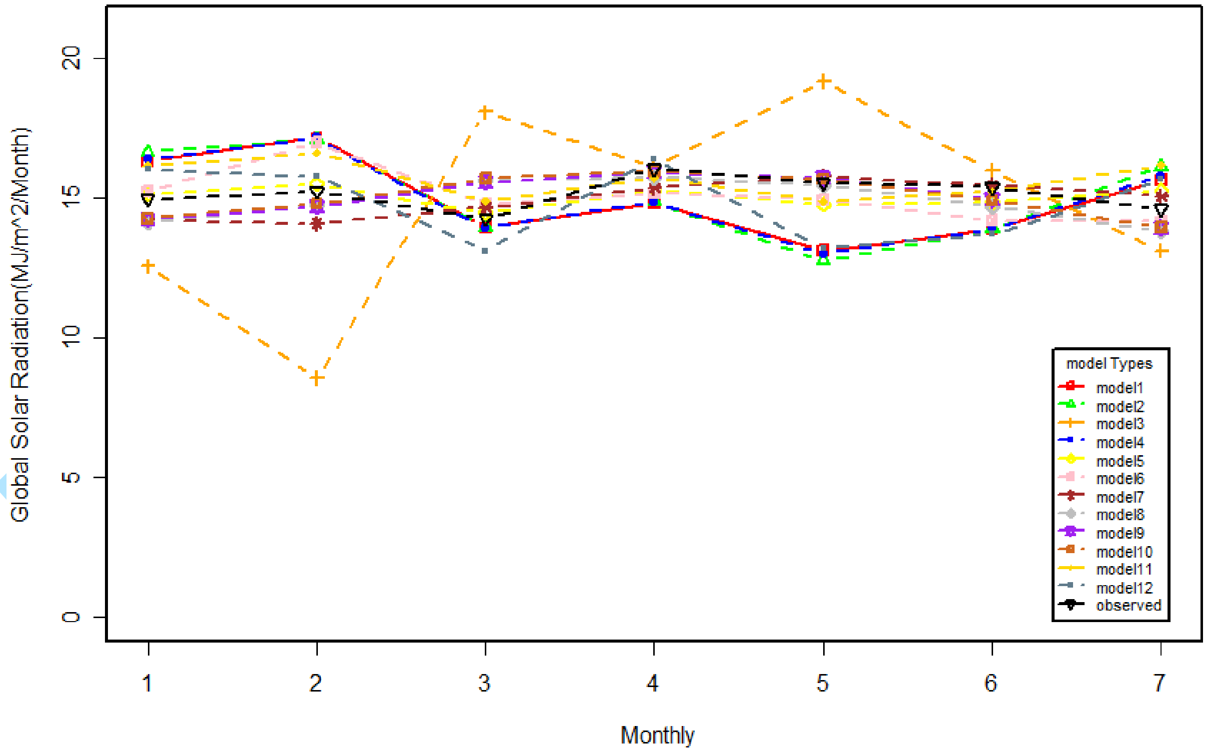

Figure 6: Trend of monthly estimate of global solar radiation compared with observed for Port Harcourt (Dry Season)

Table V: Twelve Formulated Models for Sokoto, Ilorin and Port Harcourt (Wet Season)

MODEL #	SOKOTO	ILORIN	PORT HARCOURT
1	$\frac{R_s}{R_0} = 0.223 + 0.623\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = 0.205 + 0.699\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = 0.140 + 0.774\left(\frac{n}{N}\right)$
2	$\frac{R_s}{R_0} = 1.250\left(\frac{n}{N}\right) - 0.420\left(\frac{n}{N}\right)^2$	$\frac{R_s}{R_0} = 1.782\left(\frac{n}{N}\right) - 1.273\left(\frac{n}{N}\right)^2$	$\frac{R_s}{R_0} = 1.973\left(\frac{n}{N}\right) - 2.218\left(\frac{n}{N}\right)^2$
3	$\frac{R_s}{R_0} = 13.25 - 57.12 + 83.98\left(\frac{n}{N}\right)^2 - 40.04\left(\frac{n}{N}\right)^3$	$\frac{R_s}{R_0} = -2.61 + 24.14\left(\frac{n}{N}\right) - 62.59\left(\frac{n}{N}\right)^2 - 54.12\left(\frac{n}{N}\right)^3$	$\frac{R_s}{R_0} = 7.317 - 87.47\left(\frac{n}{N}\right) + 350.17\left(\frac{n}{N}\right)^2 - 456.9\left(\frac{n}{N}\right)^3$
4	$\frac{R_s}{R_0} = 0.803\left(\frac{n}{N}\right)^{0.609}$	$\frac{R_s}{R_0} = 0.808\left(\frac{n}{N}\right)^{0.531}$	$\frac{R_s}{R_0} = 0.761\left(\frac{n}{N}\right)^{0.508}$
5	$\frac{R_s}{R_0} = 0.466\exp\left[0.597\left(\frac{n}{N}\right)\right]$	$\frac{R_s}{R_0} = 0.378\exp\left[0.816\left(\frac{n}{N}\right)\right]$	$\frac{R_s}{R_0} = 0.249\exp\left[1.126\left(\frac{n}{N}\right)\right]$
6	$\frac{R_s}{R_0} = -6.07 + 7.412\left(\frac{n}{N}\right) - 10.027\log\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} + 1.687\left(\frac{n}{N}\right) - 0.901\log\left(\frac{n}{N}\right)$	$\frac{R_s}{R_0} = 0.234 + 0.620\left(\frac{n}{N}\right) + 0.091\log\left(\frac{n}{N}\right)$
7	$\frac{R_s}{R_0} = 0.077 + 1.005\left(\frac{T_{max}}{65}\right)$	$\frac{R_s}{R_0} = -1.459 + 4.240\left(\frac{T_{max}}{65}\right)$	$\frac{R_s}{R_0} = -1.109 + 3.105\left(\frac{T_{max}}{65}\right)$
8	$\frac{R_s}{R_0} = 2.052 - 2.086\,(\theta)$	$\frac{R_s}{R_0} = 0.699 - 0.276\,(\theta)$	$\frac{R_s}{R_0} = 1.596 - 1.759(\theta)$
9	$\frac{R_s}{R_0} = -0.123 + 0.224\Delta T^{0.5}$	$\frac{R_s}{R_0} = -0.838 + 0.466\Delta T^{0.5}$	$\frac{R_s}{R_0} = -0.471 + 0.301\Delta T^{0.5}$
10	$\frac{R_s}{R_0} = 0.246 + 0.401\frac{\Delta T}{N}$	$\frac{R_s}{R_0} = -0.055 + 0.807\frac{\Delta T}{N}$	$\frac{R_s}{R_0} = -0.059 + 0.657\frac{\Delta T}{N}$
11	$\frac{R_s}{R_0} = 0.81 - 1.19\left(\frac{n}{N}\right) + -1.81\left(\frac{Tmax}{65}\right)$	$\frac{R_s}{R_0} = -3.11 - 0.76\left(\frac{n}{N}\right) + 8.54\left(\frac{Tmax}{65}\right)$	$\frac{R_s}{R_0} = 0.71 + 1.01\left(\frac{n}{N}\right) - 1.4813414\left(\frac{Tmax}{65}\right)$
12	$\frac{R_s}{R_0} = 4.28 - 0.32\left(\frac{n}{N}\right) - 5.78(\theta) + 0.008\overline{RH}$	$\frac{R_s}{R_0} = 1.36 + 0.35\left(\frac{n}{N}\right) - 0.11(\theta) - 0.01\overline{RH}$	$\frac{R_s}{R_0} = -1.23 + 1.10\left(\frac{n}{N}\right) - 0.05(\theta) + 0.01\overline{RH}$

Table VI: P, MBE, RMSE and MPE values for Sokoto, Ilorin and Port Harcourt (Wet Season)

	SOKOTO				ILORIN				PORT HARCOURT			
Model #	**P**	**MBE**	**RMSE**	**MPE**	**P**	**MBE**	**RMSE**	**MPE**	**P**	**MBE**	**RMSE**	**MPE**
1	-0.65	-0.186	2.163	0.115	0.74	-0.216	1.565	0.677	0.70	-0.261	1.230	2.233
2	-0.67	-0.163	2.168	0.000	0.74	0.188	1.577	-0.156	0.68	-0.319	1.534	0.288
3	-0.08	-0.059	2.025	-0.360	0.85*	0.171	1.871	-0.550	-0.90	0.089	2.877	-1.345
4	-0.63	-0.068	2.180	-0.432	0.74	-0.304	1.582	0.011	0.71	-0.340	1.820	0.030
5	-0.46	-0.249	2.300	0.395	0.47	-0.403	2.10	0.971	0.54	-0.447	1.057	0.031
6	-0.27	0.903	2.364	-0.048	0.74	-0.051	1.579	-0.222	0.71	-0.378	1.307	0.032
7	0.23	0.001	1.619	-0.535	0.93**	-0.078	0.940	0.045	0.63	-0.175	1.066	0.119
8	0.44	0.340	2.133	-1.804	-0.94	0.001	2.643	-1.743	0.72	-0.280	0.929	2.167
9	0.61	-0.093	1.312	0.110	0.98**	-0.159	0.568	0.702	0.61	-0.179	1.278	1.358
10	0.47	-0.189	1.761	0.584	0.97**	-0.212	0.633	0.933	0.58	-0.201	1.406	1.56
11	-0.85	-0.785	3.441	2.481	0.94**	0.532	1.004	-3.348	0.72	-2.077	2.367	7.766
12	-0.49	0.456	2.767	2.623	0.74	0.943	1.129	2.897	0.67	1.878	2.123	4.567

**Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)

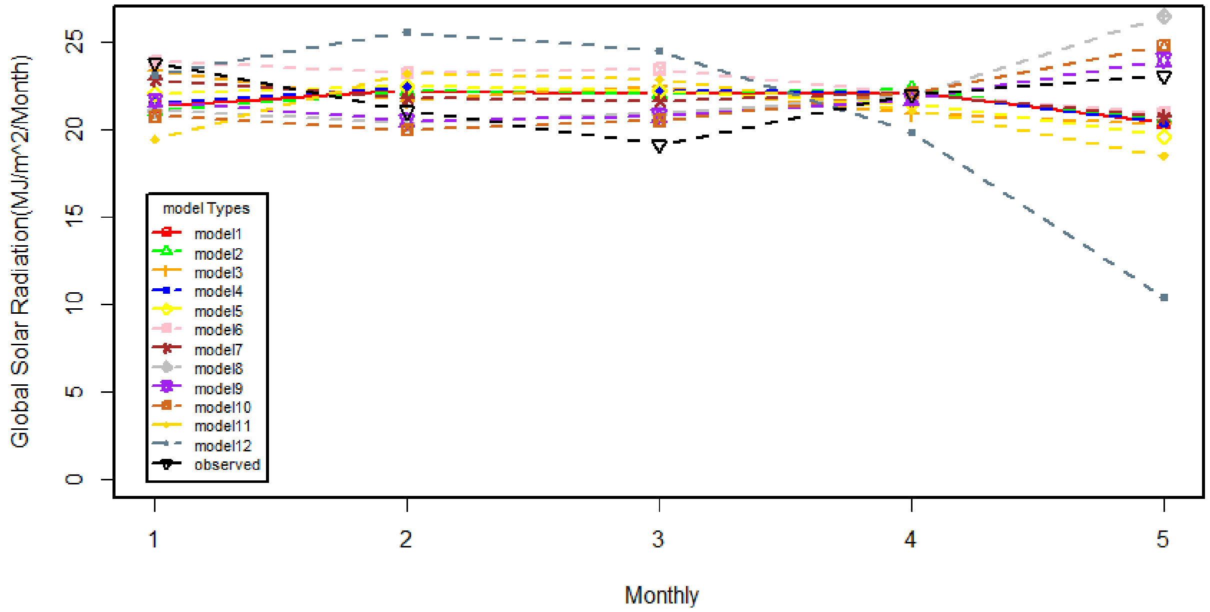

Figure 7: Trend of monthly estimate of global solar radiation compared with observed for Sokoto (Wet Season)

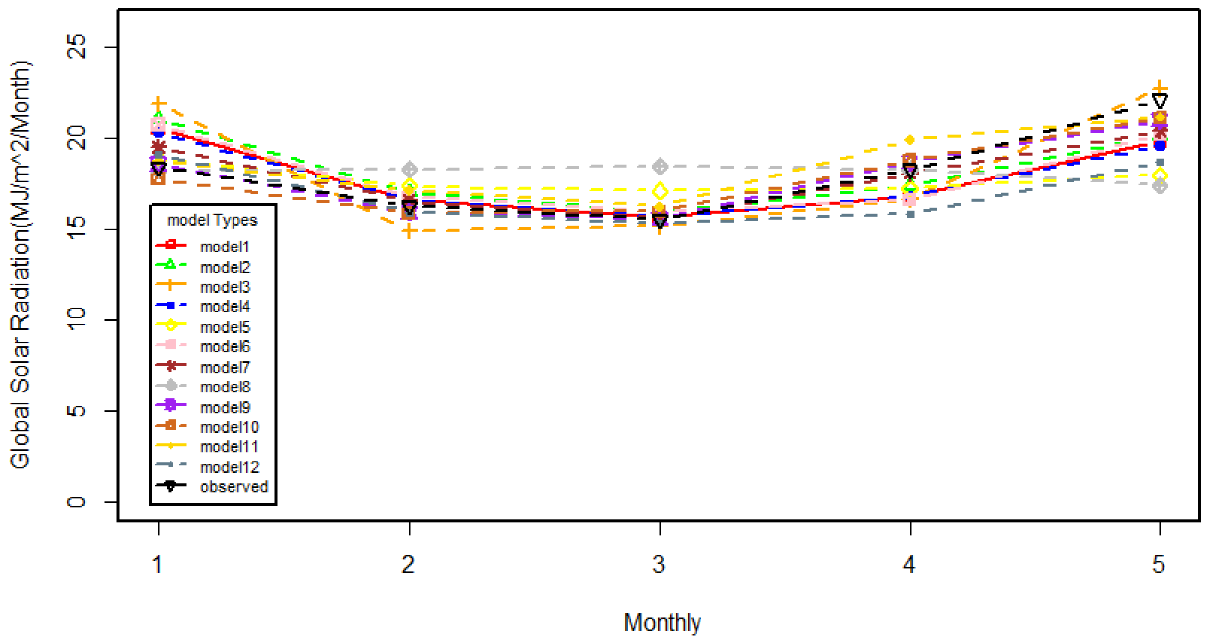

Figure 8: Trend of monthly estimate of global solar radiation compared with observed for Ilorin (Wet Season)

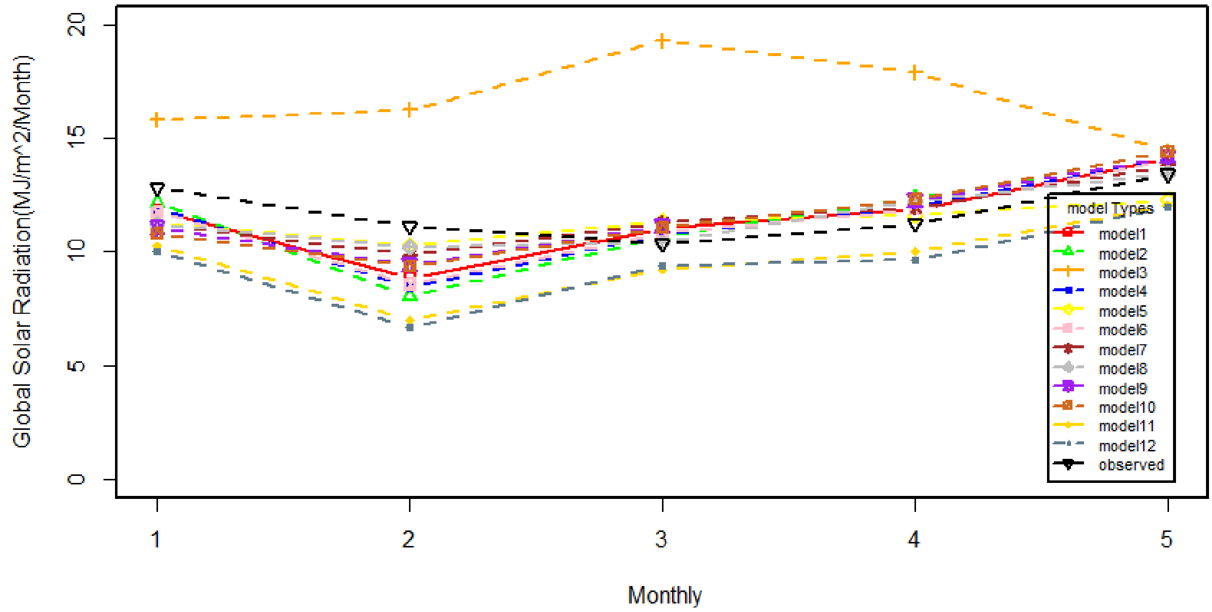

Figure 9: Trend of monthly estimate of global solar radiation compared with observed for Port Harcourt (Wet Season)

4. CONCLUSION AND RECOMMENDATION

Using twenty years of monthly average global solar radiation, sunshine hour, minimum and maximum temperature and relative humidity data in three stations, twelve empirical models were formulated in the form found in literature for whole year (Jan. -Dec.), dry (Nov. - Apr.) and wet (Jun. - Oct.) seasons to estimate their respective global solar radiation. Pearson's correlation coefficient, MBE, MPE, and RMSE were used to establish their efficacy for long and short term global solar radiation predictions. Comparison made with respect to their performance for the whole year and season reveals that the temperature based models 9 and 7 are best for prediction in Sokoto and Ilorin respectively with P value, RMSE, MPE and MBE of 0.84, 1.087, -0.189% and -0.109 in Sokoto and 0.70, 2.117, 0.756% and -0.345 in Ilorin, while all the models were considered to be efficient in Port Harcourt for global solar radiation over the whole year. The best performance was observed in the logarithmic sunshine hour based models 5 and 4 with MBE, RMSE and MPE values of -0.272, 0.889 and -0.110% in Sokoto and 0.036, 1.984 and -0.540% during the dry season. Except models 7, 9, 10 and 11 in Ilorin, other models are statistically insignificant in the wet season. The strength of our study can be accounted for by a long period of years employed to formulate the models, compared to similar studies in the literature. These models are recommended for use in the stations considered and effort should be made to further improve these models for estimating global solar radiation in other stations subject to the availability of their temperature and sunshine hour parameters.

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