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Investigation of monthly global solar radiation of Plateau State, Nigeria

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Abstract

Some human activities such as farming (e.g. type of crop planted), animal rearing, environmental management, horticulture, etc in a particular location are related to about the amount of solar energy received by the earth's surface in that area as some crops or livestock for instance; are weather sensitive. In health area for instance, higher global solar radiation (or heat) in an area can result to some diseases in a long or short run. This work is aimed at investigating the average global solar radiation of the study area as well as studying its relationship with temperature variation. The work made use of Hargreaves-Samanni global solar radiation prediction model, with the data of maximum and minimum temperature (July1, 1983 - June 30, 2005) obtained from the archive of earthdata.nasa.gov. The result showed that there was variation in the level of global solar radiation reaching the area in each of the months, and that it was higher in dry season than in rainy season. It was concluded that the global solar radiation of the area was directly proportional to the maximum temperature as well the difference between the minimum and maximum temperatures.

Keywords: Agriculture; Sunset Angle; Solar Radiation; Temperature

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1. Introduction

Solar energy is the energy emitted from the sun to the surface of the earth. It is a free form of energy and is abundant in almost all parts of the world. The interest in renewable energy sources has been on the increase, because according to (Moriaty and Honnery, 2012), if economic growth continues to rise, as seen in the past decades, the world energy demand is expected to rise to about 1000 EJ or more in 2050, both resource depletion, pollution, greenhouse gas emission and possible climate change will necessitate a shift from our continuing use of conventional fossil and nuclear fuels.

Solar energy is can be Harnessed using various technologies like solar heating, photovoltaic, solar thermal energy, solar architecture, and artificial photosynthesis (Anderson and Palkovic, 1994). These applications are found in many offices, business centres and homes today.

The amount of solar radiation over a place determines the type of crops that can survive in such a place as well as the type of animals or livestock that can be reared in the area since global solar radiation varies with location and topography (Ayegba et al., 2016). The knowledge of the exact variation of solar radiation of an area especially on monthly bases will help in no small measure in providing a guide to farmers in particular, on the crop they plant at certain times and environmental management personnel in general.

Ogolo, 2010, reports that solar radiation in the major control of weather and climate since it is the only source of energy of the earth. This implies that with adequate information on daily or monthly solar radiation of a location such as Plateau State which is considered in this work, important deductions relating to health, power, environment, agriculture, etc which are associated with weather and climate can be made.

Osueke et al. (2013), studied the global solar radiation for Enugu, Lagos, Abuja and Maiduguri and observed that, Maiduguri experienced the greatest solar irradiance range of 5.5-6.7 kwh/m^2/day, except for the months of January, November, and December.

Chiemeka and Chineke (2009), made use of minimum and maximum temperature data obtained from 1st - 30th November, 2007 using the maximum and minimum thermometers placed in the Stevenson screen at 1.5 m above ground level and observed that, the mean solar power potential obtained for the period over Uturu was 2.45 ± 0.29 kwh/m^2/day.

Medugu (2014), did similar work in Maiduguri using measured irradiation. The measurement of irradiation was done with the aid of a solar cell-based Pyranometer for a period of twelve months from November 3, 2008 through November 6, 2009. It was found that from the data gotten, maximum values of insolation occurred during the winter period while the minimum occurred during the summer period, which means higher insolation in dry season and low insolation value in rainy season.

Also in 2014, Okonkwo and Nwokoye used the data of Maximum and minimum temperature data measured in Minna (09.65°N, 06.47°E), Niger state, for a period of thirteen years (2000-2012). The data were used to establish Angstrom-type regression equations (models) to estimate the global solar radiation received on a horizontal surface in Minna. It was observed from the statistical test methods such as mean bias error (MBE), mean percentage error (MPE) and root mean square error (RMSE) that temperature data could be used for the estimation of the total solar radiation incident on a location to certain accuracy. Gajere and Abdullahi (2017) did a work in Jos. They made use of maximum and minimum temperature of Plateau State for the month of February, obtained from the database of weather online. Their work employed the use of Hargreaves-Samani method. It was observed from their work that the average global solar radiation of the area for the month of February 25.551 MJ/m^{2}day.

The peculiar nature of atmospheric condition of Plateau State coupled with the type of crops grown in the place necessitate this work as the result can help in the improvement of the farming and other environmental related activities. The major objective of this work is to determine the monthly variation of global solar radiation of the study area with a view to providing information that will be beneficial to the farmers, solar power personnel, environmentalists as well as mobile communication base station installation personnel.

2. Study area

Plateau State is located in North-central part of Nigeria, and is located between latitude 8.30^{0}N and 10.40^{0}N, and longitude 8.48^{0}E and 10.70^{0}E Figure 1, and has the altitude between 1,200m-1,829m which is mainly responsible for its cold weather. It is bounded with Bauchi state to the north east, Nasarawa state to the south west, Taraba state to the south east and Kaduna state to the North West. It has the land area of about 26,899km^2.

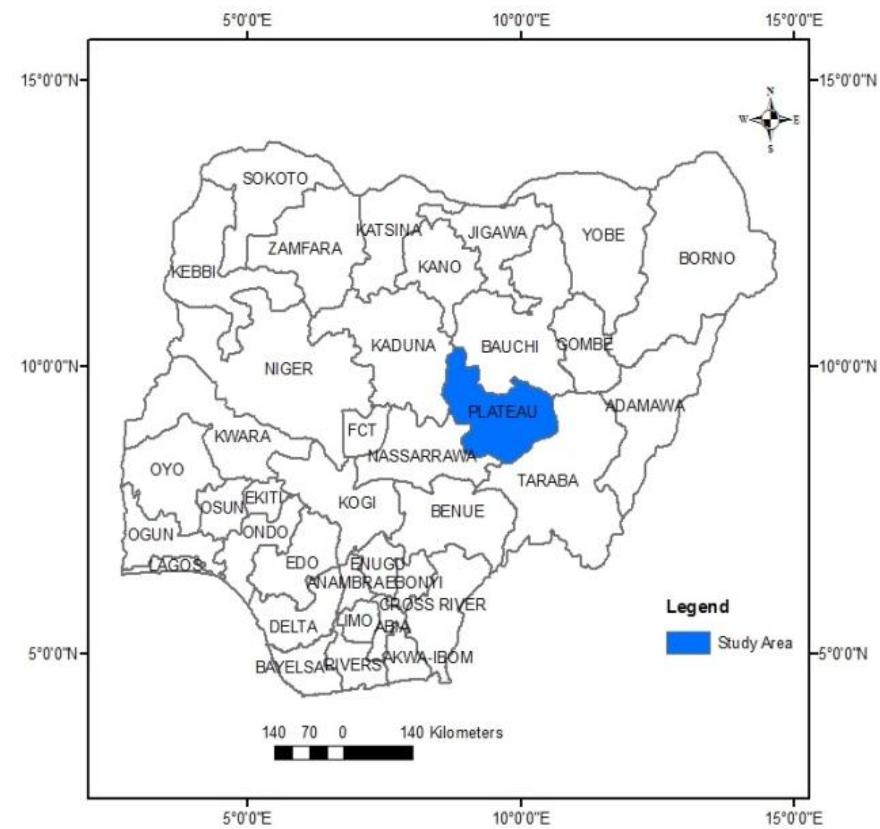

Figure1. Nigeria map showing Plateau State

The state has two seasons- dry and rainy seasons, with the rainy season from April to September, while dry season is between October and March. More than 1000 mine ponds spread across the entire state thereby exposing heavy and radioactive metals combined with the ongoing activities of surface mining by the local inhabitants emits energy to the environment, hence contributed to the warming effect of the area. Figure 1 shows the location of the study area (Plateau State) in Nigeria.

3. Materials and method

3.1. Materials

The data used in this work is a secondary data of average monthly maximum and minimum temperature, and daylight hours (July1, 1983 - June 30, 2005) obtained from earthdata.nasa.gov. The work also made Microsoft excel package, as well as the GPS coordinate point of a place of the study area.

3.2. Method

Hargreaves-Samanni's model: Hargreaves-Samanni's model is a global solar radiation prediction model that makes use of maximum and minimum air temperature of the atmosphere and the calculated extraterrestrial solar radiation of the study area. The model is represented by an equation given (Hargreaves and Samani, 1985) as:

$$R_s = K_{RS} \left(\sqrt{T_{max} - T_{min}}\right) R_a \qquad (3.1)$$

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 (Hargreaves and Samani, 1985). In this work, the value of K_{Rs} used is 0.16.

3.2.1. Calculation procedure

The following procedures lead to calculation of extraterrestrial radiation, which is then used to calculate the global solar radiation.

i. Solar radiation declination (δ): 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 has the formula given (Iqbal, 1983; Zekai, 2008) as;

$$\delta = 0.409 \; Sin\left(\frac{2\pi}{365}J - 1.39\right) \quad (3.2)$$

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 radian.

ii. Inverse relative distance Earth-sun (d_r): Inverse relative distance Earth-sun is the inverse distance of the sun relative to the earth at a location. It is calculated using the formula given (Iqbal, 1983; Zekai, 2008) as;

$$d_r = 1 + 0.033 \; Cos\left(\frac{2\pi J}{365}\right) \quad (3.3)$$

iii. Sunset angle (w_s): 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 (Iqbal, 1983; Zekai, 2008) as;

$$\omega_s = Cos^{-1}\left(-\tan(\varphi)\tan(\delta)\right) \quad (3.4)$$

where ω_s is the sunset angle (radian), δ is the solar radiation declination (radian), and φ is latitude angle of the location (radian).

iv. Extraterrestrial solar radiation (R_a): Extraterrestrial solar radiation is the power of the sun at the top of the earth's surface. The extraterrestrial radiation is calculated using the formula given (Hargreaves and Samani, 1985) as;

$$R_a = \frac{24(60)}{\Pi} G_{sc} d_r \left[w_s Sin(\varphi) Sin(\delta) + Cos(\varphi) Sin(w_s)\right] \quad (3.5)$$

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

Table 3.1. Data of average monthly maximum and minimum temperature

Months	Tmax	Tmin
JAN	41.7	17.1
FEB	44.1	18.6
MARCH	41.3	21.1
APRIL	34.1	21.7
MAY	31.4	21.7
JUNE	29.4	21.2
JULY	28	20.5
AUGUST	28.4	20.2
SEPT	30	20.2
OCT	31.6	19.4
NOV	36.9	17.5

4. Results and discussions

4.1. Results

Table 4.1. Calculated Global solar radiation

Months	Tmax (°c)	Tmin (°c)	Ra (MJ/m^2day)	Rs (MJ/m^2day)
JAN	41.7	17.1	31.214	24.77
FEB	44.1	18.6	33.243	26.86
MAR	41.3	21.1	35.806	25.75
APRIL	34.1	21.7	37.663	21.22
MAY	31.4	21.7	37.804	18.84
JUNE	29.4	21.2	37.117	17.01
JULY	28	20.5	36.872	16.16
AUG	28.4	20.2	37.310	17.09
SEPT	30	20.2	37.435	18.75
OCT	31.6	19.4	36.160	20.21
NOV	36.9	17.5	33.672	23.73
DEC	39.8	17.1	31.435	23.96

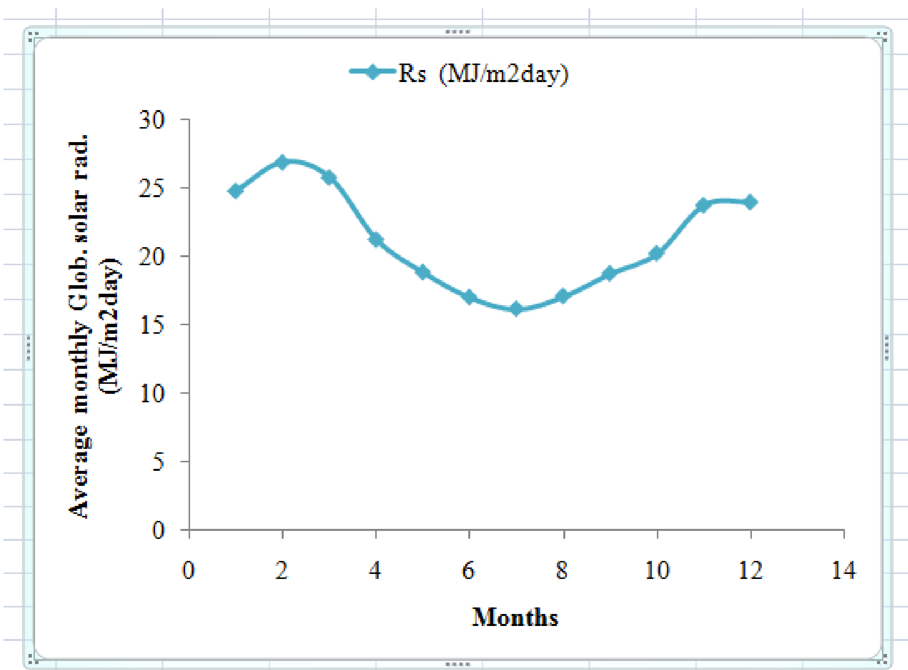

Figure 2. Graph of average monthly Global Solar Radiation

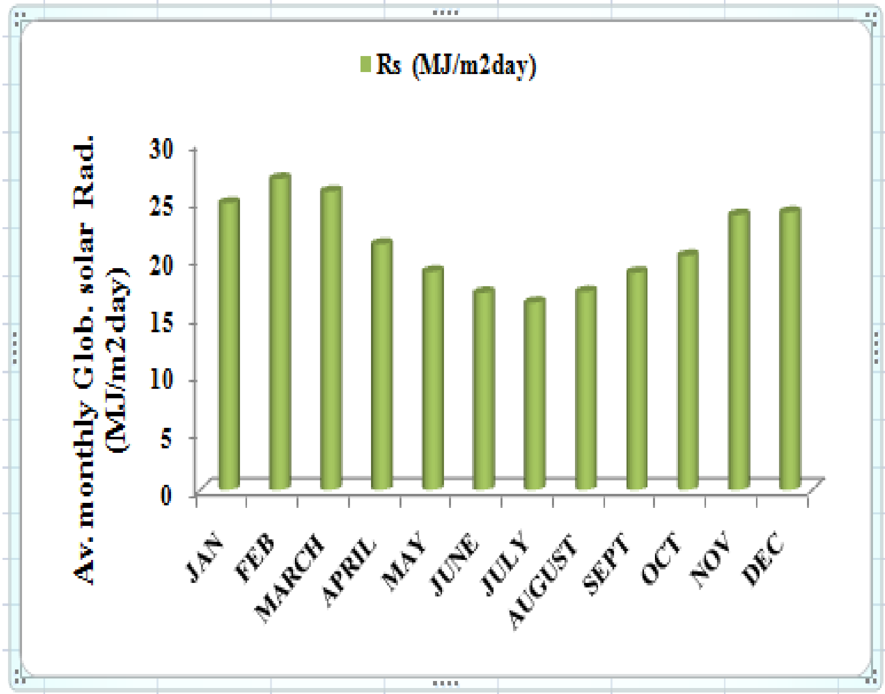

Figure 3. Chart of Graph of average monthly Global Solar Radiation

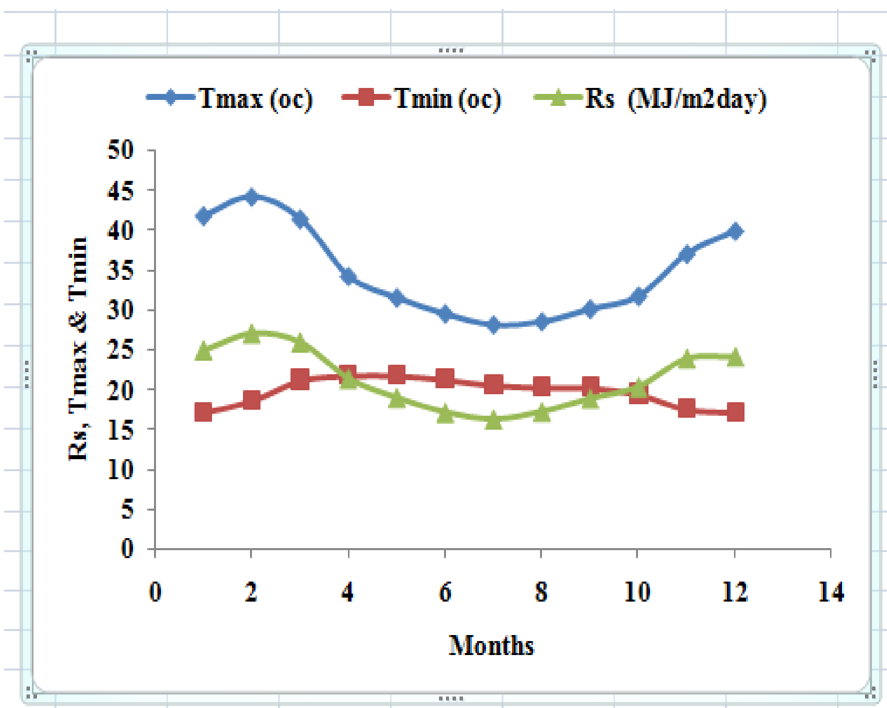

Figure 4. Graph of average monthly maximum and minimum temperature and Global Solar Radiation

4.2. Discussions

The average monthly global solar radiation for the study area has been estimated using Hargreaves-Samanni model. The data of average monthly maximum and minimum temperatures (from July1, 1983 - June 30, 2005) obtained from the archive of the Atmospheric science data centre of NASA was used.

Figure 2 shows the monthly global solar radiation, Figure 3 shows the chart of graph of average monthly global solar radiation and Figure 5 shows the graph of average monthly maximum and minimum temperature and global solar radiation.

From Figures 2 and 3, it can be observed that there was variation in the level of global solar radiation throughout the year. The global solar radiation was high from January-April and November-December, while low global solar radiation was experienced from May-September, with July being the month with the lowest average global solar radiation, and February, the highest global solar radiation.

From Figure 5, the relationship between average monthly maximum and minimum temperature and Global Solar Radiation was shown. It was observed from the figure that higher global solar radiation was experienced in the area when the difference between the maximum and minimum temperature was large, while lower global solar radiation was experienced when the difference between the maximum and minimum temperature was little. Higher level of global solar radiation was observed between January - march and November-December in which the difference between maximum and minimum temperatures were large while lower global solar radiation occurred between April and October when the difference between the maximum and minimum temperature was little. This development might be as a result of the period of rainy season (January - September) and dry season (October - March) in the area. In addition, the trend of monthly change of global solar radiation was seen to be the same as that of monthly maximum temperature. This implies that the global solar radiation of the study area increases with increase in maximum temperature and vice versa.

5. Conclusion

From the results of the calculated global solar radiation of Plateau State, it can be concluded that there was variation in the level of global solar radiation throughout the year with higher level experienced during dry season (October - March) and lower level experienced in rainy season (April-September).

It can also be concluded that global solar radiation of the study area is directly proportional to the maximum temperature values (Figure 4). This result will be important for agriculturists especially in the aspect of irrigation farming which is very common in the area. The result will guide the farmers especially when higher solar energy will be experienced by their crops, and the necessary measures such as application of more water than usual will be done. It will also aid solar power personnel in the design and installation of solar power, particularly as the design will be done based on the worst case month; i.e. month with the lowest global solar radiation, which is July. Environmental management personnel, horticulturists, livestock farmers, ecologists, etc will find this work valuable as it will help for proper planning.

6. Future works

The data used for this research work was for the period of 22 years (July1, 1983 - June 30, 2005), it is hereby recommended that recent data of temperature be used for further work in the study area.

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