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Assessment Of Global Solar Radiation: A Case Study Of Abuja, Nigeria

S. A. Ayegba

N. O. Sampson

Ibileke J. O

Akintulerewa O. S

L. S. Owa

W. Desmond Fonyuy

David-Ndahi A

Graduate Research Scientists (Students of Master of Technology),
Satellite Communications, African Regional Centre for Space Science and
Technology Education-English (ARCSSTEE), Ile-Ife, Nigeria

***Abstract:** The importance of solar radiation to humans cannot be over emphasized as it finds its applications in energy, food processing, agriculture, environmental managements, health and so on, hence there is need to assess its amount over a particular place for proper harnessing. This work is aimed at predicting the global solar radiation of Abuja, Nigeria, located between latitude 8.25^0 and 9.20^0 North and longitude 6.45^0 and 7.39^0 East, and to determine the relationship between its Global and the Extraterrestrial Solar Radiations.*

The work employs the Hargreaves-Samani model which makes use of minimum and maximum air temperature data. The data used for this work was adopted from the website of weather online limited and is for the month of February (1 to 29, 2016), a period of one month. The result shows daily maximum and minimum global solar radiations are 29.606kwh and 12.044kwh in that order.

***Keywords:** Global solar radiation, temperature, Hargreaves-Samani model, photovoltaic.*

I. INTRODUCTION

Global solar radiation which is the total amount of solar energy received by earth's surface is an important information which can be used by environmentalists, agriculturists, fish farmers, power sector personnel and even policy makers for effective planning. Solar radiation affects the earth's weather processes which determine the natural environment. Its presence at the earth's surface is necessary for the provision of food for mankind. Thus it is important to be able to understand the physics of solar radiation, and in particular to determine the amount of energy intercepted by the earth's surface at different locations [Nwokoye A. O. C, 2006)]. The amount of solar radiation over a place determines the type of crops that can survive in such a place. Also, in terms of animal rearing, the amount solar radiation over an area determines the type of animals or livestock that can be reared in the area. In the area of power supply, the amount of solar radiation available in an area is an important factor to be considered before the installations because the power output provided by a given installed solar photovoltaic system in one particular state in Nigeria may not be obtained when such system is installed in another state, with all other factors remaining constant. This is as a result of variation of solar radiation with locations, as well as topography. The amount of this energy depends on the location, time of the year, and atmospheric conditions [Helena Mitasova *et al*, *2011*]. Environmental management or regulatory agencies or bodies in various states of the country are to be aware of the solar radiation conditions of their states at some regular intervals. This will in no small measure controls any adverse effect that can result from sudden rise in global solar radiation of the area especially as global warming effect is on the rise daily. Research outcomes on studies of global solar radiation have facilitated improvement in Agronomy, power generation, environmental temperature controls, etc. [Ugwu, A. I. and Ugwuanyi, J. U., 2011]. Therefore, there is need for this type of work. The objectives of this work is to determine the global solar radiation of Abuja, Nigeria, and also to assess the relationship between the global solar radiation and the extraterrestrial solar radiation of the study area for this period of studies. Abuja, the federal capital territory is located between latitude 8.25^0 and 9.20^0 North of the equator and longitude 6.45^0 and 7.39^0 East of the Greenwich Meridian. Over the years, similar works have been done by various scientists and some are still ongoing due to the dynamic nature of weather and climatic factors. In 2008, Chiemeka, I. U. estimated the solar radiation at Uturu Abia state Nigeria, latitude 5.33˚N and 6.33˚N. The temperature data from 5th – 31st October 2007 was gotten using the maximum and minimum thermometer placed in Stevenson screen at 1.5m. He used the Hargreaves-Samani model for the work in which he stated that the mean global solar radiation obtained for the period was 1.89 - 0.82 kWh per day. The poor value gotten was attributed by him to the fact that Uturu is bounded on the west and south by a hilly escarpment.

Ugwu, A. I. and Ugwuanyi, J. U, 2011, carried out a work on the Performance assessment of Hargreaves model in estimating solar radiation in Abuja using minimum climatological data. The used the minimum and maximum temperature data adopted from Nigeria Meteorological Agency (NIMET). The data used was from January 1 to January 31 of 2009. They also made use of observed global radiation of Abuja which was obtained from the same source. Abuja is located between latitude 8.25^0 and 9.20^0 North of the Equator and longitude 6.45^0 and 7.39^0 East of the Greenwich Meridian. Hargreaves-Samani equation was used to predict the daily global solar radiation of the area. In their work, the predicted mean global solar radiation (GSR), Rs for the month under study was 18.59± 0.41 $MJm^{-2}day^{-1}$ and the observed was 21.35± 2.11 $MJm^{-2}day^{-1}$ for Abuja. They further stated that the correlation between the predicted and the observed global solar radiation Rs was 79%. The Index of Agreement (a measure of efficiency of a model) between the predicted and the observed monthly GSR values for Abuja was about 90%. The work was concluded with a recommendation that the model should be subjected to further validation involving several months data running over five years; the task in which this our work will perform a part of.

Hargreaves-Samani (1985) model accounts for solar radiation using only temperature. Although relative humidity is not explicitly contained in the equation, it is implicitly present in the difference in maximum and minimum air temperature [Ugwu, A. I. and Ugwuanyi, J. U., 2011]. The advantage of this equation is that it uses temperature data that is available at many locations (rural and urban) and requires a single calibration constant [I. U. Chiemeka1 and T. C. Chineke, 2009].

II. METHODOLOGY

DATA: The data used is a secondary data- the minimum and maximum temperature data of Abuja, Nigeria, for February 2016. It was obtained from the website of weather online limited.

METHOD: The method used in this work is Hargreaves-Samani equation model of global solar radiation determination. The advantage of this equation is that it uses temperature data that is available at many locations (rural and urban) and requires a single calibration constant [I. U. Chiemeka1 and T. C. Chineke, 2009]. The Hargreaves-Samani equation is represented as:

$$R_s = K_{RS}\left(\sqrt{T_{\max} - T_{\min}}\right)R_a \qquad \text{--------------------- 1}$$

Where T_{max} is the maximum temperature, T_{min} is minimum temperature, R_a is the extraterrestrial solar radiation of the area and K_{Rs} is adjustment coefficient., It has different values for 'interior' and 'coastal' regions. For 'interior' locations, where land mass dominates and air masses are not strongly influenced by a large water body, it is approximately 0.16 and for 'coastal' locations, situated on the coast of a large land mass and where air masses are influenced by a nearby water body, its value is approximately 0.19. In this design, the value of K_{Rs} used is 0.16. The computations were done on Microsoft excel worksheet to determine the various parameters. Also, graphs were plotted using the excel software package.

The steps determining the global solar radiation are as follows:

CALCULATION OF SOLAR RADIATION DECLINATION: Solar radiation declination is the angle made between a ray of the sun, when extended to the centre of the earth and the equatorial plane. The solar radiation declination of the area is calculated using the formula give as;

$$\delta = 23.44Cos\left\{\left(\frac{360}{365}\right) * (J + 10)\right\} \qquad \text{----------------2a}$$

where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December) and δ is solar radiation declination in degree .

Since the solar radiation declination is to be in radians for the next computation, the result of equation 2a will be converted to radian as in eq. 2b;

$$\delta_{rad} = \frac{\delta \text{ x } \pi}{180} \qquad \text{---------------------------------- 2b}$$

CALCULATION OF SUNSET ANGLE: Sunset angle is the angle of the daily disappearance of the sun below the horizon due to the rotation of the earth. Sunset time is the time in which the trailing edge of the sun’s disk disappears below the horizon. The sunset angle of a location is calculated using the formula given as;

$$\omega_s = Cos^{-1}\left(-\tan(\varphi)\tan(\delta)\right) \qquad \text{---------------- 3}$$

Where ω_s is sunset angle in radian, δ is the solar radiation declination in radian, and φ is latitude angle of the location.

CALCULATION OF INVERSE RELATIVE DISTANCE EARTH-SUN: This is the inverse distance of the sun relative to the earth at the location and is calculated as;

$$d_r = 1 + 0.033 Cos\left(\frac{2\pi J}{365}\right) \quad \text{---------------- 4}$$

CALCULATION OF EXTRATERRESTRIAL SOLAR RADIATION: Extraterrestrial solar radiation is the intensity or power of the sun at the top of the earth's surface. It is the solar radiation outside the earth's atmosphere. The extraterrestrial radiation is calculated using the formula;

$$R_a = \frac{24(60)}{\Pi} G_{sc} d_r \left[w_s Sin(\varphi) Sin(\delta) + Cos(\varphi) Sin(w_s)\right] \quad \text{------ 5}$$

where R_a is extraterrestrial radiation , d_r is the inverse relative earth-sun distance, φ is the latitude angle, w_s is the sunset angle, and Gsc is solar constant = 0.0820 MJ m^{-2} min^{-1} or 1367wm^{-2}.

CALCULATION OF GLOBAL SOLAR RADIATION: Global solar radiation is the total amount of solar energy received by earth's surface. It is the addition of the direct, diffuse and reflected solar radiations. The global solar radiation is now calculated using the values of the minimum and maximum temperature recorded for that period of time, and the value of the extraterrestrial radiation calculated from equation 5 above. It is the same equation1 and recalled as;

$$R_s = K_{RS}\left(\sqrt{T_{max} - T_{min}}\right)R_a \quad \text{--------------------- 6}$$

Days of the month	T_{min} (°c)	T_{max} (°c)
1	15	35
2	17	35
3	19	35
4	22	37
5	22	37
6	18	38
7	21	37
8	21	35
9	19	36
10	21	36
11	16	37
12	17	36
13	19	36
14	17	36
15	19	35
16	23	37
17	20	39
18	19	34
19	22	38
20	22	39
21	24	38
22	21	39
23	23	38
24	21	36
25	21	38
26	34	38
27	32	37
28	27	37
29	26	37

Table 1: Temperature data

Table 1 shows the minimum and maximum temperature data for the month of February, 2016 obtained from the websites of weather online limited (http://www.weatheronline.co.uk/weather/).

III. RESULTS AND DISCUSSIONS

φ = 8.725, K_{RS} = 0.16, month = February, Year = 2016.

Days	J	d_r (rad)	δ (degree)	δ (rad)	ω_s (rad)	R_a(KWH)	K_{RS}	T_{min} (°c)	T_{max} (°c)	Rs (KWH)
1	32	1.0281	17.57593	0.3068	1.5716	40.973	0.16	15	35	29.318
2	33	1.0278	17.30637	0.3021	1.5664	40.910	0.16	17	35	27.770
3	34	1.0275	17.03168	0.2973	1.5664	40.856	0.16	19	35	26.148
4	35	1.0272	16.75194	0.2924	1.5665	40.800	0.16	22	37	25.283
5	36	1.0269	16.46724	0.2874	1.5666	40.744	0.16	22	37	25.248
6	37	1.0265	16.17766	0.2824	1.5666	40.686	0.16	18	38	29.113
7	38	1.0262	15.88329	0.2773	1.5667	40.627	0.16	21	37	26.002
8	39	1.0258	15.58421	0.2720	1.5668	40.568	0.16	21	35	24.286
9	40	1.0255	15.28051	0.2667	1.5669	40.507	0.16	19	36	26.722
10	41	1.0251	14.97229	0.2613	1.5670	40.445	0.16	21	36	25.063
11	42	1.0247	14.65962	0.2559	1.5670	40.382	0.16	16	37	29.609
12	43	1.0244	14.34262	0.2504	1.5671	40.318	0.16	17	36	28.119
13	44	1.0240	14.02136	0.2448	1.5672	40.254	0.16	19	36	26.555
14	45	1.0236	13.69595	0.2391	1.5673	40.188	0.16	17	36	28.028
15	46	1.0232	13.36648	0.2333	1.5674	40.121	0.16	19	35	25.677
16	47	1.0228	13.03305	0.2275	1.5675	40.053	0.16	23	37	23.979
17	48	1.0224	12.69576	0.2216	1.5675	39.985	0.16	20	39	27.886
18	49	1.0219	12.3547	0.2157	1.5676	39.915	0.16	19	34	24.735
19	50	1.0215	12.00999	0.2096	1.5677	39.845	0.16	22	38	25.501
20	51	1.0211	11.66171	0.2036	1.5678	39.774	0.16	22	39	26.239
21	52	1.0206	11.30998	0.1974	1.5679	39.702	0.16	24	38	23.768
22	53	1.0202	10.9549	0.1912	1.5680	39.629	0.16	21	39	26.901
23	54	1.0197	10.59657	0.1850	1.5681	39.556	0.16	23	38	24.512
24	55	1.0193	10.2351	0.1787	1.5682	39.482	0.16	21	36	24.466
25	56	1.0188	9.870604	0.1723	1.5683	39.407	0.16	21	38	25.997
26	57	1.0183	9.503179	0.1659	1.5684	39.331	0.16	34	38	12.586
27	58	1.0179	9.132938	0.1594	1.5685	39.255	0.16	32	37	14.044
28	59	1.0174	8.75999	0.1529	1.5685	39.178	0.16	27	37	19.823
29	60	1.0169	8.384447	0.1464	1.5686	39.100	0.16	26	37	20.749

Table 2: Calculated parameters

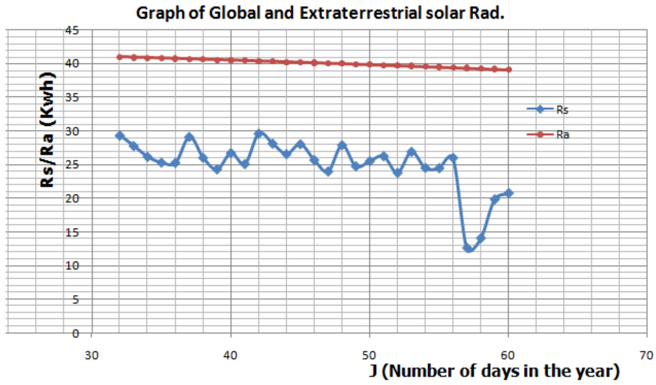

Figure 1: Graph of global solar radiations and extraterrestrial radiations

This study made use of Hargreaves-Samani model to estimate the global solar radiation of Abuja using minimum-maximum temperature data of February, 2016. The data was adopted from the archive of weather online on their website - http://www.weatheronline.co.uk/weather/maps/. The data was gotten from their website on November 6, 2016.

The values of various terms including the extraterrestrial radiations were calculated using their various formulas in a Microsoft excel worksheet.

The results as shown in table 2 indicate that maximum global solar radiation of Abuja for the period under study was 29.609kwh while the minimum radiation was 12.044kwh. These radiations occurred at the maximum/minimum temperatures of 37^0c /16^0c, and 38^0c/34^0c respectively. The increase in the maximum value of the global solar radiations from 26.491kwh in the work done by Ugwu, A. I and Ugwuanyi, J. U. in 2011 for the month of January 2009 to 29.609kwh in February 2016 for the same Abuja may be attributed to the effects of global warming which has resulted in making the surface of the earth warmer than it should be. The implication is that if this gradual increase in global solar radiation (3.118kwh) in seven years (2009 -2016) is not checked, it will reach a period in which its effect will be unhealthy for humans and other living things- fishes, livestock, crops on the farm, etc. The control of this can be done through proper environmental management such as planting of trees, aforestation, avoiding or reducing the use environmental polluting fuels amongst others. On the other hand, it is a welcome development in the area of alternative power supply especially the solar power system which is presently seen by many Nigerians and even many parts of the world as one of the solutions to regular epileptic power supply.

Fig. 1 shows the graphical relationship between the extraterrestrial solar radiation and global solar radiation. The figure shows that there is no defined relationship between the two radiations as regards this work. As the extraterrestrial solar radiation decreases slowly and linearly from left towards right, and global solar radiation decreases and increases in random form, and at one point decreases sharply from left towards right. The sharp decrement in the global solar radiation might be due to the "uncommon" minimum temperature value of 34^0c that occured at that point.

IV. CONCLUSION

The data of maximum and minimum temperature values adopted from the website of weather online limited have been used to determine the extraterrestrial solar radiation and global solar radiation of Abuja. The computations of various parameters were done in excel worksheet using their formulas. From the computations, the global and extraterrestrial solar radiations where gotten using Hargreaves-Samani's model, such that the daily maximum and minimum global solarI. radiations are 29.606kwh and 12.044kwh in that order, while the daily maximum and minimum extraterrestrial solar radiations are 40.973kwh and 39.1kwh respectively. The maximum global solar radiation of 29.606kwh shows the increase in its value from 26.491kwh predicted by Ugwu, A. I and Ugwuanyi, J. U. in 2011, in their work in which maximum and minimum temperature data of Abuja adopted from Nigeria Meteorological Agency (NIMET) for the month of January, 2009 was used to predict global solar radiation of the area using Hargreaves-Samani's model. The 3.118kwh rise in global solar radiation in seven years (2009-2016) as seen in this work may be attributed to global warming, and adequate measures should be put in place by environmental regulatory agencies in the country to prevent further such increase.

V. RECOMMENDATIONS

Although, the data used by Ugwu, A. I and Ugwuanyi, J. U. for their work was adopted from Nigeria Meteorological Agency (NIMET) , and the one used in this work was adopted from weather online limited (http://www.weatheronline.co.uk/weather/), the results from the two works agreed with each other to some extent. The prediction of the global solar radiations of Abuja during rainy season and early part of harmattan period should be used in further research works.

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