Evaluating the Performance of Some Predictive Models for Estimating Global Solar Radiation across the Varying Climatic Conditions in Nigeria.

E.O. Ogolo, Ph.D.

Department of Physics, The Federal University of Technology, Akure, Nigeria.

E-mail: emogolo@yahoo.com

ABSTRACT

The performance of both temperature and sunshine dependent models were evaluated for different selected tropical sites, which are situated across four different climatic zones (Sahelian, Guinea Savannah, Midland, and Coastal area) in Nigeria using different performance indicators. The regression constants were obtained for the first, second, and third order Angstrom type (Garci, 1994 and Hargreaves and Samani, 1982) models for all the stations using the method of regression analysis. Model evaluation performance analyses were carried out to determine which model(s) is/are more suitable for a given climatic condition.

The results indicated that the third order Angstrom type correlations do not improve the accuracy of estimation of global radiation. In addition, the result also revealed that the temperature and sunshine hour dependent models are more suitable for the simulation of global radiation in the Sahelian and Guinea Savannah climatic conditions, respectively; while all the models exhibited the tendency to perform suitably well in the Midland and the Coastal areas.

On the seasonal consideration, the sunshine hour dependent models were found more suitable for the estimation of solar global radiation across all the varying climatic conditions during the dry season. However, all the models were found suitable during the wet season except for the Sahelian where only the temperature dependent models have been found exclusively suitable.

(Keywords: performance indicators, global solar radiation, models, regression analysis, sunshine hour and temperature)

INTRODUCTION

Solar radiation exhibits ultimate control of the weather and climate because it is the primary source of the earth's energy. The sun through the emission of solar radiation provides about 99.97 percent of the heat energy required for the planet's physical processes. The availability of solar radiation data and the relevant meteorological variables are crucial to solar engineers and architects in order to predict accurately the available solar energy resource. Solar radiation data is necessary for determining cooling loads for buildings, prediction of local air temperature, and for estimating power levels that can be generated from photovoltaic cells. Solar radiation data is always important for the design of any solar energy conversion device energy (Gopinathau, 1992).

Several methods have been developed around the world to estimate incoming solar radiation using irradiative transfer models and satellites (Atwater and Ball, 1978; Weymouth and Le Marshall, 1994; Caballos and Moura, 1997; Dissing and Wendler, 1998; Gultrepe et al., 2001). Most of the models were developed over a complex topography around the mountainous areas where there was no radiation data for validation and calibration hence there was the need for more complex algorithms to explain the irradiative flux.

In view of the above shortcomings, it became necessary to generate and calibrate empirical relationships that estimate incoming solar radiation as a function of other known meteorological variables such as relative sunshine hours, cloudiness and temperature; such empirical models based on the measured weather parameters were developed by Angstrom (1924), Prescott (1940), Fagbenle (1992), Udo (2002), Hargreaves and Samani (1982), Garci

(1994), Akpabio (2004), Mahmood and Hubbard (2002), and Khalil et al. (2008).

In this study, both linear and polynomial regression techniques were used to develop some predictive models classified as sunshine hours and temperature dependent for the estimation of global solar radiation for four tropical stations covering four different climatic zones in Nigeria. The present study is encouraged by the widespread application of solar radiation as an alternative source of power generation in Nigeria. Nigeria is divided into four climatic zones (Olaniran, 1983) according to the moisture distribution including topography which consequently affect the solar energy receipts at different solar stations. The performance of the models for each climatic zone was tested as to determine which of them would be suitable for each particular climatic condition.

Locations of the Study

Nigeria is situated between latitudes 4^o and 14^o North of the equator and between longitudes 3^o and 15^o east of the Meridian (Iloeje,1965). Nigeria's climate is characterized by strong latitudinal zones, becoming progressively drier as one moves north from the coast. Rainfall is the key climatic variable, and there is a marked alternation of wet and dry seasons in most areas.

We have classified the country into four climatic zones (Olaniran1983), namely the Coastal Zone, the Guinea Savannah Zone, the Midland Zone and the Sahelian Zone (Figure 1). The Coastal Zone is dominated by tropical maritime (mT) air for most years. This is found along the coast up to 100 to 150 kilometers inland. The annual temperature here ranges from 27^oC to 30^oC. Relative humidity in the region is as high as 80% and characterized with over 300cm of annual rainfall having double peaks of rainfall. They also have a long wet season typically 7-10 months (Iloeje, 1965). Port Harcourt is located within the Coastal Zone.

The Guinea Savannah Zone, where Lokoja is located, experiences the dominance of mT air for about seven months and tropical continental (cT) air for the remaining seven months annually. The stations within this zone are found further inland after the Coastal Zone. The zone experiences longer temperature ranges, lower annual rainfall, and a shorter wet season of about 6 – 8 months than the coastal region and a well marked dry season of 4-6 months (Iloeje, 1965). The region has a widespread vegetation belt and has an annual rainfall of 100 to 200cm with annual relative humidity of 60%.

The Midland Zone, where Jos is located, is dominated by a tropical continental air mass and is predominantly highlands. The topography effectively is usually responsible for usual long period of the humid condition due to localized convection.

Kano is situated in the Sahelian Zone, a region where cT air mass predominates and the mT air mass invades for between 2 and 3 months at most, because of its distance from the coastal environment. This zone embraces all stations in the north-eastern extremity of Nigeria. This type of climatic environment has a highly accentuated continentality with a wide annual and diurnal range of about 15^oC to 20^oC. Dry season is excessively long, up to 8 to 10 months and desert-like conditions prevail (Iloeje, 1965).

METHODOLOGY

The methodology of this investigation is discussed under two major subheadings. The first sub-section deals with the model description while the second considers the acquisition and treatment of data used in this study.

Model Description

In this study, two major models whose basic requirements utilize temperatures and sunshine duration have been used. The basic characteristic of these models is the correlation of global solar radiation with the atmospheric variables of the environments where the study is being carried out. A foremost correlation model, which is popularly and most widely used for estimating the monthly average daily global solar radiation on a horizontal surface, Rs (MJ/m^2 day) was originally developed by Angstrom (1924) while Prescott (1940) put the correlation in a convenient form defined and described as follow:

$$\overline{Rs}/\overline{Ro} = a + b\,(n/N) \qquad \textbf{(1)}$$

Where Ro is the monthly average daily extraterrestrial radiation (MJ/m^2 day), n is the sunshine hours otherwise called the day-length while ‘a’ and ‘b’ are the regression constants. The physical significance of the regression constants is that ‘a’ represent the case of overall atmospheric transmission for an overcast sky condition (i.e. n/N); while b is the rate of increase of $\overline{Rs}/\overline{Ro}$ with $\overline{n}/\overline{N}$.

The sum of ‘a’ and ‘b’ (i.e. a+b) significantly represents the overall transmission under clear sky condition or clear sky index.
The extraterrestrial solar radiation otherwise known as Angot radiation receipt on a horizontal surface in MJ/m^2 day was obtained using the following expression:

$$Ro= \frac{24}{\pi} Isc\ (Eo)\left[cos\varphi cos\delta sin\omega + \frac{\pi\omega}{180} sin\varphi sin\delta\right] \quad \textbf{(2)}$$

Where Eo is the factor chosen for the correction of the Earth’s orbit ω is the sunrise/sunset hour both respectively given by:

$$Eo = 1+ 0.033cos\left(\frac{2\pi dn}{365}\right) \quad \textbf{(3)}$$

$$\omega = arc\ cos(-tan\varphi tan\delta) \quad \textbf{(4)}$$

The declination angle of the sun δ is given according to Spencer (1975) in degree as:

$$\delta = (0.006918-0.399912cos\Gamma + 0.070257sin\Gamma - 0.006758cos2\Gamma + 0.0000907sin2\Gamma - 0.002697cos3\Gamma + 0.00148sin3\Gamma)\frac{180}{\pi} \quad \textbf{(5)}$$

Where Γ is the day angle radiance which is expressed as:

$$\Gamma = \frac{2\pi(dn-1)}{365} \quad \textbf{(6)}$$

The maximum possible sunshine durations, N, otherwise called the day length is obtained using:

$$N = \frac{2}{15}\omega\frac{180}{\pi} \quad \textbf{(7)}$$

In addition to the above model (see Equation1) otherwise known as the first order Angstrom, the investigator had also used the following second and the third order Angstrom type correlations which have also been proposed by different authors (Singh, 1996; Fagbenle, 1992; Mosalam, 1986, Ulgen and Hepbasli, 2002).

$$Rs/Ro = a + b(n/N) + c(n/N)^2 \quad \textbf{(8)}$$

$$Rs/Ro = a + b(n/N) + c(n/N)^2 + d(n/N)^3 \quad \textbf{(9)}$$

Where a, b, c and d are the regression constants which are functions of the location of investigation.

Other models, besides the Angstrom-Prescott models, that were used in this study were based on temperature data. This is relevant in a location where sunshine hour data is not available. In particular, we have Hargreaves and Sammani (1982) and Garcia (1994) models which have been successfully used to simulate global solar radiation.

Hargreaves and Sammani (1982) proposed an empirical equation expressed in the form of a linear regression between the clearness index and the square root of ΔT given as:

$$\frac{Rs}{Ro} = a + b\ \Delta T^{0.5} \quad \textbf{(10)}$$

Where ΔT is the difference between maximum and minimum temperatures values; while ‘a’ and ‘b’ are the regression constants.

Garcia (1994) is an adaptation of Angstrom-Prescott with a slight modification described as follows:

$$\frac{Rs}{Ro} = a + b\frac{\Delta T}{N} \quad \textbf{(11)}$$

Where all the terms assume their usual meanings as had already been explained above.

Acquisition and Treatment of Observational Data

Data for all the parameters used in this study were extracted from the monthly meteorological observation at the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos, Nigeria.

The parameters include sunshine hours, global solar radiation, minimum and maximum temperature. The data were collected for four tropical stations which spread across the four main geographical zones in Nigeria.

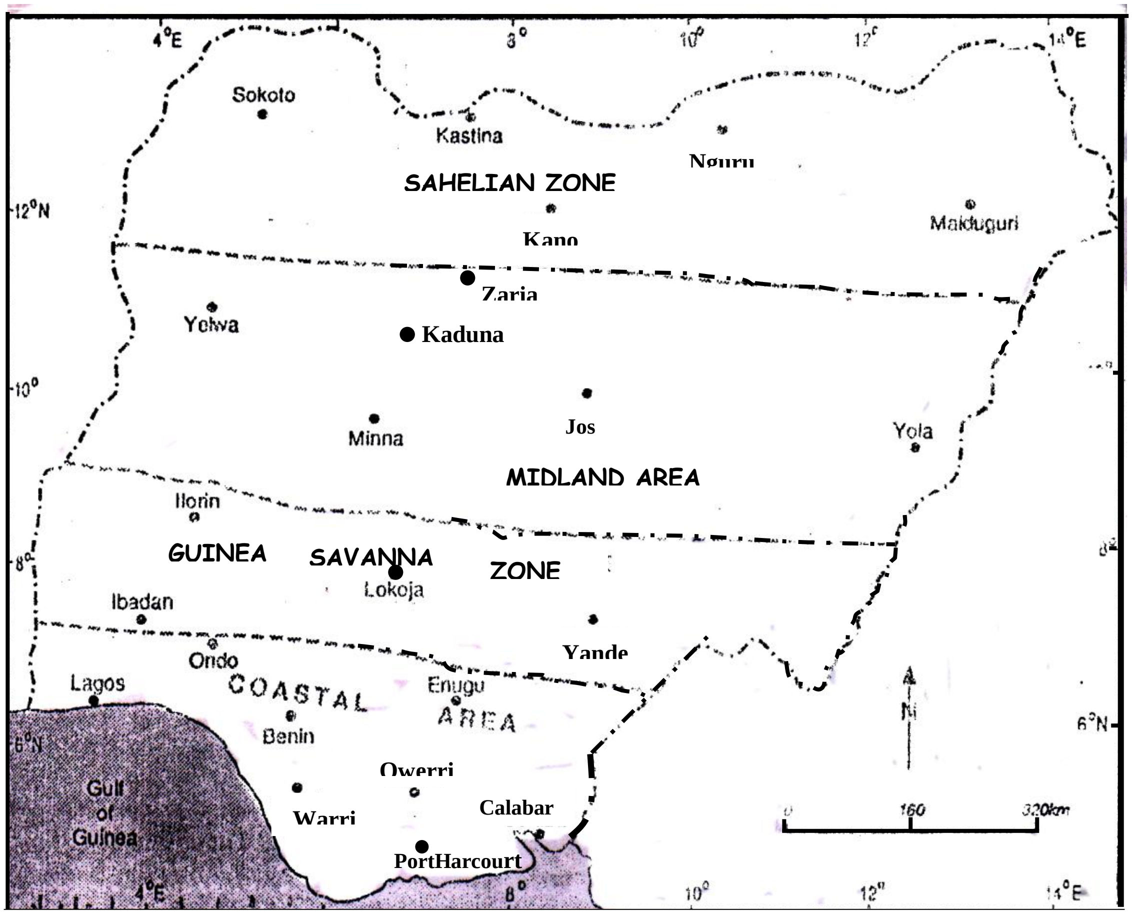


Figure 2: Map of Nigeria showing the Data Collection Stations and Geographical Region.

These include Port Harcourt -a coastal station; Lokoja - a Guinea savannah station; Jos – a Midland station and Kano - a Sahelian station (Figure 1).

The observation of total global radiation in all the tropical stations was carried out by pyranometer with linearity $\pm$5% from 0 to 2800W/m^2 having accuracy better than 0.5% and a resolution of 1watt/m^2. The daily sunshine hours (n) was measured by Campbell stokes sunshine. The maximum and minimum thermometer was used to determine the lowest and the highest temperature of air for each day. These are positioned at a height of 1.5 meters above the ground in a white louvered shelter called Stevenson screen at each station.

Table 1: Geographical Locations and Duration of Data on Parameters.

Name of Stations	Location	Duration of Observation of Data	Type of Climatic Zone
Kano	12.07°N, 8.43°E	1995-2000 for sunshine hours 1970-1989 for maximum and Minimum Temperature	Sahelian
Jos	9.12°N, 5.95°E	1994-2002 for sunshine hour 1981-2000 for maximum and Minimum Temperature	Midland
Lokoja	7.23°N, 5.17°E	1983-1995	Grassland Savannah
Port Harcourt	4.55°N, 7.00°E	1976-1992	Coastal

As shown on Table 1, more than a decade of data was used in modeling global solar radiation for all the locations except Kano and Jos, where we have a dearth of sunshine hour data. Hence, for Kano and Jos, limited data on daily sunshine hours measured for half a decade (1995-2000) while a decade and two decades data on both maximum and minimum temperature were used, respectively, to build the temperature biased model.

The daily extraterrestrial radiation, Ro, and the maximum possible sunshine, N, durations needed for modeling were determined for each of the stations according to Duffie and Beckman (1991) and Igbal (1993) using the standard procedure described by Equations (2) and (7). The daily obtained values of Ro and N were further averaged into monthly values $\bar{R}$ and $\bar{N}$, respectively.

All of the data used in this study were subjected to a quality control and relevant statistical tests before applying them to the models. This was done by plotting time variation graph to determine the spurious values and all omissions in the data were appropriately determined. The processed data was substituted appropriately into the Equations 8-11.

VALIDATION OF RESULTS

The developed multiple regression equations were used to calculate global radiation for all of the locations spread across the four climatic zones. The calculated values of global radiation are then compared with the measured data for the locations. The performance of each of the models was tested statistically by calculating the mean bias error (MBE), root mean square (RMSE) and the mean percentage (MPE) errors and other statistical concepts. These indicators are defined respectively as:

$$\mathrm{MBE} = \left[\frac{\sum(i,\mathrm{Rest} - i,\mathrm{Robs})}{\mathrm{n}}\right] \quad \textbf{(12)}$$

$$\mathrm{RMSE} = \left[\frac{\sum(i,\mathrm{Rest} - i,\mathrm{Robs})^2}{\mathrm{n}}\right]^{\frac{1}{2}} \quad \textbf{(13)}$$

$$\mathrm{MPE} = \left[\sum\left(\frac{i,\mathrm{Robs} - i,\mathrm{Rest}}{i,\mathrm{Robs}}\mathrm{X}100\right)\right]/\mathrm{n} \quad \textbf{(14)}$$

Where $i,Rest$ and $i,Robs$ are the respective *i*th estimated and the observed mean values of global solar radiation, and n is the total number of observations.

In general a low RSME and MBE are desirable while positive MBE shows overestimation while a negative MBE indicates underestimation. However, for a long term performance of the examined regression equations MPE is preferred. Just like MBE, a positive value of MPE provides the average amount of over-estimation in the estimated values, while the negative value indicates underestimation. Other statistical indicators used in the analysis include Standard Error of Estimate (SEE), Index of Agreement (ID), and Average model error (AR).

RESULTS AND DISCUSSION

Using the technique of least square regression, linear and polynomial regression equations were developed based on Equations 1, 8, 9, 10, and 11.

Regression coefficients were determined for all of the stations distributed across all the four climatic zones in Nigeria. The regression coefficients for all of the models and the corresponding values of the performance indicators are shown in Table 2.

On the table, we have all the models generated for all the stations including the first and the second order of the Angstrom-Prescott type correlations. It would be observed that there was no third order of the Angstrom model for almost all the stations except Kano. For most stations and seasons, the results of the regression for the third order exhibits co-linearity with the second order indicating that the third order does not significantly improve the accuracy of the estimation of global radiation for almost all the stations.

Figure 2 shows the comparisons between the monthly mean of the estimated for all the models developed for the tropical stations and the observed global radiation. It could be seen from the figures that the predictive values by the entire models exhibit a good variation trend along side with the observed global radiation for all the stations except for Lokoja where all the temperature dependent models appear to behave differently between August and October.

Table 2: Regression Coefficients of Model Equations for the Selected Locations.

Location	Models	Regression Coefficients				MBE	RSME	SEE	AR	MPE(%)	ID	CR
		a	b	c	d							
Kano	1st order Angstrom	0.441	0.292	-	-	-0.02	2.43	16.13	1.00	-0.40	1.00	0.58
	2nd order Angstrom	1.111	-1.828	1.66	-	0.24	2.20	15.68	1.00	0.70	1.00	0.69
	3rd order Angstrom	0.838	-0.653	-	0.76	0.02	14.80	39.29	1.01	-2.50	0.99	0.16
	Hagreaves&Samani	0.175	0.126			-0.08	1.72	9.44	1.00	-0.29	1.00	0.76
	Garcia	0.417	0.194			-0.09	1.77	8.83	1.00	-0.33	1.00	0.76
Lokoja	1st order Angstrom	0.248	0.509	-	-	-0.07	1.28	9.77	0.99	-0.37	1.00	0.78
	2nd order Angstrom	0.168	0.835	0.32	-	-0.09	1.25	9.48	0.99	-0.43	1.00	0.79
	Hagreaves&Samani	0.211	0.0917			-0.57	3.10	9.61	0.97	-3.10	1.00	0.39
	Garcia	0.381	0.142			-0.55	3.24	8.71	0.97	-3.00	1.00	0.32
Jos	1st order Angstrom	0.278	0.485	-	-	-1.53	3.72	7.91	0.94	-6.95	1.00	0.93
	2nd order Angstrom	0.154	0.933	0.37		-1.45	3.75	8.57	0.94	-6.55	1.00	0.92
	Hagreaves&Samani	0.129	0.166			4.51	22.38	12.38	1.14	17.58	0.98	0.87
	Garcia	0.359	0.333			4.43	20.89	12.29	1.13	17.19	0.98	0.93
PH	1st order Angstrom	0.222	0.58	-	-	-0.65	1.56	11.24	0.96	-4.96	1.00	0.84
	2nd order Angstrom	0.153	1.149	1.07	-	-1.05	2.28	46.1	0.93	-8.09	1.00	0.83
	Hagreaves&Samani	0.191	0.282			0.32	1.12	43.2	1.03	2.42	1.00	0.90
	Garcia	0.183	0.293			-0.23	0.79	42.45	0.99	-1.36	0.99	0.89

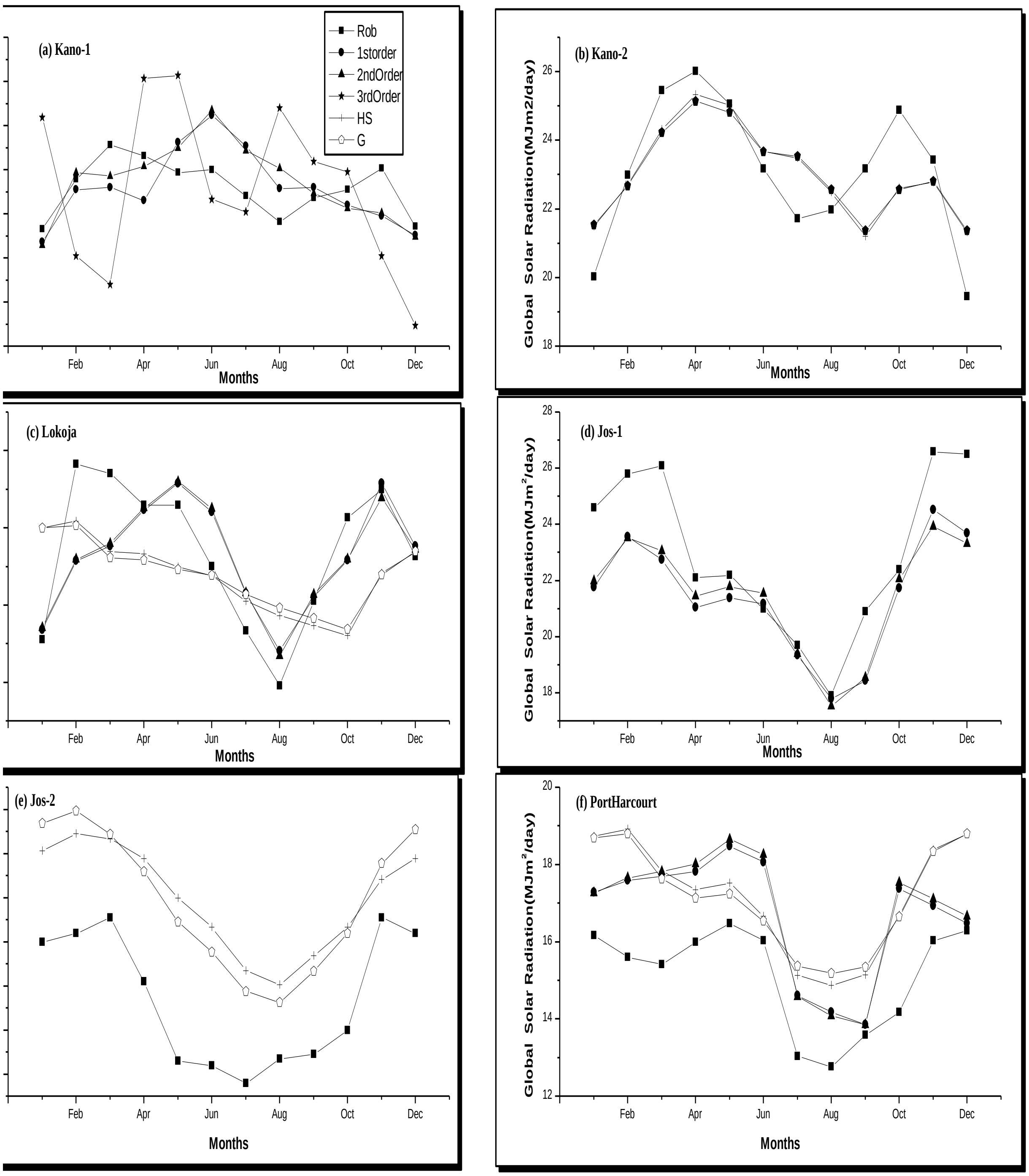
During this period, it was observed that, while other models defined a trough in August; Garcia (1994) and Hargreaves-Samani (1994), respectively, delayed till October. Another case of irregular variation observed is found with the third order of Angstrom for Kano where the model exhibits a mirror-like variation with the observed. For each of these cases mentioned above, the correlation coefficients (see Table 2) indicate a poor agreement between the simulated and the observed.

The performance of each of the above developed models was tested statistically by validating the simulated radiation values as compared with the observed values. Table 2 presents a summary of the results of the statistical indicators used for determining the performance level of each of the models for the different stations under consideration.

From Tables 2, 3, and 4, it can be seen that neither ‘a’ nor ‘b’ vary with latitude or altitude in any systematic mode. However, the values of the sum of the regression constants (a + b) (for the first order Angstrom correlation types) averaged over the period of recording the data vary according to the location of each of the station.

The constant ‘a’ and ‘b’ had been determined for the different climatic conditions in Nigeria (See Table 2). The sum (a+b) exhibits an increasing trend from the arid environment with high latitude to the coastal stations with low latitude. The values of the sum (a +b) obtained are 0.733, 0.757, 0.787 and 0.802 for Kano, Lokoja, Akure and Port Harcourt respectively (see Table 2). Though ‘a’ and ‘b’ are empirical constants and as earlier pointed out under methodology, their values depend on latitude, relative sunshine hours, elevation above sea level, relative humidity, maximum air temperature and so on.

The physical significance of the sum of the two constants (a+b), is a measure of the overall atmospheric transmission for totally cloudy condition and is a function of the type of thickness of the cloud.



Figures 2 a-f: Comparison between the Observed and the Predicted Monthly Average Global Solar Radiation, $\overline{Rs}$ for (a, b) Kano-Sahelian, (c) Lokoja-Midland, (d, e) Jos-Guinea Savannah, and (f) Portharcourt-Coastal Region.

Table 3: Regression Coefficients of Model Equations for the Selected Locations and the Corresponding Values of the Statistical Indicators During the Dry Season.

Locations	Models	Regression Coefficients			MBE	RSME	SEE	AR	MPE	ID	CR
		a	b	c					(%)		
Kano	1st order Angstrom	0.611	0.090		-0.04	0.75	1.79	1.00	-0.08	1.00	0.850
	2nd order Angstrom	0.334	0.984	0.708	-0.10	0.91	1.61	1.01	-0.39	1.00	0.840
	Hargreaves & Samani	1.195	-0.130		1.39	2.73	2.77	1.00	5.77	1.00	0.560
	Garcia	1.670	-0.734		3.12	13.59	7.23	1.00	11.71	1.00	0.210
Lokoja	1st order Angstrom	0.398	0.263		-0.22	0.69	0.96	0.99	-1.01	1.00	0.930
	2nd order Angstrom	1.901	-5.008	4.567	0.07	1.82	5.29	1.01	0.19	1.00	0.490
	Hargreaves & Samani	0.935	-0.104		-0.34	1.29	4.14	0.99	-1.81	1.00	0.650
	Garcia	0.710	-0.135		-0.31	1.24	4.1	0.99	-1.65	1.00	0.660
Jos	1st order Angstrom	0.392	0.368		-1.75	3.40	2.65	0.93	-7.25	0.99	0.615
	2nd order Angstrom	1.140	-1.561	1.232	-1.77	3.37	1.29	0.93	-7.34	0.99	0.739
	Hargreaves & Samani	0.436	0.081		1.30	1.940	1.24	1.00	5.03	0.99	0.297
	Garcia	0.595	0.120		1.32	1.990	1.25	1.00	5.09	0.99	0.292
PH	1st order Angstrom	0.462	-0.088		-0.13	1.34	0.33	0.96	-7.48	1.00	0.998
	3rd order Angstrom	0.806	-1.691	4.985	-1.03	1.1	0.26	0.95	-6.79	1.00	0.987
	Hargreaves & Samani	0.414	0.006		-0.23	0.323	1.92	1.05	-1.71	1.00	0.323
	Garcia	0.443	0.013		-0.42	0.61	2.55	0.99	-2.82	1.00	0.415

The results confirm more cloud cover for the stations close to the ocean (i.e., coastal stations) than we have for stations in the Sahelian region.

Four different models were developed for four tropical stations situated in the different climatic conditions in Nigeria. For each of the model, some performance indicators (namely MBE, RSME, Standard Error of Estimate (SEE), MPE%, Index of Agreement (ID)) were determined for the locations under consideration. For better performance, the lowest MBE RSME, SEE, MPE% values are desired. For Kano, the first and the third order of the Angstrom have the lowest MBE of 0.02 each, this is followed by 0.08 and 0.09 for Hargreaves-Samani (1982) and Garci (1994) models but the RSME for the temperature dependent models (1.72 and 1.77, respectively) are lower compared with the first and the second order Angstrom (2.43 and 2.20, respectively).

Larger values of the Standard Error of Estimate (SEE) is undesirable. In this study the lowest values of SEE of 8.83 and 9.44 were found, respectively for Hargreaves-Samani (1982) and Garci (1994) models (temperature dependent models), while the SEE for the first and second order of Angstrom were 16.13 and 15.68, respectively.

The index of agreement between the simulated radiation values when compared with the observed is found to be unity which indicates good agreement between them. The lowest mean percentage error (MPE %) of 0.058 and 0.028 were found for Hargreaves-Samani (1982) and Garci (1994) models respectively followed by -0.031 for the first order of the Angstrom correlation type. Both Hargreaves-Samani (1982) and Garci (1994) models have the highest correlation coefficient of 0.76 each followed by 0.75 for the second order of Angstrom.

From the foregoing, the temperature dependent model is strongly recommended for simulating global solar radiation for the stations in the Sahelian Zone in Nigeria. Among all the models tested, both Hargreaves-Samani and Garcis Models scored lowest MBE, RSME, SEE, and MPE (%) and both have the highest correlation coefficient as shown on Table 2 and confirmed in Figure 2.

Both the first and the second order of the Angstrom correlation type may be considered as a second class model for this environment in questions in view of the overall results of the performance indicator shown in the present analysis.

Lokoja is situated in the mainland climatic zone in Nigeria. There were four models developed for this station namely the first and the second order of Angstrom, Hargreaves and Samani (HS), and the Garci (G) models. The regression coefficients for the regression equations were developed for this environment (see Table 2). The MBE values for the models, respectively, are -0.07, -0.09,-0.57, and -0.57 while their RSME values are 1.28, 1.25, 3.10, and 3.24, respectively. The highest correlation coefficient between the simulated and the observed include 0.780 and 0.790 was found respectively for the first and second order of Angstrom followed by 0.390 and 0.320 for Hargreaves & Samani (HS) and Garci (G), respectively. This shows that there is a stronger fitting between the predicted and the observed values.

From the foregoing, it is clear that the best performing and suitable model in this climatic condition is the first and the second order of Angstrom correlation type which was found to have the lowest values of MBE, RSME, SEE and high correlation coefficient (see Table 2). In addition, the Angstrom models have the lowest MPE% values (see Table 2) compared with the temperature dependent models which have the tendency of overestimating the solar radiation for the Midland zones. Here, the results of the statistical indicators shows that the sunshine hour dependent models are more suitable than the temperature dependent models for simulations of global solar radiation for this climatic environment.

The performances of the four prediction models developed for Jos (a tropical station located in the grassland/forest zone) were found to be quite satisfactory. The correlation coefficients as shown on Table 2 range from 0.870 to 0.930. The MPE% for the sunshine hour dependent is negative (-6.95% and -6.55%) and positive (17.58 and 17.19) for the temperature dependent models. The general significant of this observation shows that Angstrom model has the tendency for underestimation while the temperature dependent models have the propensity for overestimation of global solar radiation for this region. This is further confirmed by the average ratio (AR) computed for the models, (less than unity indicates underestimation and greater than unity implies overestimation) and the variation trend curves (See Table 2 and Figure 2 d & e).

The SEE and RSME values for the sunshine hour's models are lower compared with the temperature dependent as seen on Table 2. The results of the performance indicators show that the Angstrom models will perform suitably well in this region than the temperature dependent models. However, proper calibration of all the models may improve their performance level for this region.

The level of performance of the prediction model for Port Harcourt, a coastal station is not different from the grassland/forest zone which has just been discussed above. The correlation coefficient is generally high for all the models, having the highest value of 0.900 for Garcia model to 0.830 for the second order of Angstrom correlation type. Also from Table 2, it was observed that the MPE% and AR values indicate that all the models except Garcia model underestimate the global solar radiation for the costal stations. The absolute values of MBE and RSME are lower for the temperature dependent models when compared with the Angstrom model. The general performance of all the models for the coastal stations is good but the temperature dependent models are more suitable in view of the results of the performance indicators for all of the models.

Seasonal Model Performance

Nigeria has the climatic characteristic of the evident dry and wet seasons that correspond to the months of November to March and April to October, respectively. The alternation of wet and dry season is in association with north-south movement of ICTZ following the position of the Sun relative to the earth. In view of this seasonal effect and considering the fact that the amount of solar radiation receipt at the earth surface for different prevailing weather conditions during each of the seasons vary, a different set of predictive models were developed. Tables 3 and 4 contain the results of the validation tests carried out on all the various predictive models developed respectively for the two different seasons, using the performance.

Table 4: Regression Coefficients of Model Equations for the Selected Locations and the Corresponding Values of the Statistical Indicators During the Wet Season.

Locations	Models	Regression Coefficients			MBE	RSME	SEE	AR	MPE	ID	CR
		a	b	c					(%)		
Kano	1st order Angstrom	0.394	0.329		-0.12	3.33	0.35	1.00	-0.98	1.00	0.040
	2nd order Angstrom	1.719	6.944	5.136	0.40	2.18	0.18	1.02	1.50	1.00	0.080
	Hagreaves & Samani	0.028	0.17		0.04	0.13	1.14	1.00	0.10	1.00	0.990
	Garcia	0.326	0.292		0.07	0.12	1.39	1.00	0.21	1.00	0.980
Lokoja	1st order Angstrom	0.235	0.524		-0.17	0.08	1.12	0.99	-0.94	1.00	0.990
	2nd order Angstrom	0.220	0.588	0.070	-0.20	0.09	1.14	0.99	-1.11	1.00	0.990
	Hagreaves & Samani	-065	0.321		-1.33	3.47	7.56	0.93	-8.03	1.00	0.760
	Garcia	0.034	0.627		-1.33	3.40	7.53	0.93	-7.94	1.00	0.740
Jos	1st order Angstrom	0.351	0.295		-1.65	3.78	6.72	0.96	-8.57	1.00	0.750
	2nd order Angstrom	0.600	0.671	0.909	1.65	4.00	31.96	0.95	8.57	0.98	0.690
	Hagreaves & Samani	0.127	0.136		1.66	3.85	17.74	1.00	7.82	1.00	0.740
	Garcia	0.345	0.257		1.67	3.63	33.57	1.00	7.94	0.96	0.800
PH	1st order Angstrom	0.260	0.487		-0.62	2.00	7.15	0.96	-510	1.00	0.840
	2nd order Angstrom	0.236	0.695	0.408	-0.75	2.16	7.30	0.95	-6.34	1.00	0.850
	Hagreaves & Samani	0.358	0.28		0.43	2.11	1.59	1.05	3.45	1.00	0.960
	Garcia	0.031	0.599		-0.40	1.74	1.45	0.99	-2.36	1.00	0.970

The seasonal performances of the models as given by their performance indicators for Kano are shown on Tables 3 and 4. During the dry season, the first and the second order Angstrom Prescott (the sunshine dependent models) have the lowest MBE, RSME and SEE for Kano (see Table 3). These two models have the highest coefficient correlation of 0.85 and 8.40, respectively, which are significantly higher than HS and the G models which have 0.56 and 0.210, respectively. Furthermore, it was observed from the results that the sunshine dependent model has the lowest MPE values compared with the temperature dependent However, during the wet season, the values for MBE, RSME and SEE are low for the temperature dependent predictive models when compared with the Angstrom Prescott predictive models.

The correlation coefficients of Hargreaves & Sammani and Garci are 0.990 and 0.980, respectively, unlike, the first and the second Angstrom Prescott predictive model which have an extremely low correlation of 0.040 and 0.08 (See Table 4). From the above, this study shows that the sunshine hour dependent predictive model is recommended as being suitable for the simulation of solar radiation during the dry season while the temperature dependent predictive models are better than the sunshine model for wet season in this climatic condition.

The performance of the models for the Midland condition (Lokoja) is also investigated for both dry and wet seasons and the results also shown in the Tables 3.0 and 4.0. For the dry season, it is observed that the first order of Angstrom has the highest correlation coefficients and the lowest RSME and SEE values while the MPE and AR values indicate a perfect agreement between the observed and the predicted solar radiation values (see Table 3). The correlation coefficient of the temperature dependent models ranges between 0.65 and 0.66 and higher RSME and SEE values (see Table 3) compared with the first order of Angstroms. The correlation coefficient of the second order of Angstroms is 0.49 and higher

RSME and SEE values when compared with the rest predictive models.

From the foregoing, it is evident that the first order Angstrom model is more suitable than the temperature dependent model for the simulation of solar radiation for the Midland during the dry season. Table 4 shows the results of the performance indicators for all the predictive models during the wet season for the Midland region. The correlation coefficients range from 0.76 to 0.99 with the first and the second order of Angstrom Prescott having the highest of 0.99.

In addition, the MBE, RSME and the SEE values for the sunshine dependent predictive models are extremely low compared with the temperature dependent models besides all the model exhibit the tendency for underestimations as indicated by the negative values of MBE, MPE and the values of AR which are less than unity for all. In general, results of the performance indicator for all the models for both the dry and wet season shows that Angstrom models are better than the temperature dependent models for the simulation of solar radiation for the midland environments.

The performance level of all the predictive models for Jos (situated in the Forest/Savannah) both for the dry and wet seasons are shown in Tables 3 and 4. For the dry season, the correlation coefficient ranges from 0.29 to 0.74 with the temperature dependent models having the least values ranging from 0.29 to 0.30. However, RSME, SEE and MPE values are much higher for the sunshine hour dependent models than the temperature dependent models.

Further analysis confirms that the Angstrom model underestimates solar radiation by ±7.0% while the temperature model overestimates by 5.0%. The inconsistency observed in this result is not unconnected with the irregularities involved in the collection of the observed data which is associated with the handling of the instruments or process of transfer of data. For instance, the data simulated by the temperature dependent model shows an increasing trend between November and December while the observed values exhibits a decreasing trend during this period. The variance in the behavior of the model in relation to the reference data is responsible for the poor correlation coefficient.

For the present situation, the first and the second order of Angstrom models are considered to be more suitable if both are properly calibrated for the simulation of global solar radiation for this climatic environment. However, the behavior of the models for the wet season is quite satisfactory. The correlation coefficients for all the models range between 0.69 and 0.800. It is also observed from table 5 that all the models exhibit the tendency for overestimation except the first order of Angstrom which has negative MPE value (-8.57%) while the rest models have MPE ranging from 7.82% for Hargreaves and Samani (1982) to 8.57% for the second order of Angstrom type of correlation. Both the temperature dependent models and the sunshine hour dependent model will be suitable for the prediction of global solar radiation for the Midland, if they are well calibrated with processed observed data with high integrity.

Port Harcourt is an industrial city in the Niger Delta situated very close to the Atlantic Ocean in Nigeria. The performances of the four models were examined seasonally for Port Harcourt. The first order of Angstrom Prescott has the highest correlation coefficient of 0.81 followed by Garcia (1994) predictive model with 0.690 but the second order of Angstrom Prescott (1924) has the least value of 0.290 while Hargreaves and Samani has correlation coefficient of 0.480. However, the MPE values (see Table 3) for the first order Angstrom, Hargreaves and Sammani (1982) including Garcia (9182) predictive model exhibits the tendency for underestimation with the present data while the second order of Angstrom has a very high tendency for overestimation because it has the highest MPE value of 10.64% (see Table 3).

Hence, from the results of the performance indicators for the dry season, this study has found three models suitable for the simulation of solar radiation, they are, first order of Angstrom-Prescott, Hargreaves-Samani (1982) and Garci (1994) models in view of their low MBE and RSME values and high coefficient correlations. For the wet season, all the models were found suitable. The correlation coefficients for all the models range from 0.84 to 0.97 but higher for the temperature dependent models (see Table 4) which are also found to have the lowest SEE, MBE values compared with the Angstrom models. However, all other predictive models manifest a strong tendency for overestimation of solar radiation during the wet season for the coastal condition as indicated by their high values of MPE but this appear more stronger for the sunshine hour dependent the temperature dependent models.

CONCLUSION

Model calculations were carried out using a few models (sunshine hour and temperature dependent) for the estimation of monthly mean global solar radiation for the various geographical stations in Nigeria ranging from the Coastal Region to the Sahelian environment. The results of this work show clearly the importance of developing empirical approaches for formulating the global solar radiation field reaching the earth at different stations and seasons in the varying climatic regions in Nigeria.

Different predictive models categorized as temperature and sunshine hour dependent were developed in this study based on some empirical equations (see Equations 1, 8, 9, 10, and 11) for four stations (Kano, Lokoja, Jos, and Port Harcourt) characterized by diverse climatic conditions. The regression coefficients were determined for each of the stations according to the empirical equations defined for each station. It was observed that the sum of the coefficients 'a' and 'b' increases from the Sahelian Region towards the coastal station; this is because the coefficients are quite related to geographical and meteorological condition of any given place.

The dearth of data on sunshine hours in most of our meteorological stations in Nigeria had in no small dimension limited the scope of this work. This is only available for few stations across Nigeria. Generally, it was observed that for most of the stations except for Kano, the third order of Angstrom type model exhibits collinearity with the second order.

The implication of this observation is that the third order of Angstrom type does not have any significant improvement on the accuracy of estimation of global in most of the stations hence the first and the second order correlations between the monthly mean daily clearness index and the relative possible sunshine duration for the selected stations were proposed even for both dry and wet seasons too. Further work is been done in this area with a view of enlarging the scope by increasing the number of the atmospheric variables.

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ABOUT THE AUTHOR

Dr. E.O. Ogolo, is a faculty member in the Department of Physics, Federal University of Technology, Akure, Nigeria. Dr. Ogolo's research interests include solar radiation modeling and climatic modeling.

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