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# ESTIMATION OF GLOBAL SOLAR RADIATION OF PORTHARCOURT, NIGERIA

# AND HOW IT IS INFLUENCED BY DAILY TEMPERATURE RANGE

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**Abstract**

The total amount of solar radiation reaching the earth's surface in a particular location affects both plants and animals positively and negatively, hence the need to know its value at a particular period. The objectives of this work are to determine the daily Global Solar Radiation of Portharcourt, and to determine how temperature ranges affects its value. Hargreaves-Samani model was used for the Global Solar Radiation of the area using the maximum and minimum temperature data for December 2016, obtained from the achieve of weather online limited. The result shows the maximum and minimum Global Solar Radiations of 23.038MJ/$m^2$day and12.79MJ/$m^2$day in that order for the month of December. It was also concluded that the Global Solar Radiation of the area increases with increase in daily temperature range and vice versa.

*Keywords: Solar energy, Temperature, Hargreaves-Samani model, Sunset angle, livestock*

## 1. Introduction

A global study of the world distribution of global solar radiation requires knowledge of the radiation data in various countries and for the purpose of worldwide marketing, the designers and manufacturers of solar equipment will need to know the mean global solar radiation available in different and specific regions (Ibrahim, 1985).

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 (Ayegba, *et al*, 2016).

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]. Thus, there is need to estimate the global solar radiation of Portharcourt after some years in which such research works were carried out in the area. Similar works, though with different methods have been done in the area under study as well as other parts of the country.

In the work of Augustine C. and Nnabuchi M. N. (2009), monthly mean daily data for global solar radiation and sunshine hours for a period of seventeen years (1999 - 2007) for Calabar, Enugu and Port Harcourt respectively were used determine the mean monthly global solar radiation of the study areas. It was observed that the measured monthly mean daily global radiation was 14.37MJ/$m^2$day. Also, D. O. Akpootu and Y. A. Sanusi (2015) carried out another work using the method that is almost similar to that of Augustine C. and Nnabuchi M. N. in 2009. In the work, multiple linear temperature-based regression models were developed to estimate the monthly mean daily global solar radiation on horizontal surfaces using maximum and minimum temperature parameters of 1990-2010 for Port-Harcourt obtained from Nigeria Meteorological Agency (NIMET), Oshodi, Lagos, Nigeria.

Chiemeka, I. U. in 2008 predicted the solar radiation at Uturu Abia state Nigeria, latitude 5.33˚N and 6.33˚N using the temperature data from 5th – 31st October 2007, gotten from the maximum and minimum thermometer placed in Stevenson screen at 1.5m. He used the Hargreaves-Samani model and observed that the mean global solar radiation obtained for the period was 1.89 - 0.82 kWh per day. He attributed the poor value gotten to the fact that Uturu is bounded on the west and south by a hilly escarpment.

This work intends to predict the global solar radiation of Portharcourt, as well as determining how the global solar radiation of the area is affected by daily temperature range.

## 2. Study area

The study area, Portharcourt is located in South-South Nigeria. It lies along Bonny River and is the capital of River state as well as the largest city in Rivers state. The study area has two major seasons namely the wet and dry seasons, with the rainy season from April to November while the dry season is from December to February. Portharcourt lies between latitude 4.70$^0$N and 4.83$^0$N, and longitude 6.93$^0$E and 7.11$^0$E. Its warmest period is from February to April.

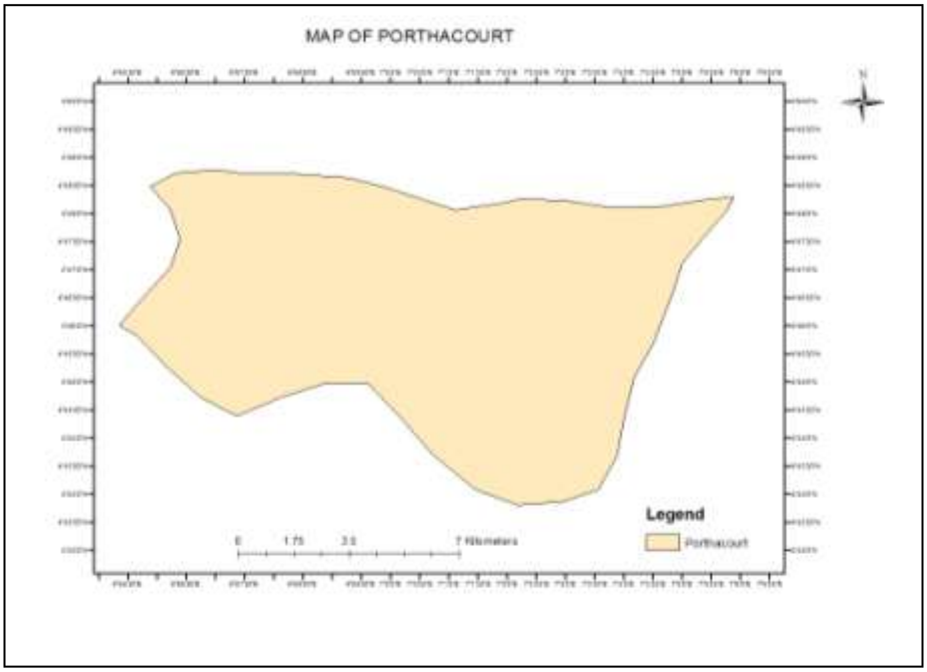


Fig.1: Map of the study area

## 3. Materials and Methods

**3.1 Materials:** The material used for the work is the data of maximum and minimum temperature gotten from the achieve of weather online limited. Microsoft excel worksheet was used for the computations and plotting of graphs while ArcGIS software (version 10.3) was used to create the map of the study area.

**3.2 Methods:** This work makes use of Hargreaves-Samani model of global solar radiation prediction. The Hargreaves-Samani equation is given as:

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

Where $T_{max}$ is the maximum temperature ($^0$c), $T_{min}$ is minimum temperature ($^0$c), $R_a$ is the extraterrestrial solar radiation (MJ/m$^2$day) and $K_{Rs}$ is adjustment coefficient (does not have unit).

$K_{Rs}$ has the value of approximately 0.16 for interior area (i.e. area not close the water body) and approximately 0.19 for coastal locations (situated on the coast of a large land mass and where air masses are influenced by a nearby water body). In this design, the value of $K_{Rs}$ in this design is 0.19 because of proximity of Portharcourt to water body.

### 3.2.1 Analysis for the prediction of Global Solar Radiation

The following the procedure followed in determining global solar radiation.

**i. Calculation of solar radiation declination:** Solar radiation declination is defined as 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 is represented mathematically as;

$$\delta = 0.409 Sin\left(\frac{2\pi}{365}J - 1.39\right) \text{ ----------------------------- } 2$$

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

ii. **Calculation of inverse relative distance Earth-sun:** Inverse relative distance Earth-sun is the inverse distance of the sun relative to the earth at a location. It is represented as;

$$d_r = 1 + 0.033 Cos\left(\frac{2\pi J}{365}\right) \text{ ---------------- } 3$$

iii. **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. It is calculated using the formula given as;

$$\omega_s = Cos^{-1}\left(-\tan(\varphi)\tan(\delta)\right) \text{ ----------------- } 4$$

Where $\omega_s$ is sunset angle in radian, $\delta$ is the solar radiation declination in radian, and $\varphi$ is latitude angle of the location in radian.

iv. **Calculation of extraterrestrial solar radiation:** Extraterrestrial solar radiation is the intensity or power of the sun at the top of the earth's surface. The extraterrestrial radiation is calculated using;

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

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

**Calculation of Global Solar Radiation:** Global solar radiation is the total amount of solar energy received by earth's surface. It is the sum of the direct, diffuse and reflected solar radiations, as is calculated using the formula given as;

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

Table 1: Data of maximum and minimum temperature for the month of December, 2016, obtained from the archive of weather online limited.

| Tmax | Tmin |
|---|---|
| **34** | 27 |
| **33** | 24 |
| **31** | 24 |
| **30** | 26 |
| **33** | 20 |
| **34** | 23 |
| **34** | 27 |
| **32** | 23 |
| **34** | 23 |
| **31** | 24 |
| **34** | 23 |
| **31** | 21 |
| **34** | 22 |
| **33** | 23 |
| **32** | 23 |
| **32** | 23 |
| **34** | 25 |
| **34** | 24 |
| **34** | 23 |
| **34** | 25 |
| **33** | 23 |
| **34** | 24 |
| **34** | 23 |
| **33** | 24 |
| **34** | 21 |
| **30** | 19 |
| **31** | 20 |
| **33** | 21 |

| | |
|---|---|
| **32** | 19 |
| **34** | 24 |
| **33** | 24 |

## 4.0 Results and discussions

### 4.1 Results

Table 2: Calculated parameters

| s/n | J | φ(rad) | dr (rad) | δ (rad) | ws | Ra ($MJ/m^2day$) | Tmax | Tmin | ks | Rs |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 336 | 0.0841 | 1.0290 | -0.3885 | 1.5363 | 33.749 | 34 | 27 | 0.19 | 16.965 |
| **2** | 337 | 0.0841 | 1.0293 | -0.3907 | 1.5361 | 33.716 | 33 | 24 | 0.19 | 19.218 |
| **3** | 338 | 0.0841 | 1.0295 | -0.3927 | 1.5359 | 33.686 | 31 | 24 | 0.19 | 16.934 |
| **4** | 339 | 0.0841 | 1.0298 | -0.3946 | 1.5357 | 33.657 | 30 | 26 | 0.19 | 12.790 |
| **5** | 340 | 0.0841 | 1.0300 | -0.3964 | 1.5355 | 33.630 | 33 | 20 | 0.19 | 23.038 |
| **6** | 341 | 0.0841 | 1.0302 | -0.3981 | 1.5353 | 33.605 | 34 | 23 | 0.19 | 21.176 |
| **7** | 342 | 0.0841 | 1.0305 | -0.3996 | 1.5352 | 33.582 | 34 | 27 | 0.19 | 16.881 |
| **8** | 343 | 0.0841 | 1.0307 | -0.4011 | 1.5350 | 33.560 | 32 | 23 | 0.19 | 19.129 |
| **9** | 344 | 0.0841 | 1.0309 | -0.4024 | 1.5349 | 33.541 | 34 | 23 | 0.19 | 21.136 |
| **10** | 345 | 0.0841 | 1.0311 | -0.4036 | 1.5348 | 33.524 | 31 | 24 | 0.19 | 16.852 |
| **11** | 346 | 0.0841 | 1.0313 | -0.4047 | 1.5347 | 33.508 | 34 | 23 | 0.19 | 21.116 |
| **12** | 347 | 0.0841 | 1.0314 | -0.4056 | 1.5346 | 33.495 | 31 | 21 | 0.19 | 20.125 |
| **13** | 348 | 0.0841 | 1.0316 | -0.4065 | 1.5345 | 33.484 | 34 | 22 | 0.19 | 22.038 |
| **14** | 349 | 0.0841 | 1.0318 | -0.4072 | 1.5344 | 33.475 | 33 | 23 | 0.19 | 20.113 |
| **15** | 350 | 0.0841 | 1.0319 | -0.4078 | 1.5344 | 33.468 | 32 | 23 | 0.19 | 19.077 |
| **16** | 351 | 0.0841 | 1.0321 | -0.4083 | 1.5343 | 33.463 | 32 | 23 | 0.19 | 19.074 |
| **17** | 352 | 0.0841 | 1.0322 | -0.4086 | 1.5343 | 33.460 | 34 | 25 | 0.19 | 19.072 |
| **18** | 353 | 0.0841 | 1.0323 | -0.4089 | 1.5342 | 33.459 | 34 | 24 | 0.19 | 20.103 |
| **19** | 354 | 0.0841 | 1.0324 | -0.4090 | 1.5342 | 33.460 | 34 | 23 | 0.19 | 21.085 |
| **20** | 355 | 0.0841 | 1.0325 | -0.4090 | 1.5342 | 33.464 | 34 | 25 | 0.19 | 19.074 |
| **21** | 356 | 0.0841 | 1.0326 | -0.4089 | 1.5342 | 33.469 | 33 | 23 | 0.19 | 20.109 |
| **22** | 357 | 0.0841 | 1.0327 | -0.4086 | 1.5343 | 33.477 | 34 | 24 | 0.19 | 20.114 |
| **23** | 358 | 0.0841 | 1.0328 | -0.4082 | 1.5343 | 33.487 | 34 | 23 | 0.19 | 21.102 |
| **24** | 359 | 0.0841 | 1.0328 | -0.4077 | 1.5344 | 33.498 | 33 | 24 | 0.19 | 19.094 |
| **25** | 360 | 0.0841 | 1.0329 | -0.4071 | 1.5344 | 33.512 | 34 | 21 | 0.19 | 22.958 |
| **26** | 361 | 0.0841 | 1.0329 | -0.4064 | 1.5345 | 33.528 | 30 | 19 | 0.19 | 21.128 |
| **27** | 362 | 0.0841 | 1.0330 | -0.4056 | 1.5346 | 33.546 | 31 | 20 | 0.19 | 21.140 |
| **28** | 363 | 0.0841 | 1.0330 | -0.4046 | 1.5347 | 33.566 | 33 | 21 | 0.19 | 22.093 |
| **29** | 364 | 0.0841 | 1.0330 | -0.4035 | 1.5348 | 33.588 | 32 | 19 | 0.19 | 23.010 |
| **30** | 365 | 0.0841 | 1.0330 | -0.4023 | 1.5349 | 33.613 | 34 | 24 | 0.19 | 20.196 |
| **31** | 366 | 0.0841 | 1.0330 | -0.4009 | 1.5350 | 33.639 | 33 | 24 | 0.19 | 19.174 |

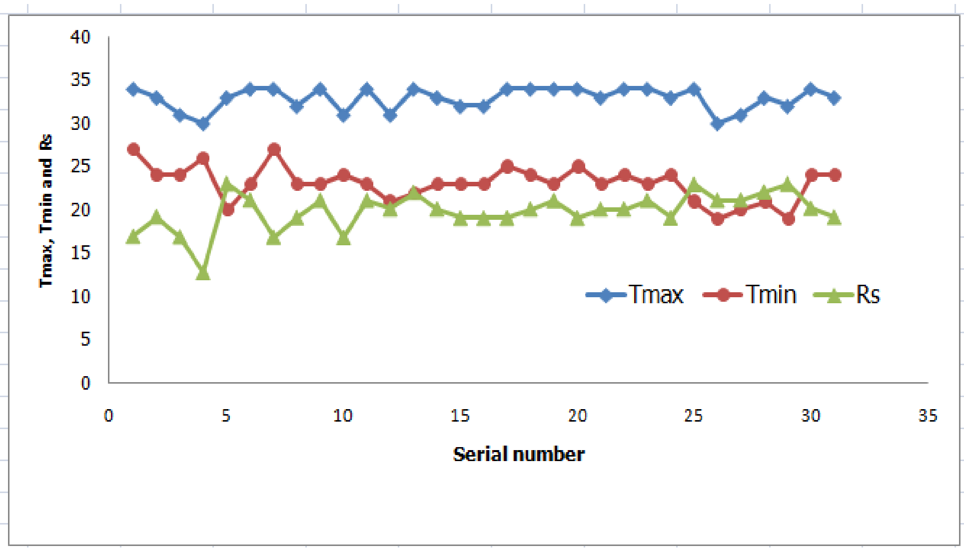


Fig.2: Graph of global solar radiation, maximum and minimum temperature

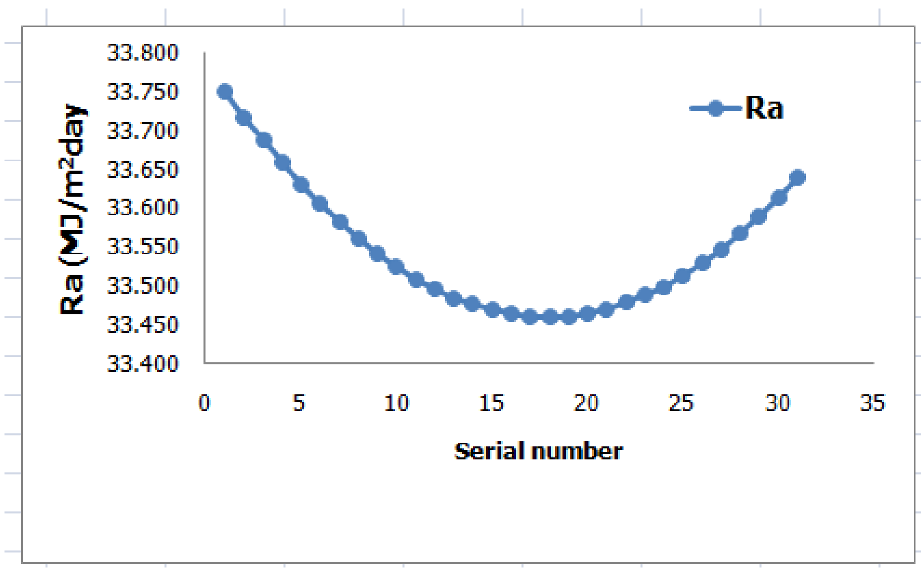


Fig. 3: Graph of extraterrestrial solar radiation

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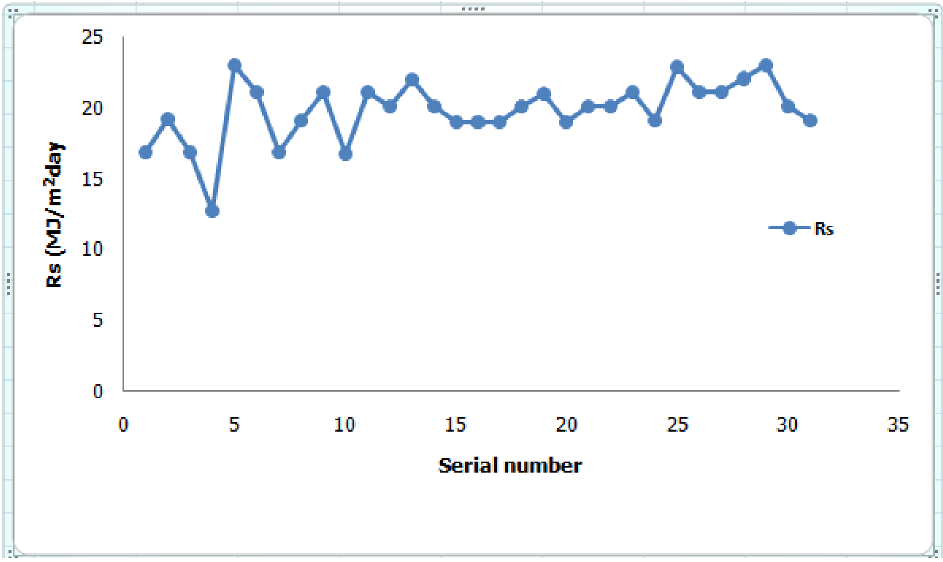


Fig. 4: Graph of Global solar radiation

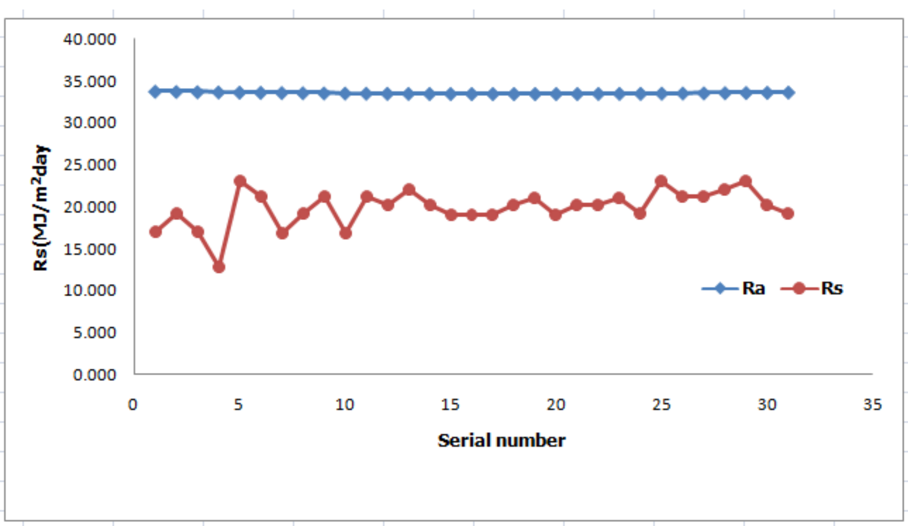


Fig. 5: Graph of global solar radiation and extraterrestrial solar radiation.

## 4.2 Discussions

The data of maximum and minimum temperature of Portharcourt for the month of December, 2016 obtained from the achieve of weather online limited was used to predict the Global Solar Radiation of the study area. The work employs the Hargreave-Samanni model of Global Solar Radiation prediction. From the analysis, it was observed that the maximum Global Solar

Radiation of Porthacourt for the month of December was 23.038 $MJ/m^2day$ while the minimum value was 12.79 $MJ/m^2day$ (Table 2). In a work done by D. O. Akpootu and Y. A. Sanusi (2015) in which the maximum and minimum temperature data from 1990 to 2010 was used to estimate the monthly global solar radiation of Portharcourt, it was observed that measured global solar radiation for the month of December was 20.0157$MJ/m^2day$. Thus, the maximum value of 23.038 $MJ/m^2day$ gotten from this work though greater than the one for 1990-2010 data is an indication of gradual increase in the solar radiation reaching the surface of the earth , a situation which can be attributed to global warming. The Global Solar Radiation (Rs) variation does not affect the extraterrestrial solar radiation (Ra), as the extraterrestrial solar radiation appears to be linear in its change while the global solar radiation varies in random form, as shown in figure 5. Fig. 2 represents the relationship between the Global Solar radiation, maximum and minimum temperatures. It was observed that the global solar radiation of the study area was at its highest level when the difference between the maximum and minimum temperature of a particular day was the highest among the differences, and it was at its lowest level when the difference between the maximum and minimum temperature of a particular day was the least. The maximum and minimum Global Solar Radiations occurred when the temperature differences were $13^0c$ and 4 $^0c$ respectively. In other words, global solar radiation is not directly affected by maximum or minimum temperature of the day but the difference between the daily maximum and minimum temperature of the area. Furthermore, the mean daily Global Solar Radiation for the month was 19.842 $MJ/m^2day$ . This result agrees with the work of Augustine C. and Nnabuchi M. N in 2009. In their work, the mean daily global solar radiation for the month of December, 2009 was 14.37 $MJ/m^2day$. The increase in the radiation by 5.472 from 2009 to 2016 was as a result of global warming currently experienced in many parts of the world. This result will be important for environmental management personnel as the situation could pose danger when allowed to continue in this form without putting measures in place by respective bodies. It is also important to Agriculturists because the change or continuous increase in Global Solar Radiation of an area will no doubt affect the crops on the farm as well as the livestock.

## 5. Conclusion

From the results, it was discovered that the minimum and maximum daily global solar radiation are 12.79$MJ/m^2day$ and 23.038$MJ/m^2day$, while the mean daily global solar radiation was

19.842 $MJ/m^2day$, a value which to a large extent agrees with the result of Augustine C. and Nnabuchi M. N in 2009 for the same area. In addition, the measured global solar radiation of 20.0157$MJ/m^2day$ for the month of December between 1990-2010 by D. O. Akpootu and Y. A. Sanusi (2015) and the maximum value of 23.038 $MJ/m^2day$ and mean daily value of 19.842 $MJ/m^2day$ are in agreement considering the current increase in solar radiation reaching the earth's surface across the globe. As for the influence of daily temperature ranges on global solar radiations, it can be concluded that daily global solar radiation increases with increase in daily temperature range or difference and vice versa. Thus, global solar radiation will be high when the temperature difference of the day is high and it will be low when the temperature difference of the day is low. Furthermore, the minimum and maximum daily global solar radiation of 12.79$MJ/m^2day$ and 23.038$MJ/m^2day$ translate to 3.553kwhr and 6.399kwhr per square meter of solar energy, and with the solar energy conversion of about 10% (Sunday, 2011), there will be available energy of 0.35kwhr to 0.64kwr for every square meter area of solar cells exposed to space in the area. Solar power system engineers and installers will find this information valuable.

## 6. Recommendation

This research work makes use of data of maximum and minimum temperature of only the month of December for 2016. Although the result gotten agrees with the previous works done in the area by some researchers, data of some recent years such as between 2010 and 2016 should be used for further research work.

## 7. Acknowledgement

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