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Predicting The Global Solar Radiation In Ikwo Using Insolation-Sunshine Correlation

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--***ABSTRACT***--

Knowledge of the global solar radiation received at a particular location on the earth's surface is of utmost importance in order to design and evaluate the performance of any device using solar energy at that location. In this paper the data from the measurements and recordings of the number of sunshine hours in a day undertaken by the Nigerian Meteorological Agency (South East Zone) were analyzed using pertinent equations to predict the monthly mean daily global solar radiation in Ikwo, Nigeria (Latitude 6.18 ^{0}N, Longitude 8.13 ^{0}E). The results show that the monthly mean daily sunshine hours range from a minimum of 2.73 hours to a maximum of 7.85 hours while the predicted monthly mean daily global solar radiation on a horizontal surface range from a minimum of 14.30MJm^{-2}day^{-1} to a maximum of 22.57MJm^{-2}day^{-1}.

KEYWORDS: *monthly mean daily sunshine hours, monthly mean daily global solar radiation*

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I. INTRODUCTION

The importance of electricity for economic growth and national development cannot be overemphasized. The main sources of fuel for electricity generation as of now are nonrenewable. The use of these conventional fuels leads to environmental degradation. It is therefore pertinent to foster renewable energy sources to make the environment eco-friendly [1]. Solar radiation can provide the much needed renewable energy to energy-deficient third world countries like Nigeria which has abundant untapped solar influx [2]

Solar radiation received at a particular location on the earth's surface depends on two main factors namely the extraterrestrial solar irradiance and the state of the atmosphere. The extraterrestrial solar irradiance is the rate at which solar energy arrives on a horizontal surface at the top of the atmosphere. It varies according to the latitude of the location, the distance of the Earth form the Sun and the time of the year. On any particular day, it varies from zero at sunrise to a maximum at noon and back to zero at sunset [3].

When solar radiation enters the atmosphere a part of the incident energy is removed through the processes of scattering, absorption and reflection. The scattering of solar radiation is mainly by atmospheric molecules and aerosols. The absorption of solar radiation is mainly by ozone (O_3), water vapour (H_2O), oxygen (O_2), carbon (IV) oxide (CO_2) as well as clouds.

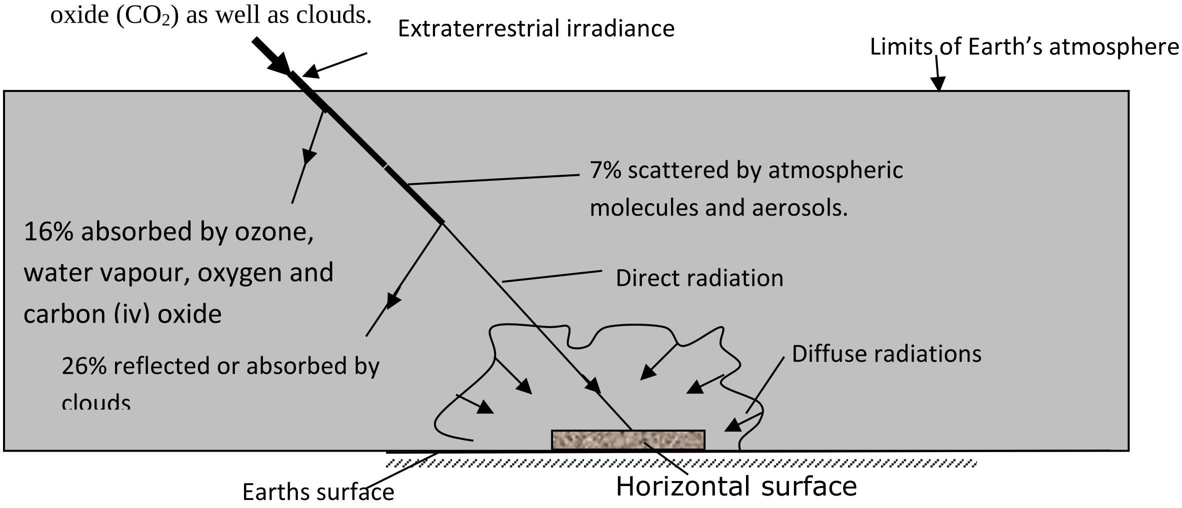

Fig 1: Fate of solar radiation in the atmosphere

The reflection of solar radiation is mainly by the clouds and this plays an overriding part in reducing the energy density of the solar radiation reaching the surface of the earth [4]. The fate of solar radiation in the earth's atmosphere is shown in figure Fig. 1 [5]

The radiation arriving on the ground directly in line with the solar disc is called direct or beam radiation. A portion of the scattered and multiply 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[6].

Global radiation can be measured by means of an instrument called a pyranometer which measures all the radiation incident on it within a solid angle of 2π. Such an instrument is not available at all sites where solar energy conversion devices are located due to high cost and in places where they are available periodic breakdown due to lack of maintenance is a vey big problem[2]

It is therefore necessary to predict solar radiation levels using other meteorological data that are available. There are about 100 formulas for estimating the surface insolation. They are basically categorized according to time scale which are hourly, daily and weekly. Since 1980's satellite imagery data have been adopted in preference to surface insulation estimation and this method have been checked to have a root mean square error (RMSE) of 10% for monthly values . However for areas where such techniques are unavailable we are left with empirical formulas to use [7].

This situation necessitates the use of other meteorological data such as sunshine hours, air temperature, relative humidity, cloud cover, precipitation, etc, to develop models for predicting solar radiation in sites of interest. A good number of authors have used these meteorological parameters either singly or in combination to predict the monthly mean daily global solar radiation on a horizontal surface for some towns in Nigeria. [8]

Most of the available data points to the fact that the greatest influence on solar radiation data at a site of interest is exerted by the number of hours of sunshine during a day, and it is a very useful indicator of the amount of solar radiation arriving at that site. [9].

This work is designed to predict the annual variation of the mean daily global solar radiation at Ikwo using insolation - sunshine correlation. The data analyzed were from the daily number of sunshine hours recorded by the Nigerian Meteorological Agency (South East Zone).

II. THEORETICAL CONSIDERATIONS

On the long-term basis, the monthly mean daily global radiation on a horizontal surface,,is related to the monthly mean daily sunshine hours, (that is the sum of sunshine hours in the month divided by the number of days in the month) by the formula [10]

$$\frac{\bar{H}}{\bar{H}_o} = \left(0.29\cos\phi + 0.52\frac{\bar{S}}{\bar{L}}\right) \quad (1)$$

where $\bar{H}_0$ is the extraterrestrial monthly mean daily radiation on a horizontal surface, ϕ is the latitude of the location and $\bar{L}$ is the monthly mean day length.

The extraterrestrial monthly mean daily radiation on a horizontal surface is given by [10]

$$\bar{H}_o = \frac{1}{N_1 - N_2 + 1}\sum_{N_1}^{N_2} H_o \quad (2)$$

where H_o is the extraterrestrial irradiation during the day from sunrise to sunset on a horizontal surface, N_1 is the day number at the beginning of the month and N_2 is the day number at the end of the month.

The value of H_o at any place and for any day of the month is given by [11]

$$H_o = \left(24/\pi\right) I_{sc} E_o \cos\phi\cos\delta\sin\omega_s + \left(24/180\right) I_{sc} E_o \omega_s \sin\phi\sin\delta \quad (3)$$

where I_{sc} is the solar constant in $MJm^{-2}\,h^{-1}$, E_o is the eccentricity correction factor of the Earths orbit, ϕ is the latitude of the location, δ , is the solar declination and ω_s is the sunrise hour angle in degrees.

The value of the solar constant in $MJm^{-2}\,h^{-1}$ used in this work is given by [10]

$$I_{sc} = \frac{1670\text{x}3600}{1000000} \quad (4)$$

The eccentricity correction factor, E_0 on any day of the month is given by [12]

$$E_o = 1 + 0.033\cos\left(360N/365\right) \quad (5)$$

where N is the day number.

The sunrise hour angle in degrees, ω_s , at any place and in any day of the month is given by [13]

$$\omega_s = \cos^{-1}\left(-\tan\phi \tan\delta\right) \tag{6}$$

For a given month the mean day length, $\bar{L}$, is given by [10]

$$\bar{L} = \frac{1}{N_1 - N_2 + 1}\sum_{N_1}^{N_2} L \tag{7}$$

where N_1 is the day number at the beginning of the month, N_2 is the day number at the end of the month and L is the length of each day of the month that is the number of hours from sunrise to sunset.
The day length of any given day of the month at any place is given by [13]

$$L = \left(2/15\right)\cos^{-1}\left(-\tan\phi \tan\delta\right) \tag{8}$$

where ϕ is the latitude of the location and δ is the solar declination, that is the angular position of the Sun at solar noon with respect to the plane of the equator.
The solar declination on any day in degrees is given by [14]

$$\delta = 23.45\sin\left[360\left(N + 284\right)/365\right] \tag{9}$$

where N is the day number of the year ranging from N=1 on 1^{st} January to N=365 on 31^{st} December.

III. DATA COLLECTION AND ANALYSIS

The number of bright sunshine hours during the day was measured and recorded every day by the Nigerian Meteorological Agency for the period from January 1996 to date.

The instrument used in the sunshine duration measurement is the Campbell-Stokes sunshine recorder. The device consists of a solid quartz glass sphere, typically about 10 cm in diameter mounted on top of a 2.20 m stand. As sunlight passes through the sphere, it becomes focused and burns a line through a piece of a treated and calibrated paper which is positioned beneath the quartz glass sphere. [12]. As the sun blazes across the sky, the hot image of the sun traces a scorching path on the paper. The intensity and the position of the burn indicates the time and the strength of the sunshine [16].

This sunshine recorder requires manual intervention and skilled interpretation [17]. The major advantage of the device is its simplicity and ease of use. There are no moving parts and it thus requires very little maintenance. The unit can be used anywhere in the world with little or no modification to the design [18].

The following steps were taken to analyze the data collected. Firstly, the average number of hours for each month of the period covered was obtained by dividing the total number of hours for the month by the number of days in the month. Secondly, the monthly mean daily sunshine hours, , was obtained for each month by adding the monthly values and dividing by the number of years involved.

After this, the monthly mean day length, $\bar{L}$, was calculated for each month of the year using equations (9), (8) and (7). Next, the extraterrestrial monthly mean daily radiation on a horizontal surface, $\bar{H}_0$, was calculated using equations (9), (6), (5), (4) (3) and (2). Finally, the monthly mean daily global solar radiation on a horizontal surface, $\bar{H}$, was calculated using equation (1).

IV. RESULTS AND DISCUSSION

Table 1 shows the calculated values of the monthly mean daily bright sunshine hours, $\bar{\mathbf{S}}$, the monthly mean day length, $\bar{\mathbf{L}}$, the extraterrestrial monthly mean daily radiation on a horizontal surface, $\bar{\mathbf{H}}_\mathbf{0}$, and the monthly mean daily global solar radiation on a horizontal surface, $\bar{H}$.

A careful examination of table 1 shows that the maximum values of the monthly mean daily sunshine hours and the monthly mean daily global radiation on a horizontal surface are 7.85 hours and 22.57 MJ m^{-2} day^{-1} respectively and they occur in the month of December. This value is within what is expected of a tropical site [4], [19] .

Another point worthy of note is that the minimum values of the monthly mean daily sunshine hours and the monthly mean daily global radiation on a horizontal surface are 2.73 hours and 14.30 $MJm^{-2}day^{-1}$ respectively and they occur in the month of August. Again this value is within what is expected of a tropical site [4], [19] . The month they occur is also well expected. This is the month that is characterized by heavy rainfalls. In fact from the daily records it is in August that we have the greatest number of days with zero sunshine hours during the period being considered. It is pertinent to also state here that from the records of temperature made during the same period August has the lowest monthly mean daily average temperature of 27.10°C.

Table 1

ANNUAL VARIATION OF MONTHLY MEAN DAILY VALUES

Month	$\bar{S}$ (h)	$\bar{L}$ (h)	**$\bar{H}_0$ (MJm^{-2} day^{-1})**	**$\bar{H}$ (MJm^{-2} day^{-1})**
JAN	6.95	11.58	35.82	21.47
FEB	6.67	11.74	37.01	21.56
MAR	5.59	11.95	37.54	19.91
APR	6.52	12.18	36.44	20.61
MAY	6.58	12.37	34.41	19.40
JUN	5.33	12.46	33.15	16.89
JUL	4.04	12.40	34.85	15.91
AUG	**2.73**	12.24	35.47	**14.30**
SEP	4.22	12.02	36.95	17.36
OCT	5.70	11.79	37.73	20.32
NOV	7.37	11.61	35.83	22.12
DEC	**7.85**	11.54	35.22	**22.57**

From the records presented in table 1 the average values of the monthly mean daily sunshine hours and the monthly mean daily global radiation on a horizontal surface are 6.19 hours and 19.34 MJ m^{-2} day^{-1} which are consistent with values obtained where direct measurement of global radiation are carried out [4], [19].

Fig. 2 shows the annual variation of the clearness factor or index, . It a measure of the attenuation of the extraterrestrial global radiation in passing through the turbulent atmosphere before reaching the ground surface and defined mathematically as the ratio of the monthly mean daily global radiation on a horizontal surface to the extraterrestrial monthly mean daily radiation on a horizontal surface or . The smaller the value the greater the reduction magnitude of the extraterrestrial global radiation. Maximum attenuation occurs in August and minimum in December.

To further substantiate the reliability and validity of the predicted results, fig. 3 is presented to compare the predicted values of the monthly mean daily global radiation on a horizontal surface for Ikwo (Latitude 6.18^0 N) and measured values for Enugu (Latitude 6.44^0 N).

Since Ikwo is slightly closer the equator than Enugu, it is expected that the values of the monthly mean daily global radiation on a horizontal surface for Ikwo and that for Enugu should follow the same trend month wise with values for Ikwo greater than those for Enugu. This what the graph clearly depicts.

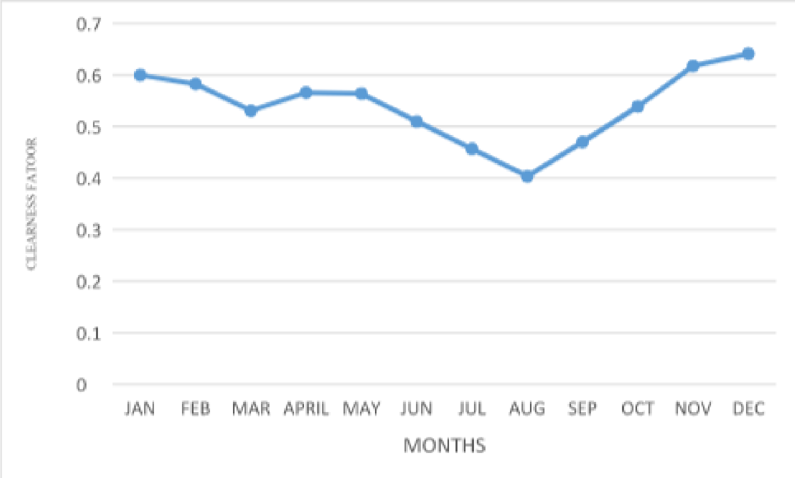

Fig. 2 : Annual variation of the clearness factor

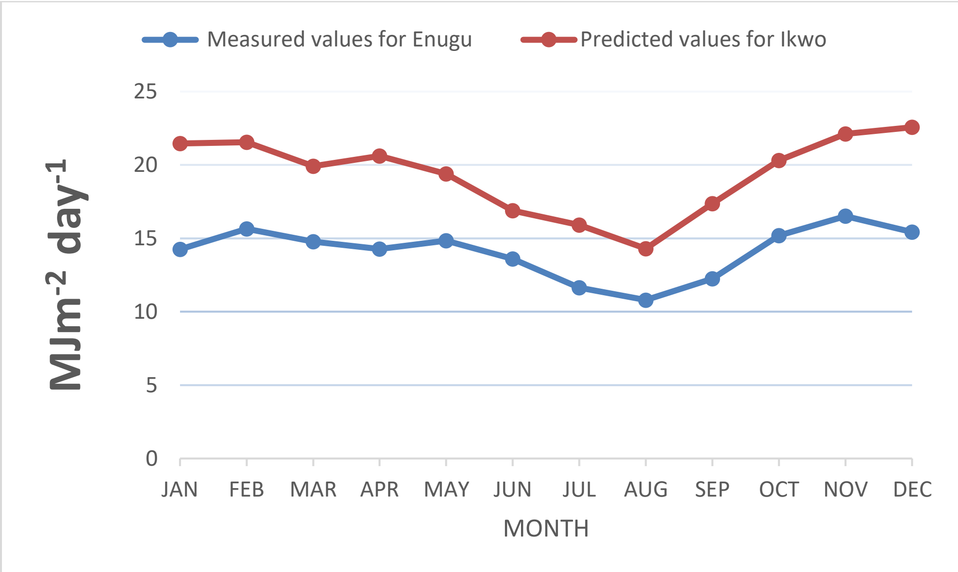

Fig. 3: Comparson of the predicted values of the monthly mean daily global radiation on a horizontal surface for Ikwo and the measured values for Enugu

V. CONCLUSION

Results obtained from daily measurements of the number of sunshine hours and calculations using equations (1) to (9) show that the maximum value of monthly mean daily global radiation on a horizontal surface was 22.57 MJ m^{-2} day^{-1} and it occurred in December while the minimum value was 14.30 MJ m^{-2} day^{-1} and it occurred in August. These results were found to be consistent with measured values at similar tropical sites.

In view of the above, we can conclude that it is quite possible to estimate and predict the monthly mean daily global radiation on a horizontal surface using the more easily set up measurement of sunshine hours per day.

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