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Full Length Research Paper

Estimation of solar radiation at Uturu, Nigeria

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The estimation of the solar radiation at Uturu latitude 05.33°N and 06.03°N was carried out in this work. The temperature data were obtained from 5th – 31st October, 2007) using the maximum and minimum thermometer placed in the Stevenson screen at 1.5 m The Hargreaves equation was used to estimate the solar radiation at Uturu. The mean global solar radiation obtained for the period is 1.89 ± 0.82 kwh per day. A comparison of the mean solar radiation result obtained at Uturu and that obtained by Chineke (2007) at Umudike (5°29'N, 7°33'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 Uturu is low. This difference may be attributed to the fact that Uturu is bounded on the West and South by a hilly escarpment.

Key words: Global solar radiation, Hargreaves equation.

INTRODUCTION

Donald (1982), 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 the oceans. It warms the planet and gives us our everyday wind and weather. Without the sun's 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 daily 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, cloud cover and geographic location. In this work, the Hargreaves equation was used to estimate the global solar radiation at Uturu based on the available climate parameters of measured maximum and minimum temperature and the computed values of the extraterrestrial solar radiation (EXRAD) and maximum day light duration (N). Uturu has been chosen for this study primarily due its geographic location, being bound on the west and south by hilly escarpment as high as 240 m above the sea level. Secondly the climate of Uturu varies significantly with the seasons of the year.

Theoretical Background

Chineke (2002) noted that solar radiation data are available in several forms. To understand and use these 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 radiation and the instrument used.
iv. The receiving surface orientation. This is usually and sometimes inclined at a fixed slope, or normal to the beam radiation.
v. If averaged, the period over 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 theoretical 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) = 1367 W/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 atmosphere where there is no cloud.
DF = Day factor
SC = Solar Constant.
January 1 = day 1
Dec. 31 = day 365
Feb. 1 = day 32.
$180^0 = \pi$ rad

from the instrument's meter. The near total absence of accurate solar radiation databases for Nigeria and the need to develop solar energy 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; Swartman, 1963) require many climatic parameters like sunshine hours, temperatures (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 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 in this work too. The work of Chineke 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.

$$Rs = 0.16\, Ra\, Td^{1/2} \qquad 1$$

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

$$I_O = I_{sc}\left[1+0.034\cos\left(\frac{360N}{365.25}\right)\right] \ (\mathrm{W/m^2}) \qquad 2$$

Where I_o 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

Chiemeka (2007) noted that Uturu is one of the communities that make up settlements in Isuikwuato local government Area of Abia state. It is located within latitudes 05.33°N and 06.03°N, and longitudes 07.10° E and 07.29° E, and is bounded on the west and south by a hilly escarpment as high as 240 m above sea level. Allowing for slight variations in weather conditions, which might occur as a result of differences in location, climate data for Uturu community is based on weather conditions at National Horticultural Research institute (N.H.R.1) meteorological station at Mbato Okigwe. The climate of Uturu is seasonal. The wet season in the community generally commences in March, with rainfall peak in July and September and a mean annual rainfall of about 1367 - 1672.4 mm and a total of not less than 97 rainy days per year. The mean annual temperature in Uturu ranges from 25.23 – 27. 20°C.

In this work, we made use of maximum and minimum thermometer 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 October 2007 representing the commencement of the harmattan season. In all twenty-seven readings were taken starting from the 5th of October to 31st October 2007. 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, to ensure that the temperature inside and outside the Stevenson screen are the same. The Stevenson screen was raised to a height of 1.5m above the ground at Abia State University, Uturu Weather observatory site. The reading of the daily temperature variables, the maximum and minimum temperatures where 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 October, 2007, at latitudes 05.33°N and 06.03°N out side the earths atmosphere at Uturu, Nigeria is as shown in Figure 1: The highest extraterrestrial solar radiation value of 10.23kwh was obtained on the 5th day, while the lowest value of 9.82 kwh was obtained on the 31st 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

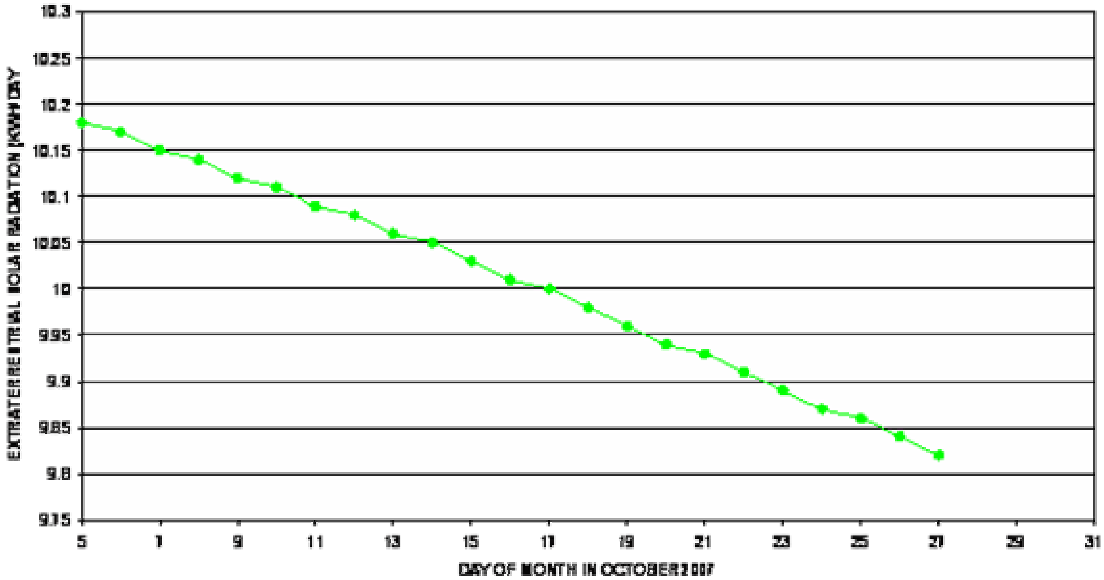

Figure 1. Extraterrestrial solar radiation at Uturu from October 5 - 31, 2007

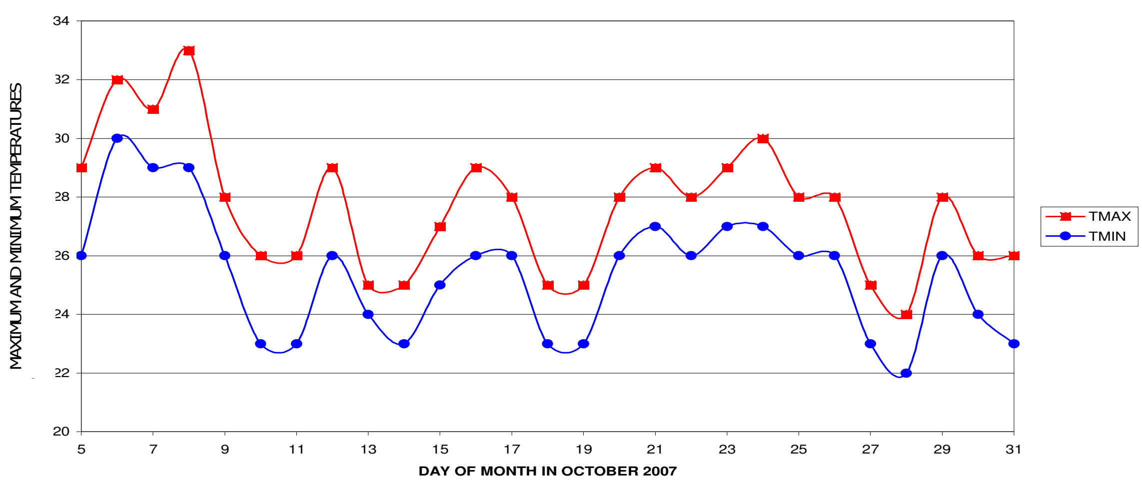

Figure 2. Measured maximum and minimum temperatures at Uturu.

and a surface normal (called cosine effect) outside the earths 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. The mean of the solar radiation at the entrance into the earth's atmosphere known as extraterrestrial solar radiation obtained for the period at Uturu is 6.70 ± 0.21 kwh. In Figure 2 is shown the measured maximum and minimum temperatures at Uturu from October 5 - 31, 2007. The values were obtained using the maximum and minimum thermometer placed in the Stevenson screen at 1.5 m above the ground. The values ranged from 24°C (day 28) to 33°C (day 8) and 22°C (day 28) to 30°C (day 6) for the maximum and minimum temperatures respectively. In Figure 3 is shown the global solar radiation at Uturu from October 5 - 31, 2007. The values were computed with the hargreaves equation given as;

$$Rs = 0.16 R_a T_d^{1/2}.$$

Where T_d is the daily temperature difference (maximum minus minimum) and R_a is the extraterrestrial solar radiation and the maximum day light duration (N) were computed by the routine in Table 1: 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 temperatures remain high and the heat is conserved so that the

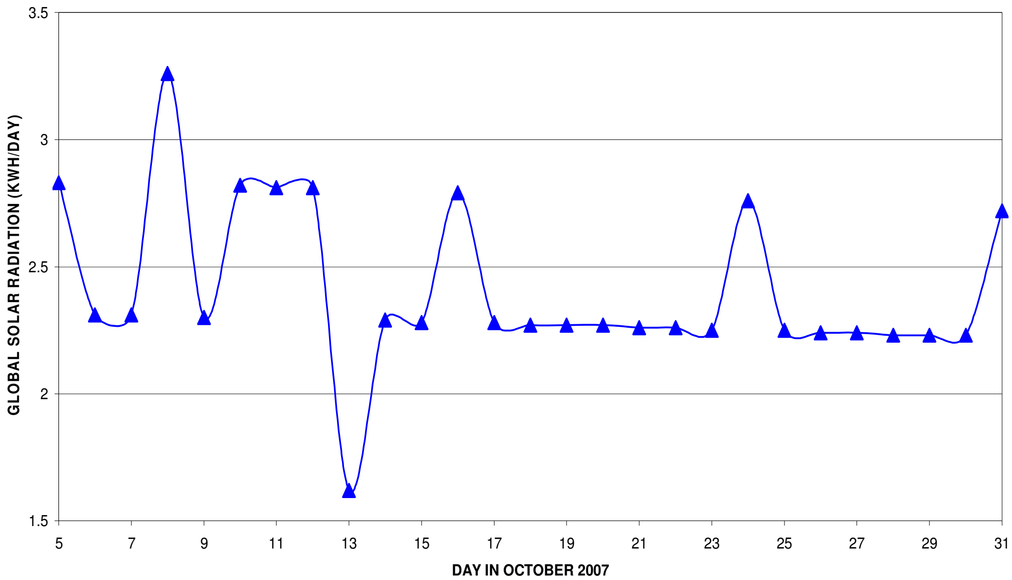

Figure 3. Global solar radiation from October 5 - 31, 2007 at Uturu.

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

S/NO	October 2007	DYEAR	EXRAD	GLORAD	TMAX(^{O}C)	TMIN(^{O}C)
1	5	278	10.23	2.83	29	26
2	6	279	10.22	2.31	32	30
3	7	280	10.2	2.31	31	29
4	8	281	10.19	3.26	33	29
5	9	282	10.18	2.3	28	26
6	10	283	10.17	2.82	26	23
7	11	284	10.15	2.81	26	23
8	12	285	10.14	2.81	29	26
9	13	286	10.12	1.62	25	24
10	14	287	10.11	2.29	25	23
11	15	288	10.09	2.28	27	25
12	16	289	10.08	2.79	29	26
13	17	290	10.06	2.28	28	26
14	18	291	10.05	2.27	25	23
15	19	292	10.03	2.27	25	23
16	20	293	10.01	2.27	28	26
17	21	294	10	2.26	29	27
18	22	295	9.98	2.26	28	26
19	23	296	9.96	2.25	29	27
20	24	297	9.94	2.76	30	27
21	25	298	9.93	2.25	28	26
22	26	299	9.91	2.24	28	26
23	27	300	9.89	2.24	25	23
24	28	301	9.87	2.23	24	22
25	29	302	9.86	2.23	28	26
26	30	303	9.84	2.23	26	24
27	31	304	9.82	2.72	26	23
Error = $\pm 0.5^{0}$C						

night temperature is also high, resulting in less temperature range during the day. The T_d takes into account changes in radiation due to proximity to oceans, mountains, 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, we will use the term direct to signify solar irradiance coming directly from the sun's disc, and the term diffuse to indicate solar irradiance coming from all other directions. The sum of direct and diffuse solar irradiance is called the global or total solar irradiance. In this work we will use the term global to indicate this sum. The routine given in Table 1 can be used to compute R_a and N where the latitude is supplied in degree radian. Note that $180^o = \Pi$ radian. The values computed with the Hargreaves equation are shown in Table 2 and plotted in Figure 3. The global solar radiation (GLORAD) at Uturu is highest on day 8 (3.26kwh) and lowest on the 13 (1.62kwh). The mean global solar radiation obtained for the month of October, 2007 at Uturu is 1.89 ± 0.82kwh.

Conclusion

The estimation of the solar radiation at Uturu latitude 05.33°N and 06.03°N were carried out in this work. The temperature data were obtained from 5th – 31st October, (2007) using the maximum and minimum thermometer placed in the Stevenson screen at 1.5 meters above the ground. The Hargreaves equation was used to estimate the solar radiation at Uturu. The equation in Table 1 was used to calculate the daily theoretical radiation and the maximum day light duration. The mean global solar radiation obtained for the period is 1.89 ± 0.82 kwh per day, while the mean of the solar radiation at the entrance into the earth atmosphere at Uturu known, as extraterrestrial solar radiation obtained for the period is 6.70 ± 0.21 kwh. The Table 2 showed the temperature measurements and solar radiation (kwh) at Uturu. The extraterrestrial solar radiation on a surface, measured maximum and minimum temperature at Uturu 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 Uturu and that obtained by Chineke (2007) at Umudike (5°29'N, 7°33'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 Uturu is low. This difference may be attributed to the fact that Uturu is bounded on the West and South by a hilly escarpment. Offiong (2003) reported that the average solar radiation received in Nigeria per day is as high as 20 MJ/m^2 depending on the time of the year and location. A comparison of the global solar radiation estimate obtained at Uturu and that reported by Offiong showed that the solar radiation obtained at Uturu is 34% less than that reported by Offiong.

REFERENCES

Agbaka AC (1996). Solar Power and Applications. Cel-Bez Publishers, Owerri.

Bamiro OA (1981). Empirical Relations for the Determination of Solar Radiation in Ibadan, Nigeria. Solar Energy, 31: 85 – 94.

Chineke TC, Jagtap SS (1995). A Comparison of three Empirical Models for Estimating Solar Radiation in Nigeria. Afr. J. Sci. Technol., Series A, 11: 45 – 48.

Chineke TC(2002). A Robust Method of Evaluating the Solar Energy Potential of a Data Sparse Site. The Physical Scientist (c) 2002, 1 (1): 59 – 69.

Chineke TC (2007). Renewable Energy: Equations for Estimating Global Solar Radiation Data Sparse Regions. Science Direct, pp.1 – 13.

Chiemeka IU (2007). Determination of aerosol composition and concentration during the 2004/2005 harmattan season at Uturu, Nigeria. Advances in Science and Technology, 1(2): 128.

Davies JA (1966). "Radiation and Evaporation Approximate for Nigeria" Ph.D. Thesis, University of London.

Donald CA (1982). Meteorology Today: An Introduction to Weather, Climate and the Environment. West Publishing Co.

Ezekwe CI (1988). The Solar Radiation Climate of Nigeria. Solar and Wind Technology. 5: 563 – 571.

Hargreaves GL, Hargreaves GH, Riley JP (1985). Irrigation Water Requirements for Senegal River Basin. J..irrig. & Drain. Engr., 111(3): 264 – 275.

Offiong A (2003). Assessing the Economic and Environmental Prospects of stand-By solar powered systems in Nigeria. J. of Applied Sci. and Environmental Management, 7(1): 37-42.

Radosavijevic JA (2001). Definition of Intensity of Solar Radiation on Horizontal and Oblique Surfaces on Earth. Working and Living Environmental Protection. 2 (1): 77-86.

Swartman RK, Ogunlade O (1963). Solar Radiation Estimates from Common Parameters, Solar Energy, 56: 145 – 158.