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Full Length Research Paper

Relationship between global solar radiation and sunshine hours for Calabar, Port Harcourt and Enugu, Nigeria

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The monthly mean daily data for global solar radiation and sunshine hours for a period of seventeen years (1999 - 2007) for Calabar, Enugu and Port Harcourt respectively have been used to develop a number of regression equations. The values of the global solar radiation estimated by the models 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 determination (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 for Calabar, Port Harcourt and Enugu are $\frac{\overline{H}_P}{\overline{H}_O} = -0.499 + 4.294\frac{\overline{n}}{\overline{N}} - 4.769\left(\frac{\overline{n}}{\overline{N}}\right)^2$, $\frac{\overline{H}_P}{\overline{H}_O} = 0.177 + 1.048\frac{\overline{n}}{\overline{N}} - 1.070\left(\frac{\overline{n}}{\overline{N}}\right)^2$ **and** $\frac{\overline{H}_P}{\overline{H}_O} = 0.177 + 1.048\frac{\overline{n}}{\overline{N}} - 1.070\left(\frac{\overline{n}}{\overline{N}}\right)^2$ **respectively. Where** $\frac{\overline{H}_P}{\overline{H}_O}$ **is clearness index and** $\frac{\overline{n}}{\overline{N}}$ **is fraction of sunshine hour. The equations could be employed in estimating global solar radiation of location that has the same geographical location information as Calabar, Port Harcourt and Enugu.**

Key words: Sunshine hours, clearness index, global solar radiation.

INTRODUCTION

Energy is the motive force behind the sustained technological development of any nation and Nigeria is blessed with reasonably high quantities of various energy resources. These include the non-renewables such as crude oil, natural gas, coal and uranium and the renewables such as biomass, solar, wind and hydro energy. At present, the dominant energy source used in Nigeria is oil and its derivatives, accounting for over 75% of the total energy consumption, except in the rural areas where biomass in the form of fuel wood dominates (UNIDO, 2003).

Energy trends indicates that world oil production will reach peak and start a long downward slide some day when the fossil fuel and gas would have exhausted. At next 40 years, the oil reserves would be depleted to the point where it would be economically unviable to continue exploration. The environmental consequences of harnessing these non–renewable energy sources are assuming alarming proportions. Oil extraction has created so much ecological problems that the inhabitants of the Niger Delta region of Nigeria are beginning to think that coming from the oil rich area is a curse rather than a blessing (UNIDO, 2003).

The awareness of the limited availability of these resources and their associated environmental problems is making it imperative that we shift emphasis to the renewable energy resources. Renewable energy technology is capable of alleviating the already over stretched ecosstem and capable of supplying the energy necessary for rapid development, especially the rural areas by encouraging the establishment of cottage industries and by stemming the rural urban drift. One of the most viable

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options particularly in Nigeria is the abundant solar energy falling on the surface of the earth.

In any solar energy conversion system, the knowledge of global solar radiation is extremely important for the optimal design and the prediction of the system performance.

A global study of the world distribution of global solar radiation requires knowledge of the radiation data in various countries and for the purpose of world wide marketing, the designers and manufacturers of solar equipment will need to know the mean global solar radiation available in different and specific regions (Ibrahim, 1985).

Obviously, the best way of knowing the amount of global solar radiation at a site is to install pyranometer at many locations in the given region and look after their day to day maintenance and recording, which is a very costly exercise. The alternative approach is to correlate the global solar radiation with the meteorological parameters at the place where the data is collected. The resultant correlation may then be used for locations of similar meteorological characteristics.

Solar radiation passing through the atmosphere to the ground surface is known to be depleted through scattering, reflection, and absorption by the atmospheric constituents like air molecules, aerosols, water vapour, ozone and clouds. The reflection of solar radiation is mainly by clouds and this plays an overriding part in reducing the energy density of the solar radiation reaching the surface of the earth (Exell, 2000).

The encounter of solar radiation particularly with clouds lead to the variation in intensity of sunshine and the number of sunshine hours at the ground surface: The variation however is not due only to the clouds but also to the angle of incidence of the sun's rays with the ground surface and its azimuth (Babatunde, 1988). These in turn, are due to the rotation of the earth round the sun and the inclination of its axle with the plane of its orbit round the sun. The result is the variation in the number of hours of sunshine and its intensity on the earth's surface. The variation is from latitude to latitude. Thus, a solar radiation measurement parameter is obtained and defined as the ratio of the actual number of hours of sunshine received at a site to the number possible in the day that is the length of the day. The ratio is known as fraction of sunshine hours $\frac{\bar{n}}{\bar{N}}$. It is found to vary daily and seasonally (Igbal, 1979; Shears et al., 1981).

The radiation arriving on the ground directly in line with the solar disk is called direct or beam radiation. A portion of the scattered and reflected radiation goes back to space and a portion reaches the ground from the sky hemisphere as diffuse radiation. The sum total of direct and diffuse radiation is called global radiation (Igbal, 1983). The amount of total (global) solar radiation, H, eventually obtained on the ground surface is found to be to be a fraction of the extraterrestrial radiation, H_O, at the top of the atmosphere of the site. Extraterrestrial radiation is the maximum amount of solar radiation available to the earth at the top of the atmosphere and H is the amount of the radiation eventually available at the ground surface after scattering, reflection, and absorption in the atmosphere. The ratio, H/H_O, is a possible measure of the transparency of the atmosphere to solar radiation. Thus, the ratio is used to define the coefficient of transmission or the transmittance of the atmosphere (Babatunde et al., 1990).

A number of correlations involving global solar radiation and sunshine hours for different locations in Nigeria have been studied by different workers. For example, (Sambo, 1985) developed a correlation with solar radiation using sunshine hours for Kano with the regression coefficients a = 0.413 and b = 0.241 for all the months between 1980-1984, (Arinze and Obi, 1983) developed a correlation with solar radiation using sunshine hours in Northern Nigeria with regression coefficients a = 0.2 and b = 0.74, (Burari et at., 2001) developed a model for estimation of global solar radiation in Bauchi with regression coefficients a =0.24 and b = 0.46. Other workers (Ojosu, 1984; Fagbenle, 1990; Folayan, 1983; Adebiyi, 1988; Turton, 1987; Bamiro, 1983) developed theoretical and empirical correlations of broad applicability to provide solar data for systems design in most Nigeria cities. We observed that the regression coefficients are not universal but depends on the climatic conditions. This work aims at investigating suite of models that can use to relate global solar radiation and sunshine hours for Calabar, Port Harcourt and Enugu.

METHODOLOGY

The monthly mean daily data for sunshine hours for Calabar, Port Harcourt and Enugu were collected from the archives of the Nigerian Meteorological Agency, Federal Ministry of Aviation, Oshodi, and Lagos. The global solar radiation data were obtained from renewable energy for rural Industrialization and development in Nigeria. The data obtained, covered a period of seventeen years (1991-2007) for Calabar (latitude 4.97°N, longitude 88.35°E and altitude 6.14 m above sea level), Port Harcourt (latitude 4.85°N, longitude 7.02°N and 19.55 m above sea level) and Enugu (latitude 7.55°N, longitude 6.47°E and altitude141.50 m above sea level).

Data analysis

The monthly averages data processed in preparation for the correlations are presented in Tables 1, 2 and 3 for Calabar, Port Harcourt and Enugu respectively.

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

The first correlation proposed for estimating the monthly mean daily global solar radiation on a horizontal surface $\bar{H}$ ($MJm^{-2}day^{-1}$) using the sunshine duration data is due. Angstrom (1924) and Prescott (1940) have put the Angstrom correlation in more convenient form as:

$$\frac{\bar{H}_M}{\bar{H}_O} = a + b\frac{\bar{n}}{\bar{N}} \quad (1)$$

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

Month	$\bar{n}$ (hours)	$\bar{N}$ (hours)	$\frac{\bar{n}}{\bar{N}}$	$\bar{H}_M$ ($MJm^{-2}day^{-1}$)	$\bar{H}_O$ ($MJm^{-2}day^{-1}$)	$\bar{K}_T = \frac{\bar{H}_M}{\bar{H}_O}$
Jan	3.889	11.75	0.3309	14.0004	34.28	0.4084
Feb	4.546	11.84	0.3839	16.3656	36.06	0.4538
Mar	4.292	11.97	0.3586	15.4512	37.52	0.4118
Apr	4.544	12.11	0.3752	16.3584	37.48	0.4365
May	4.206	12.23	0.3439	15.1416	36.24	0.4178
Jun	3.636	11.72	0.3102	13.0896	35.13	0.3726
Jul	3.233	11.74	0.2754	11.6388	35.61	0.3268
Aug	3.415	11.89	0.2872	12.2940	37.05	0.3318
Sept	3.747	11.98	0.3128	13.4892	37.26	0.3620
Oct	3.925	11.87	0.3307	14.1300	36.18	0.3905
Nov	3.983	11.76	0.3387	14.3388	34.38	0.4171
Dec	3.684	11.71	0.3146	13.2624	33.19	0.3996

Table 2. Meteorological data and global solar radiation for Port Harcourt.

Month	$\bar{n}$ (hours)	$\bar{N}$ (hours)	$\frac{\bar{n}}{\bar{N}}$	$\bar{H}_M$ ($MJm^{-2}day^{-1}$)	$\bar{H}_O$ ($MJm^{-2}day^{-1}$)	$\bar{K}_T = \frac{\bar{H}_M}{\bar{H}_O}$
Jan	4.72	11.75	0.4017	14.40	34.25	0.4204
Feb	4.81	11.84	0.4063	16.26	35.50	0.4580
Mar	4.32	11.94	0.3609	15.16	36.52	0.4151
Apr	4.70	12.11	0.3881	16.68	37.28	0.4474
May	4.99	12.22	0.4083	15.16	36.54	0.4149
Jun	4.12	12.28	0.3355	13.96	35.13	0.3974
Jul	2.56	12.25	0.2089	12.99	35.71	0.3638
Aug	2.41	12.11	0.1990	12.52	37.15	0.3370
Sept	3.33	11.98	0.2779	14.02	37.56	0.3733
Oct	4.22	11.87	0.3555	14.29	35.18	0.4062
Nov	5.48	11.77	0.4656	14.00	34.48	0.4060
Dec	5.72	11.72	0.4881	14.37	32.39	0.4437

Where a and b are regression constants, $\bar{H}_M$ is the measured monthly mean daily global radiation, $\bar{n}$ is the monthly mean daily bright sunshine hours, $\bar{N}$ is the maximum possible monthly mean daily sunshine hours or the day length, $\frac{\bar{n}}{\bar{N}}$ is the fraction of sunshine hours, $\bar{H}_O$ is the monthly mean extraterrestrial solar radiation on horizontal surface, given by Iqbal (1983) as follows:

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

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.

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

Month	$\bar{n}$ (hours)	$\bar{N}$ (hours)	$\frac{\bar{n}}{\bar{N}}$	$\bar{H}_M$ (MJm^{-2}day^{-1})	$\bar{H}_O$ (MJm^{-2}day^{-1})	$\bar{K}_T = \frac{\bar{H}_M}{\bar{H}_O}$
Jan	6.35	11.58	0.5484	14.25	35.82	0.3978
Feb	6.55	11.74	0.5579	15.65	37.01	0.4229
Mar	5.99	11.95	0.5013	14.77	37.54	0.3934
Apr	6.45	12.18	0.5296	14.27	36.44	0.4916
May	6.49	12.37	0.5247	14.85	34.41	0.4316
Jun	5.35	12.46	0.4294	13.61	33.15	0.4106
Jul	3.86	12.40	0.3113	11.65	34.85	0.3343
Aug	3.78	12.24	0.3088	10.80	35.47	0.3044
Sept	4.45	12.02	0.3702	12.26	36.95	0.3318
Oct	5.94	11.79	0.5038	15.18	37.73	0.4023
Nov	7.50	11.61	0.6459	16.51	35.83	0.4608
Dec	6.93	11.54	0.6005	15.42	35.22	0.4378

The accuracy of the estimated values was 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 (%) are stated by El – Sebaii et al., (2005) as follows:

$$\mathrm{MPE} = \left[\sum\left(\bar{H}_{i,cal} - \bar{H}_{i,meas}\right)\right] / n \qquad (3)$$

$$RMSE = \left[\sum\left(\bar{H}_{i,cal} - \bar{H}_{i,meas}\right)^2 / n\right]^{\frac{1}{2}} \qquad (4)$$

$$\mathrm{MPE} = \left[\sum\left(\frac{\bar{H}_{i,meas} - \bar{H}_{i,cal}}{\bar{H}_{i,meas}} X100\right)\right] / n \qquad (5)$$

Where $\bar{H}_{i,cal}$ and $\bar{H}_{i,meas}$ is the ith calculated (predicted) and measured values and n is the total number of observations. Iqbal (1983), Halouani (1993), Almorox (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 et al. (2002).

RESULTS AND DISCUSSION

The values for sunshine hours, day length, and fraction of sunshine hours, global solar radiation, extraterrestrial solar radiation and clearness index for Calabar, Port Harcourt and Enugu are presented in Tables 1, 2 and 3 respectively. Tables 4, 5 and 6 contains summaries of various linear regression analyses, obtained from the application of equation (1) to the monthly mean values for the variable under study for Calabar, PortHarcourt and Enugu respectively. 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.

Linear correlation

The correlation coefficient of 0.951 existing between the clearness index and monthly mean daily fraction of sunshine indicates that there is a high positive correlation between the measured monthly mean daily fraction of sunshine hours and the monthly mean daily clearness index. Also, the value of coefficient of determination of 0.903 implies 90.3% of clearness index can be accounted using fraction of sunshine. The model for Calabar is given by

$$\frac{\bar{H}}{\bar{H}_o} = 0.018 + 1.139\frac{\bar{n}}{\bar{N}} \qquad (6)$$

The correlation coefficient of 0.852 existing between the clearness index and monthly mean daily fraction of sunshine indicates that there is a high positive correlation between the measured monthly mean daily fraction of sunshine hours and the monthly mean daily clearness

Table 4. Shows regression equations and statistical indicators for Calabar.

Equations	R	R^2	MBE	RMSE	MPE
$\frac{\overline{H}_P}{\overline{H}_o} = 0.018 + 1.139\frac{\overline{n}}{\overline{N}}$	0.951	0.903	0.035	0.734	0.50
$\frac{\overline{H}_P}{\overline{H}_O} = -0.499 + 4.294\frac{\overline{n}}{\overline{N}} - 4.769\left(\frac{\overline{n}}{\overline{N}}\right)^2$	0.961	0.923	0.015	0.235	0.36

Table 5. Shows regression equations and statistical indicators for Port Harcourt.

Equations	R	R^2	MBE	RMSE	MPE
$\frac{\overline{H}_P}{\overline{H}_O} = 0.2946 + 0.3059\frac{\overline{n}}{\overline{N}}$	0.852	0.726	0.018	0.538	0.54
$\frac{\overline{H}_P}{\overline{H}_O} = 0.177 + 1.048\frac{\overline{n}}{\overline{N}} - 1.070\left(\frac{\overline{n}}{\overline{N}}\right)^2$	0.877	0.769	0.011	0.356	0.31

Table 6. Shows regression equations and statistical indicators for Enugu.

Equations	R	R^2	MBE	RMSE	MPE
$\frac{\overline{H}_P}{\overline{H}_O} = 0.191 + 0.433\frac{\overline{n}}{\overline{N}}$	0.857	0.735	0.308	0.692	2.20
$\frac{\overline{H}_P}{\overline{H}_O} = 0.177 + 1.048\frac{\overline{n}}{\overline{N}} - 1.070\left(\frac{\overline{n}}{\overline{N}}\right)^2$	0.871	0.758	0.023	0.586	0.42

index. Also, the value of coefficient of determination of 0.726 implies 72.6% of clearness index can be accounted using fraction of sunshine. The model for Port Harcourt is given by

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.2946 + 0.3059\frac{\overline{n}}{\overline{N}} \tag{7}$$

The correlation coefficient of 0.857 existing between the clearness index and monthly mean daily fraction of sunshine indicates that there is a high positive correlation between the measured monthly mean daily fraction of sunshine hours and the monthly mean daily clearness index. Also, the value of coefficient of determination of 0.735 implies 73.5% of clearness index can be accounted using fraction of sunshine. The model for Enugu is given by

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.191 + 0.433\frac{\overline{n}}{\overline{N}} \tag{8}$$

Quadratic correlation

The correlation coefficient of 0.857 exists between the clearness index, monthly mean daily fraction of sunshine hours, also coefficient of determination of 0.923 implies that 92.3% of clearness index can be accounted using fraction of sunshine . The model for Calabar is given by

$$\frac{\overline{H}_P}{\overline{H}_O} = -0.499 + 4.294\frac{\overline{n}}{\overline{N}} - 4.769\left(\frac{\overline{n}}{\overline{N}}\right)^2 \tag{9}$$

The correlation coefficient of 0.857 exists between the clearness index, monthly mean daily fraction of sunshine hours, also coefficient of determination of 0.769 implies that 76.9% of clearness index can be accounted using fraction of sunshine. The model for Port Harcourt is given by

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.177 + 1.048\frac{\overline{n}}{\overline{N}} - 1.070\left(\frac{\overline{n}}{\overline{N}}\right)^2 \tag{10}$$

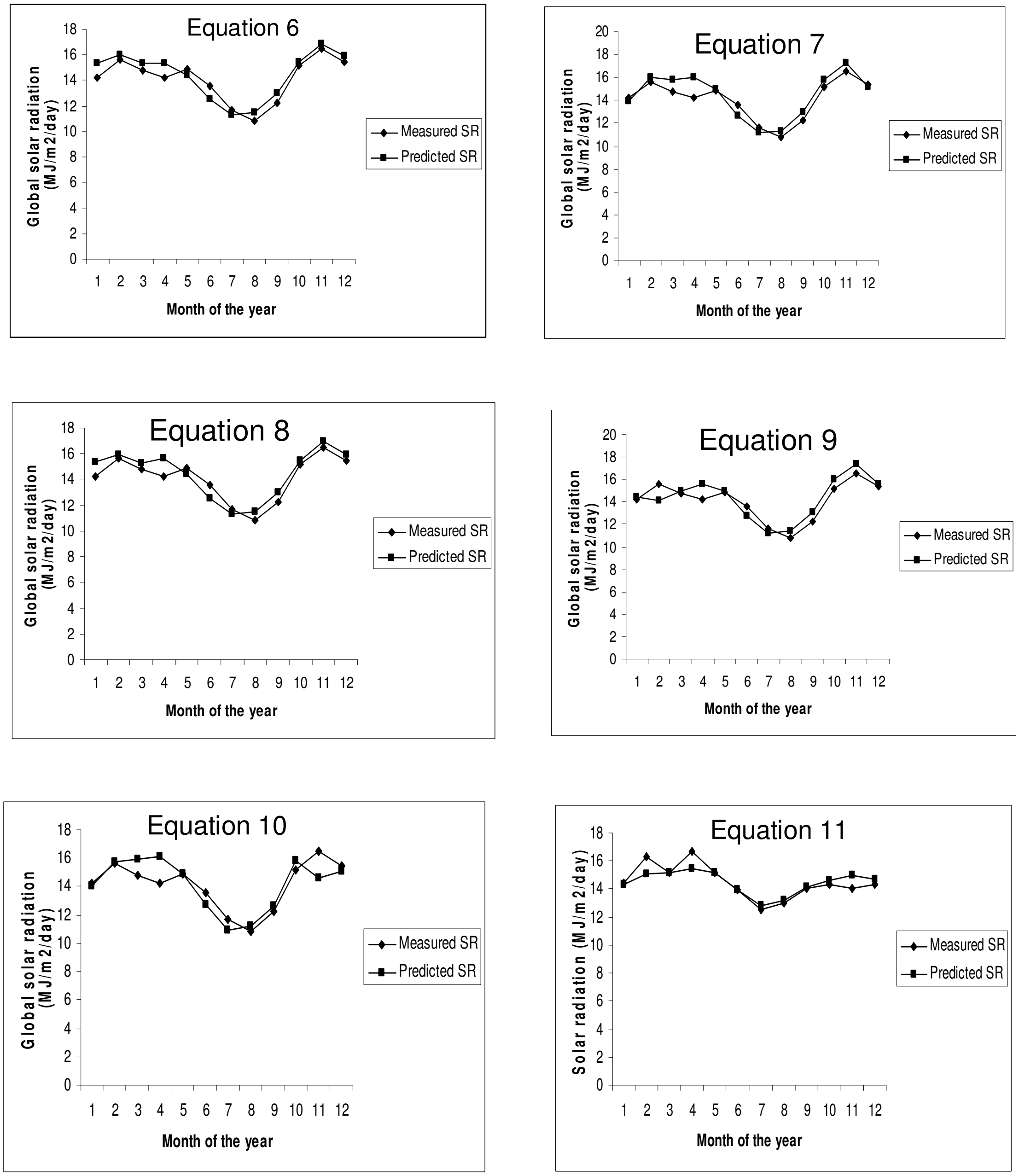

Figure 1. (Eqn.6-11) Comparism of the measured and predicted values of correlation equations.

The correlation coefficient of 0.857 exists between the clearness index, monthly mean daily fraction of sunshine hours, also coefficient of determination of 0.758 implies that 75.8% of clearness index can be accounted using fraction of sunshine. The model for Enugu is given by

$$\frac{\bar{H}_p}{\bar{H}_0} = 0.032 + 1.162\frac{\bar{n}}{\bar{N}} - 0.788\left(\frac{\bar{n}}{\bar{N}}\right)^2 \qquad (11)$$

For better analysis the developed correlations will be considered that have high values of correlation coefficient R and coefficient of correlation R^2: Equations (6), (7), (8), (9), (10), and (11). Equations (9), (10) and (11) have the highest values of correlation coefficient and coefficient of determination, while the others have low values of correlation coefficient and coefficient of determination. Furthermore, there is a remarkable agreement between the observed and the predicted values of global solar radiation for seventeen years from our correlations (Figure 1).

From Tables 4, 5 and 6, based on the highest values of correlation coefficient, coefficient of determination and least values of MBE, RMSE and MPE, equations (9), (10) and (11) are the best regression equations suitable for estimating global solar radiation in Calabar, Port Harcourt and Enugu respectively.

The values of the regression coefficients obtained for Calabar, Port Harcourt and Enugu were found to be different. These differences suggest that regression coefficients associated with meteorological data changes with latitude and atmospheric conditions.

Conclusion

The monthly mean daily global solar radiation and fraction of sunshine hours have been employed in this study to develop several correlation equations using SPSS computer software program. It was observed that equations (9), (10) and (11) have the highest values of correlation coefficients and coefficient of determinations for Calabar, Port Harcourt and Enugu respectively which gives good results when considering statistical indicators, that is, MBE, RMSE and MPE. The regression equations for Calabar, Port Harcourt and Enugu with the smallest values of MBE, RMSE and MPE are

$$\frac{\overline{H}_P}{\overline{H}_O} = -0.499 + 4.294\frac{\bar{n}}{N} - 4.769\left(\frac{\bar{n}}{N}\right)^2,$$

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.177 + 1.048\frac{\bar{n}}{N} - 1.070\left(\frac{\bar{n}}{N}\right)^2 \text{ and}$$

$$\frac{\overline{H}_P}{\overline{H}_O} = 0.177 + 1.048\frac{\bar{n}}{N} - 1.070\left(\frac{\bar{n}}{N}\right)^2 \text{ respectively.}$$

The equation could be employed in estimating global solar radiation of location that has the same geographical location information as Calabar, Port Harcourt and Enugu.

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