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Regression Analysis for Global Solar Radiation: A Case Study for Minna, Nigeria

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ABSTRACT

A Model of Global solar radiation for atmospheric, environmental and human well-being in Minna, North-Central, Nigeria has been carried out. An empirical correlation equation of the Angstrom type was developed to predict the monthly mean daily global solar radiation incident on a horizontal surface in Minna latitude 9.56°N, longitude 6.54°E, North-Central, Nigeria. Data on monthly mean daily sunshine hours and the global solar radiation amongst others covering a period of about twenty years (1990 – 2010) for Minna was collected from Nigerian Meteorological Agency, Abuja, Nigeria. The required correlation was obtained through regression analysis. The empirical correlation equation obtained is $-1.0243 + 4.2538$; Results obtained were validated using statistical indicators and compared with measured data and previous findings. Thus, the result obtained is expected to increase baseline data required for human and environmental purposes in Minna, Nigeria.

Key words: Global, Solar, Radiation, Energy, Sunshine hours, Regression.

INTRODUCTION

Solar energy is a derived energy from the sun. Research results show that energy from solar source is viable for homes and industries [1-2]. The yearly solar energy per day reaching Nigeria is between 3.7kWm⁻²day⁻¹ in the coast zones and 7.0kWm⁻¹day⁻¹ in the semi-desert regions [2]. Further research made estimated that a total of 5.08x10¹² kWh of energy is received each day in Nigeria. Some atmospheric elements and ozone determines the amount of solar irradiant received on the earth surface. The amount of solar irradiant on a given position on the surface of the earth must be known in order to be able to determine how a given solar system will perform in a specific position. Two factors; extra-terrestrial solar radiation and atmospheric condition determine the energy received [3].

This depends on the latitudinal position of the place, time of the year and distance from the sun. On a day given, this ranges from the minimum value of zero at rising of the sun and attains a maximum value at noon time and fall back to the minimum value of zero when the sun sets[4]. In the atmosphere, solar radiations are partly scattered, absorbed and reflected. Molecules and aerosols are the major cause of scattered

radiation in the atmosphere while the cloud plays a role in reflection. The reflected radiation reduces the energy density with the earth receives [5]. This also depends on earth's rotation round the sun and how it is inclined about its axis, resulting in changing length of time when the sun shines and the intensity of the sun on the surface of the earth [3].

SOLAR ENERGY

Developing countries like Nigeria has so much to gain from solar energy since it is located in the tropics. Local dwellers which do not have access to the countries grid can take advantage of solar photovoltaic energy to provide the needed energy for fringes, lighting, communication and farm irrigation. The People's Republic of China has championed a large scale production and manufacture of photovoltaic cells and devices for energy production. Much of these are for export. Solar thermal energy is in the right position to be the solution to large scale production of heat for the various sectors of agriculture, industries, commerce and homes. Solar ponds have been used for purification desalination. Harnessing solar radiation, is one of the common and cost effective technology in use [6].

The parts of the world lying between 35°N and 35°S which have at least 2000 hours of bright sunshine per year is normally accepted to be suitable for utilization of energy from the sun [7].

SOLAR RADIATION

Nigeria as a nation receives average daily solar radiation maximum in the range of (20 – 22) MJ/m²/day in the coastal area, (27 – 35) MJ/m²/day in the North-east and North-west zones, and (25 – 28) MJ/m²/day in the inland of Southern region and the North-central zone (NIMET's 2009 and 2010). Whereas, the minimum average solar radiation the country received is in the range of (7- 17) MJ/m²/day; with coastal areas having the lowest range and the northeast and northwest having the upper range. Total and precise global solar radiation data at a defined region are highly essential for regional climate assessment and crop growth modelling [13].

MINNA AREA CASE STUDY

Minna city is selected based on the peculiarity of the climate and the significance in the popularization of solar electricity in Nigeria. A case study on this city shows the average annual climate data in the following range: ambient temperature (28.16 –33.04 °C), solar radiation (206.24 – 272.55 W/m²), wind speed (1.73 – 4.73 m/s) and relative humidity (38.81 – 74.03 %). The cumulative rainfall as contained in the bulletin shows that the North-east, North-west and most part of North-central recorded rainfall in the range of (300 – 1000) mm; the entire South-east and part of South-west recorded rainfall in the range of (2000 – 3000) mm; while the rest of the country recorded rainfall in the range of (3000 – 4500) mm. However, the review indicated that 2010 rainfall is 269.3 mm less than 2009 rainfall. [8].

MEASUREMENT OF GLOBAL SOLAR RADIATION VIA ANGSTROM MATHEMATICAL MODEL

Marketers, manufacturers and designers need to have knowledge of the mean global solar irradiation in different places and regions of the world. By installing pyranometer in several places is the major and common method for measuring radiation in a region and undertaking a daily recording

and maintenance. This is expensive to undertake. Another option is by correlating world solar irradiation with meteorological parameters in a particular location were data is obtained. The effective correlation can then be for places with same meteorological features [9]. However, Mathematical model used for predicting solar radiation when not available are instrumental and not just an alternative to observation but, are powerful tools used for understanding observations, development and testing of theory. For locations where time-series of air temperature and measures of precipitates are only available as summaries on a monthly basis, the monthly available data is used to estimate global radiation. Monthly time procedure is indeed adequate for use into climate models. This is useful to agronomists, climatologists, engineers, and others who work routinely on climate data [10].

In this study, the Angstrom type of correlation equation was used to make prediction for solar radiation in Minna (latitude 9.56°N, longitude 6.54°E at altitude of 306m above sea level), North-Central, Nigeria.

METHODOLOGY

Data such as global solar radiation with monthly mean sunshine hours amongst others was collected from Minna and Abuja Nigerian Meteorological Agency. The data span a period of twenty years (1990 – 2010) for

$$\frac{\overline{H_M}}{\overline{H_O}} = a + b\frac{\overline{n}}{\overline{N}} \qquad\qquad 3.1$$

Where: $\overline{H_M}$ is the measured monthly mean daily global solar radiation on a Horizontal surface (mJm^{-2}day^{-1})

Minna (latitude 9.56°), North-Central, Nigeria. The required model was obtained through regression analysis. Results obtained were validated through statistical techniques using measured data and previous findings. This study develops and models a module to compliment a generated regression equation capable of predicting the monthly mean daily sunshine hours and the global solar radiation for Minna, which will increase baseline data required for design of solar energy applications for use in Minna, North-Central, Nigeria as well as other locations on the same latitude as Minna.

DATA COLLECTION

Required Data such as hours from the monthly mean daily sunshine, maximum and minimum temperature, humidity and the radiation of global solar amongst others were collected from the Nigerian Meteorological Agency, Minna and Abuja, Nigeria. The data collected covers a period of twenty years (1990 – 2010) for Minna (latitude 9.56°N, longitude 6.56°E at altitude 306m above sea level), North-Central, Nigeria. Mathematical Model: Angstrom-Prescott equation

Out of the correlations existing, equation of regression of the Angstrom–Prescott has been described as being the simplest. The equation, in the form expressed by [3] is as presented below:

$\overline{n}$ = the monthly mean daily bright sunshine

hours, $\overline{N}$ = the maximum possible monthly mean daily sunshine

$\overline{H_O}$ = the monthly mean extra-terrestrial solar radiation on horizontal surface (mJm^{-2}day^{-1}), and a and b are regression constants. Regression constants 'a' and 'b' for any solar

model used are very essential for high accuracy in measurement of global solar radiation in the location of interest [12]. Openibo (2011) rightly quoted from Augustine and Nnabuchi (2009a): Equations (3.2 and

$$\overline{H_o} = \frac{24}{\pi} I_{sc} E_o \left(\frac{\pi}{180} \omega_s \sin\phi \sin\delta + \cos\phi \cos\delta \sin\omega_s \right)$$

3.2

$$\overline{N} = \frac{2}{15} \cos^{-1} \left(-\tan\phi \tan\delta \right)$$

3.3

Solar angle of declination δ is given approximately to be:

$$\delta = 23.45 \sin\left(\frac{360(n+248)}{365} \right)$$

3.4

I_{sc} is the solar constant (118.104MJ m^{-2}day^{-1}), Day number characteristic N, is given

ϕ is the latitude angle and,

ω_s is the sunset hour angle given as:

$$\omega_s = \cos^{-1} \left(-\tan\phi \tan\delta \right)$$

3.5

The model development approach adopted in this study was consistent with the empirical form reported by [11] amongst others. Thus, several authors have expressed the Angstrom–Prescott regression equation in different forms.

Typical Regression Analysis

The use of regression analysis, help to acquired empirical correlation between daily

$$\frac{\overline{H}}{\overline{H_0}} = a + b \frac{\overline{S}}{\overline{S_0}}$$

3.6

Where, $\overline{H}$ is the monthly average daily global radiation on a horizontal surface (mJm^{-2} day^{-1}),

$\overline{H_0}$ is the monthly average daily extra-terrestrial radiation on a horizontal surface (mJm^{-2} day^{-1}),

$\overline{S}$ is the monthly average daily number of hour of bright sunshine,

3.3) can deduce the monthly mean daily extra-terrestrial irradiation $\overline{H_O}$ and monthly mean day length $\overline{N}$.

sunshine hours and the global solar radiation was obtained.

The angstrom-type regression equation, relating the monthly average daily global radiation to the average daily sunshine hours, and, which with precision has helped global solar radiation prediction in many areas.

$\overline{S_0}$ is the monthly average daily maximum number of hours of possible sunshine (or day length) and a, b are regression constants to be determined.

In developing the model, the hourly global solar radiation, which were obtained using Gun Bellani distillate were converted and standardized, using the conversion factor calculated from equation 3.7

$H = (1.35 \pm 0.176)\, H_{GB}$ 3.7

where: H is the hourly global solar radiation in mJ/m² H_{GB} though not applicable below, is Gun-Bellani distillate. Adopting the

$$H_\sigma = \frac{24 \times 3.6 \times 10^{-3} \times Isc}{\pi}\left[1 + 0.033\cos\left(360\frac{\overline{D}}{365}\right)\right]$$ 3.8

$\cos\phi\,\cos\delta\,\sin w + w\sin\phi\,\sin\delta$

Where:

$ISC = 1367\ Wm^{-2}$ is the solar constant,

ϕ is the latitude of the location,

$\overline{D}$ is the Julian day number,

δ is the declination angle.

The declination angle is given by

$$\delta = 23.45\sin\left(360\frac{(248+D)}{365}\right)$$ 3.9

The maximum possible sunshine duration or number of hour of insolation, $\overline{S_0}$ is given by

$$\overline{S}_0 = \left(\frac{2}{15}\right)\omega$$ 3.10

where, ω is the sunset hour angle for typical day (D) of each month, obtained from equation 3.11

$$\omega = \cos^{-1}\left(-\tan\phi\,\tan\delta\right)$$ 3.11

In this work, $\overline{H}_0$ and $\overline{S}_0$ were computed for each month by using equation (3.8) and (3.10), respectively. The regression coefficients "a" and "b" in equation (3.6) were calculated from values of $\overline{H}/\overline{H}_0$ and $\overline{S}/\overline{S}_0$.

The values of the monthly average daily global radiation $\overline{H}$ and the average number of hours of sunshine, all for Minna, were obtained from daily measurements

approach reported by [6], [11], equation 3.8 has helped to analyse on a horizontal surface, extra-terrestrial solar radiation.

covering a period of 20 years (1990 – 2010) from Nigerian Meteorological Agency, Abuja, Nigeria.

The method of least square was used to obtain the constants "a" and "b" as follows.

$$a = \frac{\sum\frac{\overline{H}}{\overline{H}_0}\sum\left(\frac{\overline{S}}{\overline{S}_0}\right)^2 - \sum\frac{\overline{S}}{\overline{S}_0}\sum\frac{\overline{S}}{\overline{S}_0}\frac{\overline{H}}{\overline{H}_0}}{M\sum\left(\frac{\overline{S}}{\overline{S}_0}\right)^2 - \left(\sum\frac{\overline{S}}{\overline{S}_0}\right)^2}$$ 3.12

$$b = \frac{M \sum \frac{\overline{S}}{S_0} \frac{\overline{H}}{H_0} - \sum \frac{\overline{S}}{S_0} \sum \frac{\overline{H}}{H_0}}{M \sum \left(\frac{\overline{S}}{S_0}\right)^2 - \left(\sum \frac{\overline{S}}{S_0}\right)^2}$$

3.13

Where, M is the number of data points [14].

Root Mean Square Error (RMSE)

One of vital indicators that is statistically employed is Root Mean Square Error (RMSE) for predictions of compared solar radiation models. RMSE of little value are desired, but can generate a substantial increase in the indicator due to little error in the total. Large RMSE values are possible just as a small MBE or vice versa. Equation 3.15 was used to estimate Root Mean Square Error (RMSE)

$$RMSE(\%) = 100 \left(\frac{1}{H_m}\right)\left(\sum \frac{E_i}{M}\right)^{0.5}$$

3.14

Table 1: Derived Monthly Average Solar Radiation Data from Angstrom type equation for Minna (1990-2010)

MONTH	$\overline{S}$ (hr)	$\overline{S_0}$ (hr)	$\frac{\overline{S}}{S_0}$	$\overline{H}$ (MJm⁻²day⁻¹)	$\overline{H_0}$ (MJm⁻²day⁻¹)	$\frac{\overline{H}}{H_0}$	$\overline{T}_{max}$(°C)	$\overline{T}_{min}$(°C)	$\overline{T}_{av}$ (°C)	$\frac{\overline{T}_{min}}{\overline{T}_{max}}$
JAN.	3.8727	11.4439	0.3384	21.8272	16.8255	1.2973	35.0399	20.5733	27.8066	1.7032
FEB.	4.2318	11.5387	0.3667	22.9727	15.9854	1.4371	37.0733	23.2684	30.1709	1.5933
MAR.	3.2500	11.7612	0.2763	23.1272	14.7126	1.5719	38.2657	25.3171	31.7914	1.5115
APR.	2.9273	12.0272	0.2434	21.7954	13.4101	1.6253	36.5664	25.2400	30.9032	1.4487
MAY	4.0864	12.0124	0.3402	19.7000	12.1293	1.6242	33.4588	23.7394	28.5991	1.4094
JUNE	3.4182	12.4873	0.2737	18.1818	12.4354	1.4621	31.0938	22.3752	26.7345	1.3897
JULY	2.6000	12.5573	0.2071	17.0181	12.9539	1.3137	29.3749	21.9953	25.6851	1.3355
AUG.	2.2727	12.4528	0.1825	16.9955	13.9107	1.2218	29.1567	21.8001	25.4784	1.3375
SEP.	3.2591	12.2346	0.2664	18.7181	15.1903	1.2322	30.0791	21.5226	25.8009	1.3976
OCT.	4.9273	11.9592	0.4120	19.6000	16.5412	1.1849	31.5659	21.6849	26.6254	1.4557
NOV.	4.6273	11.6999	0.3955	22.7500	17.3344	1.3124	35.0692	19.8918	27.4774	1.7627
DEC.	4.2182	11.5010	0.3668	22.3455	17.3736	1.2862	35.0592	19.2424	27.1508	1.8219

RESULTS AND DISCUSSIONS

Processed Meteorological and Global Solar radiation Data

The calculated averages of the monthly mean daily sunshine duration (hours), day length $\overline{S_0}$ (hours), fraction of sunshine hours $\frac{\overline{S}}{S_0}$, global solar radiation $\overline{H}$ (mJm⁻²day⁻¹), extraterrestrial global radiation $\overline{H_0}$ (mJm⁻²day⁻¹), and clearness index $\frac{\overline{H}}{H_0}$ over the range of 20 years (2000 – 2010) for Minna (latitude, longitude at altitude above sea level was obtained), North-Central, Nigeria is presented in a tabula form.

Average values determined for the clearness index $\frac{\overline{H}}{H_0}$, maximum daily temperature $\overline{T}$

max (°C), minimum daily temperature $\overline{T}$ min(°C), average daily temperature $\overline{T}$ av(°C), ratio of minimum to maximum daily temperature $\dfrac{\overline{T}_{min}}{\overline{T}_{max}}$., and relative humidity $\overline{RH}$ (%) over the range of 20 years (1990 – 2010) for Minna (latitude, longitude at altitude above sea level to be obtained) is presented in tabular form.

For Table 1, It should be noted and observed that there is a drop in radiation in both the measured and calculated monthly solar radiation after the month of march, as Minna average solar radiation experience "a change" in both measured and calculated hours of sunshine. Though the difference between measured and calculated radiation ranges at 6 – 11 Mjm⁻²day⁻¹, the maximum was experience at the month of March with high heat energy and a "uniform sharp rise" beginning from the month of September downwards which gives room to more energy efficiency in Minna at this particular times of the year. As presented in Table 1, sunshine hours S(hr) in Minna peaked at February, May and October. Whereas, poor radiations

occurred in the months of July and August which gives room to poor availability and storage of energy. Insufficient available stored energy will also not give room to optimum performance of the PV Systems.

As observed in Table 1, that values of minimum sunshine hours (daily monthly mean) and the global radiation (monthly mean daily) on a surface horizontally, for Minna are 2.2727 hours and 16.9955MJm⁻²day⁻¹ respectively. These minimum values occur in the month of August. Similarly, these values are characteristic of a Northern Nigeria climatic condition. In tropical and Sahara climate, August is a month characterized by heavy rainfall.

Two types of global solar radiation were observed from the result, as revealed in Table 1, There were irradiation values at a high value in the dry season connected with sunshine hours of long duration (usually above 4 hours/day) and cloudy skies. Secondly, there were low irradiation values in the rainy season. This is the time when the clouds bearing rain normally pervade the sky. Such periods are connected sunshine hour at lowest level.
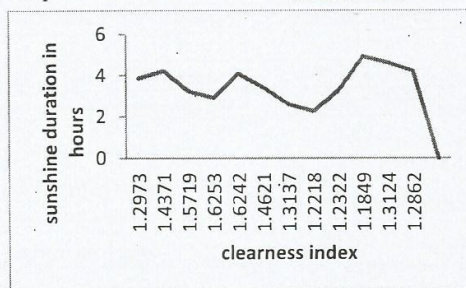

Figure 1 Diagram showing variation of Clearness Index with Sunshine Hours for Minna (1990-2010)

Sunshine duration hours is determined by how much clearness index, which also in turn lies between the solar radiation parameters. From the literatures, it's worthy of note that radiation from solar

flux magnitude is above the threshold value of 210Wm⁻² when insolation instrument records bright sunshine hours. Hence, about the month of October, a very huge sunshine hour

(mean daily) is recorded due to the high clearness index as seen in Table 1.

REGRESSION ANALYSIS

Correlation between Sunshine Hours and Global Solar Radiation

$$\frac{\overline{H}}{H_0} = -1.0243 + 4.2538\frac{\overline{S}}{S_0} \qquad 4.1$$

Values of correlation coefficients **a** and **b** are

-1.0243 and 4.2538 respectively with r^2 value of 0.874. Relationship between clearness index $\dfrac{\overline{H}}{H_0}$ and relative sunshine duration $\dfrac{\overline{S}}{S_0}$, for Minna (1990-2010) is presented in Figure 2

Analysis from the statistical regression, generate empirical correlation from equation 4.1 which was adequate and fit the radiation data processed in Table 1 for the global solar radiation and sunshine hours correlation.
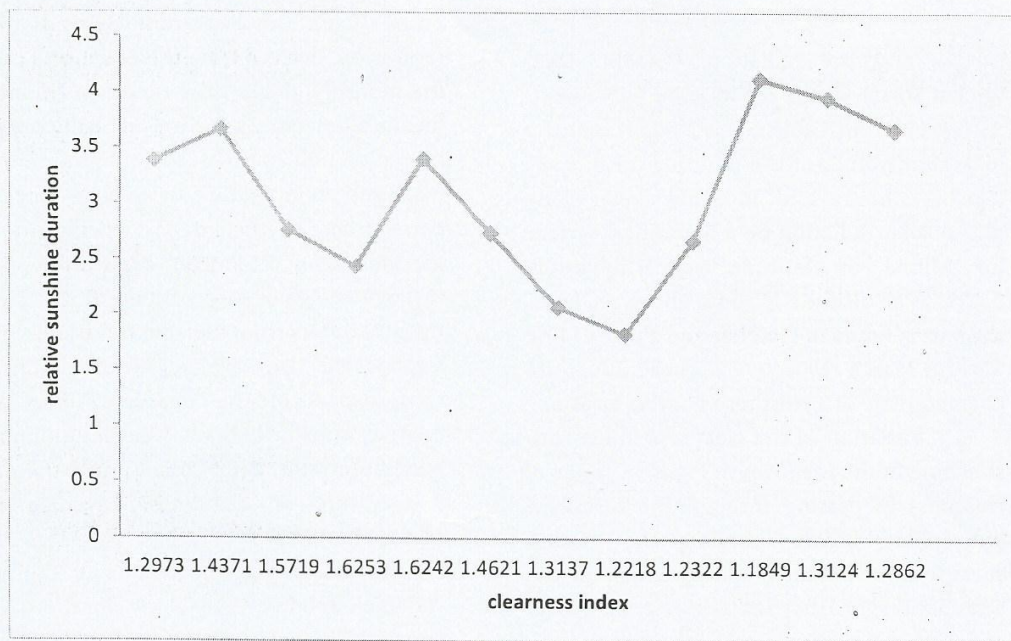

Figure 2 Relationship between Clearness Index and Relative Sunshine Duration for Minna (1990-2010)

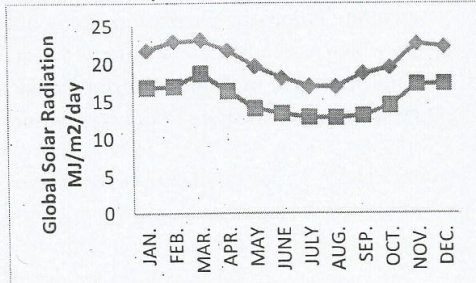*Correlation between Clearness Index and Monthly Average Daily Temperature*

Figure 2 Comparison between Measured and Calculated Monthly Global Solar Radiation for Minna (1990-2010)

Figure 3 Relationship between Clearness Index and Monthly Average Daily Temperature for Minna (1990-2010)

Figure 4 shows the comparison of the calculated averages of sunshine duration $\overline{S}$ (hours) of monthly mean day using Angstrom model, and the radiation $\overline{H}$ (MJm⁻²day⁻¹) (global solar) which are in good agreement. As presented in Table 1, it is evident that the maximum values of the monthly mean daily sunshine hours and monthly mean daily global solar radiation on a horizontal surface for Minna on latitude 9.56°N/longitude 6.56°E at an altitude of 306m above sea level, are 4.9273 hours in October and 23.1272 MJm⁻²day⁻¹ in March respectively. These values are characteristic of a Northern Nigeria location.

Variation of the clearness index with sunshine hours is shown in Figure 1. Index of clearness in passing through the turbulent atmosphere before reaching the ground surface is an obtained measurement of the attenuation of the extra-terrestrial global radiation. From several reports in the literature, there is a general consensus that the smaller the value of the clearness index, the greater the reduction in the magnitude of

$$\frac{\overline{H}}{H_0} = -1.0243 + 4.2538 \frac{\overline{S}}{S_0}$$

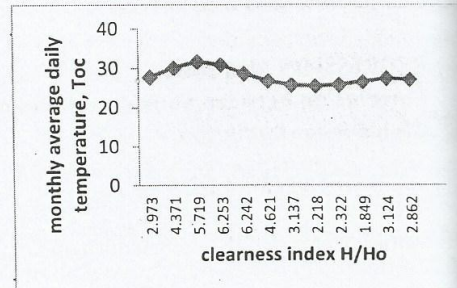This relationship is evident from Figure 2.

the extra-terrestrial global solar radiation. From Table 1, the different analyses of linear regression, derived from the equation (4.1) to the monthly global solar radiation (monthly mean value), daily temperature, daily relative humidity and ratio of daily minimum to maximum temperature, it is clear that the correlation coefficient r, coefficient of determination R^2, Mean Bias Error, MBE (MJm⁻²) and Root Mean Square Error, RMSE (MJm⁻²) differs from variable to variable. This implies that, there are statistically significant relationships of the clearness index and relative sunshine hour, the minimum to maximum ratio, daily temperature, the daily temperature at a monthly average and relative humidity.

Considering the results of the 'one variable' relative sunshine duration and clearness index correlation, the correlation coefficient will be recorded with the use of relative sunshine duration through an empirical relationship of:

A critical observation of the constants of regression, $a = -1.0243$ and $b = 4.2538$, shows nearness agreement with the recorded average from the tropics, which are (a = -1 and b = 4). Due to the peculiarity of the solar radiation in Minna, the values obtained in the tropic regions vary as shown in many literatures today.

The atmosphere transmissivity for solar radiation globally, under a perfect clear sky situation has been interpreted through the total coefficients of the regression $(a + b)$. This shows that the solar radiation transmissivity under a perfect clear sky situation for Minna is the total coefficients of regression, $(a + b) = (-1.0243 + 4.2538)$, which is 3.2295. The equation was therefore employed the monthly mean daily global solar radiation prediction on a surface horizontally, from hours of sunshine measured for Minna. The values obtained, indicates that there is a variety of the measured monthly mean daily fraction of sunshine hours $\dfrac{\overline{S}}{\overline{S_0}}$ and the monthly mean daily clearness index $\dfrac{\overline{H}}{\overline{H_0}}$ correlation, thus, the global solar radiation (monthly mean daily) on a horizontal surface at Minna, North-Central Nigeria.

In addition to the clearness index and relative sunshine duration correlation, relationship between clearness index and other meteorological parameters such as monthly daily temperature average, humidity, and minimum to maximum monthly daily temperature average ratio, were similarly investigated.

To achieve this, the precision of individual model employed in the global solar radiation estimate was verified by finding MBE (the mean bias errors) and RMSE (the root mean square error). It has been noted that the lower the RMSE, the more accurate the equation used. Positive MBE produced over estimation and a negative MBE produced under estimation. Several authors recommend that a nil mark for MBE is ideal and down RMSE is desired.

CONCLUSION

Sunshine duration data and global solar radiation carried out through linear regression analysis by means of the least-squares technique gave an Angstrom-type radiation model suitable for estimating monthly average daily global irradiation incident on horizontal surfaces in Minna (latitude, longitude to be obtained), North-Central, Nigeria. The empirical correlation equation obtained as stated in the previous chapters 3 and 4, where regression constants "a" and "b" were found to be -1.0243 and $+ 4.2538$.

The maximum and minimum values of the global solar radiation were found to be $MJm^{-2}day^{-1}$ and $MJm^{-2}day^{-1}$ respectively, occurring in significant Month respectively. Good agreement between measured values and values predicted by the developed correlation, the percentage error between the measured and predicted values ranged, which makes the correlation useful in estimating global solar radiation in the climatic zone like Minna.

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