ESTIMATION OF MEAN MONTHLY GLOBAL SOLAR RADIATION FOR MINNA USING SUNSHINE HOURS

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Abstract

The correlation between sunshine hours and global solar radiation described by Angstrom is one of the important models employed in the estimation of global solar radiation where data are lacking. This paper presents the estimation of global solar radiation for Minna, Nigeria (latitude 9.37° N, longitude 6.32° E) using Angrom-Prescott model. Sunshine hours data used as the input parameter were collected from the Nigeria Meteorological Agency (NIMET), Minna. From the result obtained, the highest value of monthly radiation on a horizontal surface within the period of this study was recorded in April as 24.25 $MJm^{-2}day^{-1}$ while the lowest value was recorded in Ju1y as 16.70 $MJm^{-2}day^{-1}$. The mean monthly global radiation on a horizontal surface for Minna during the 2-year period is found to be 20.45 $MJm^{-2}day^{-1}$. This shows that Minna is a viable location for solar energy applications.

Keywords: Global solar radiation, Sunshine hours, Air mass.

Introduction

Almost all the energy on earth comes from the sun. The total solar energy absorbed by the earth's atmosphere, oceans and land masses is approximately 3.85×10^{24} J per year (Wikipedia, 2012). The total power density of the solar radiation at the mean earth-sun distance on a plane perpendicular to the direction of the sun, outside the earth's atmosphere, is referred to as the solar constant. Its value is 1353 Wm^{-2}. This value decreases as the solar radiation traverses the earth's atmosphere.

As the solar radiation passes through the earth's atmosphere, its intensity and wavelength bands are affected by the atmospheric constituent such as water vapour, ozone, carbon dioxide, and other aerosols. Attenuation of solar radiation is due to the following phenomena:
(i) absorption of infrared radiation by water vapour and absorption of UV wavelengths by ozone,
(ii) scattering by dust and aerosols, and
(iii) reflection/absorption by clouds.

The path-length of the sun's radiation through the atmosphere also affects the intensity of the solar radiation received at the earth's surface. The ratio of the actual length of the light path through the atmosphere to the minimum path length when the sun is directly overhead is known as the **optical air mass**. When the sun is directly overhead, the optical air mass is unity and the radiation is described as air mass one (AM1) radiation. Radiation outside the earth's atmosphere is described as AM0 radiation. As the air mass increases, the solar irradiance decreases.

According to Ezeilo (1983), the availability of solar radiation on the earth's surface varies with latitude and geographical location. The regions lying between 15° and 35° latitude north and south, respectively, seem to be most favourably located. They have relatively little rains and clouds such that over 90% of the incident sunshine is direct radiation and the yearly sunshine hour is usually over 3000 hours. The next most favourable region is the equatorial belt from 15°N to 15°S which receives about 2300 hours of sunshine per year with very little seasonal variation. The high humidity and frequent clouds in this belt generally result in a high proportion of solar radiation taking the form of scattered radiation. On the average, the intensity of radiation received at the earth's surface decreases from the equator to either pole. The intensity is highest at the equator where the latitude $= 0^{0}$, and least at the poles where $= 90^{0}$.

Two other factors influencing the availability of solar energy are geometric in nature. The earth rotates on its axis with a period of approximately 24 hours; hence sunlight is available for only an average of 12 hours a day. Next the earth's axis of rotation is tilted approximately 23.5^{0} to the normal of its plane of revolution about the sun. Together, these two effects act to produce a shift in the number of hours of daylight and a geometrical situation in which the sun is almost never directly overhead, thereby enhancing light losses due to various atmospheric phenomena (Neville, 1995).

Solar radiation received at the earth's surface can be categorised into two components: direct and diffuse components. The sum of the direct solar radiation and diffuse solar radiation is called **global solar radiation**. Knowledge of the amount of the global solar radiation at a location of interest is required in the design and evaluation of the performance of solar energy devices, hence the need to study solar radiation characteristics in the local environment. However, lack of measuring instruments and techniques involved and poor maintenance culture, especially in developing countries, have led to unavailability of solar radiation data (Agbo, Baba and Obiekezie, 2010; Medugu and Yakubu, 2011) This situation has led to the development of several theoretical models for estimating global solar radiation using available meteorological parameters such as sunshine hours, maximum and minimum temperature e.t.c.

The focus of this work is to use Angrom-Prescott model to estimate global solar radiation in Minna (9.37^{0} N, 6.32^{0} E) using sunshine hours as the input parameter.

Methodology

Data Collection

The sunshine hours data used in this work were obtained from the Nigeria Meteorological Agency (NIMET) at Minna Airport. The data used are for the years 2009 and 2010. The values of the mean daily sunshine hours for each month of the two years, as well as the monthly average for the two-year period were determined.

Analysis

The Angstrom-Prescott model was used to estimate the horizontal global solar radiation for Minna based on the available data of sunshine hours. The monthly average of horizontal global radiation on a horizontal surface is given by Duffie and Beckman (1991) as:

$$\frac{\bar{H}}{\bar{H}_o} = a + b\frac{\bar{S}}{\bar{S}_o}$$

(1)

Where:

$\bar{H}$ = the monthly average daily global radiation on a horizontal surface ($MJm^{-2}day^{-1}$);

$\bar{H}_0$ = the monthly average daily extraterrestrial radiation on a horizontal surface ($MJm^{-2}day^{-1}$);

$\bar{S}$ = the monthly average daily number of hours of bright sunshine;

$\bar{S}_o$ = the monthly average daily maximum number of hours of possible sunshine.

The regression coefficient a and b have been obtained from the relationship given by Tiwari and Saageeta (1997) as:

$$a = -0.110 + 0.235Cos\emptyset + 0.323\left(\frac{\bar{S}}{\bar{S}_o}\right)$$

$$b = 1.449 - 0.553Cos\emptyset - 0.694\left(\frac{\bar{S}}{\bar{S}_o}\right)$$

(2)

where Ø = latitude of the location.

The values of H_o and S_o are calculated using the following relations from Duffie and Beckman (1991) as stated by Medugu and Yakubu (2011):

$$H_O = \frac{24 \times 3600}{\pi} \times I_{SC}\left[1.0 + 0.033\left(\frac{360dn}{365}\right)\right] \times \left[cos\emptyset cos\delta sin\omega_S + \frac{\pi}{180}\omega_S sin\delta sin\emptyset\right]$$

(3)

where:

I_{sc} = the solar constant given as 1367 Wm^{-2}.

Ø = latitude of the location,

δ = declination angle, given as:

$$\delta = 23.45\sin\left[\frac{360}{365}(284 + dn)\right]$$

(4)

dn = day number of the year from January 1 to December 31.

ω_s = sunset hour angle given by:

ω_s = $\cos^{-1}(-\tan\emptyset\tan\delta)$

(5)

$$S_O = \frac{2}{15}\omega_S$$

(6)

Results and Discussion

The monthly means of sunshine hours for each of the two years and the month average for the 2-year period are presented in Table 1.

Table 1: Monthly mean sunshine hours for Minna

Month	Sunshine Hours (2009)	Sunshine Hours (2010)	2009/2010 Average (Hr)
January	7.7	9.2	8.45
February	6.7	9.0	7.85
March	6.4	6.6	6.50
April	7.0	10.1	8.55
May	7.2	6.0	6.60
June	5.0	5.0	5.00
July	5.0	3.3	4.15
August	4.7	3.6	4.15
September	5.7	5.0	5.35
October	7.1	6.7	6.90
November	8.8	9.4	9.10
December	9.6	9.7	9.65

In this work solar radiation for Minna was computed using the Angstom-Prescott model. Equations 1 – 6 are used to estimate the global radiation on horizontal surface at Minna using sunshine hour as the common meteorological parameter. Tables 2a and 2b present the monthly mean values of global solar radiation ($\bar{H}$) and extraterrestrial radiation ($\bar{H}_0$) for 2009 and 2010, while Table 3 presents the average monthly values of global solar radiation ($\bar{H}$) and extraterrestrial radiation ($\bar{H}_0$) for 2009 and 2010.

Table 2a: Monthly mean values of daily solar radiation for Minna in 2009

Month	ω_s (deg)	$\bar{S}$(hr)	$\bar{S}_0$(hr)	$\bar{S}/\bar{S}_0$	a	b	$\bar{H}_0$(MJm^{-2}day^{-1})	$\bar{H}$(MJm^{-2}day^{-1})
Jan	86.32	7.70	11.51	0.67	0.34	0.44	32.14	**20.30**
Feb	87.77	6.70	11.70	0.57	0.31	0.51	34.70	**20.70**
Mar	89.60	6.40	11.95	0.54	0.29	0.53	36.96	**21.44**
Apr	91.63	7.00	12.22	0.57	0.31	0.51	37.88	**22.60**
May	93.26	7.20	12.43	0.58	0.31	0.50	37.37	**22.40**
Jun	94.09	5.00	12.55	0.40	0.25	0.63	36.74	**18.38**
Jul	93.70	5.00	12.49	0.40	0.25	0.63	36.90	**18.50**
Aug	92.26	4.70	12.30	0.38	0.25	0.64	37.44	**18.31**
Sep	90.30	5.70	12.04	0.47	0.27	0.57	37.07	**20.27**
Oct	88.34	7.10	11.78	0.60	0.32	0.49	35.18	**21.42**
Nov	86.67	8.80	11.56	0.76	0.37	0.37	32.61	**21.30**
Dec	85.91	9.60	11.45	0.84	0.39	0.32	31.29	**20.72**

Table 2b: Monthly mean values of daily solar radiation for Minna in 2010

Month	ω_s (deg)	$\bar{S}$(hr)	$\bar{S}_o$(hr)	$\bar{S}/\bar{S}_o$	a	b	$\bar{H}_o$(MJm^{-2}day^{-1})	$\bar{H}$(MJm^{-2}day^{-1})
Jan	86.32	9.20	11.51	0.80	0.38	0.35	32.14	21.17
Feb	87.77	9.00	11.70	0.77	0.37	0.37	34.70	22.71
Mar	89.60	6.60	11.95	0.55	0.30	0.52	36.96	21.73
Apr	91.63	10.10	12.22	0.83	0.39	0.33	37.88	25.06
May	93.26	6.00	12.43	0.48	0.28	0.57	37.37	20.63
Jun	94.09	5.00	12.55	0.40	0.25	0.63	36.74	18.38
Jul	93.70	3.30	12.49	0.26	0.21	0.72	36.90	14.66
Aug	92.26	3.60	12.30	0.29	0.22	0.70	37.44	15.77
Sep	90.30	5.00	12.04	0.42	0.26	0.62	37.07	18.96
Oct	88.34	6.70	11.78	0.57	0.31	0.51	35.18	20.93
Nov	86.67	9.40	11.56	0.81	0.38	0.34	32.61	21.53
Dec	85.91	9.70	11.45	0.85	0.40	0.32	31.29	20.73

Table 3: Monthly average values of daily solar radiation for Minna in 2009 and 2010

Month	ω_s (deg)	$\bar{S}$(hr)	$\bar{S}_o$(hr)	$\bar{S}/\bar{S}_o$	a	b	$\bar{H}_o$(MJm^{-2}day^{-1})	$\bar{H}$(MJm^{-2}day^{-1})
Jan	86.38	8.45	11.52	0.73	0.36	0.39	32.14	**20.83**
Feb	87.77	7.85	11.70	0.67	0.34	0.44	34.70	**21.94**
Mar	89.60	6.50	11.95	0.54	0.30	0.53	36.99	**21.59**
Apr	91.63	8.55	12.22	0.70	0.35	0.42	37.88	**24.25**
May	93.26	6.60	12.43	0.53	0.29	0.54	37.37	**21.58**
Jun	94.09	5.00	12.55	0.40	0.25	0.63	36.74	**18.38**
Jul	93.70	4.15	12.49	0.33	0.23	0.67	36.90	**16.70**
Aug	92.26	4.15	12.30	0.34	0.23	0.67	37.44	**17.10**
Sep	90.30	5.35	12.04	0.44	0.27	0.59	37.07	**19.64**
Oct	88.35	6.90	11.78	0.59	0.31	0.50	35.18	**21.18**
Nov	86.67	9.10	11.56	0.79	0.38	0.36	32.61	**21.43**
Dec	85.91	9.65	11.45	0.84	0.39	0.32	31.29	**20.73**
							Average =	**20.45**

Computed $\bar{H}$ values shown in Tables 2 and 3 are plotted along with $\bar{s}$ values shown in Table 1, as shown in Figures 1 and 2.

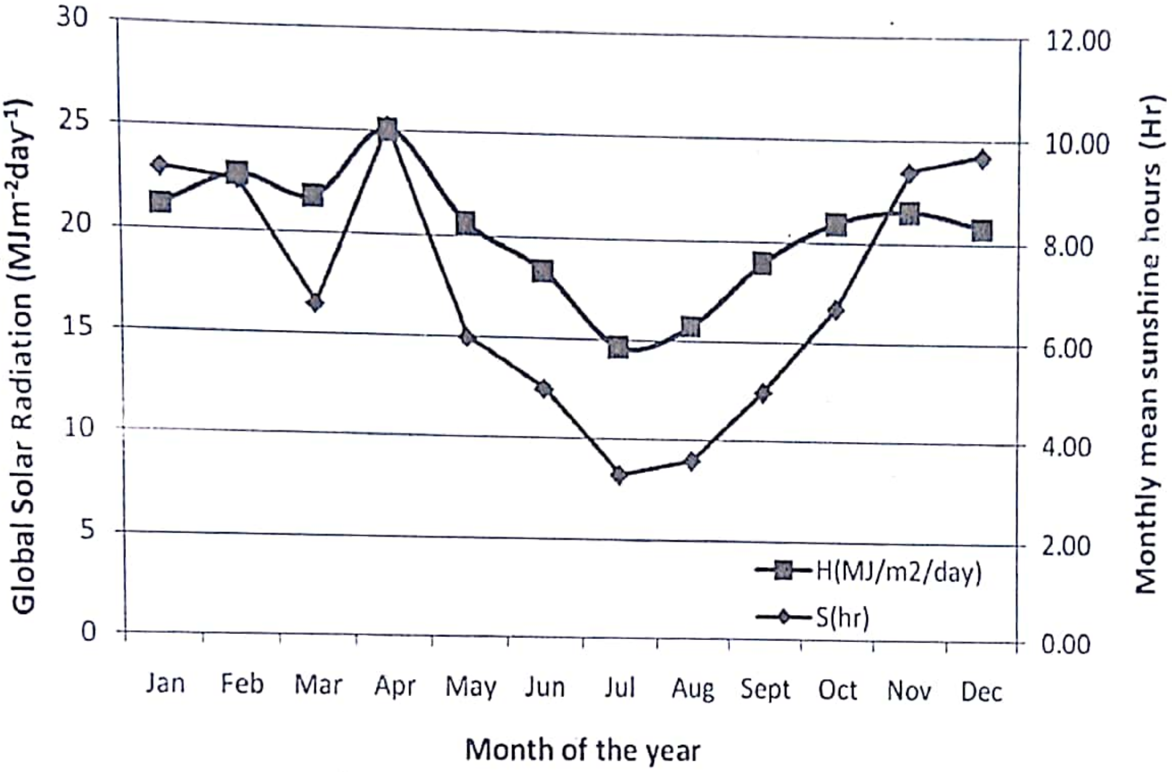

Figure 1a: Variation between monthly mean global radiations ($\overline{H}$) and sunshine hours (S) for 2009

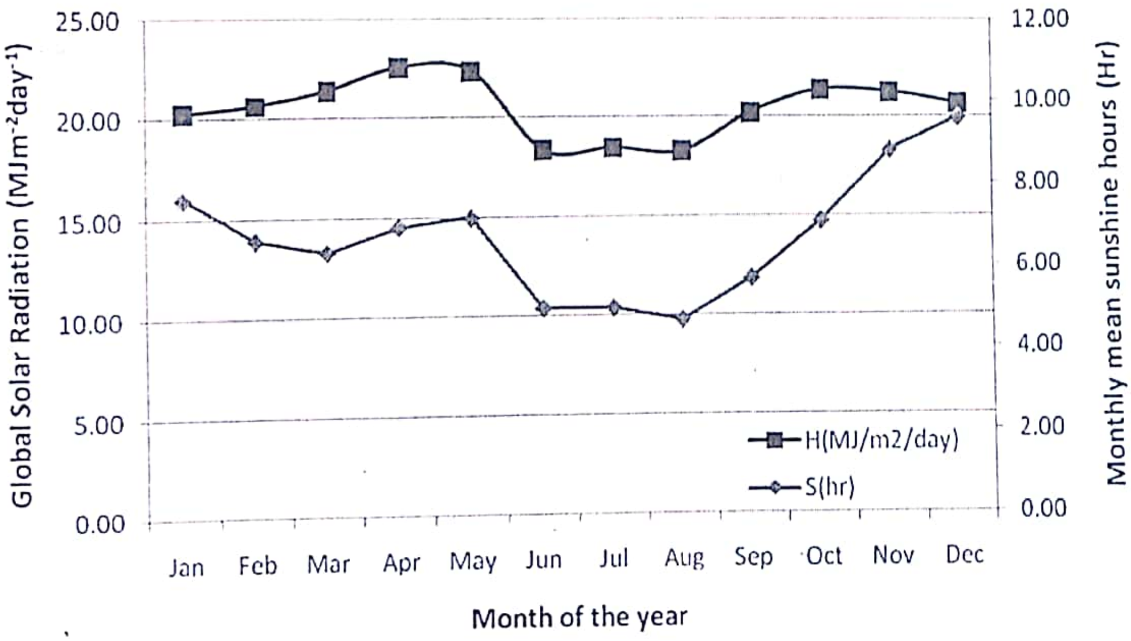

Figure 1b: Variation between monthly mean global radiations ($\overline{H}$)and sunshine hours (S) for 2010

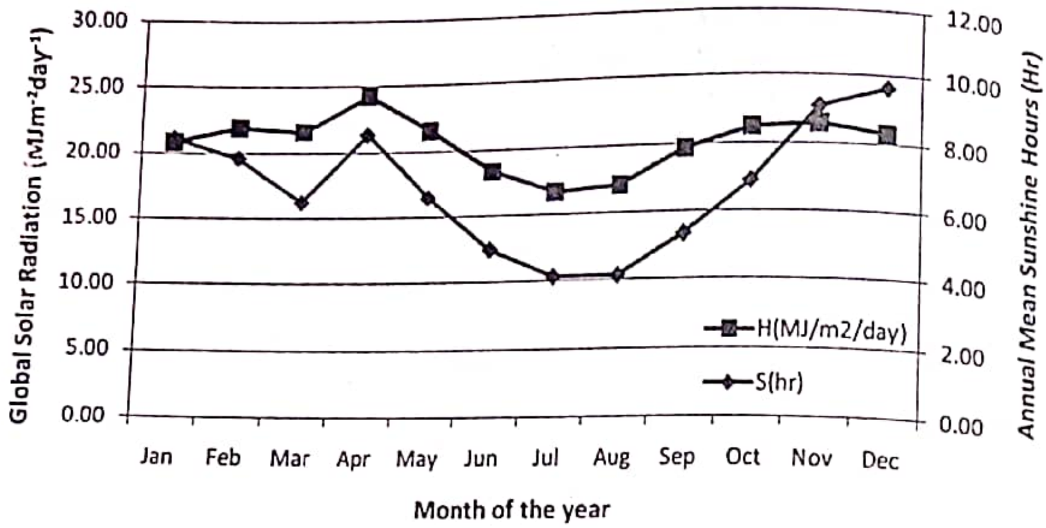

Figure 2: Variation between two-year monthly mean global radiations () and sunshine hours (S) for Minna

From Figure 2, it can be observed that the highest monthly daily global radiation on a horizontal surface within the period of this study was recorded in the month of April with the value 24.25 $MJm^{-2}day^{-1}$. Also, high global solar radiation was recorded in the month of February, March, May, October and November with the values of 21.94 $MJm^{-2}day^{-1}$, 21.59 $MJm^{-2}day^{-1}$, 21.58 $MJm^{-2}day^{-1}$, 21.18 $MJm^{-2}day^{-1}$ and 21.43 $MJm^{-2}day^{-1}$ respectively. The radiation values are slightly lower in January and December with 20.83 $MJm^{-2}day^{-1}$ and 20.73 $MJm^{-2}day^{-1}$ respectively as a result of high density dust particles during the harmattan season.

On the other hand, the lowest value of global solar radiation was recorded in July with 16.70 $MJm^{-2}day^{-1}$. Similar values were obtained in June, August and September with 18.38 $MJm^{-2}day^{-1}$, 17.10 $MJm^{-2}day^{-1}$ and 19.64 $MJm^{-2}day^{-1}$ respectively. This could be explained in terms of peak period of cloud cover during the rainy season. The average monthly global radiation on a horizontal surface for Minna during the 2-year period is found to be 20.45 $MJm^{-2}day^{-1}$.

Similarly, it can be observed from Figure 2 that the mean monthly global radiation increases linearly with sunshine hour between the months of April and October. However, there is a slight deviation from this trend between November and March. This deviation could be explained in terms of high density of harmattan dust particles during the dry season.
The knowledge of the availability and variation of global solar radiation in a site of interest is very important for the design of solar energy applications. The above results show the values as well as the monthly variation of global solar radiation in Minna.

Conclusion

Accurate estimation of global solar radiation of a location of interest is vital for proper design and analysis of solar energy devices. To this end, an estimation of the mean monthly global radiation for Minna has been carried out using Angrom-Prescott correlation.

The result obtained shows that the highest monthly daily global radiation on a horizontal surface within the period of this study was recorded in the month of April with the value 24.25 $MJm^{-2}day^{-1}$

while the lowest value was recorded in July as 16.70 $MJm^{-2}day^{-1}$. Generally, the values of the monthly daily global radiation are higher during the dry season than the rainy season. The mean monthly global radiation on a horizontal surface for Minna during the 2-year period is found to be 20.45 $MJm^{-2}day^{-1}$. Studies show that Nigeria receives an average solar radiation of about 25.2 $MJm^{-2}day^{-1}$ in the far north and about 12.6 $MJm^{-2}day^{-1}$ in the coastal latitudes (Ileoje, 1997). This shows that Minna is a viable location for solar energy applications as solar energy is available all year round.

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