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Estimation of Monthly Solar Radiation at Take-Off Campus, Federal University Dutsin-Ma, Katsina State, Nigeria

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Abstract

The research is aimed at estimating the monthly global solar radiation at the Take-Off Campus of Federal University Dutsin-Ma, Katsina State, Nigeria from March 2018 to April 2019. The study area lies exactly between longitude 7 ˚ 30'20.32 " E of the Greenwich meridian and latitude 12 ˚ 27' 38.66 " N of the equator. This research made use of Hargreaves- Samani equation in estimating the amount of solar radiation on the proposed buildings using daily temperature data (minimum and maximum) obtained from the meteorological station of the University. The monthly estimated global solar radiation values were estimated to be 17.82, 19.88, 34.18, 19.21, 18.61, 18.16, 18.02, 21.61, 20.77, 23.72, 24.40, 25.56, 26.24 and 15.18 ($MJm^{-1}d^{-1}$). Solar radiation data is essential for climate studies, weather forecasting and climate change research that can provide insights into regional and global balance and also solar radiation data provides information about the amount of solar energy available in a specific location, which is essential for accurate solar energy forecasting

Keywords: Hargreaves, Solar Radiation, Temperature, Extra-terrestrial Radiation, Clearness Index

1. Introduction

Solar radiation data are not easily available in all locations due to higher cost maintenance problems and difficulty in measurements. Therefore, accurate knowledge of solar radiation at the earth's surface is essential which resulted in using empirical coefficients to estimate global solar radiation based on the readily available meteorological parameters like sunshine hour, temperature and relative humidity out of which temperature is the most commonly available data which can be used as the input for temperature-based models at any location. Solar radiation serves as the primary driving force for atmospheric and biospheric processes (Nando, 2012). Understanding global solar radiation trends is crucial, especially as the depletion of fossil fuels and environmental concerns associated with traditional energy sources escalate (Chineke, 2002). With the urgent need to transition from fossil fuels to renewable energy, solar radiation has gained prominence as the largest and most studied renewable energy source (Hargreaves &

Samani, 1983). Despite the sun's constant energy emission, challenges exist in harnessing it effectively. Earth intercepts only a fraction of solar energy, and atmospheric conditions, including clouds and dust, along with Earth's rotation, limit exposure to solar energy. Additionally, weather patterns and atmospheric conditions influence the rate at which solar energy reaches the Earth's surface (Peter & Steven, 1999). The cumulative solar energy arriving at a unit area during one hour is termed solar radiation or insulation (U.S Tech. white paper, 2006). Understanding these factors is crucial for evaluating insulation levels and ensuring the successful introduction and sustainability of solar energy technology.

The sun emits energy 365 days a year, 24 hours a day, at a very high and generally steady rate. The world's energy needs could easily be met if all of this energy could be transformed into forms that could be used on Earth. This is not feasible, though, for the following reasons:

a) The earth rotates so that a collection device on the surface is exposed to solar radiation for only around half of each 24-hour period and will be guaranteed to receive only a small portion of the energy that exits the sun (Chineke, 2002).
b) Atmospheric conditions like dust and clouds can occasionally drastically lower the quantity of solar energy that reaches the surface of the earth.

The rate at which solar energy reaches the surfaces of the globe is also influenced by weather patterns and other atmospheric factors that deflect incoming rays. Solar radiation, also known as insulation, is the total amount of solar energy that enters a unit of area (m^2) in a single hour (Minerals Management Service, 2006). Acknowledging the abundance, cleanliness, and free nature of solar energy, there is a growing emphasis on its use for electricity generation, particularly amidst concerns over dwindling natural gas supplies (Hargreaves, 1994). This work is intended to research into this subject and bring out reasonable findings. Hence, the data obtained will provide useful information on the global solar radiation in Federal University Dutsin-Ma take-off site. Empirical coefficients appeared in correlation equations based on temperature have been found using the latest computing MATLAB software.

In this research and in line with the study problems stated above, the aim of this work is to estimate the global solar radiation in take-off site Federal University Dutsin-Ma where the Hargreaves-Samani model was employed to estimate global solar radiation. The specific objectives of this study were the monthly data were computed from the daily record of minimum and maximum temperatures taken at 1:00PM from the meteorological station of Federal University Dutsin-Ma and the data of the measured values the daily extraterrestrial radiation were computed and the data of the measured values the daily global solar radiation were also computed so as to have some knowledge on the monthly global solar radiation in take-off site Federal University Dutsin-Ma. These are based on climatological parameters of maximum and minimum temperatures from March 2018 to April 2019. Hence, the obtained solar radiation data can be used in urban planning and building design to optimize energy efficiency and reduce reliance on nonrenewable energy sources within the university and beyond.

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Solar radiation is the common term used to describe the energy that is sent to the earth's surface from the sun in the form of radiant energy. The best design and performance forecast of any solar energy conversion system depend on an understanding of the sun's radiation levels worldwide (Wong & Chow, 2001). In order to effectively model the tools or mechanisms involved in the management of phenomena employing these weather data, such as those mentioned previously, an urgent requirement for daily weather data, such as minimum and maximum temperatures, rainfall, and global solar radiation, becomes necessary (Ugwu & Ugwuanyi, 2011). The location and season of the year affect the possible amount of radiation that can reach the Earth's surface. The potential radiation varies at different latitudes and seasons due to variations in the sun's position. Recorded data is the most reliable source for determining the amount of global solar radiation at a point. Agrometrological computations frequently need daily sun radiation data, especially when calculating an irrigation water budget or running a crop growth simulation model, although these are only measured at a few locations (Chiemeka, 2008). In fact, it is estimated that, on a global scale, the ratio of weather stations gathering data on solar radiation to those gathering data on temperature is 1:500 (Peter & Steven, 1999). Solar radiation data on the earth’s surface is required for engineers, agriculturists and hydrologists in many applications. Solar energy is free, clean and inexhaustible source of energy. Its effective harnessing and utilization are of importance to the world especially at this time of rising fuel costs and environmental effects such as depletion of the ozone layer and greenhouse effect. The potential amount of radiation that can reach the Earth’s surface is determined by its location and time of the year. Due to differences in the position of the sun, the potential radiation differs at various latitudes and in different seasons (Ugwu & Ugwuanyi, 2011). A number of formulae and methods have been developed to estimate global solar radiation many studies have been calculated to estimate incoming solar radiation in Nigeria. (Angstrom, 1924) was the first scientist known to suggest a simple linear relationship to estimate global solar radiation. Ugwu & Ugwuanyi (2011) carried out a research at Federal University of Technology Yola on predictive performance of Hargreaves-Samani model in estimating solar radiation in Yola, Adamawa State, Nigeria using maximum and minimum temperature. Also, from the correlation index of agreement results and the plots of observed values of global solar radiation the model has shown itself to be reasonably accurate method for estimating global solar radiation, the model has the tendency to overestimate and under predict the lower and higher range of the observed distribution that can produce an index of agreement of 95%. This is an excellent indication that the model performs equally well considering the uniqueness of climatological data in each month of the year. (Hassan & Onimisi, 2011) published a paper titled ‘Assessment of global solar radiation potential at Nigerian Defence Academy permanent site Afaka, Kaduna, Nigeria for the period of March, April and May 2012, the study makes use of Hargreaves- Samani model that adopts the available data to assess. The information will assist the policy makers in the academy to know exactly the particular days and time in the months under consideration when not to subject military personnel to vigorous training simply because it is the period of maximum sunshine in the region. The Hargreaves- Samani model appears to be suited for most agro-meteorological studies requiring solar radiation data and it can be extended to areas where radiation is not or is only rarely measured by meteorological networks.

2. Study Area

Dutsin-Ma is one of the local governments of Katsina state, North-Western Nigeria, it lies on latitude 12^{o} 26' N and longitude 7^{o} 29' E. it is bounded by Kurfi and Charanchi LGAs to the North, Kankia LGAs to the East, Safana LGA and Dan-Musa LGA to the West and Matazu LGA to the Southeast. The Federal University Dutsin-Ma is located at kilometer sixty Katsina-Kankara Road, Dutsin-Ma local government area of Katsina State. The take-off site of Federal University Dutsin-Ma as shown in Figure 1, is located in Dutsin-Ma local Government area of Katsina state. The area lies between longitude 7^{o} 30' 20.32" E of the Greenwich meridian and latitude 12^{o} 27' 38.66 "N of the equator. Figure 1 below is the site map of the study area**.**

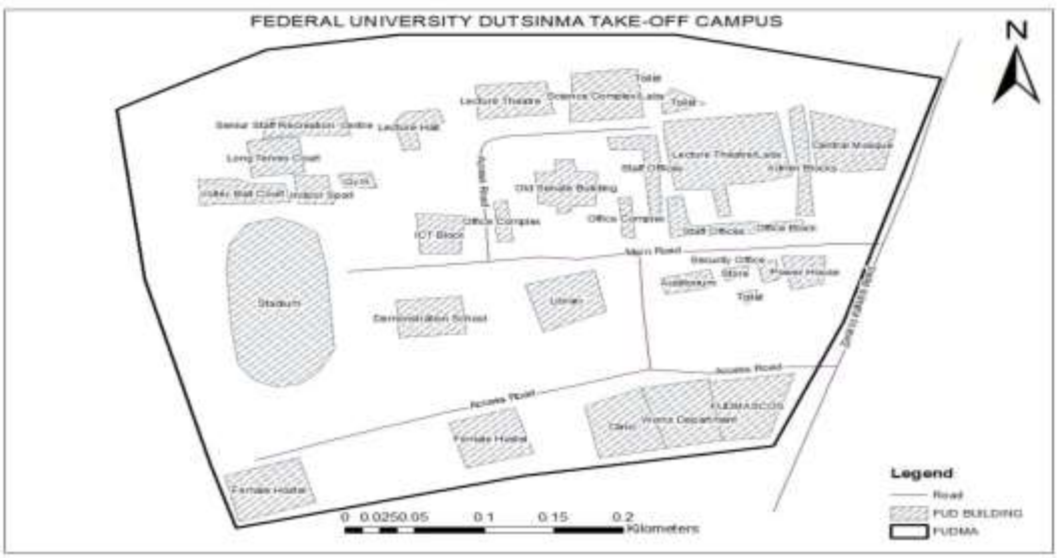

Figure 1: Site Map of Federal University Dutsin-Ma.

3. Materials and Methods

For the purpose of this research, Hargreaves-Samani method was employed. The temperature data (minimum and maximum) were recorded for a period of one year (1^{st} March 2018 to 30^{th} April 2019) at 1PM from take off campus meteorological station. The data were computed to get the monthly values of the estimated solar radiation using the MATLAB software.

The Hargreaves-Samani method was employed is express as follows. (Hargreaves, 1994) Where among the first to suggest that solar radiation could be estimated from the difference between daily maximum and daily minimum air temperature and extraterrestrial radiation. The form of the equation introduced by Hargreaves and Samani is,

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

Where:

T_{max} and T_{min} are mean daily maximum and minimum air temperature (°C) for period (generally one year).

R_a is the extraterrestrial radiation.

K_r is the empirical coefficient.

R_s and R_a are measured in $MJm^{-1}d^{-1}$.

Initially, K_r was set to 0.17 for arid and semiarid climate. (Hargreaves, 1994), recommended using K_r = 0.16 for interior region and K_r = 0.19 for coastal region. Katsina, being located in an interior position, the K_r value applied is 0.16. The extraterrestrial radiation R_a can be calculated for any given day of the year and latitude according to the equations from (Duffie & Beckman, 1980).

$$R_a = \frac{1440}{\pi}[G_{sc}\,.\,d_r][\psi s\, Sin(\varphi)Sin(\delta) + Cos(\varphi)Cos(\delta)Sin(\psi s)] \quad (2)$$

Where:

G_{sc} is solar constant (0.0820 $MJm^{-2}min^{-1}$); d_r is the inverse relative distance from earth to the sun

ψs is sunset hour angle (rad); φ is the latitude (rad); and δ is the solar declination (rad).

In the above equation, the daily values of φ, d_r, δ and ψs are given by the following equations;

$$d_r = \frac{1 + 0.033\, cos2\pi JD}{365} \quad (3)$$

$$\delta = \frac{0.409Sin[2\pi JD - 1.39]}{365} \quad (4)$$

$$\psi s = arCos(-tan\varphi\,.\,tan\delta) \quad (5)$$

Where, JD is called the day index/ Julian day. All data obtained were further treated statistically, using appropriate graphs and tables in the discussion section. Graphs are specifically constructed to convey information on the changes of the T_{max} and T_{min}, which are required to offer a constructive guidance on the data interpretation in line with the set objectives.

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4. Results

Table 1, shows the computed monthly values of T_{max},T_{min}, TD, TA, R_a, R_s, and Kt for the period of March 2018 to April 2019.

Table 1: Monthly Computed Values

Month	T_{max} (°C)	T_{min} (°C)	TD (°C)	TA (°C)	R_a ($MJm^{-1}d^{-1}$)	R_s ($MJm^{-1}d^{-1}$)	Kt
March	37.1967	36.2419	0.9548	36.7193	37.8531	17.8213	0.4713
April	38.4233	37.0443	1.3790	37.7338	34.4138	19.8879	0.5631
May	36.6064	31.529	5.0774	34.0677	32.4809	34.182	1.0545
June	32.7967	30.9096	1.8870	31.8531	30.842	19.2156	0.6232
July	29.3967	27.8354	1.5612	28.6161	31.4448	18.6197	0.5920
August	28.8354	27.5419	1.2935	28.1887	34.0315	18.164	0.5350
September	30.8317	29.8233	1.0083	30.3275	36.7382	18.0268	0.4905
October	34.1205	32.6903	1.4302	33.4054	38.1935	21.6167	0.5659
November	33.1667	31.8767	1.2400	32.4966	38.3065	20.7718	0.5422
December	28.3354	26.7419	1.5935	27.5387	38.1396	23.7214	0.6219
January	30.0774	28.4032	1.6741	29.2403	38.4367	24.4024	0.6348
February	30.9428	29.1357	1.8071	30.0390	38.7115	25.5685	0.6604
March	37.0544	35.0421	2.0122	36.0482	37.8531	26.2422	0.6937
April	39.9233	38.0733	1.8500	38.9983	35.4138	15.1838	0.6714

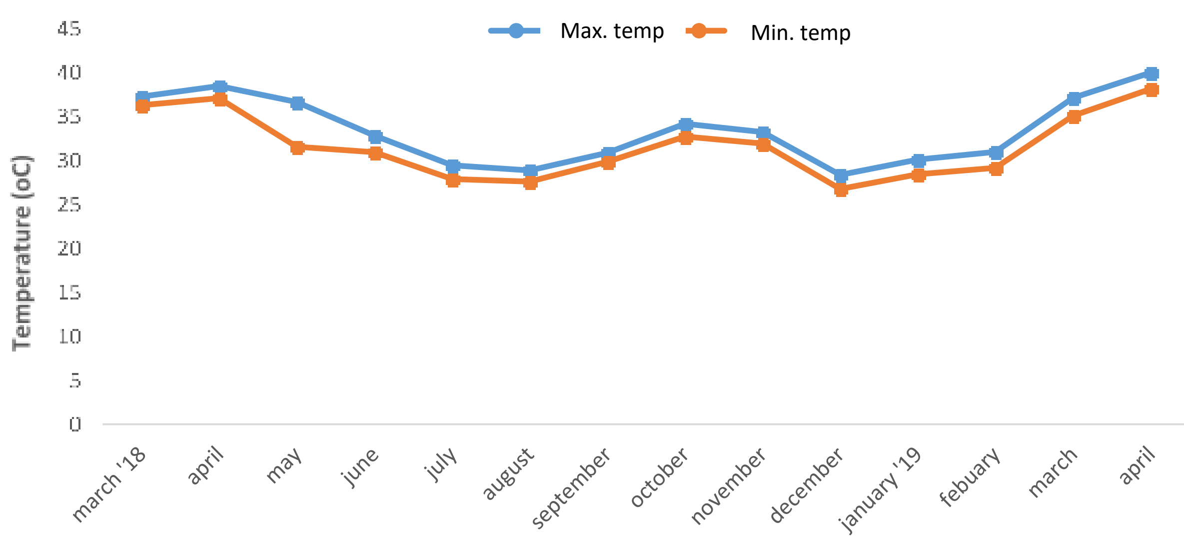

Figure 2: Monthly Maximum and Minimum Temperature from March 2018 to April 2019

The Figure 2, shows the time series plot of the monthly maximum and minimum temperatures. The plot showed a nonlinear trend which can be attributed to the nature

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of most atmospheric parameters of having nonlinearity in the behaviour due to dependence on changes of other atmospheric variables lie wind seed humidity or atmospheric pressure. Both the two curves shows almost same trend, this agrees with the computed monthly values in Table 1.

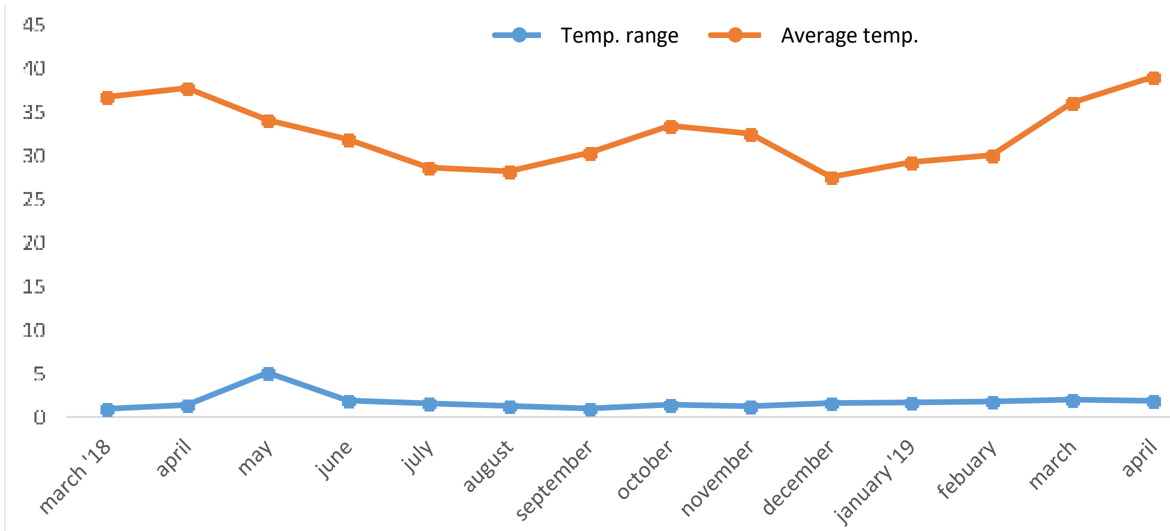

Figure 3: Monthly Temperature Difference (range) and Temperature Average.

The temperature difference plot shift to be linear in all the months under consideration except for May this agrees with the computed monthly value from Table 1 and can be correlated to the dry/heat season in that month. But for the temperature average the plot moves to fluctuate July and August being the lowest this is correlated to the dry/rainy season in that months as there are uncontrolled changes in atmospheric variables due to rainfall and high humidity in the period. April (2018), October and April (2019) exhibiting the highest rise in the plot. This nonlinearity is a natural and normal trend for atmospheric variables like the temperature.

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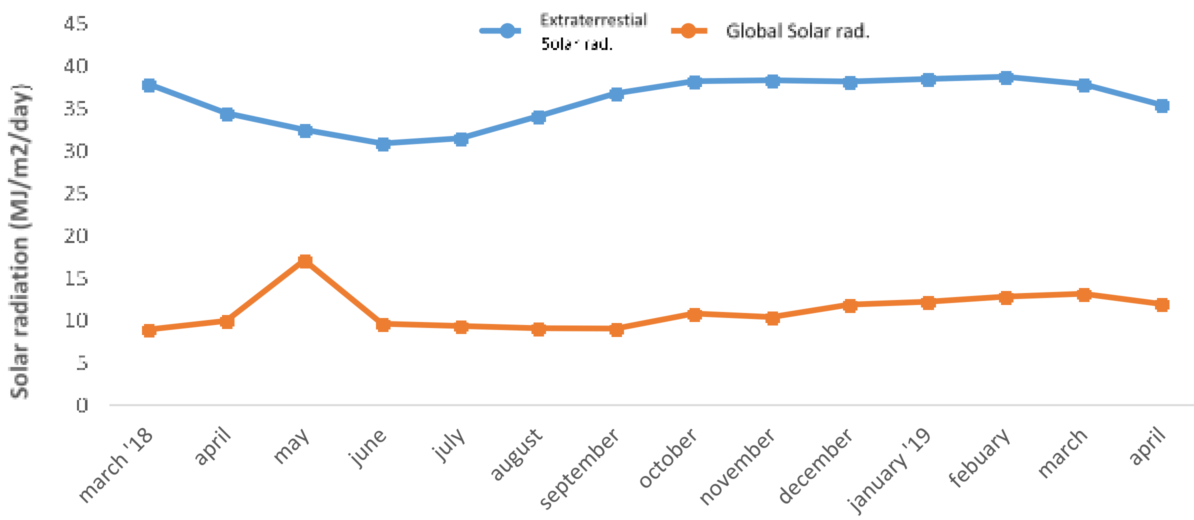

Figure 4: Estimated Monthly Solar Radiation and Extraterrestrial Radiation from March 2018 to April 2019

In Figure 4, depict the monthly extraterrestrial radiation (Ra) tends to be lower in the months of April to July, exhibit linearity from the month of October, November, December (2018) and January, February (2019). The solar radiation plot (Rs) tends to be linear from the month of March (2018) to April (2019) except for April and May (2018) that the curve is higher this can be attributed to the higher amount of solar radiation in those months which agrees with the computed values from Table 1.

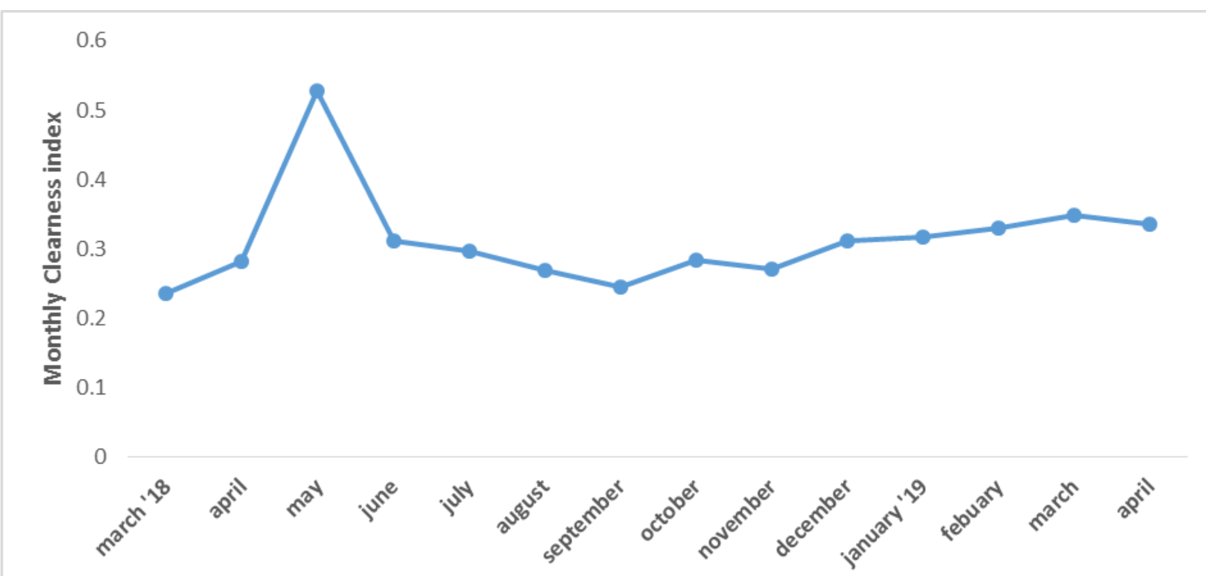

Figure 5: Monthly Clearness index, Kt.

From Figure 5, the clearness index K_t is the ratio of the solar radiation that would be received at the same location under clear sky conditions. In Figure 4 the plot exhibit almost similar trend with that of the solar radiation as K_t is a measure of atmospheric

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conditions affecting the amount of direct sunlight reaching the earth's surface. This implies that under normal clear sky condition the total amount of solar radiation that will be account for will be the same in the study location.

5. Conclusion

The global solar radiation in Federal University Dutsin-Ma with mean values of 17.82, 19.88, 34.18, 19.21, 18.61, 18.16, 18.02, 21.61, 20.77, 23.72, 24.40, 25.56, 26.24 and15.18 respectively were computed (March, 2018 – April, 2019 the months under consideration). Based on the observations and results obtained in this research it has shown a great potential for solar energy which if harnessed could solve some of the power problems in the university. Despite the very great simplification, the model employed here appears to be well suited for the estimation of daily global solar radiation records and the model have a major advantage as it uses only daily minimum and maximum temperature records.

6. Recommendations

The following are recommended by this research, (1) by analyzing historical solar radiation data, energy forecasters can identify patterns and trends in solar energy generation, helping them predict future energy production levels. (2) Solar radiation data is also valuable for educational purposes, raising awareness about renewable energy and promoting sustainable practices. (3) Energy forecasting models incorporate solar radiation data to predict the availability and variability of solar energy, enabling grid operators to plan and manage the integration of solar power into the electricity grid. (4) Solar radiation data is valuable for agricultural applications including crop growth modeling irrigation and optimizing greenhouse conditions. (5) It is crucial for designing and optimizing solar systems such as solar panels and solar water heaters to maximize energy production and also assessing their potential.

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