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Full Length Research Paper

Analysis of some meteorological data for some selected Cities in the Eastern and Southern zone of Nigeria

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The monthly mean daily global solar radiation, sunshine duration hours, maximum temperature, Cloudiness index and relative humidity data for some selected cities in the Eastern and Southern zone of Nigeria covering a period of seventeen years (1990 - 2007) were used to generate several linear and multilinear regression equations. The values of the solar radiation estimated by the equations and the measured solar radiation were tested using the mean bias error (MBE), root mean square error (RMSE) and mean percentage error (MPE) statistical techniques. The values of the correlation coefficient (R) and coefficient of correlation (R^2) were also determined for each equation. The equations with the highest values of R, R^2 and least values of MBE, RMSE and MPE are suitable for predicting global solar radiation in the Eastern and Southern part of Nigeria. The developed equations can be used for estimating solar radiation in other locations with similar geographical information.

Key words: Cloudiness index, solar radiation, sunshine hours, relative humidity, maximum temperature.

INTRODUCTION

Nigeria is blessed with abundant amount of sunshine. It has been found that there is an estimated 3,000 h of annual sunshine. It is also estimated that Nigeria has over 97,000 rural communities (Oti, 1995), whose population is characterized with deprivation from conventional energy, arising from poor supply infrastructure. For instance, about 18% only of the rural population had access to electricity by 1991/1992 (FOS, 1996). Where convectional energy is available, its supply is unreliable. The readily available and widely utilized energy in the rural areas is the renewable energy type, particularly fuel wood, agricultural and animal wastes, wind energy and solar energy; which are mainly used for cooking, cottage industrial applications, winnowing and open-to sun-drying process. Mini hydropower and biogas are yet to be popular, as rural energy in Nigeria, perhaps due to the more advanced conversion technologies associated with them.

Solar radiation data may be considered as an essential requirement to conduct feasibility studies for solar energy systems. The knowledge of solar energy, preferably gained over a long period should be useful not only to the locality where the radiation data is collected but for the wider world community.

In developing countries such as Ghana, India, Nigeria etc, the facility for global radiation measurement is available at a few places while bright sunshine hours are measured at many locations. Some cannot even afford the equipments and techniques involved. For such countries it is essential that correlations be developed so as to predict global solar radiation from readily measured data. Several such correlations already exist for some developing countries (Ibrahim, 1985; Turton, 1987; Abdalla, 1987; Sambo, 1986; Bakhah et al., 1985; Falayi and Rabiu, 2005; Sanusi and Aliyu, 2005).

This paper is a continuation of the effort to develop predictive techniques for several countries so as to provide a basis for the future regional iso-radiation maps. The paper also developed models which can be used to predict monthly mean daily global solar radiation incident on a horizontal surface in some selected cities in the Eastern and Southern zone in Nigeria.

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METHODOLOGY

The measured monthly mean daily values of sunshine hours, maximum temperature, cloud cover and relative humidity for the cities of Owerri in Imo State, Enugu in Enugu State, Warri in Delta State and Calabar in Cross River State collected from the archives of the Nigerian Meteorological Agency, Oshodi, Lagos State while the global solar radiation data were collected courtesy of the Renewable Energy For Rural Industrialization and Development in Nigeria. The four cities being studied lie on the latitudes and longitudes (lat 5.41^{0}N, long 7.20^{0}E) for Owerri, (lat 7.55^{0}N, long 6.45^{0}E) for Enugu, (lat 5.50^{0}N, long 5.68^{0}E) for Warri and (lat 5.02^{0}N, long 7.88^{0}E) for Uyo respectively.

To develop the models, the global solar radiation data measured in (Kwhm^{-2}day^{-1}) was converted to (MJm^{-2}day^{-1}) using a factor of 3.6 proposed by Iqbal (1983).

The liner regression model used in correlating the measured global solar radiation data $\frac{\overline{H}_M}{\overline{H}_O}$ with fraction of sunshine $\frac{\overline{n}}{\overline{N}}$ is given after Angstrom (1924) and later modified by Page (1964):

$$\frac{\overline{H}_M}{\overline{H}_O} = a + b\frac{\overline{n}}{\overline{N}} \tag{1}$$

Where; a and b are regression constants, $\overline{H}_M$ is the measured monthly mean daily global radiation, $\overline{H}_O$ is the monthly mean extraterrestrial solar radiation on horizontal surface, given by Iqbal (1983) as follows:

$$\overline{H}_O = \frac{24}{\pi} I_{sc} E_O \left(\frac{\pi}{180} w_s \sin\phi \sin\delta + \cos\phi \cos\delta \sin w_s \right) \tag{2}$$

Where; I_{sc} is the solar constant, E_O is the eccentricity correction factor, ϕ is the latitude, δ is the solar declination and w_s is the hour angle.

The expressions for I_{sc}, E_O, δ and w_s are given by Iqbal (1983):

$$I_{sc} = \frac{1367 X 3600}{1000000} \text{ (MJm}^{-2}\text{day}^{1}\text{)} \tag{3}$$

$$E_O = 1 + 0.033COS\left(\frac{360N}{365} \right) \tag{4}$$

$$\delta = 23.45Sin\left[\frac{360(N + 284)}{365} \right] \tag{5}$$

Where' N is the characteristic day number for each month.

$$w_s = Cos^{-1}(-\tan\phi \tan\delta) \tag{6}$$

Other regression models were obtained by the modification of the Angstrom-Page model.

The various meteorological data are related to global solar radiation. Multiple linear regression and correlation analysis of five parameters ($\frac{\overline{H}_M}{\overline{H}_O}$, $\frac{\overline{n}}{\overline{N}}$, T_M, $\frac{\overline{c}}{\overline{C}}$ and R) were employed to estimate the global solar radiation. Where $\frac{\overline{H}_M}{\overline{H}_O}$ is the clearness index, $\frac{\overline{n}}{\overline{N}}$ is the fraction of sunshine duration, T_M is the maximum temperature, $\frac{\overline{c}}{\overline{C}}$ is the Cloudliness index and R is the relative humidity. SPSS Computer Software Program was used in evaluating model parameters.

The accuracy of the estimated values were tested by calculating the Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE). The expressions for the MBE (MJm^{-2}day^{-1}), RMSE (MJm^{-2}day^{-1}), and MPE (%) is stated by El – Sebaii and Trabea (2005) as follows:

$$MPE = \left[\sum \left(\overline{H}_{i,cal} - \overline{H}_{i,meas} \right) \right] / n \tag{7}$$

$$RMSE = \left[\sum \left(\overline{H}_{i,cal} - \overline{H}_{i,meas} \right)^2 / n \right]^{\frac{1}{2}} \tag{8}$$

$$MPE = \left[\sum \left(\frac{\overline{H}_{i,meas} - \overline{H}_{i,cal}}{\overline{H}_{i,meas}} X100 \right) \right] / n \tag{9}$$

Where $\overline{H}_{i,cal}$ and $\overline{H}_{i,meas}$ is the ith calculated (predicted) and measured values and n is the total number of observations. Iqbal (1983), Halouani (1993), Almorox et al. (2005) and Che et al. (2007) have recommended that a zero value for MBE is ideal and a low RMSE is desirable. The RMSE test provides information on the short-term performance of the studied model as it allows a term – by – term comparism 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 values provide the averages amount of overestimation in the calculated values, while the negative values gives underestimation. A low value of MPE is desirable by Akpabio and Etuk (2002).

The values of the meteorological data and global solar radiation data for the four cities are presented in Tables 1 - 4.

RESULTS AND DISCUSSION

The regression constants a and b for Owerri, Enugu, Delta and Calabar were determined by correlating the global solar radiation with the meteorological data. The values of the regression constants are found to be different from those obtained by Hussain (2005), Bala

Table 1. Meteorological data and global solar radiation for Owerri.

Month	$\overline{T}_M$ (°C)	$\frac{\overline{n}}{\overline{N}}$	$\frac{\overline{c}}{\overline{C}}$	$\frac{R}{100}$	$\overline{H}_O$ (MJm^{-2}day^{-1})	$\overline{H}_M$ (MJm^{-2}day^{-1})	$\overline{K}_T = \frac{\overline{H}_M}{\overline{H}_O}$
JAN.	33.88	0.4275	0.0546	0.66	34.28	14.46	0.4201
FEB.	35.11	0.4497	0.0568	0.69	36.06	15.51	0.4509
MAR.	34.17	0.3967	0.0629	0.76	37.52	15.09	0.4041
APR.	33.17	0.4255	0.0666	0.78	37.48	17.19	0.4450
MAY	32.14	0.4728	0.0671	0.78	36.24	16.28	0.4183
JUN	30.87	0.3803	0.0644	0.83	35.13	14.54	0.3974
JUL.	29.28	0.2564	0.0702	0.86	35.61	13.10	0.3506
AUG.	29.37	0.2207	0.0692	0.87	37.05	13.42	0.3516
SEPT.	30.28	0.2765	0.0691	0.84	37.26	14.43	0.3763
OCT.	31.02	0.3388	0.0673	0.82	36.18	14.81	0.3949
NOV.	32.84	0.4642	0.5800	0.77	34.38	15.41	0.4072
DEC.	33.29	0.4611	0.0533	0.75	33.19	14.84	0.4329

Table 2. Meteorological data and global solar radiation for Enugu.

Month	$\overline{T}_M$ (°C)	$\frac{\overline{n}}{\overline{N}}$	$\frac{\overline{c}}{\overline{C}}$	$\frac{R}{100}$	$\overline{H}_O$ (MJm^{-2}day^{-1})	$\overline{H}_M$ (MJm^{-2}day^{-1})	$\overline{K}_T = \frac{\overline{H}_M}{\overline{H}_O}$
JAN.	35.81	0.5484	0.0310	0.46	35.82	16.09	0.4492
FEB.	37.69	0.5579	0.0472	0.49	37.01	17.65	0.4769
MAR.	37.30	0.5013	0.0571	0.61	37.54	18.05	0.4808
APR.	35.57	0.5296	0.0652	0.71	36.44	18.56	0.5093
MAY	34.07	0.5247	0.0666	0.77	34.41	17.93	0.5211
JUN.	32.65	0.4294	0.0681	0.80	33.15	15.59	0.4703
JUL.	31.62	0.3113	0.0712	0.82	34.85	14.23	0.4083
AUG.	31.14	0.3088	0.0711	0.83	35.47	14.37	0.4051
SEPT.	31.96	0.3702	0.0702	0.82	36.95	15.24	0.4124
OCT.	32.91	0.5038	0.0669	0.78	37.73	14.58	0.3864
NOV.	34.93	0.6459	0.0536	0.65	35.83	17.29	0.4826
DEC.	35.49	0.6005	0.0385	0.52	35.22	16.46	0.4673

(2001), Burari and Sambo (2001), Awachie and Okeke (1990), Akpabio and Etuk (2002), Fagbenle (1990), Badamus and momoh (2005) etc. These differences suggest that regression coefficients associated with sunshine hours and other meteorogical data changes with latitude and atmospheric conditions.

The sum of the regression coefficients (a+b) is interpreted as the transmissivity of the atmosphere for global solar radiation under perfectly clear sky conditions (Revfein, 1983). Similarly the intercept "a" is interpreted as the transmissivity of an overcast atmosphere. It is therefore important to examine the regression relation we have developed and compare it with others in terms of the value of the atmospheric transmissivity under clear skies, which compares favourably with the figure of 0.6 - 0.7 reported for the tropics (Turton, 1987). In general the clear sky transmissivity of most tropical, regions seems to lie between 0.68 - 0.75 (Ibrahim, 1985; Turton, 1987; Abdalla, 1987; Sambo, 1986; Bakhah et al., 1983).

A close examination of Tables 5 - 6 show that the maximum values of the fraction of sunshine occurred in the month of November. These values are within what is expected of a tropical site (Exell, 2000; Okogbue and Adedokun, 2005). The month of occurrence is not expected because of the harmattan season when aersol mass loading greatly reduces the intensity of solar radiation (Babatunde, 2001) and (Babatunde and Aro, 2000). However it should be noted that insolation instrument records hours of bright sunshine when solar radiation flux density is above the threshold value of 210 Wm^{-2}. Hence during the month of November a very high mean daily sunshine hours is obtained because it has a high clear-

Table 3. Meteorological data and global solar radiation for Warri.

Month	$\bar{T}_M$ (°C)	$\frac{\bar{n}}{\bar{N}}$	$\frac{\bar{c}}{\bar{C}}$	$\frac{R}{100}$	$\bar{H}_O$ (MJm^{-2}day^{-1})	$\bar{H}_M$ (MJm^{-2}day^{-1})	$\bar{K}_T = \frac{\bar{H}_M}{\bar{H}_O}$
JAN.	33.00	0.4027	0.0650	0.567	35.56	11.02	0.3099
FEB.	33.68	0.4061	0.0684	0.591	36.01	12.55	0.3485
MAR.	33.45	0.3855	0.0694	0.644	36.54	13.76	0.3766
APR.	32.86	0.4086	0.0695	0.711	35.44	15.94	0.4498
MAY	31.93	0.4025	0.0678	0.741	33.41	11.30	0.3382
JUN.	30.53	0.3305	0.0700	0.783	33.55	12.31	0.3669
JUL.	28.77	0.1867	0.0707	0.830	34.95	12.91	0.3694
AUG.	28.89	0.1911	0.0706	0.819	35.77	12.19	0.3408
SEPT.	29.99	0.2149	0.0697	0.811	36.85	13.55	0.3677
OCT.	31.28	0.3589	0.0683	0.766	37.93	14.56	0.3839
NOV.	32.74	0.4825	0.0664	0.682	35.33	13.91	0.3937
DEC.	32.66	0.4478	0.0656	0.600	35.12	12.46	0.3548

Table 4. Meteorological data and global solar radiation for Uyo.

Month	$\bar{T}_M$ (°C)	$\frac{\bar{n}}{\bar{N}}$	$\frac{\bar{c}}{\bar{C}}$	$\frac{R}{100}$	$\bar{H}_O$ (MJm^{-2}day^{-1})	$\bar{H}_M$ (MJm^{-2}day^{-1})	$\bar{K}_T = \frac{\bar{H}_M}{\bar{H}_O}$
JAN.	33.00	0.5484	0.0637	0.46	34.56	14.47	0.4187
FEB.	33.68	0.5579	0.0655	0.49	36.17	15.50	0.4285
MAR.	33.45	0.5013	0.0686	0.61	37.67	15.09	0.4006
APR.	32.86	0.5296	0.0691	0.71	37.45	17.19	0.4590
MAY	31.93	0.5247	0.0692	0.77	36.98	16.28	0.4402
JUN.	30.53	0.4294	0.0692	0.80	35.86	14.54	0.4055
JUL.	28.77	0.3113	0.0700	0.82	35.67	13.10	0.3673
AUG.	28.89	0.3088	0.0692	0.83	37.09	13.42	0.3618
SEPT.	29.99	0.3702	0.0685	0.82	37.34	14.43	0.3864
OCT.	31.28	0.5038	0.0663	0.78	36.41	14.81	0.4068
NOV.	32.74	0.6459	0.0675	0.65	34.59	15.41	0.4455
DEC.	32.66	0.6005	0.0622	0.52	33.79	14.84	0.4391

ness index.

Tables 5 - 8 contain summaries of various linear regression analyses, obtained from the application of equation (1) to the monthly mean value for the five variables under study. It is clear that the correlation coefficient R, coefficient of determination R^2, MBE (MJ/m^2/day), RMSE (MJ/m^2/day) and MPE (%) vary from one variable to another variable.

It was observed that combination of sunshine hours, maximum temperature, cloudiness index and relative humidity gave better results (Tables 5 - 8). Figures 1 - 4 show a remarkable agreement between the observed and predicted values of global solar radiation.

For better analysis the developed correlation will be considered that has high value of correlation coefficient R and coefficient of correlation R^2.

From Tables 5 - 8, based on the highest values of correlation coefficient, coefficient of determination and least values of MBE, RMSE and MPE, the following equations:

$$\frac{\bar{H}}{\bar{H}_O} = -0.02\frac{\bar{n}}{\bar{N}} + 0.01\bar{T}_M - 0.05\frac{\bar{c}}{\bar{C}} + 0.08\frac{R}{100},$$

$$\frac{\bar{H}}{\bar{H}_O} = -1.39 + 0.02\frac{\bar{n}}{\bar{N}} - 6.59\frac{\bar{c}}{\bar{C}} + 1.10\frac{R}{100} + 0.04\bar{T}_M,$$

$$\frac{\bar{H}}{\bar{H}_O} = -1.06 + 0.23\frac{\bar{n}}{\bar{N}} + 0.01\bar{T}_M + 10.22\frac{\bar{c}}{\bar{C}} + 0.33\frac{R}{100},$$

Table 5. Regression equations and statistical indicators for Owerri.

Equations	R	R^2	MBE	RMSE	MPE
$\frac{\overline{H}}{\overline{H}_O} = 0.278 + 0.331\frac{\overline{n}}{\overline{N}}$	0.891	0.793	0.219	2.781	0.367
$\frac{\overline{H}}{\overline{H}_O} = -0.076 + 0.015\overline{T}_M$	0.886	0.785	0.455	3.342	0.293
$\frac{\overline{H}}{\overline{H}_O} = 0.718 - 0.401\left(\frac{R}{100}\right)$	0.795	0.632	0.566	3.922	0.988
$\frac{\overline{H}}{\overline{H}_O} = 0.507 - 0.863\frac{\overline{c}}{\overline{C}}$	0.270	0.073	0.673	4.432	0.329
$\frac{\overline{H}}{\overline{H}_O} = -0.024\frac{\overline{n}}{\overline{N}} + 0.009\overline{T}_M - 0.046\frac{\overline{c}}{\overline{C}} + 0.079\frac{R}{100}$	0.948	0.899	0.884	1.122	0.047

Table 6. Regression equations and statistical indicators for Enugu.

Equations	R	R^2	MBE	RMSE	MPE
$\frac{\overline{H}}{\overline{H}_O} = 0.336 + 0.247\frac{\overline{n}}{\overline{N}}$	0.618	0.382	0.219	2.761	0.311
$\frac{\overline{H}}{\overline{H}_O} = -0.019 + 0.127\overline{T}_M$	0.646	0.417	0.444	3.212	0.253
$\frac{\overline{H}}{\overline{H}_O} = 0.538 - 0.119\left(\frac{R}{100}\right)$	0.378	0.143	0.533	3.812	0.678
$\frac{\overline{H}}{\overline{H}_O} = 0.507 - 0.863\frac{\overline{c}}{\overline{C}}$	0.270	0.073	0.523	4.112	0.321
$\frac{\overline{H}}{\overline{H}_O} = -1.39 + 0.02\frac{\overline{n}}{\overline{N}} - 6.59\frac{\overline{c}}{\overline{C}} + 1.10\frac{R}{100} + 0.04\overline{T}_M$	0.824	0.663	0.114	1.112	0.017

Table 7. Regression equations and statistical indicators for Warri.

Equations	R	R^2	MBE	RMSE	MPE
$\frac{\overline{H}}{\overline{H}_O} = 0.29 + 0.42\frac{\overline{n}}{\overline{N}}$	0.897	0.795	0.219	2.761	0.311
$\frac{\overline{H}}{\overline{H}_O} = -0.297 + 0.022\overline{T}_M$	0.921	0.848	0.444	3.212	0.253
$\frac{\overline{H}}{\overline{H}_O} = 0.309 + 0.082\frac{R}{100}$	0.221	0.049	0.533	3.812	0.678
$\frac{\overline{H}}{\overline{H}_O} = -0.041 + 5.950\frac{\overline{c}}{\overline{C}}$	0.329	0.108	0.523	4.112	0.321
$\frac{\overline{H}}{\overline{H}_O} = -1.06 + 0.23\frac{\overline{n}}{\overline{N}} + 0.01\overline{T}_M + 10.22\frac{\overline{c}}{\overline{C}} + 0.33\frac{R}{100}$	0.947	0.897	0.114	1.112	0.017

Table 8. Regression equations and statistical indicators for Uyo.

Equations	R	R^2	MBE	RMSE	MPE
$\frac{\bar{H}}{\bar{H}_O} = 0.290 + 0.253\frac{\bar{n}}{\bar{N}}$	0.891	0.793	0.323	2.157	0.345
$\frac{\bar{H}}{\bar{H}_O} = -0.009 + 0.013\bar{T}_M$	0.649	0.421	0.543	3.332	0.259
$\frac{\bar{H}}{\bar{H}_O} = 0.491 - 0.114\frac{R}{100}$	0.509	0.260	0.578	3.218	0.699
$\frac{\bar{H}}{\bar{H}_O} = 0.730 - 4.701\frac{\bar{c}}{\bar{C}}$	0.377	0.142	0.590	4.908	0.354
$\frac{\bar{H}}{\bar{H}_O} = -1.06 + 0.23\frac{\bar{n}}{\bar{N}} + 0.01\bar{T}_M + 10.22\frac{\bar{c}}{\bar{C}} + 0.33\frac{R}{100}$	0.917	0.841	0.231	1.564	0.077

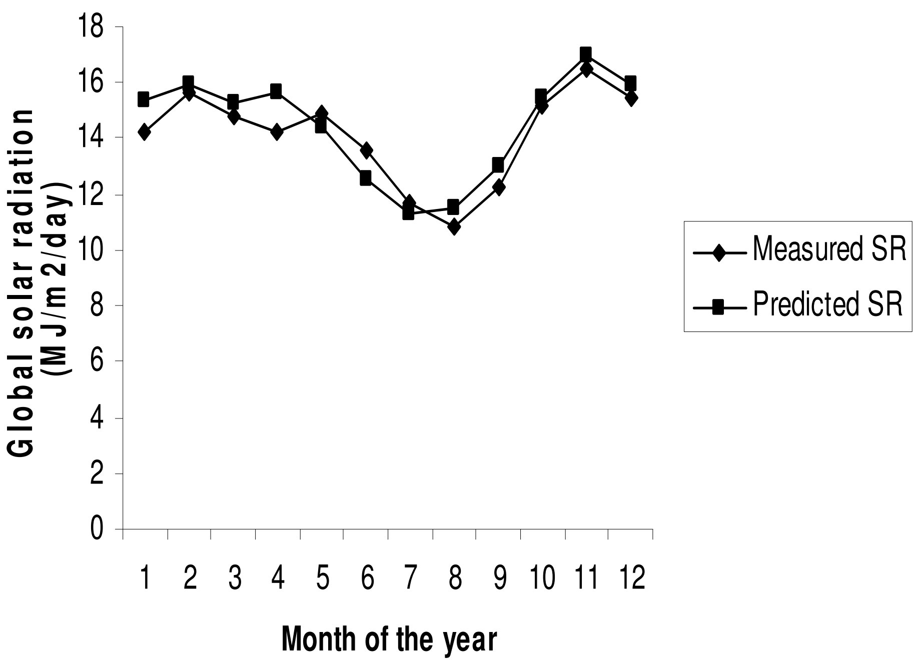

Figure 1. Comparism between the measured and predicted global solar radiation for Owerri.

$$\frac{\bar{H}}{\bar{H}_O} = 0.08 + 0.31\frac{\bar{n}}{\bar{N}} - 0.001\bar{T}_M + 2.39\frac{\bar{c}}{\bar{C}} + 0.03\frac{R}{100}$$

Are the best regression equations suitable for estimating global solar radiation in Owerri, Enugu, Delta and Uyo respectively.

Conclusion

SPSS computer software program was used to develop several linear and multilinear regression equations for some selected cities in the Eastern and Southern part of Nigeria. Based on the values of the correlation coefficient and coefficient of determination and least values of MBE, RMSE and MPE, the equations:

$$\frac{\bar{H}}{\bar{H}_O} = -0.02\frac{\bar{n}}{\bar{N}} + 0.01\bar{T}_M - 0.05\frac{\bar{c}}{\bar{C}} + 0.08\frac{R}{100},$$

$$\frac{\bar{H}}{\bar{H}_O} = -1.39 + 0.02\frac{\bar{n}}{\bar{N}} - 6.59\frac{\bar{c}}{\bar{C}} + 1.10\frac{R}{100} + 0.04\bar{T}_M,$$

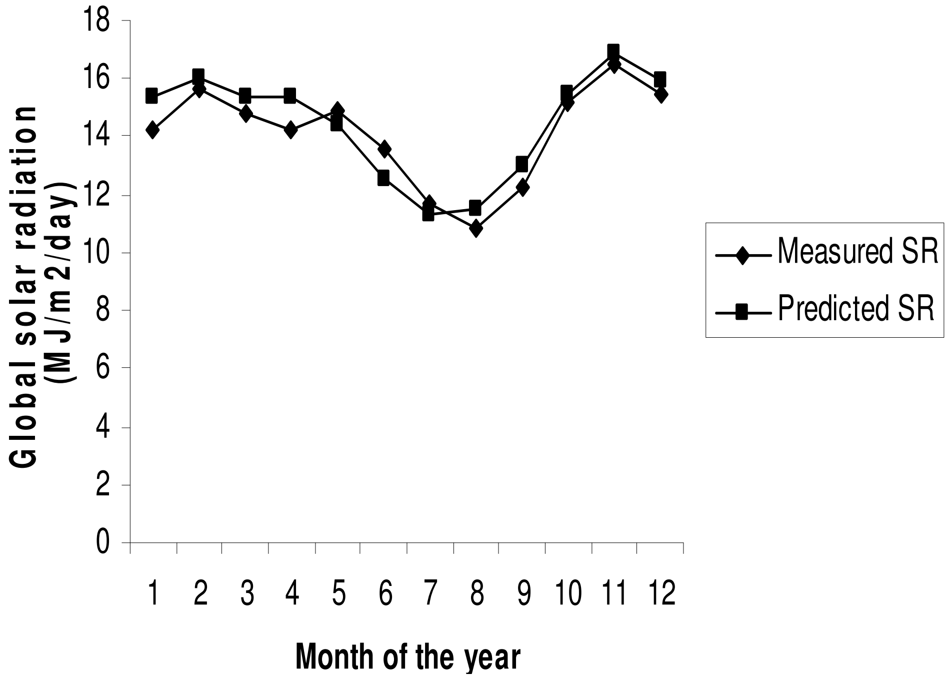

Figure 2. Comparism between the measured and predicted global solar radiation for Enugu.

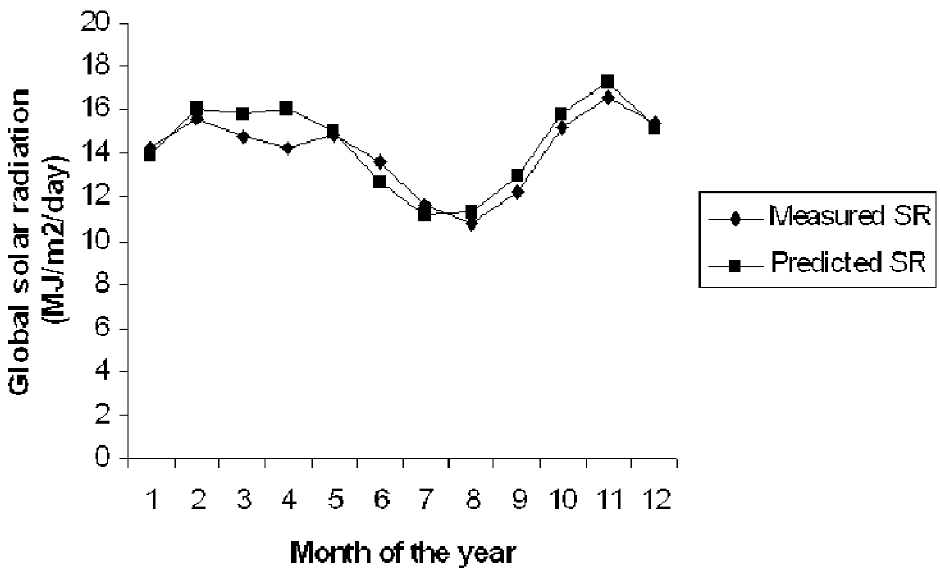

Figure 3. Comparism between the measured and predicted global solar radiation for Warri.

$$\frac{\overline{H}}{\overline{H_O}} = -1.06 + 0.23\frac{\overline{n}}{\overline{N}} + 0.01\overline{T}_M + 10.22\frac{\overline{c}}{\overline{C}} + 0.33\frac{R}{100}$$

and

$$\frac{\overline{H}}{\overline{H_O}} = 0.08 + 0.31\frac{\overline{n}}{\overline{N}} - 0.001\overline{T}_M + 2.39\frac{\overline{c}}{\overline{C}} + 0.03\frac{R}{100}$$

have been found suitable for predicting the monthly mean daily solar radiation in Owerri, Enugu, Warri and Uyo respectively.

The derived data and correlation will provide a useful source of information to designers of renewable energy and air-conditioning systems for these areas. It would also enrich the National Energy data bank. Consequently, the work should be extended to other zones of the

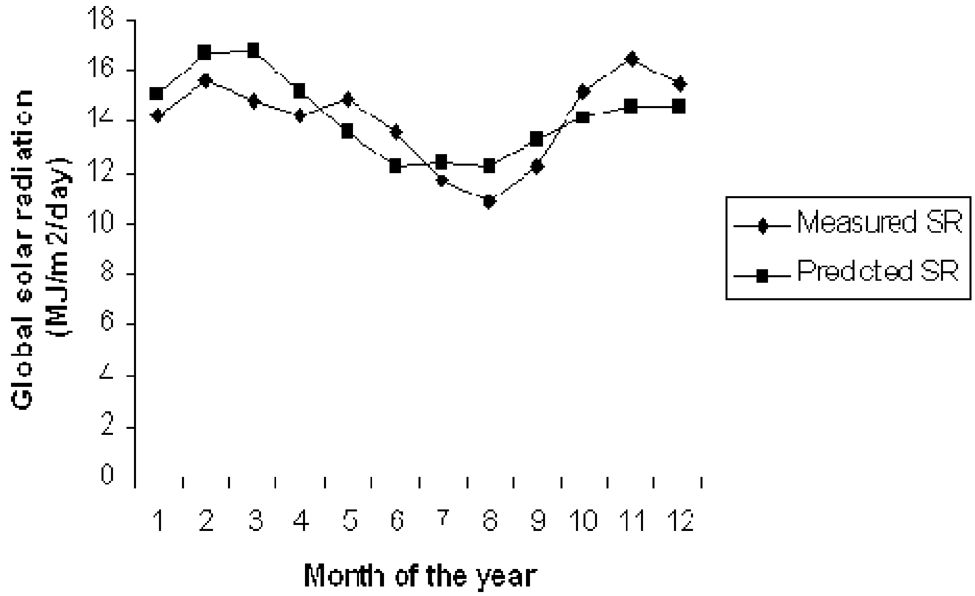

Figure 4. Comparism between the measured and predicted global solar radiation for Uyo.

country.

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