



Assessment of the Global Solar Energy Potential in Ilorin, Kwara State. North Central Nigeria

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ABSTRACT

This paper assessed the solar energy potential of Ilorin, Kwara State Capital, North Central Nigeria, for a period of four years (2005-2008) using monthly average of maximum and minimum temperatures, solar radiation and latitude as obtained from the Nigeria Meteorological Agency (NIMET), Ilorin state office, and analysed. Ilorin the capital city of kwara state, Nigeria is located on latitude 9.70N and longitude 4.50E with an area of about 100 km². Procedure employed involved the use of Hargreaves-Samani's equation as a method of estimating Global solar radiation using minimum climatological data. The values of the global solar radiation for the period under study varies from 14.04-22.42 MJm⁻² month⁻¹ in 2005, 14.00 - 22.20 MJm⁻² month⁻¹ in 2006, 16.20 - 22.58 MJm⁻² month⁻¹ in 2007, and 15.04 - 22.97 MJm⁻² month⁻¹ in 2008. These values suggest that there is potential in solar radiation reaching Ilorin. The result from this study conducted indicates that there exists a huge solar irradiation potential that can be used as a base line for any possible application of solar irradiation generation in Ilorin.

Keywords: Solar radiation, Energy, Potentials

INTRODUCTION

Solar radiation is the main driving force of the processes in the atmosphere, as well as in the biosphere. Therefore, it is very important to humanity as it can be used for space heating, solar water heating and for electricity generation. Knowledge of solar radiation data is also indispensable for many solar-energy-related applications (Nando, 2012). Comprehensive knowledge of global solar radiation of a particular location is a useful tool in study and design of the economic viability of devices that depends on use of solar energy. There is need for the development of renewable energy resources in order to have a stable, reliable, and pollution free resources that will do away with the use of convectional energy resources to produce energy (Offiong, 2003). Currently, a high proportion of the world total energy productions are generated from fossil fuel such as oil and coal. The trends of energy indicate that world oil production will reach peak and start a long downward slide when the fossil fuel and gas would have been consumed (Offiong, 2003). The studies that have gained speed on the new and renewable energy sources are encouraged because energy resources used

today are rapidly decreasing and cause environmental pollution. Solar radiation is the largest renewable energy source and it has been studied recently due to its importance. The Knowledge of the declining level of these resources and their related environmental challenges has necessitated the shift emphasis from use of fossil fuels to the renewable energy resources such as solar radiation generation (Chineke, 2002).

As a result of declining supply of natural gas, increase emphasis on the use of solar energy and other renewable energy sources in generating electricity should be developed in order to eliminate problems associated with the use of convection energy resources. Solar energy is abundant, free and clean. Now that there is the campaign for the popularization of solar energy for domestic and industrial uses, the need to know how to evaluate insulation levels for any

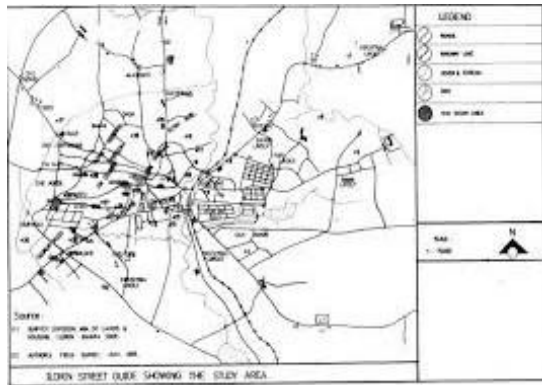
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site becomes paramount. When that is done, the introduction and sustainability of solar energy



meeting point between the Northern and Southern cultures (Oyebanji, 1993).

Fig. 1: Map of Ilorin municipality showing physical features

technology will be assured (Babatunde, 1988). This paper is aimed at assessing the Global solar energy potential of the study location. Thus, it focused at estimating the solar irradiation potential in Ilorin using monthly average of maximum and minimum temperatures, solar radiation and latitude, as obtained from NIMET, as well as to use Hargreave’s Equation to compute the Global solar radiation reaching the study location. and to established solar irradiation data on the location which then forms a base line for the design and performance of solar application system in the area.

Data Collection and Treatment

In this research, the Hargreaves Equation is used to assess the global solar radiation in Ilorin, based on the available climatological parameters. The study make use of monthly average maximum and minimum temperatures, solar radiation and latitude as obtained from the Nigeria meteorological agency (NIMET), Ilorin office and analysed.

It is globally accepted that fossil fuels are finite and it is only for a matter of time before their reserves becomes exhausted. Estimate of reserves of fossil fuel all reach the same conclusion that extensive use of these reserves worldwide and in the current manner will continue for no more than some decades to come. So the need for supplementary and even alternatives that will be non-depletable energy resource have been recognized and referred to as renewable energy resources. So, the knowledge of the amount of solar radiation in a given location is essential in the field of solar energy physics. This in effect helps one to have a fair knowledge of the insulation power potential over the location.

Hargreaves and Samani (1982) were among the first to suggest that R_s could be estimated from the difference between monthly average maximum and monthly average minimum air temperature and extra-terrestrial radiation. The form of the equation introduced by Hargreaves and Samani is:

$$R_s = K_r (T_{max} - T_{min})^{0.5} R_a \dots\dots\dots(1)$$

Where,

T_{max} and T_{min} = monthly average maximum and minimum air temperature ($^{\circ}C$), R_a = extra-terrestrial radiation, R_s Global solar radiation and k_r = empirical coefficient. Units of R_s and R_a are the same. Hargreaves recommended using $K_r = 0.16$ for interior region and $K_r = 0.19$ for coastal region. Ilorin, being located in the North and West coastal region, the K_r value applied is 0.19. The extra-terrestrial radiation (R_a $MJm^{-2}month^{-1}$) can be calculated by using the equation below;

$$R_a = \frac{1440}{\pi} (G_{sc} \cdot dr)(\psi s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\psi s)) \dots\dots\dots(2)$$

Where,

G_{sc} = solar constant ($0.0820 MJm^{-2}month^{-1}$), dr = inverse relative distance from earth to sun, ψs = sunset hour angle (rad), φ = latitude (rad) and δ = solar declination (rad). The values of φ , dr , δ and ψs can be calculated using the following equations;

$$dr = 1 + 0.033 \cos\left(\frac{2\pi JD}{365}\right) \dots\dots\dots(3)$$

$$\delta = 0.409 \sin\left(\frac{2\pi JD}{365} - 1.39\right) \dots\dots\dots(4)$$

$$\psi = \arccos(-\tan\varphi \tan\psi) \dots\dots\dots(5)$$

Where JD = day of the year.

METHODOLOGY

Study Area

Ilorin is the capital city of Kwara state. It is located on latitude $9.7^{\circ}N$ and longitude $4.5^{\circ}E$ with an area of about $100km^2$ squares (Kwara state Diary, 2007). It is divided into Ilorin West, Ilorin East and Ilorin South. It is situated in the transitional zone, between the forest and the savannah region of Nigeria i.e. the North and the West coastal region, it therefore serves as a

Equations (1) and (2) is then used (with inputs from equations 3,4 and 5) to compute the global solar radiations and extra-terrestrial radiation as shown in tables 1-4 below

Angstrom equation can also be used to calculate extra –terrestrial radiation on horizontal surface given by the following equation:

$$\frac{H_m}{H_o} = a + b \left(\frac{n}{N}\right) \dots\dots\dots(6)$$

H_m = monthly average daily global radiation

H_o = monthly extra-terrestrial radiation

n = monthly average daily hours of bright sunshine

N = monthly average day length

a & b = climatologically determine regression constant.

Where H_o is given by:

$$H_o = \frac{24}{\pi} I_{sc} \left(1 + 0.033 \cos \frac{360n}{365}\right) (\cos \phi \cos \delta \sin \omega_s + \frac{\pi}{180} \omega_s \sin \phi \sin \delta)$$

Most of the correlation models for estimating global solar energy potentials are based on sunshine hours (Augustina, 2009), relative humidity and sunshine hours (Gopinathan, 1988), Declination angle and latitude (Jennifer *et al.*, 2004), sunshine duration, relative humidity, maximum temperature, latitude, altitude, and location (Sabbagh *et al.*, 1977). This research paper is limited to the use of monthly average of maximum and minimum temperature, solar radiation and latitude with reasonable accuracies.

Extral- Terrestrial Solar Radiation

The radiation arriving outside the earth’s atmosphere is referred to as extra-terrestrial solar radiation. Knowledge of the spectral distribution of this radiation is important in such applications as, for example, the photovoltaic power systems of satellites. Moreover, the radiation which reaches the earth is a function of the extra-terrestrial radiation. The flux density of extra-terrestrial radiation is given by the solar constant, which is defined as the amount of electromagnetic radiation that comes from the sun at a distance of one astronomical unit (1AU)

and fall on a specific perpendicular area. It is measured by satellites in space and found to be approximately 1353 Wm⁻² (USA Tech., 2006)

Solar Radiation on the Earth Surface

Solar radiation has to pass through the atmosphere before reaching the earth’s surface. The amount of radiation falling on the earth’s surface depends on several factors such as Earth to sun distance, atmospheric effects, declination angle etc. The distance between the sun and the earth is not a constant since the earth’s path around the sun is an ellipse. Less energy is received when the earth is furthest from the sun. The amount of actual solar radiation we received on the earth surface is a fraction of the solar constant. This is because the earth atmosphere blocks out some of the sun’s radiation. We also received less solar radiation depending on distance away from the sun and angle away from the sun. The sun is actually emitting about two billion times more energy than what is received by the earth (Exell, 2000)

Measurement of Solar Radiation

In order to assess the available solar energy arriving on the earth’s surface, measurements of solar radiation at locations on the earth are essential. The solar radiation reaching the earth’s surface consists of two components: direct and diffuse solar radiation. The former component is that part of the direct solar beam which reaches the earth surface directly from the sun without being scattered, reflected or dispersed in any form. The latter component is that part of the solar radiation which reaches the earth’s surface as a result of scattering, reflection, and other dispersion of the solar beam. The sum of the direct and diffuse components of solar radiation gives the total (global) solar radiation. When the sun’s rays pass through the atmosphere, some energy is scattered and some is absorbed in the atmosphere and hence attenuation of solar radiation takes place.

Solar radiation can be measured by several different types of instruments having various characteristics and degree of accuracy. A Pyranometer is used for measuring global radiation.

RESULTS

Table 1: Monthly average temperature and global solar radiation calculated for YEAR 2005

MONTH	Tmax. °C	Tmin. °C	T.D	Ra(MJm ⁻²)	Rs(MJm ⁻²)
January	33.01	24.92	8.13	38.20	20.70
February	33.05	24.22	8.83	38.24	21.59
March	32.18	22.68	9.50	38.28	22.42
April	29.40	20.40	9.00	38.32	21.84
May	29.73	21.73	8.00	38.36	20.61
June	28.02	22.02	6.01	38.40	17.88
July	27.02	22.01	5.01	38.44	16.35
August	27.12	23.43	3.69	38.48	14.04
September	28.20	22.13	6.07	38.52	18.03
October	30.04	23.02	7.02	38.56	19.41
November	32.30	24.20	8.1	38.60	20.87
December	33.20	24.70	8.5	38.64	21.40

Table 2: Monthly average temperature and global solar radiation calculated for YEAR 2006

MONTH	Tmax. °C	Tmin. °C	T.D	Ra(MJm ⁻²)	Rs(MJm ⁻²)
January	32.43	25.42	7.01	38.20	19.15
February	33.74	26.01	7.73	38.24	20.20
March	34.22	25.05	9.17	38.27	22.20
April	30.73	22.04	8.69	38.31	21.45
May	29.22	22.06	7.16	38.35	19.49
June	28.22	23.55	4.67	38.39	15.76
July	26.92	22.43	4.49	38.43	15.47
August	26.82	22.02	4.80	38.47	16.01
September	27.21	23.55	3.66	38.51	14.00
October	29.42	23.20	6.22	38.55	18.27
November	33.08	24.40	8.68	38.59	21.60
December	33.18	24.49	8.69	38.63	21.64

Table 3: Monthly average temperature and global solar radiation calculated for YEAR 2007

MONTH	Tmax. °C	Tmin. °C	T.D	Ra(MJm ⁻²)	Rs(MJm ⁻²)
January	31.43	25.01	6.42	38.20	18.39
February	33.74	27.99	5.75	38.24	17.42
March	37.03	27.96	9.07	38.28	21.90
April	30.71	25.62	5.09	38.32	16.42
May	27.35	22.57	4.78	38.36	15.93
June	25.40	20.28	5.12	38.40	16.51
July	26.94	22.02	4.92	38.44	16.20
August	29.86	23.92	5.94	38.48	17.82
September	29.61	24.03	5.58	38.52	17.29
October	31.71	25.56	6.15	38.56	18.17
November	35.68	29.37	6.31	38.60	18.42
December	35.38	25.92	9.46	38.64	22.58

Table 4: Monthly average temperature and global solar radiation calculated for YEAR 2008

MONTH	Tmax. °C	Tmin. °C	T.D	Ra(MJm ⁻²)	Rs(MJm ⁻²)	Rs(MJm ⁻²)
January	39.43	32.01	7.42	38.20	19.77	19.77
Febuary	37.06	30.29	6.77	38.24	18.90	18.90
March	39.51	29.53	9.98	38.28	22.97	22.97
April	37.02	27.47	9.55	38.32	22.49	22.49
May	33.08	24.72	8.36	38.36	21.07	21.07
June	29.92	23.20	6.72	38.40	18.91	18.91
July	29.10	24.86	4.24	38.44	15.04	15.04
August	35.89	30.08	5.81	38.48	17.62	17.62
September	34.94	27.51	7.43	38.52	19.95	19.95
October	35.26	27.90	7.36	38.56	19.87	19.87
November	35.29	27.06	8.23	38.60	21.04	21.04
December	36.71	28.59	8.12	38.64	20.92	20.92

Table 5: Ilorin Solar Radiation D (ml/month)

YEAR	2005	2006	2007	2008
January	14.00	14.50	13.70	12.90
Febuary	16.00	14.20	15.30	15.19
March	16.80	14.63	15.63	14.30
April	14.80	14.76	15.10	14.75
May	15.10	15.30	14.00	15.76
June	13.68	14.27	13.14	13.91
July	24.94	15.40	14.45	14.15
August	12.51	14.76	13.81	15.26
September	13.60	14.16	13.61	14.95
October	13.60	15.37	13.23	13.39
November	16.90	15.40	15.03	14.95
December	15.50	14.80	16.10	14.07

Table 6: Statistic of Monthly Average H (MJ/m²/month) For 2005-2008 at $\mu = 1.357$

YEAR	2005	2006	2007	2008
January	19.00	19.68	18.59	17.51
Febuary	21.71	19.27	20.76	20.61
March	22.80	19.85	21.22	19.41
April	20.08	20.03	20.49	20.02
May	20.49	20.76	19.00	21.39
June	18.56	19.36	17.83	18.88
July	18.38	20.89	19.61	19.20
August	16.98	20.03	18.74	20.74
September	18.46	19.22	18.47	20.30
October	18.46	20.86	17.96	18.17
November	22.93	20.90	20.39	20.30
December	20.03	20.01	21.85	19.10

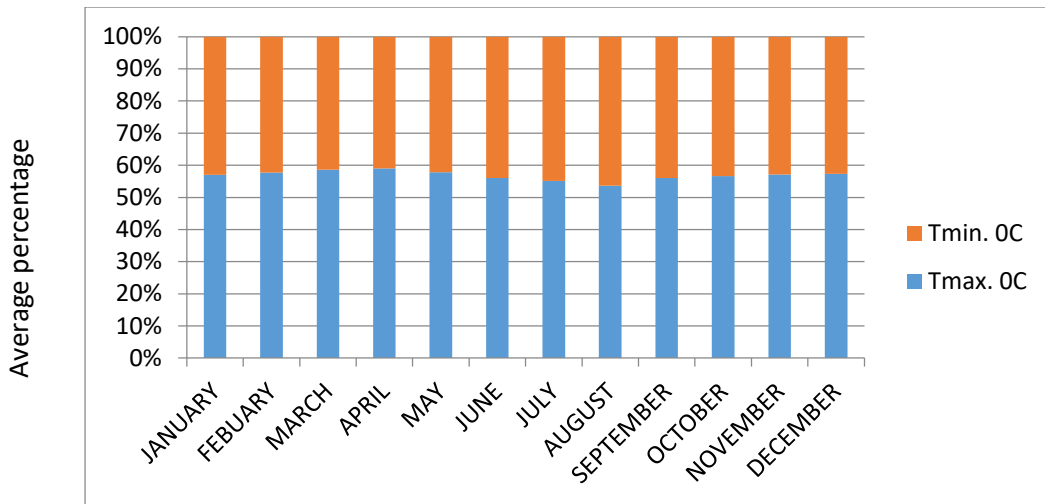


Figure 1: Max. and Min. Temperature for the year 2005

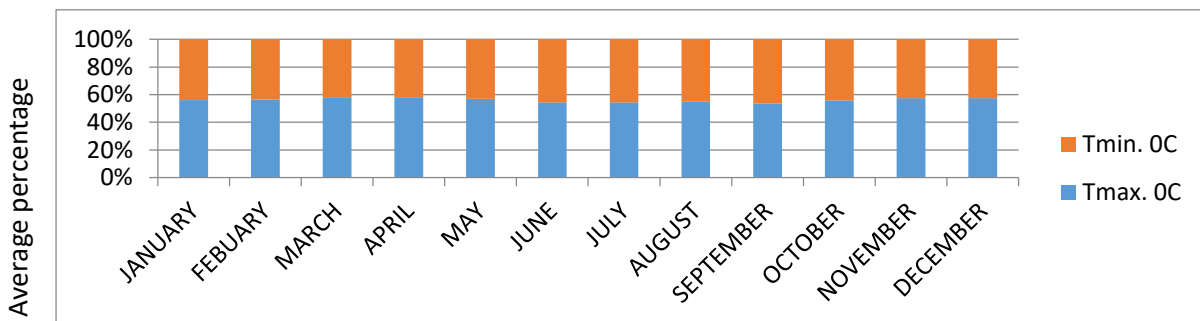


Figure 2: Max. and Min. Temperature for the year 2006

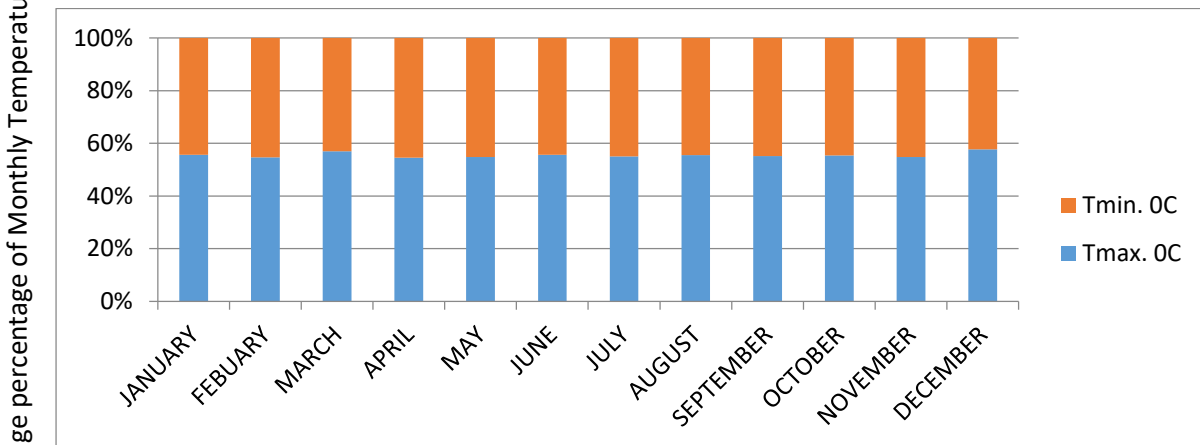


Figure 3: Max. and Min. Temperature for the year 2007

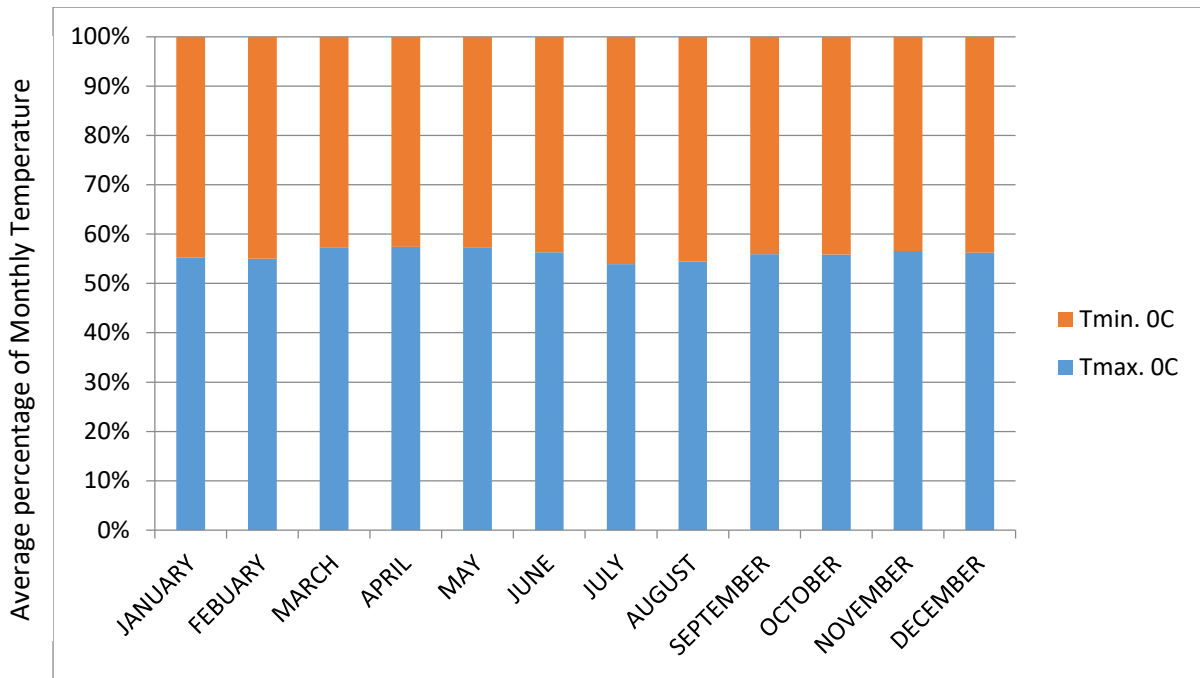


Figure 4: Max. and Min. Temperature for the year 2008

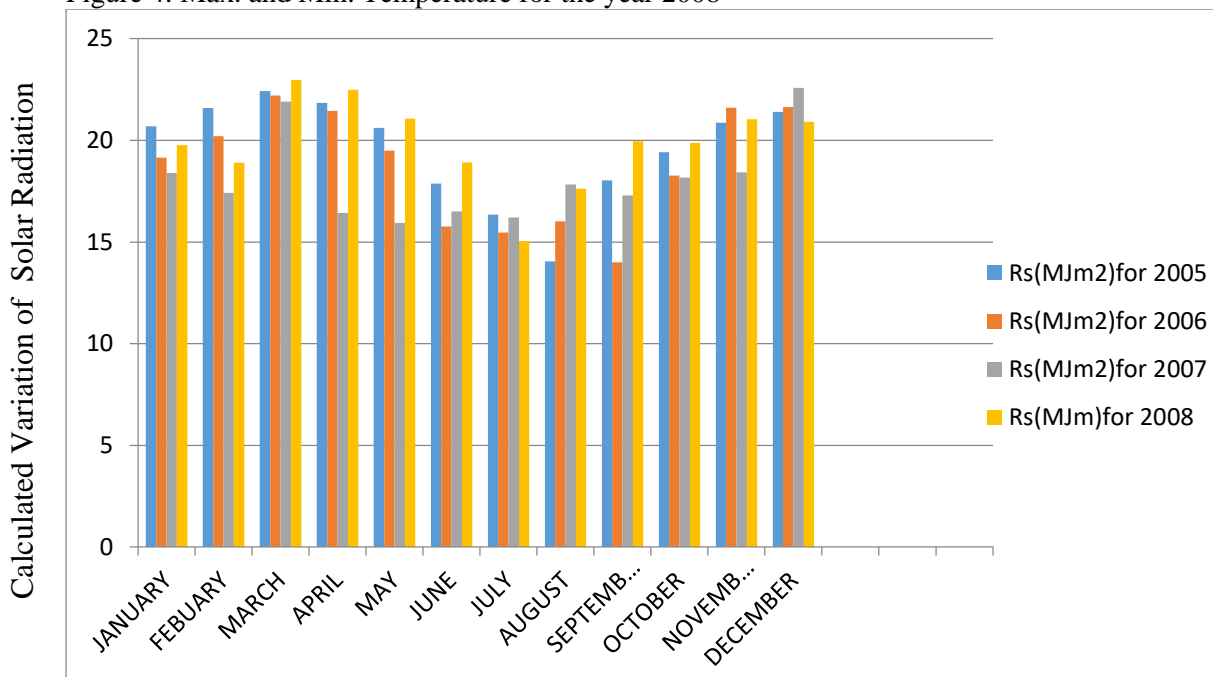


Figure 5: Variation of calculated global solar radiation for period 2005-2008

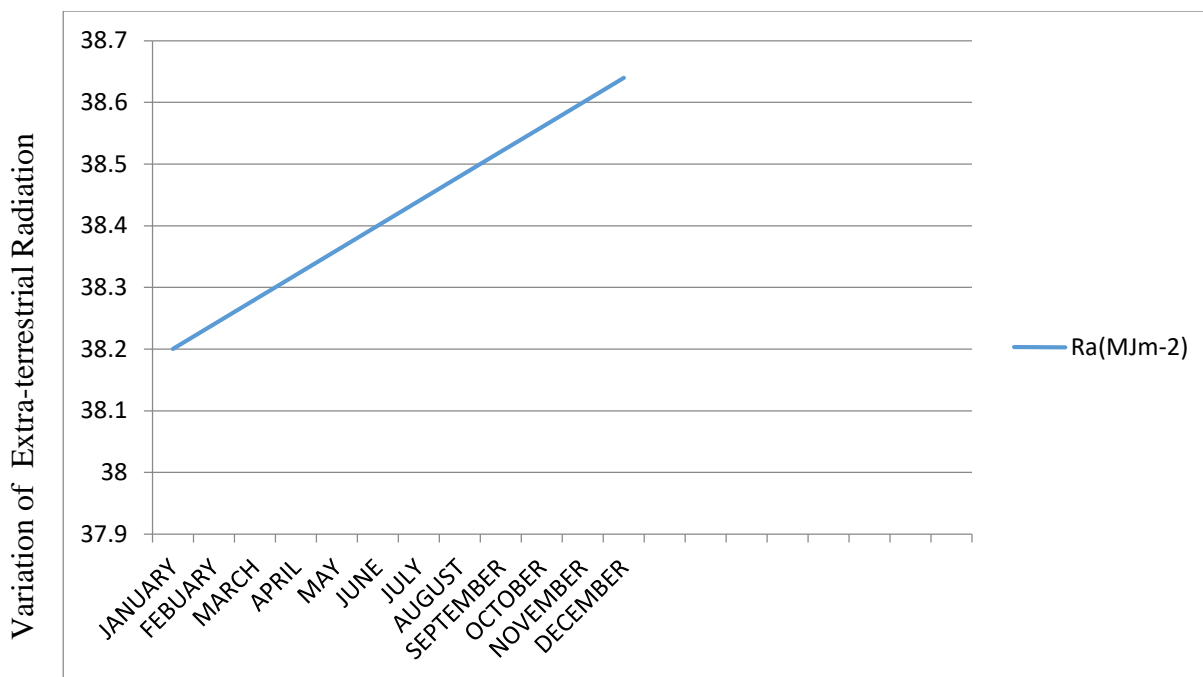


Figure 6: Variation of calculated Extra-terrestrial Radiation with the month of the year

DISCUSSIONS

The values of monthly temperature difference (T.D) were obtained by subtracting maximum temperature from minimum temperature. Extra-terrestrial radiation was calculated using equation (2). Using these two inputs, global solar radiation per month was calculated and the results tabulated as indicated in tables 1-4 above. Tables 1-4, indicates all the measured monthly average maximum and minimum temperatures, calculated values of temperature difference (T.D), extra-terrestrial radiation and Global solar radiations for the period under study (2005-2008). Table 5 **indicates** monthly average of solar radiation datas D (ml/month). Table 6 indicate Statistic of Monthly Average H (MJ/m²/Month) for year 2005-2008 at $\mu = 1.357$.

There was a slight variation in the values of temperature different (T.D) obtained for each year and this could be as a result of transit period of the season from the dry to unset of rain season. The variation of maximum and minimum temperatures was indicated in figure 1-4 above for each year with Tmax greater than 50% every year. This is an evident of high solar intensity in the study location.

The values of the global solar radiation for the period under study varies from 14.04-22.42 MJm⁻²month⁻¹ in 2005, 14.00-22.20 MJm⁻²month⁻¹ in 2006, 16.20-22.58 MJm⁻²month⁻¹ in 2007, and 15.04-22.97 MJm⁻²month⁻¹ in 2008.

These values reveal that there was an evidence of increase in the values of the global solar radiation in the location, with the year 2008 recording the highest ranging from 15.04-22.97 MJm⁻²month⁻¹ and year 2006 recording the least ranging from 14.00-22.20 MJm⁻²month⁻¹.

The highest extra-terrestrial solar radiation value was recorded in the month of December with a value of 38.64 MJm⁻²month⁻¹ and the lowest value was obtained in the month of January with the value of 38.20 MJm⁻²month⁻¹ as shown in figure 6 above. The reason is that extra-terrestrial radiation increases slightly with days of the month from the 1st day of January, and continue to increase slightly till it reaches December where it began to reach a pick and remains constant for days and finally it takes a gradual downward. The region of continuous rise can be explained as period of increased dryness of atmosphere from the effect of the departing cold weather which is characterized by haze, mist fog and dust all of which contributes to shade for the solar radiation to deliver its full strength on the surface.

The variation of Global solar radiation calculated for each year is shown in figure 5 above. The period of maximum Global radiation

is recorded between February-April with highest value recorded in march 2008 (as shown in figure 5 above) and the period of minimum Global radiation was recorded between July-October with least value recorded in September 2006 (as shown in figure 5 above) for each years. The temperature of Ilorin range from 33⁰C-34⁰C from November to January while from February to April the value ranges between 34⁰C-53⁰C (Ilorin Atlas, 1982). Comparing this result of maximum global radiation value of range 14.00 - 22.97 MJm⁻²month⁻¹ obtained for the period under study to results of similar works carried out in south-western state of Ibadan yields Global radiation values of range 10.62 and 16.91 MJm⁻²month⁻¹, the outputs of Global radiation obtained in this work is higher and means a greater global solar energy potential in Ilorin the kwara state capital. Also with reference to Offiong that reports an average solar radiation for Nigeria per month as a whole to be as high as 20MJm⁻² depending on the time of the year (offiong, 2003), it can be stated conveniently that the result obtained in this work is in strong agreement with his findings

Conclusion

The global solar radiation at Ilorin within the period of study exhibits monthly variation ranging from 14.00 - 22.97 MJm⁻²month⁻¹, which shoot above Offiong's benchmark of good average radiation level needed for radiant energy application for energy source. However the result of this study shows that, there is greater availability of solar radiation in Ilorin and also solar energy devices will function successfully throughout the year in the area. This research work will also provide a useful source of information in the design and estimation of performance of solar application systems which is gaining attention in Nigeria. Hence there is a good global solar radiation potential in the studied location with bright prospects for solar energy utilization.

Recommendations

Global solar radiation can be determine either by direct measurement using pyranometer or by estimation using climatological parameters such as sunshine hours, relative humidity, maximum and minimum temperature solar radiation, cloud cover and geographical location.

Determination of monthly solar radiation on a horizontal surface can be obtained by using the

following equations based on the combination of the measured parameters mention above.

1. Hargreaves and Samani Equation
2. Angstrom Equation

For this paper Hargreaves and Samani Equation was used for the analysis. It is now recommended that Angstrom Equation can be as well used for the analysis.

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