NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Evaluation of the Mean Solar Energy Potential at Usen Metropolis, Edo State, Nigeria

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Article Info

Keywords: *Solar radiation, Hargreaves-samani's equation, temperature, extraterrestrial, climatological*

Received 09 May 2023
Revised 30 May 2023
Accepted 19 June 2023
Available online 3 Sept. 2023

https://doi.org/10.5281/zenodo.8313027

ISSN-2682-5821/

Abstract

This study investigates the average solar radiation potential in Usen metropolis of Nigeria, for a period of October, 2022 through January, 2023, Usen lies between Latitude 70 ^{0} 14^1 North and 70^0 34^1 North of equator and Longitude 60^0 14^1 East of Greenwich Meridian. The climate is sub humid and the average temperature is about 40^{0}C in dry season. The method employed involved the use of Hargreave-samani's equations as a method of estimating the Solar radiation using minimum climatological data that will record daily maximum and minimum temperatures for the four (4) months while the weather station parameters (sunset, hour angle, extraterrestrial solar radiation etc) were directly derived from the latitude of the area. Results obtained revealed that the Solar radiation of Usen Metropolis of Nigeria within the period of investigation exhibit monthly variation with mean values of 20.21,22.89, 25.03 and22.29MJ/m^2/day respectively in the months of October, 2022 to January,2023. While the average of 22.6/6MJ/m^2/day for the four months. The information obtained from this study experimentation will go a long way to establish a solar irradiation data in the area which will then form a baseline for any planned application of solar irradiation in the area such as design of Solar photovoltaic systems.

1.0. Introduction

The main objective of photovoltaic (PV) research industry is to develop high efficiency low-cost photo voltage cells (modules). Photovoltaic technology clearly offers tremendous environmental benefits in that it requires no fuel and produces no emissions or other waste beyond that inherent in the manufacturing process. Moreover, photovoltaic have proven to be deployed for a wide range of applications that have traditionally relied on diesel generators. The use of photovoltaic cell has increased in the last few decades as their manufacturing cost have decreased and as many people have become more concerned about energy use.

Unfortunately, solar cells are still far too expensive to produce a significant fraction of the world's energy needs. Solar radiation is the radiant energy that is emitted by the sum from a nuclear fusion reaction that creates electromagnetic energy [1], it is the main driving force of the processes in the atmosphere, as well as the biosphere.

The knowledge of solar radiation data is also indispensable for many solar energy related applications comprehensive knowledge of solar radiation of a particular location is a useful tool in the study and design of the economic viability of devices that depend on the use of solar energy. Knowing the amount of solar radiation in a given location or area is essential in the field of solar

energy physics and in the design and installation of solar photovoltaic systems. This is effect helps one to have a fair knowledge of the insolation power potential of the location or area.
Solar is the most abundant source of energy in the world. The energy from the sum can be harnessed through solar thermal systems, passive heating systems and photovoltaic (PV) system. The limitations of solar energy include: efficiency of converters, affected by clouds and aerosols,[2], and chaotic [3] solar energy is significant for tropical countries due to their population, better access to solar radiation, and impact on the economy through tourism.
Consequent upon this, a large number of researches on solar radiation exist in literature. Notable one is [4] reported that solar energy has more potential than wind energy in Akure, Ondo State of Nigeria, [5] estimated the solar potential for three locations within Nigeria using simulated Typical Meteorological year (TMY2) data. The authors reported solar radiation potential for Kano, Onitsha and Lagos as 6.08, 4.43 and 4.42KWhm^{-2} respectively. The solar radiation potential in the Northern and Southern region of Nigeria has been reported as 5.62 up to 7.01 and 3.54 up to 5.43 KWhm^{-2} respectively using artificial neural network [6]. The need to study and investigate mean solar energy potential at Usen metropolis of Edo State, Nigeria at high temporal resolution using in-situ-data has necessitated this study. This per investigates the variation of temperature and solar radiation, as well as solar energy potential for selected locations in Usen.

2.0. Materials and Methods

In this study, Hargreave-Samani's method of estimating Solar radiation from maximum and minimum daily temperatures was employed. The Hargreave-Samani's equations were used to determine the solar radiation in Usen Metropli of Nigeria based on the available climatological parameters of measured maximum and minimum temperatures. The temperature data were recorded for period of four months (October, 2022 to January, 2023) in Usen, A Mercury Thermometer was placed on top of an array of solar panels and the temperature readings taken from 6.00am to 8.00pm daily for the four months. The maximum and minimum daily temperatures were obtained and used in the [7] in Equation (1).

$$R_s = k_p (T_{max} - T_{min})^{0.4} R_a \qquad (1)$$

Where, Tmax and T_{min} are mean daily maximum and minimum air temperature (^{0}c)
Ra: is the extraterrestrial solar radiation
K_8 : is the empirical coefficient:[8] recommended value for
K_1 = 0.16 for interior region and
Kr = 0.19 for coastal regime, Usen, being related in an interior position, Kr was taken as 0.16
The R_a in MJ/m^2/day was calculated for a given day of the year and latitude using [9]
Equations

$$Ra = \frac{1440}{\pi} (G_{sc} dr/\psi s \sin(\text{Ø}) \sin(\delta) + \text{Cos}(\theta)\,\text{Cos}(\delta)\,\text{Sin}(\psi s)) - \qquad (2)$$

Where,
G_{se} = Solar constant (0.0820MJ/M^2/minute)
dr = Inverse relative distance from the earth to the sun
Ψs = Sunset hour angle (rad)
δ = Latitude (rad) and δ = solar declination
In equation 2

$$dr = 1 + 0.0033 \text{ Cos } \left(\frac{2\pi JD}{365} \right) \qquad (3)$$

$\delta = 0.409\sin\left(\frac{2\pi JD}{365} - 1..39\right)$ (4)

$\Psi s \;= \arc(-\tan\,\theta\tan\delta\,)$ (5)

Where JD = day of the year

From the daily maximum and minimum temperatures readings, the temperature difference (TD) and mean temperature were calculated for each day and Table 1.0 shown the summary of the temperature values for the months 2nd October, 2022 to January, 2023. While Table 2.0 shown how dr, δ , Ψs , R_a and R_s were calculated for 1st of January, 2023.

Table 1: Maximum and Minimum Temperature Readings for the Months of October, 2022 to January, 2023

	OCTOBER				NOVEMBER					DECEMBER			JANUARY			
Date	**T_{max} ^0C**	**T_{min} ^0C**	**T.D**	**T.a**	**T_{max} ^0C**	**T_{min} ^0C**	**T.D**	**T.a**	**T_{max} oC**	**T_{min} oC**	**T.D**	**T.a**	**T_{max} oC**	**T_{min} oC**	**T.D**	**T.a**
1	46	27	19	36.5	43	26	17	34.5	43	26	17	33	44	30	14	37
2	46.5	29	17.5	37.8	42.5	25.5	17	34	48	27	21	37.5	42	31	11	36.5
3	45	28	17	36.5	42	25	17	33.5	47	28	19	37.5	37	27	10	32
4	47	26	21	36.5	44	25	19	34.5	48	28	20	38	41	29	12	35
5	43	27	16	35	45	25	20	35	47	27	20	37	46	31	15	38 25
6	42	26	16	34	46	28	18	37	43	28	15	34.5	43	26	17	34.5
7	41	25	16	33	46	30	16	38	46	27	19	36.5	44	31	13	37.5
8	42	26	16	34	43	28	15	35.5	47	30	17	38.5	42	29	13	35.5
9	42.5	26	16.5	34.5	47	30	17	38.5	45	28	17	36.5	41	31	10	36
10	44	27	17	35.5	45	29	16	37	46	29	17	37.5	40	26	14	33
11	43	28.5	14.5	35.8	48	28	20	38	48	28	20	38	42	30	12	36
12	42	26	16	34.3	8.5	28	10.5	33.3	45	27	18	36	40	26	14	33
13	43	26	17	34.5	43.5	26	17.5	34.8	46	29	17	37.5	38	25	13	31.5
14	46	29	17	37.5	43.5	28	15.5	35.8	45	28	17	36.5	42	26	16	34
15	46	28	18	37	43	25	18	34	46	28	18	37	40	26	14	33
16	47	27	20	37	47	30	17	38.5	47	29	18	38	42	26	16	34
17	43	23	20	33	44	26	18	35	48	30	18	39	44	23	18	35
18	42	29.5	12.5	35.8	43	29	14	36	41	28	13	34.5	36	23	13	29.5
19	44	28	16	36	44	25	19	34.5	48	30	18	39	40	25	17	31.5
20	43	29	14	36	43	26	17	34.5	46	28	18	37	36	26	11	28
21	46	28.5	17.5	37.5	46	28	18	37	45	27	18	36	41	26	15	33.5
22	45	33	12	34	45	30	15	37.5	46	27	19	36.5	39	26	13	32.5
23	44	26	18	5	45	27	18	36	46	28	18	37	45	26	19	35.5
24	42	29.5	12.5	35.8	46	30	16	38	45	25	20	35	39	28	11	33.5
25	42	24.5	15.5	33.3	45	28.5	16.5	36.8	44	28	16	36	35	27	8	31
26	45	27	18	36	44	24	20	34	43	28	16	35	33	23	10	28
27	48	33	15	40.5	46	30	16	38	37	27	20	32	43	24	19	33
28	48	30	18	39	46	26	20	36	48	28	20	38	37	24	13	30.5
29	42	26	16	3433	-	-	-	-	46	27	19	36.5	35	25	10	30
30	39	27	12	34.5	-	-			46	26	20	36	39	28	11	33.5
31	41	28	13	34.5	-	-	-	-	47	22	25	34.5	-	-	-	-

MEAN	43.9	27.5	16.2	35.9	44.4	27.4	17.1	37.1	45.6	27.6	18.3	36.5	40.2	26.8	13.4	32.4
MAX	48	33	21	40.5	48	30	20	38.5	48	30	21	39	46	31	19	38.5
MIN	39	23	12	33	42	24	10.5	33.3	41	22	13	32	33	23	10	28

Table 2.0: Summary of Temperature values for the Months of October, 2022 to January, 2023

	October, 2022				November, 2022				December, 2022				January, 2023			
	T_{max} ^0C	T_{min} ^0C	TD ^0C	T_a ^0C	T_{max} ^0C	T_{min} ^0C	TD ^0C	T_a ^0C	T_{max} ^0C	T_{min} ^0C	TD ^0C	T_a ^0C	T_{max} ^0C	T_{min} ^0C	TD ^0C	T_a ^0C
Mean	43.5	27.5	16.3	35.9	44.4	27.4	17.1	37.1	45.6	27.6	18.5	36.5	40.2	26.8	13.4	32.4
Max	48.0	33.0	21.0	40.5	48.0	30.0	20.0	38.5	48.0	30.0	21.0	39.0	46.0	31.0	19.0	38.5
Min	39.0	23.0	12.0	33.0	42.0	24.0	10.5	33.5	41.0	22.0	13.0	32.0	33.0	23.0	10.0	28.0

Source: Daily temperature readings for the Months of October, 2022 to January, 2023

Note: T_{max} = Maximum Temperature
T_{min} = Minimum Temperature
T_a = Average Temperature

Procedure: Calculation of d_r, δ, Ψ_s Ra and Rs for 1st January, 2023

1. Inverse relative distance from the earth to the sun

$$dr = 1 + 0.33\cos\frac{2\pi JD}{365}$$, Where JD = day of the year = 01

$$dr = 1 + 0.33\cos\left(\frac{2\pi 0.1}{365}\right) = 1.32995 \text{ rad}$$

2. Solar declination

$$\delta = 0.409\sin\left(\frac{2\pi JD}{365} - 1.39\right) = 0.409\sin(-1.37279) = -0.40108092 \text{ rad}$$

3. Sunset hour angle

$$\Psi_s = \text{arc Cos}(-\tan\theta\tan\delta)$$
$$= \text{arc Cos}(-\tan(0.122)\tan(-0401008092)$$
$$= \text{arc Cos}\{-0.123(-0.423)\}$$
$$= \text{arc Cos}(0.05212)$$
$$= 1.518622 \text{ rad}$$

4. Extraterrestrial solar radiation

$$Ra = \frac{1440}{\pi}\left\{C_{1sc}dr \mid Q_s \text{ Sin}(\theta) + \text{Cos}(\theta)\text{ Cos}(8)\sin(\psi)\right\}$$
$$= \frac{1440}{\pi}\left\{0.0820 \times 1.32995 \mid 1.518622 \text{ Sin}(0.122)\text{ Sin}(-0.401008092)\right\}$$
$$+ \text{Cos}(0.122)\text{ Cos}(-0401008092)\text{ Sin}(1.518622)\}$$
$$= 458.37(0.10906)1\text{-}0.0713 + 0.9117)$$
$$= 41.98 MJ/m^2/day.$$
$$= \frac{41.98 MJ/m^2/day \times 1000 KW}{60m \times 60s}$$
$$= 11.6 KWh/m^2/day$$

5. Global Solar Radiation

$$R_s = K_r (T_{max} - T_{min})^{0.5} Ra$$

$= 0.16(19)^{0.4} \times 41.98MJ/M^2/day$
$= 0.16 \times 3.25 \times 41.98$
$= 21.83MJ/m^2/day$
$= \frac{21.83MJ/m^2/day \times 1000}{60m \times 60s}$
$= 6.60KWh/m^2/day$

The procedures above was repeated for all other days from 2ndOctober, 2022to 31stJanuary,2023 and the summary of radiation values in shown in Table 3.0

Table 3.0 Summary of Radiation Values for the Months October, 2022 to January, 2023
Source: Daily temperature readings for the Months of October, 2022 to January, 2023

	October, 2022		November, 2022		December, 2022		January, 2023	
	Ra	Rs	Ra	Rs	Ra	Rs	Ra	Rs
	MJ/m²/day	MJ/m²/day	MJ/m²/day	MJ/m²/day	MJ/m²/day	MJ/m²/day	MJ/m²/day	MJ/mᵉ/day
Mean	43.02	20.21	46.01	22.89	49.13	25.03	49.80	22.29
Max	44.43	22.82	47.89	25.29	50.26	26.65	50.56	25.08
Min	41.92	18.81	44.55	20.14	47.79	22.04	50.19	18.57

Source: Calculated from data and using the appropriate formulas
Ra = Extraterrestrial Solar Radiation
Rs = Global Solar Radiation
Note: The man Global Solar radiation for the four months is $22.61MJ/m^2/day$ or $6.28KWh/m^2/day$

3.0. Results and Discussion

During the research, the calculation of maximum and minimum temperatures, extraterrestrial solar radiation and Global Solar radiation against days for the months of October, 2022 to January, 2023 as shown in Figured 1 to 12

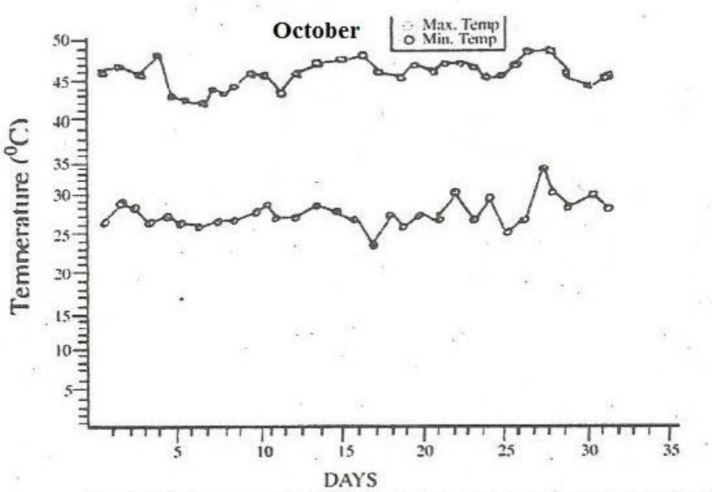

Fig 1: Maximum and Minimum Temperatures for the Month of October, 2022

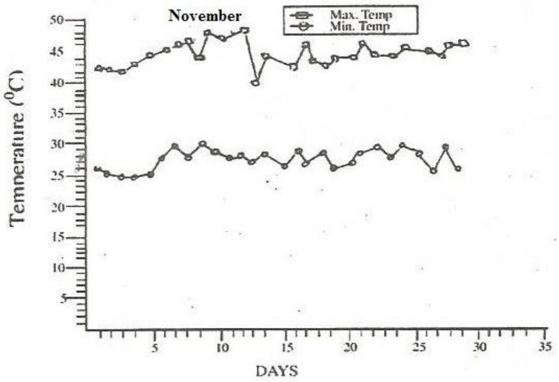

Fig 2: Maximum and Minimum Temperatures for the Month of **November 2022**

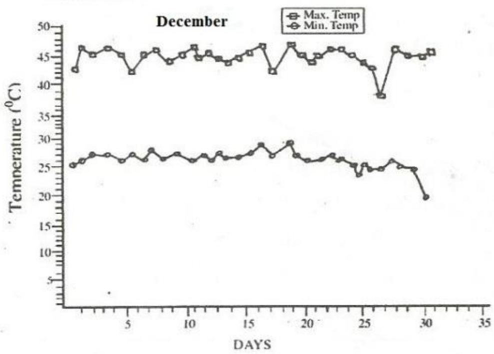

Fig 3: Maximum and Minimum Temperatures for the Month of **December, 2022**

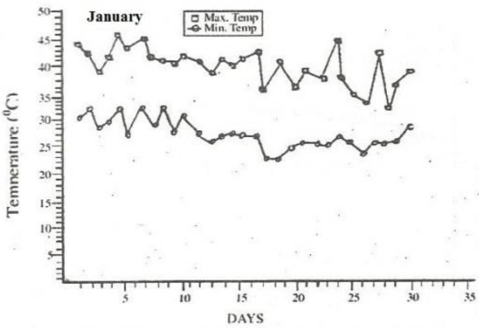

Fig 4: Maximum and Minimum Temperatures for the Month of**January, 2023**

It can be observed that the average values of temperature difference (TD) between maximum and minimum temperatures shown a slight linear widening from October, 2022 to January, 2023 (Fig 1, 2, 3 and 4). In essence, the increasing gap is a strong indicator of water vapour built up in the atmosphere and so a mark signal of linear increase in relative humidity. This gradual transit to rainy season has a linear effect of gradual widening of gap in temperature difference (TD). As can be observed from Table 3.0, the mean of the solar radiation varies between the minimum of 20.21 ± 0.04MJ/m^2/day in the month of October, 2022 to the maximum of 25.03 ± 0.04 MJ/m^2/day in January 2023. The average solar radiation for the four month is 22.61 ± 0.04MJ/m^2/day. The maximum value of solar radiation of 26.65 ± 0.04MJ/m^2/day was recorded in December, 2022 while the minimum of 18.57 ± 0.04MJ/m^2/day was recorded in the month of January, 2023. This can be linked to the fact that the maximum temperature (TD) was recorded during the month of December 2022 and the minimum in the month of January, 2023. Again, the established theory on climatic factors resurfaces by this observation.

A lot of fluctuations can be noticed in the plot of solar radiation against days in figures 9, 10, 11 and 12 with the month of January, 2023 showing the highest fluctuations. The wide gap between the two extremes in month of January, 2023 can be attributed to the change in climate from dry season to rainy season with its attendant cool, moist and aerosol laden winds as well as gradual developing clouds.

Comparing the average global solar radiation of 22.61 ± 0.04MJ /m^2/day for the four months obtained in this work with similar work carried out by [10], that reported an average solar radiation for Nigeria per day as a whole to be as high as 20MJ/m^2/day depending on the time of the year and location, it can be stated conveniently that the result obtained in this work is in strong agreement with his findings.

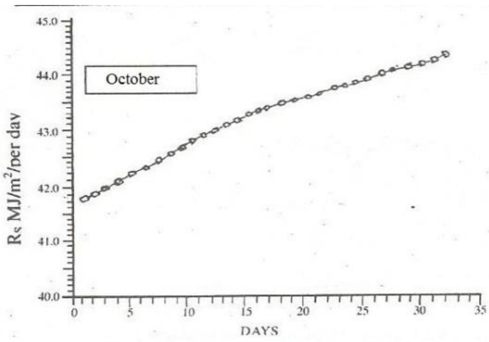

Fig 5: Extraterrestrial Solar Radiation for the Month of **October, 2022**

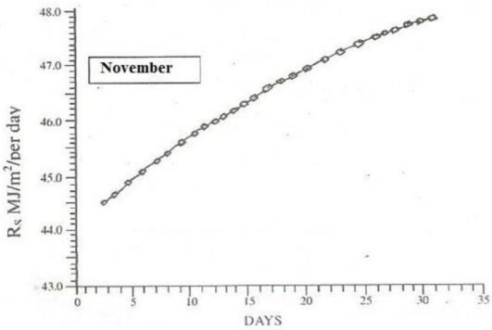

Fig 6: Extraterrestrial Solar Radiation for the Month of **November, 2022**

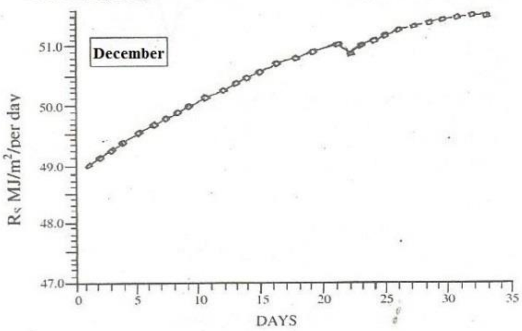

Fig 7: Extraterrestrial Solar Radiation for the Month of **December, 2022**

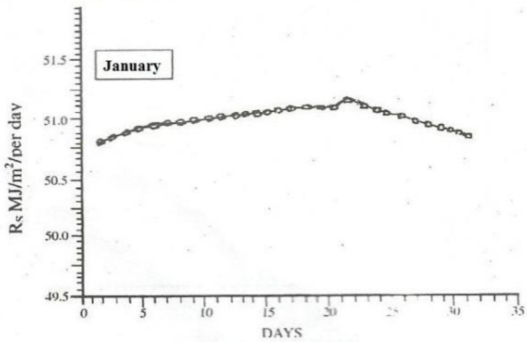

Fig 8: Extraterrestrial Solar Radiation for the Month of **January, 2023**

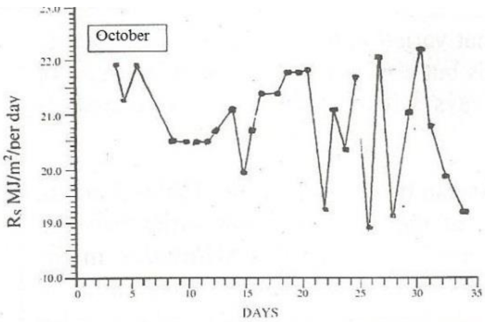

Fig 9: Global Solar Radiation from 1st to 31st **October, 2022**

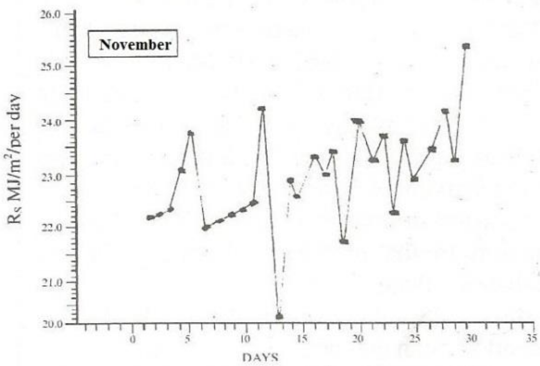

Fig 10: Global Solar Radiation from **30th November, 2022**

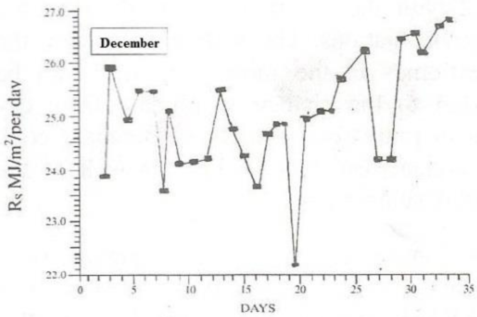

Fig 11: Global Solar Radiation from 1st to 31st **December, 2022**

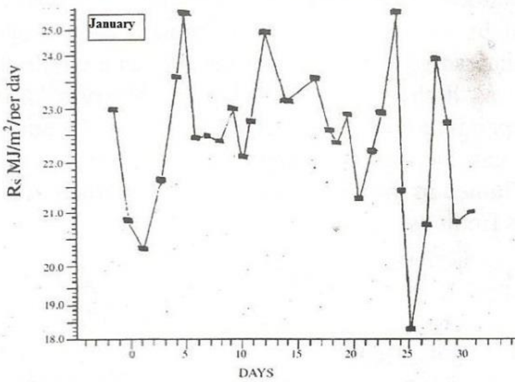

Fig 12: Global Solar Radiation from 1st to 30th **January, 202**

4.0. Conclusion and Recommendations

In this study, we have considered the variation of temperature, extraterrial solar radiation and Global Solar radiation within Usen Metropoli of Nigeria within the period of study exhibits monthly variation, mean values of 20.21, 22.89,25.03 and 22.29MJ/m$^{2/}$/day respectively in the months of October,2022 to January,2023. The average for the four months is 22.61MJ/ m^2/day which is above the 20MJ/m^2/day benchmark of good average radiation level needed for radiant energy application for solar energy source [10]. Based on observation and the result obtained in this study, the work has presented a good solar radiation application potential for Usen Area of Nigeria. Despite the very great simplification, the model employed here appears to be well suited for the estimation of daily global solar radiation and can be applied to any area or location in Nigeria or even any part of the world. The main advantages of this model when compared to other estimation methods are that it uses only daily maximum and minimum temperatures, requires no special calibration parameters while weather station parameters are directly derived from the Longitude. In addition to the above, the model provides a simple and low cost system for estimating solar radiations. The model is well suited for most agro-meteorological solar radiation data and can be used in areas where radiation is rarely measured by meteorological stations. Results obtained and presented in this study will be useful in the achievement of the sustainable development goals within the country. It is hereby recommended that:

1. Governments at all levels should sponsor researches on solar energy.
2. Researchers should pay more interest to the design and fabrication of solar power systems.
3.This research carried out at Uromi should be duplicated in other towns and cities in Nigeria..

Acknowledgement

The authors would like to express their sincere gratitude to the management of Edo State Polytechnic, Usen and Tertiary Education Trust Fund (Tetfund) for the financial support provided for this study.

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