ISSN 1115 - 960X

Ilorin Journal of Business and Social Sciences (IJBSS)

VOLUME 14, Numbers 1&2 December, 2010

PUBLISHED BY

The Faculty of Business and Social Sciences,
University of Ilorin,
P.M.B. 1515, Ilorin, Nigeria.

Subscription Information

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THE EDITOR-IN-CHIEF
ILORIN JOURNAL OF BUSINESS AND SOCIAL SCIENCES,
FACULTY OF BUSINESS AND SOCIAL SCIENCES.
UNIVERSITY OF ILORIN,
P.M.B. 1515, ILORIN, NIGERIA.

ESTIMATION OF SOLAR RADIATION IN MINNA, NIGERIA

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Abstract

The estimation of solar radiation in Minna (latitude 09.33⁰N and 11.36⁰N) was carried out in this work. The temperature data were obtained from the 1st – 30th November, 2008 using the maximum and minimum thermometer placed in the Stevenson screen at 1.5m. The Hargreaves equation was used to estimate the solar radiation in Minna. The mean global solar radiation obtained for the period is 3.63± 0.5 kWh per day. A comparison of the mean solar radiation result obtained in Minna and that obtained by Chiemeka (2008) at Uturu (05.33⁰N,7.4⁰E) in October 2007, Chineke(2007) at Umudike (5⁰.29N,7.33¹E) in October, 1997 and Chineke (2002) at Owerri (5⁰28¹N,7⁰2¹E) in October, 1997 was made.The results showed that the solar radiation in Minna is high. This difference may be attributed to the fact that Minna is bounded by a heat escarpment.

Introduction.

Chiemeka (2008) noted that the energy transferred from the sun in the form of radiant energy to the earth's surface is called solar radiation. Solar radiation is used in agriculture for crop drying, electricity generation, house heating and water heating. It is this energy that allows life to flourish. Sunlight determines the rate of photosynthesis in plants and strongly regulates the amount of evaporation from oceans. It warms the planet and gives us our everyday wind and weather. Without the suns radiant energy, the earth would gradually cool, in time becoming encased in a layer of ice. Chineke, (2007) observed that the network of stations measuring solar radiation data is sparse in many countries. In Nigeria, only few stations have been measuring the solar radiation on a consistent basis. It is therefore, necessary to approximate radiation from commonly available climate parameters such as sunshine hours, relative humidity, maximum and minimum temperatures and the computed value of extraterrestrial solar radiation (EXRAD) and maximum daylight duration (N). Minna has been chosen for this study because of its seasonal variation in its climate.

Theoretical Background.

Chineke (2002) noted that solar radiation data are available in several forms. To understand and use the data, we need to know:

(i) Whether they are instantaneous measurements (irradiance) or values integrated over some period of time (irradiation) usually hourly or daily.

(ii) The time or time period of measurement.
(iii) Whether the measurement are of beam, diffuse or total radiations and the instrument used.
(iv) The receiving surface orient[illegible]on. This is usually and sometimes inclined at a fixed slope, or normal to the beam radiat[illegible]
(v) If averaged, the period ove[illegible] which they are averaged (e.g. monthly average of daily radiation) most radiation data available are for horizontal surface.

These include both direct and diffuse radiation and are measured with thermopile type of Pyranometer. Most of these instruments provide radiation records as a function of time and do not provide a means of integrating the records. The data are usually recorded by potentiometers and are integrated graphically or electrically. In such cases where the solar radiation is recorded graphically, the value for the period is read from the graph or chart that must have been calibrated. When the data is recorded electrically, the value of the solar radiation is read off.

Table 1. Equations for Computing Rheoretical Radiation (R_a) and Maximum Daylight (N)

Location Specific Functions	
PHI	Latitude * Pi/180
DEL	(23.45*pi/180)*Sin (2.0*Pi*(284. +Julian Day)/365.)
WS	ACOS(-TAN(PHI)*TAN(DEL))
N	(2.0/15.0)*WS*180/Pi
DF	1.0+0.033*Cos(2.0*Pi(Julian Day/365.0))
R_a	(Calories/cm^2/day) = (1440.0/Pi)*SC*DF*(COS(PHI)*COS(DEL)*SIN(WS)+WS*SIN(PHI)*SIN(DEL))
Constants	
Solar constant (SC) = 1367W/m^2	
Pi = 4.0*ATAN (1.0)	

DEL = Solar Declination
PHI = Latitude of the Location
WS = Sunset hour angle
N = Maximum daylight duration at the top of the atmosphere where there is cloud.
DF = Day factor
SC = Solar Constant
January 1 = day 1
December 31 = day 365
February 1. = day 32
$180^0 = \pi$ rad

From the instruments meter, the near total absence of accurate solar radiation databases for Nigeria and the need to develop solar system for rural applications encouraged the development of the various methods of assessment of global solar radiation incident on a horizontal surface. Various equations according to (Bamiro, 1981; Davies, 1966; Ezekwe, 1988) require many climatic parameters like sunshine hours, temperature (maximum and minimum), relative humidity, etc. as input. Chineke and Jagtap (1995) compared 3 models and got the best fit with the modified temperature based on Hargreaves et al. method (1985). The temperature –based model is good for use when data on sunshine hours is lacking like is the case in Nigeria and this work too. The work of Chineke and Jagtap (1995) was based on the three Nigerian sites with measured solar radiation data and presented an equation for estimating solar radiation of the form:

$$Rs = 0.16R_aTd^{1/2}$$

Where Td = daily temperature difference (maximum minus minimum)

Ra = extraterrestrial solar radiation (generated by a computer routine listed in Table 1 and requiring the locations grid parameter)

Radosavijevic (2001) noted that, because the earth orbit is elliptical, the intensity of solar radiation received outside the earth-sun distance. Solar irradiance varies by 13.4% with the maximum irradiance occurring at the perihelion i.e. the earth is closest to the sun (January 3-5) and the minimum at the aphelion (July 5). This variation may be approximated by;

$$I_0 = I_{sc}[1+0.034COS\ (360N/365.25)]W/m^2$$

Where I0 is the extraterrestrial solar irradiance outside the earth's atmosphere and N is the day number (starting at January 1) or D year.

Materials and Measurement Procedure.

Climate data for Minna is based on weather conditions at The Geography Department, Federal University of Technology Minna weather station. The climate of Minna is seasonal. The wet season in the community generally commences in April, with rainfall peak in August and a mean annual rainfall of about 850mm-1200mm and an average of 160 rain days per year. The mean annual temperature in Minna ranges from 27.2^{0}C – 35^{0}C (Ojoye, 2002).

In this work, the maximum and minimum thermometer was used because it is easy to read and readily available too. Over the years, it has been the most frequently used instrument for solar radiation estimation due to its accuracy and simplicity. Maximum and minimum thermometers were used to measure the highest and lowest daily air temperature for the month of November, 2008 representing the commencement of the harmattan season. In all, thirty readings were taken starting from the 1st of November to 30th November, 2008. The Thermometer was placed horizontally inside the Stevenson Screen which shelters it and helps to prevent interference by rain, dew and sun's direct rays. The Stevenson Screen is painted white so that it would reflect sunlight. It has louvered sides so as to ensure free movement of air in and out of the Stevenson screen are the same. The Stevenson screen was raised to a height of 1.5m above the ground. The reading of the daily temperature varies; the maximum and minimum temperatures were taken at 10am prompt.

Results and Discussions.

Extraterrestrial solar radiation (EXRAD).

The values of the daily extraterrestrial solar radiation (EXRAD) on a horizontal surface calculated for the month of November, 2008 at Latitudes 09.36^{0}N and 11.33^{0}N outside the earth's atmosphere at Minna, Nigeria is as shown in Figure 1. The highest extraterrestrial solar radiation value of 13.52 Kwh was obtained on the 1st day, while the lowest value of 11.00Kwh was obtained on the 30th day. The graph showed that the extraterrestrial solar radiation was on the decrease continuously throughout the period. This may be attributed to the reduction of solar radiation by the cosine of the angle between the solar radiation and a surface normal (called cosine effect) outside the earth's atmosphere or as a result of the reduction of the extraterrestrial solar radiation by the atmosphere due to absorption, scattering, reflection and transmission by water vapour, carbon-dioxide, clouds, smog and particulates, etc.

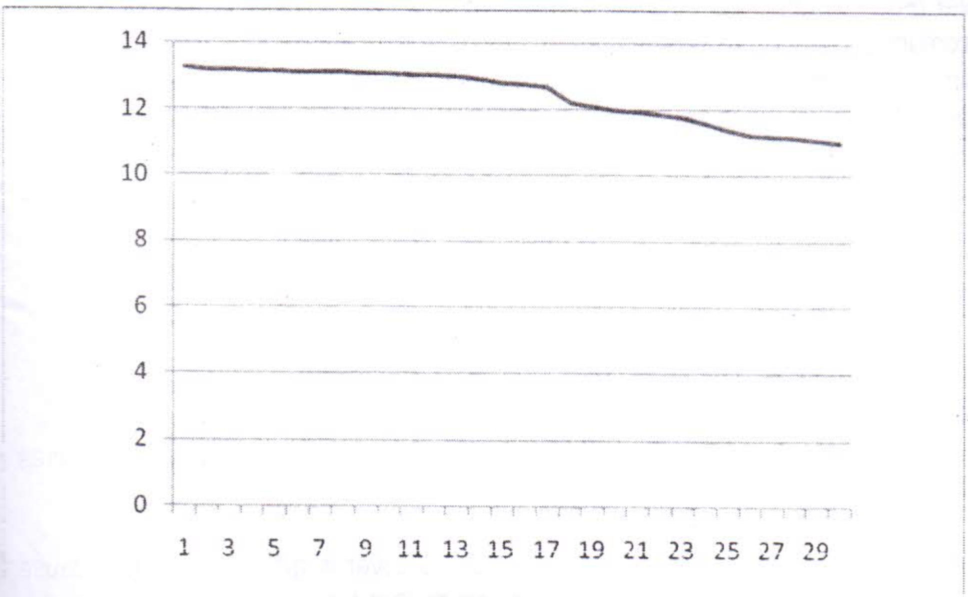

Figure 1. Extraterrestrial Solar Radiation at Minna from November 1-30, 2008.

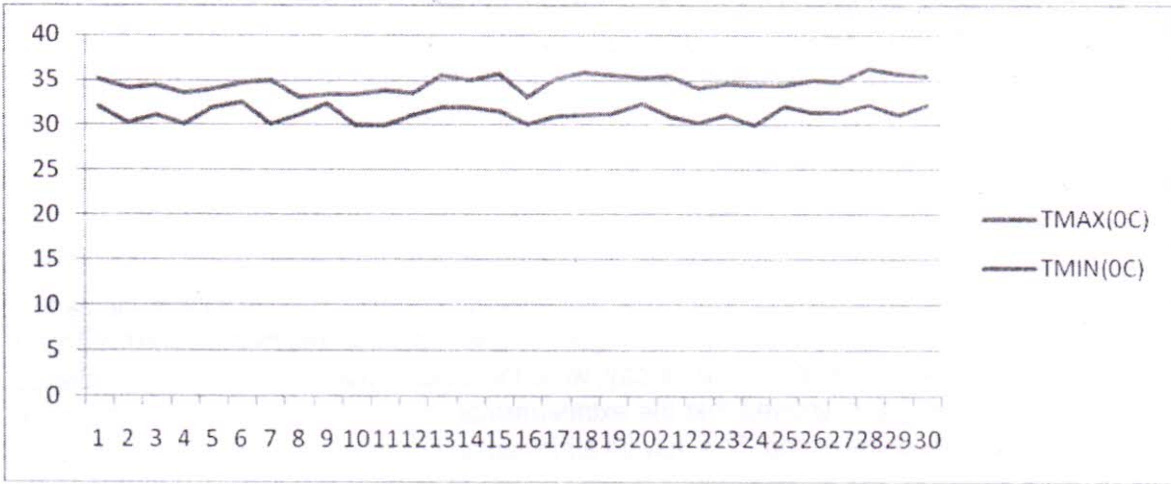

Figure 2. Measured Maximum and Minimum Temperatures at Minna.

The mean of the solar radiation at the entrance into the earth's atmosphere known as extraterrestrial solar radiation obtained for the period at Minna is 12.41$\pm$ 0.5 kWh. Figure 2 shows the measured maximum and minimum temperature at Minna for November 1-30, 2008. The values were obtained using the maximum and minimum thermometer placed in the Stevenson Screen at 1.5m above the ground. The values ranged from 33.1^{0}C (day 6) to 36.3^{0}C (day 28) and 30^{0}C (day 10, 11 & 24) to 32.6^{0}C (day 6) for the maximum and minimum temperature respectively. In Figure 3 is shown the global solar radiation at Minna from November 1 to 30th, 2008.The values were computed with the Hargreaves equation given as

$$R_s = 0.1\ R_a T_d^{1/2}$$

Where T_d is the daily temperature difference (maximum minus minimum)

R_a is the extraterrestrial solar radiation, and

The maximum daylight duration (N) were computed by the routine in Table1; it requires that the latitude of the site be input in decimals of degree (Chineke, 2007).

The temperature difference should be less when cloud cover is greater. This is because the day temperature remain high and the heat is conserved so that the night temperature is also high, resulting in less temperature range during the day. The Td takes into account changes in radiation due to the surroundings, and the altitude of the location (Chineke, 2002). The advantage of this equation is that it uses temperature data that is readily available at many locations (rural and urban), and requires single calibration constant. On the surface of the earth, we perceive a beam or direct solar irradiance that comes directly from the disc of the sun and a diffuse or scattered solar irradiance that appear to come from the directions over the entire sky.

In this work, the term "direct" was used to signify solar irradiance coming directly from the sun's disc and the term "diffuse" to indicate solar irradiance that appear to come from other directions. The sum of direct and diffuse solar irradiance is called the global or the total solar irradiance. Also, the term "global" was used to indicate this sum. The routine given in Table 1 can be used to compute Ra and N where the latitude is supplied in degree radian.
Note that $180^0 = \pi$ radian.

Table 2. Temperature measurement and solar radiation (KWH) at Minna.

S/No	Nov. 2008	DYEAR	EXRAD	GLORAD	TMAX(⁰C)	TMIN(⁰C)
1	1	301	13.25	3.61	35.1	32.2
2	2	302	13.2	4.17	34.2	30.3
3	3	303	13.19	3.89	34.5	31.1
4,	4	304	13.17	3.94	33.6	30.1
5	5	305	13.15	2.98	34	32
6	6	306	13.13	3.04	34.7	32.6
7	7	307	13.12	4.65	35	30.1
8	8	308	13.1	3.04	33.2	31.1
9	9	309	13.08	4.65	33.5	32.5
10	10	310	13.06	3.04	33.4	30
11	11	311	13.04	2.09	33.9	30
12	12	312	13.03	3.85	33.6	31.1
13	13	313	13.01	4.12	35.6	32
14	14	314	12.9	3.3	35	32
15	15	315	12.8	3.95	35.7	31.6
16	16	316	12.75	3.57	33.1	30.1
17	17	317	12.7	4.15	35.2	31
18	18	318	12.2	3.53	35.8	31.2
19	19	319	12.1	4.16	35.6	31.3
20	20	320	12	4.19	35.3	32.5
21	21	321	11.95	4.01	35.4	31
22	22	322	11.85	3.74	34.2	30.3
23	23	323	11.8	3.48	34.6	31.2
24	24	324	11.6	3.94	34.5	30
25	25	325	11.4	2.71	34.4	32.2
26	26	326	11.25	3.42	35	31.4
27	27	327	11.2	3.35	34.9	31.4
28	28	328	11.15	3.57	36.3	32.3
29	29	329	11.1	3.77	35.7	31.2
30	30	330	11	3.12	35.4	32.25

The values computed with the Hargreaves equation are shown in table 2 and plotted in figure 3. The global solar radiation (GLORAD) at Minna is highest on days 7 and 9 th (4.65Kwh) and lowest on the 11th (2.09Kwh).The mean global solar radiation obtained for the month under consideration is 3.63$\pm$ 0.5 kWh

Figure 3. Global solar radiation from November 1-30, 2008 at Minna.

Conclusions

The estimation of the solar radiation in Minna latitude 09.33°N and 11.36°N were carried out in this work. The temperature data were obtained from 1st to 30th November, 2008 using the maximum and minimum thermometer placed in a Stevenson Screen at a height of 1.5m above the ground. The Hargreaves equation was used to estimate the solar radiation at Minna. The equation in table 1 was used to calculate the daily theoretical radiation and the maximum day light duration. The mean global radiation obtained for the period is 3.63$\pm$ 0.5 kWh per day, while the mean of the solar radiation at the entrance into the earth atmosphere at Minna known as extraterrestrial solar radiation obtained for the period is 12.41 $\pm$0.21Kwh.

Table 2 showed the temperature measurement and solar radiation (Kwh) at Minna. The extraterrestrial solar radiation on a surface, measured maximum and minimum temperature at Minna and the global solar radiation is as shown in figure 1, 2 and 3 respectively. A comparison of the mean solar radiation result obtained at Minna and that obtained by Chiemeka (2007) at Uturu, Chineke (2007) at Umudike (5°29'N,7°2'E) in October 1997 and Chineke (2002) at Owerri (5°28'N,7°2'E) in October, 1997 showed that the solar radiation obtained at Minna is high. The difference may be attributed to the position of Minna. Offiong (2003) reported that the average solar radiation received in Nigeria per day is as high as 20MJ/m2 depending on the time of the year and the location. A comparison of the global solar radiation estimate obtained at Minna and that reported by Offiong showed that the solar radiation obtained at Minna is higher than that reported by Offiong.

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