EMPIRICAL MODEL FOR THE CORRELATION OF GLOBAL SOLAR RADIATION IN MAIDUGURI, NIGERIA

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ABSTRACT

This paper proposes the coefficient equation for Angstrom-Prescott type of model for the correlation of global solar radiation in Maiduguri, Nigeria using relative sunshine hour. The model regression coefficient a and b obtained are 0.288 and 0.547 respectively. The maximum and minimum values of monthly mean global solar radiation are 24.80$MJm^{-2}day^{-1}$ and 16.80$MJm^{-2}day^{-1}$ respectively. Forecasting performance parameters such as coefficient of determination R^2 = 0.998, Root Mean Square Error = 0.488, Mean Bias Error = 0.141 and Mean Percentage Error = - 0.654 are presented as analyzed for the model. The solar energy can be utilized effectively throughout the year. The model could be employed in correlating global solar radiation of locations that has the same geographical location information as Maiduguri.

INTRODUCTION

The utilization of solar energy, like any other natural resources, requires detailed information on availability. The global solar radiation potential is necessary for the designing and predicting the performance of solar energy equipment and solar potential, Sukhera and Pasha (1987). It is known that the higher the altitude the greater the solar radiation under the clear and intermediate sky conditions, but under the overcast days the solar radiation is very low in comparison with the sunny days, Becker and Boyd (1957). The mapping of the solar radiant energy on the earth`s surface is a requirement not only in the studies of climate change, environmental pollution but also in agriculture, hydrology, food industry and non-conventional energy development programs, Iqbal (1983)

Energy is linked with environmental, social and economic dimensions of sustainable development. The demand for energy, the consumption of fossil fuels and pollution level are increasing with an alarming rate worldwide. Looking into the seriousness of the problem, various stakeholders have now become aware of the urgent need for management of resources and energy conversion activities, Genwa and Chouhon (2012).

Among the non-conventional energy resources, solar energy, wind energy and biomass has emerged as most prospective option for the future, Banjade *et al* (2010). In addition that, aggressive consumption rate of fossil fuels has created unacceptable environmental problems such as greenhouse effects, which may lead to disastrous climatic consequences. Thus, renewable and clean energy such as that obtained by using solar cells is required to maintain the quality of human life as well as the environment, Mandalia *et al* (2012)

This paper uses Angstroms Model to correlate global solar radiation in Maiduguri based on the number of sunshine hours, day number and location coordinate. Maiduguri (11.85˚N, 13.16˚E) is located in North-East, Nigeria and its climate is very hot, dry in summer and cold in winter. Also, it receives a large quantity of solar radiation, especially in summer, Hussiani *et al* (2005).

MATERIAL AND METHODS

The monthly mean and daily data of Global solar radiation (wh/m^2) and sunshine hours were obtained from the Nigeria Meteorological Agency (NIMET) department, Maiduguri, North-East, Nigeria.

The first correlation proposed for estimating the monthly mean daily global solar radiation on a horizontal surface H using the sunshine hour data is due to Angstroms, (1924) and Prescott (1940) have put the Angstrom correlation in more convenient form as

$$Hg\ Ho = a + bn\ N \quad (1)$$

Where Hg is the average daily global radiation (MJm^{-2}day^{-1}), Ho is average daily extraterrestrial radiation (MJm^{-2}day^{-1}), n is the day length, N is the maximum possible sunshine hour, and a and b are empirical coefficients.

$$a = -0.110 + 0.235 \cos\phi + 0.323\ (nN) \quad (2)$$

$$b=1.449-0.553\cos\phi-0.694(nN) \quad (3)$$

The daily extraterrestrial radiation Ho was calculated from the following equation.

$$Ho = 24 \times 3600\pi Isc\ [1+0.33\cos 360\ D365]\ [\cos\varphi \cos\delta \sin\omega s + \pi\omega 180\sin\varphi\sin\delta] \quad (4)$$

Where Isc =1367 Wm^{-2} is the solar constant, Frohlich (1986) D is the Julian day number (the day of year from January 1 to December 31), φ is the latitude (rad), δ is the declination angle (rad), ωs is the sunset hour. δ and ω are given from these formulae, Duffie and Beckman (1994).

$$\delta = 23.45 \sin\ (360284+D365) \quad (5)$$

$$\omega s = \cos\text{-}1[-\tan\varphi\ \tan\delta] \quad (6)$$

The maximum possible sunshine hours N was calculated using the following equations Duffie and Beckman (1994).

$$N = 215\omega s \quad (7)$$

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 (%) Frohlich (1986) as follows:

$$MBE = [(Hi,\ cal\text{-}Hi,meas)]n \quad (8)$$

$$RMSE= [(Hi,cal\text{-}Hi,meas)2n]12 \quad (9)$$

$$MPE=[(Hi,meas\text{-}Hi,calHi,meas\times 100\%)]n \quad (10)$$

Where Hi,cal and Hi,meas is the ith calculated (predicted) and measured values and n is the total number of observation.

RESULTS AND DISCUSSION

Table 1 shows the calculated values of measured monthly mean daily sunshine hours n, possible fraction of sunshine nN, global solar radiation on a horizontal surface Hg, extraterrestrial solar radiation on a horizontal surface Ho, as well as clearness index KT .

From the regression analysis the following correlation was found to adequately fit the solar radiation data. The value of regression coefficients, a and b obtained in this research were 0.288 and 0.547 respectively. Hence the first order polynomial equation is

$$Hg\ Ho = 0.288 + 0.547nN \quad (11)$$

Table 1**:** Meteorological Data and Global Solar Radiation for Maiduguri

Month	n (hours)	N (hours)	nN	H_g ($MJm^{-2}day^{-1}$)	Ho ($MJm^{-2}day^{-1}$)	KT=HgHo
Jan	9.5	12.02	0.7905	24.80	37.61	0.6593
Feb	8.9	11.96	0.7442	24.51	37.62	0.6516
Mar	8.9	12.02	0.7403	24.48	37.61	0.6508
Apr	7.2	12.04	0.5982	22.87	37.62	0.6079
May	3.9	11.99	0.3259	16.80	37.62	0.4467
Jun	6.4	11.97	0.5347	21.80	37.61	0.5797
Jul	5.0	12.01	0.4165	19.27	37.62	0.5122
Aug	5.0	12.02	0.4156	19.25	37.61	0.5119
Sep	5.0	12.04	0.4154	19.24	37.62	0.5115
Oct	5.0	12.00	0.4167	19.27	37.61	0.5123
Nov	5.0	11.97	0.4178	19.30	37.62	0.5131
Dec	5.0	12.00	0.4165	19.27	37.61	0.5123

Figures 1 and 2 show that the maximum values of the monthly mean daily sunshine hours and monthly mean daily global solar radiation on a horizontal surface are 9.5 hours and 24.80 $MJm^{-2}day^{-1}$ respectively, and they occur in the month of January. Also the minimum values of the monthly mean daily sunshine hours and monthly mean daily global solar radiation on a horizontal surface are 3.9 hours and 16.80 $MJm^{-2}day^{-1}$ respectively,

The month of occurrence is not expected because of the harmattan season when aerosol mass loading greatly reduces the intensity of solar radiation. There is frequently changing the sunshine hours because of changing the local weather condition. From the month of May to December lie in summer season. In this summer season about 50 to 80% rainfall occur in the study. Hence the sunshine duration is minimum in May whereas the global solar radiation comparatively lower in comparison with other months. The sunshine hours in May is also the lowest due to high frequency rainfall and other climatic factors

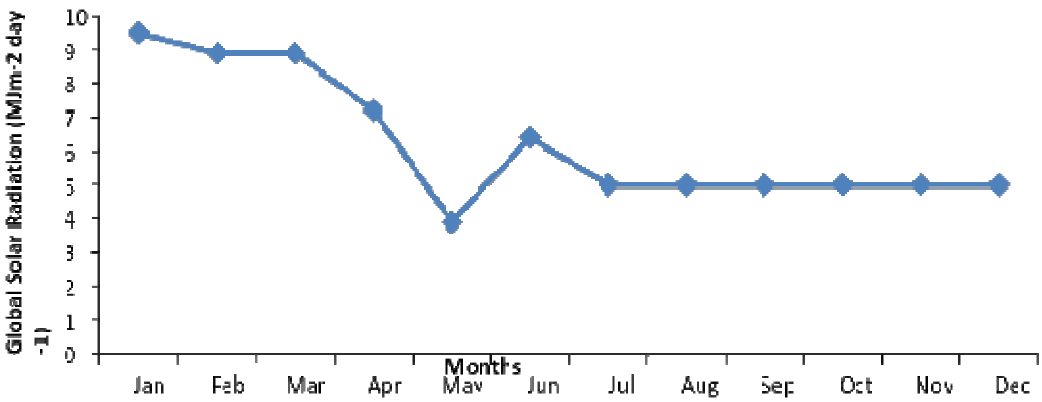

Figure 1: Monthly variation of sunshine hour

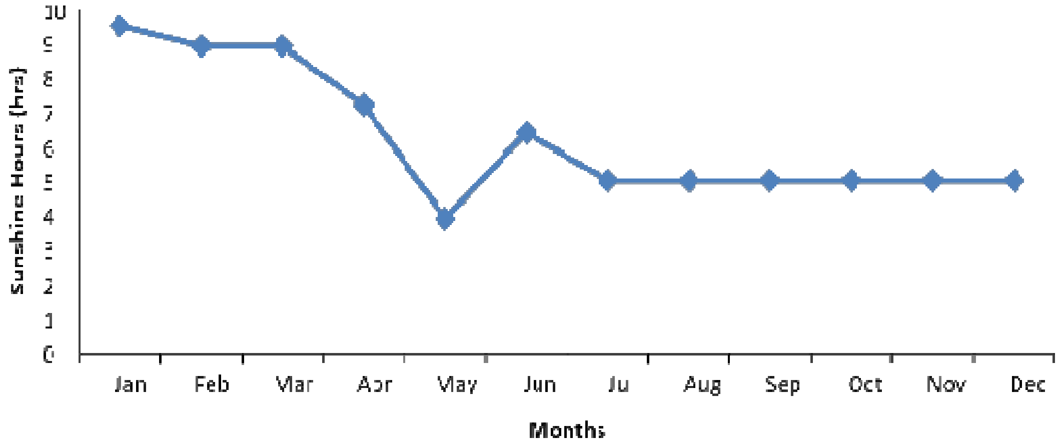

Figure 2: Monthly variation global solar radiation

Figure 3 shows that there is strong agreement in between sunshine hours and measured global solar radiation; it indicates that the sunshine hours vary from season to season due to the rotation of earth. The sunshine hours directly affects the result of global solar radiation. Also it shows that the sunshine duration gradually increases with increase in global solar radiation, after that both sunshine and global solar radiation decreases sharply due to high frequency of rainfall as well as cloudy days in May, June, July, August, September, October, November and December.

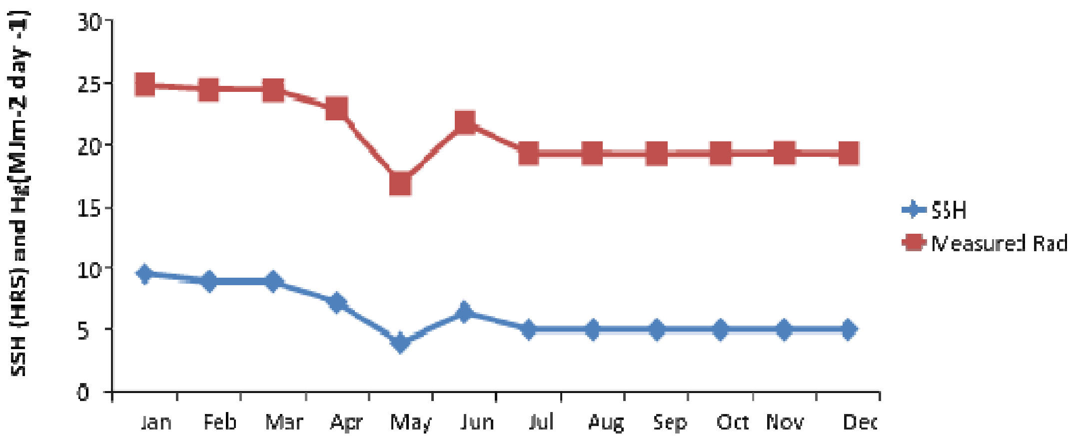

Figure 3: Comparison between monthly mean sunshine hour and monthly mean measured global solar radiation

Figure 4 shows the comparison between clearness index and relative sunshine hours, a measure of the attenuation of the extraterrestrial global solar radiation in passing through the turbulent atmosphere before reaching the ground surface. The smaller the value, the greater the reduction in magnitude of the extraterrestrial global solar radiation. The maximum attenuation occurred in January and the minimum in May.

Figure 5 shows the variation of the measured and calculated (predicted) values of global solar radiation and have a remarkable agreement during the year.

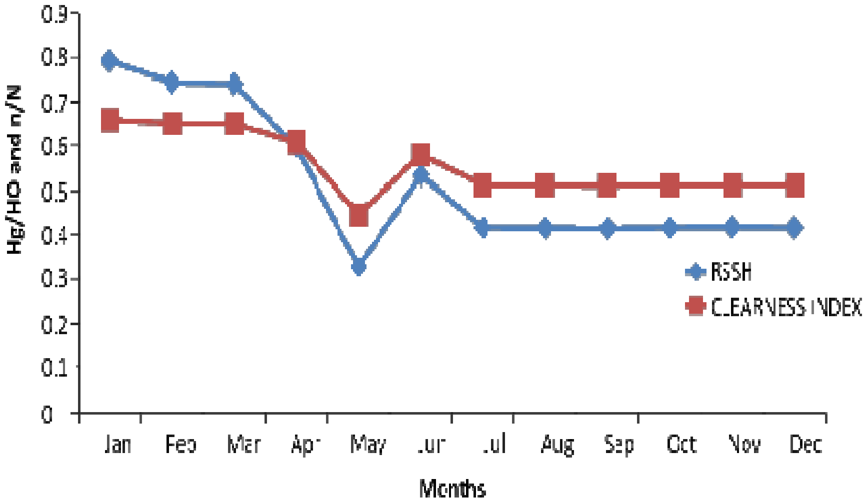

Figure 4: Comparison between Monthly Mean Clearness Index and Relative Sunshine Hour

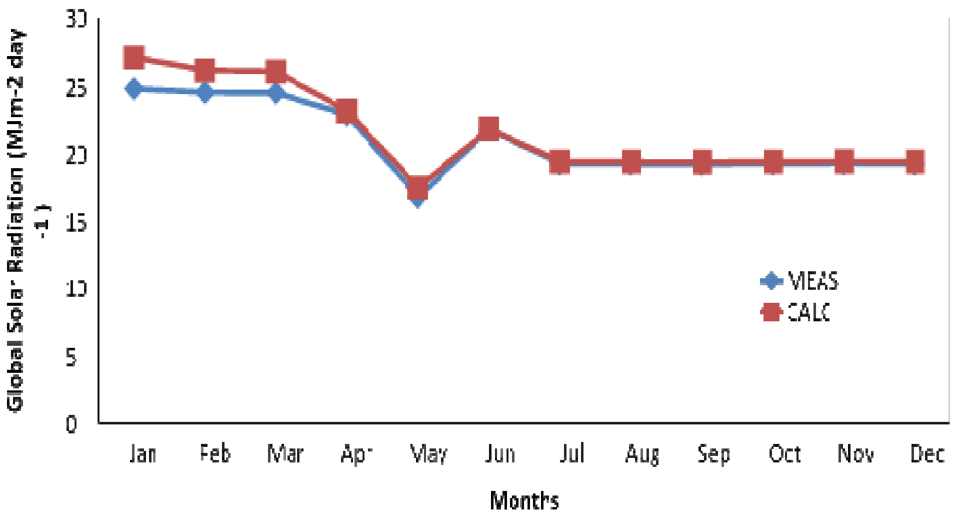

Figure 5: Comparison between measured and calculated Global Solar Radiation

CONCLUSION

The prediction model was developed using monthly mean daily values of clearness index, relative sunshine hour, and measured global solar radiation. The maximum and minimum values of monthly mean global solar radiation are found 24.80MJm^{-2}day^{-1} and16.80MJm^{-2}day^{-1} in January and May respectively. The overall performance of parameters R^2, RMSE, MBE, and MPE are found 0.998, 0.488, 0.141 and- 0.654 respectively. These statistical indices values are meaningful for correlation of global solar radiation on the basis of sunshine hour. It indicates that the correlated values of global solar radiation can be very efficiently used to compensate for the energy deficit. At the end, the model could be employed in correlating global solar radiation in the similar climatic locations.

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