COMPARATIVE STUDY OF SOLAR ENERGY ON INCLINED AND HORIZONTAL SURFACE IN MINNA, NIGER STATE, NIGERIA

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Abstract: The availability of solar energy in any location on the earth surface is affected by the time of the day, and the seasons. Therefore, accurate knowledge of the quantity available at any location and time and the dynamics is imperative for solar power system design and installation. In this study, comparative study of global solar irradiance on horizontal and inclined surfaces was carried out with the consideration of the prevailing atmospheric conditions and seasons in Minna, Nigeria. The outdoor degradation analysis was carried out on a mono-crystalline PV module rated 10 W. Two Li-200SA MA200 pyranometer sensors incorporated with CR1000 software-based data logging system with computer interface; one inclined at the latitude of the location and the other placed horizontally at the same test plane and at about three meters of height were employed to measure global solar irradiance for three years. The logger was programmed to measure and log solar irradiance at every 5 minutes intervals from 8:00 am to 7:00 pm local time for the duration of 3 years from 2016 to 2018. Data analysis was carried out to obtain the hourly, daily, monthly and yearly global energy dynamics on the two surfaces using Excel spread sheet. The result shows seasonal variations and on average the inclined surface has the greater amount of energy per year but not for all seasons of the year. The results acquired can be applied in the location for effective solar planning system.

Key words: irradiance, atmosphere, dynamics, seasons

1. INTRODUCTION

Incident rays from the sun beams enough energy onto the Earth to meet the needs of Global energy demand. In optics, rays are model of light obtained by choosing a line that is perpendicular to the wave front of the actual light that points in the direction of energy flow. This can be achieved using solar panels. The panels consist of the photovoltaic cells. When the incident rays of light from the sun strikes the surface of the solar panels, the solar panels absorb the incident rays and knocks the electrons loose from their atoms. The electrons generate electricity as they flow through the cells. This incident ray of light is a form of renewable energy that can be captured almost anywhere on the planet and converted into electricity using solar panels [1]. Solar panels were initially developed for use in space applications [2]. The installation of photovoltaic system is mainly dictated in a certain angle of inclination. It is easy to install, has low impact on surroundings [3]. In general, solar power generation works better in areas with large solar irradiation. Researchers have shown this potential in tropical [4] and deserted environments [5]. However, output power of photovoltaic system does not only depend on the absorbed power but is also affected by photovoltaic module's temperature. When sun light strikes the solar panel, only a part of energy is converted to electricity. But most of the energy just heats up the panels [6]. This heat is dissipated to the environment at a rate which depends on the ambient temperature.

The sunlight is a renewable source of energy. It is reliable and sustainable. Using solar panels to produce electrical power is ecosystem friendly. They do not emit greenhouse gases that can increase the warming of earth which have been studied to be the main cause of the drastic climate changes. Utilizing solar power can save people from depending on fossil fuels. Fossils fuels are not only non-renewable but are also the main source of carbon dioxide emissions which is the primary greenhouse gas in the atmosphere.

Solar panel mounting systems also called solar module racking are used to fix solar panels on surface like roofs, building facades, or the ground. These mounting systems generally enable retrofitting of solar panels on horizontal and inclined surfaces. There are three types of solar panel mounting systems, they include roof, tracker, and ground mounting systems [7].

2. RESEARCH METHODOLOGY

This research involves the analyses of solar energy on an inclined and horizontal plane with the consideration of seasonal variations. The research methodology involved two processes, which are data acquisition and data analysis.

2.1. Method of data acquisition

Solar irradiance data used for this research was monitored with two Li-200SA MA200 pyranometer sensors incorporated with CR1000 software-based data logging system with computer interface. One of the sensors was mounted at an angle of inclination of the latitude of the location and the other was mounted horizontally at the same test plane and at about three meters of height, to ensure adequate exposure to insolation. Both sensors measured and logged global solar irradiance on inclined and horizontal surfaces respectively for three years. The elevation equally ensures that the sensor under test is free from any shading from shrubs and protected from damage or interference by intruders. Also, the whole experimental set up is secured in an area of about four meters in diameter. The inclined sensor was tilted at approximately 10 ^{o}c (since Minna is on latitude 09^{o}37' N) to the horizontal and south-facing to ensure maximum insolation [8]. The logger was programmed to measure and log solar irradiance at every 5 minutes intervals throughout 24 hours period. The data analysis was done with sunshine hours between 8:00 am to 7:00 pm local time for the duration of 3 years (January 2016 to December 2018), to cover the two distinct and well-defined climate seasons of Minna.

2.2 Method of data analysis

Acquired data were sieved to remove night hours data using Excel spread sheet. Analysis of solar energy on horizontal plane was analysed in terms of hourly, daily, monthly, and yearly averages to obtain the energy dynamics due to seasonal variations in Minna local environment. Also, analysis of solar energy on inclined plane was done in terms of hourly, daily, monthly, and yearly averages to obtain the energy dynamics due to seasonal variations in Minna local environment. Then, the hourly, daily, monthly, and yearly trends of energy availability according to time and seasons was obtained in consideration of the two surfaces. Equally, the energy availability statistics for both horizontal and inclined surfaces were compared to deduce the difference thereof. The daily, monthly, and yearly averages were deduced using solar irradiance data from 8 am to 7 pm which are the typical sunshine hours of the study area. The months from January to December was considered for the monthly averages, while the yearly averages were from 2016 to 2018 covering all the seasons in the study area.

The difference in the availability of solar energy on the two surfaces was obtained by comparing the energy quantities obtained in the hourly, daily, monthly, and yearly averages from the two surfaces. The results showed seasonal trends.

3. RESULTS AND DISCUSSION

3.1. Analysis of the hourly global solar irradiation on horizontal plane

The mean hourly, global solar irradiance on horizontal plane were obtained from the data obtained by placing the pyranometer on horizontal surface in Minna. The data obtained covered a period of 3 years (2016 to 2018) of hourly, daily, monthly, and yearly data for Minna, Nigeria with Latitude (9^{o} 32 E) and longitude (6^{o} 37 N). The observed average hourly global solar irradiance on horizontal surface is illustrated in Figure 1. The result shows that the hourly global solar energy dynamics on horizontal surface varies during the years. These variations are because of the weather variation accompany the rotation and revolution round the sun. Also, Minna is characterized by two distinct seasons, namely, wet, and dry season [10].

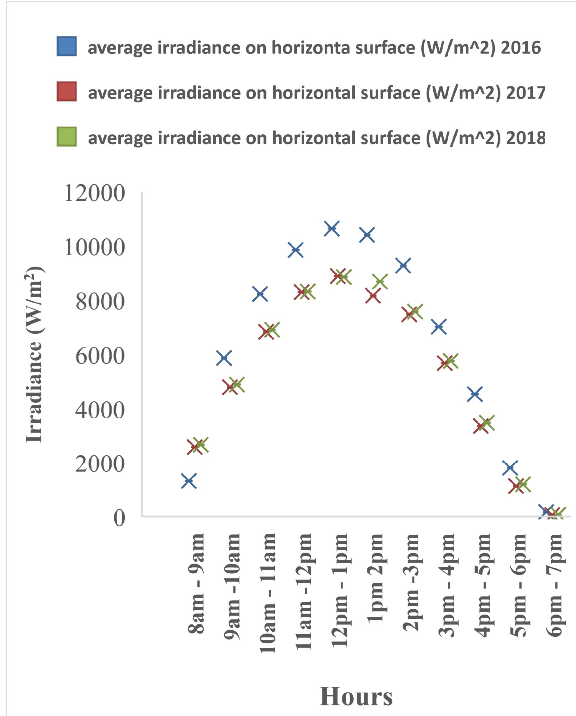


Fig. 1 - Hourly mean variation of global solar energy dynamics on horizontal plane (2016 to 2018)

As shown in Figure 1, in 2016, the maximum value generated was in the hour of 12 Noon to 1 pm with an average value of about 10631.0 W/m^2 and minimum value in the hours of 8 am to 9 am with an average value of about 1305.3 W/m^2 and 6 pm to 7 pm with an average value of about 164.1 W/m^2. Also, in 2017, the maximum value was obtained the hours of 12 Noon to 1 pm with an average value of about 8877.7 W/m^2 and Minimum values were the hour of 6 pm to 7 pm with an average value of about 56.9 W/m^2. Also, in 2018, the maximum value was obtained in the hours 12 Noon to 1 pm with an average value of about 8083.1 W/m^2 and minimum value were obtained in the hours of 6 pm to 7 pm with an average value of about 43.4 W/m^2.

3.2. Analysis of daily global solar irradiation on horizontal plane

From Figure 2, presents the summary of the daily global solar irradiance dynamics on horizontal surface in Minna for 2016 to 2018 with the days in January, February, March having the maximum values and the minimum values during April to August.

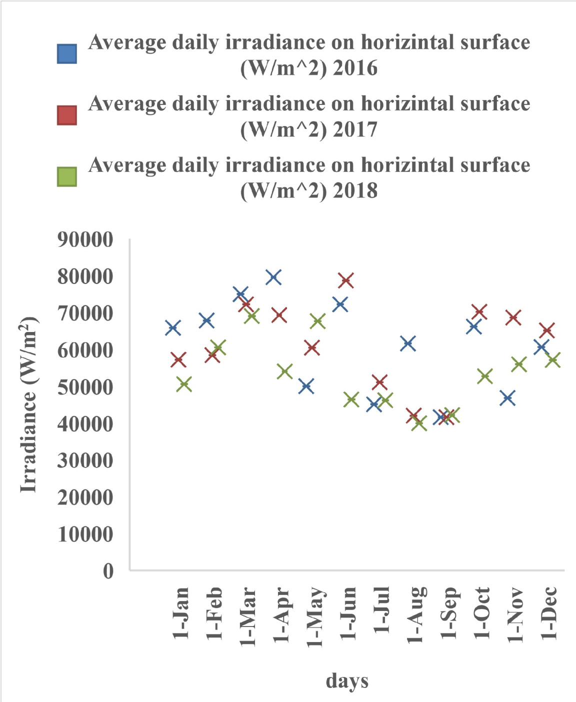


Fig. 2 - Daily mean variation of global solar energy dynamics on horizontal plane for 2016 to 2018

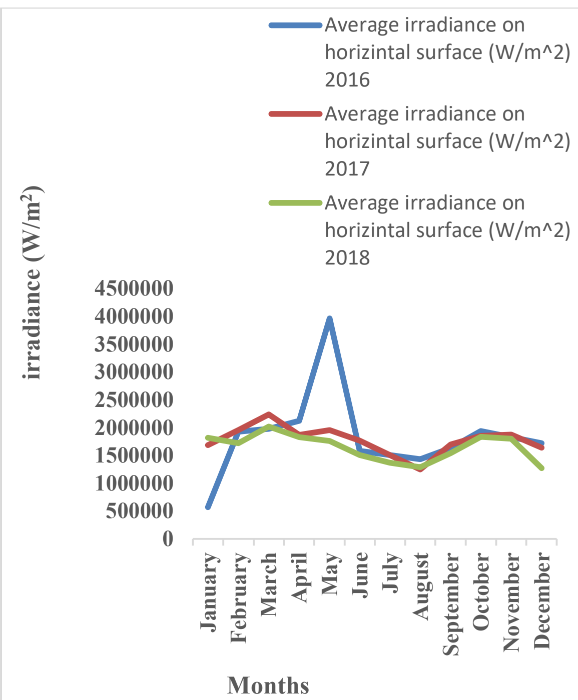


Fig. 3 - Monthly mean variation of global solar energy dynamics on Horizontal plane for 2018.

3.3. Analysis of the monthly global solar energy dynamics on horizontal plane

The average global monthly solar energy irradiance on horizontal surface is illustrated in Figure 3. As shown, the average energy irradiance varies from month to month. In 2016, the maximum value was in May with an average of about 3968731.605 W/m^2 and minimum value in January with an average value of about 572309.29 W/m^2. Also, in 2017, the average global solar energy dynamics on horizontal plane have maximum value in March, with a value of about 2239990.012 W/m^2 and minimum value on August, with a value of about 1251658.208 W/m^2. Also, in 2018, the average global solar energy dynamics on horizontal plane have maximum value in March with a value of about 2020344.1 W/m^2 and minimum value in December with a value of about 1271368.5 W/m^2.

Tables 1 to 3 illustrate the summary of the monthly averages on horizontal surface for 2016 to 2018

Table 1 - The Monthly mean average global solar irradiation on horizontal and inclined surfaces in Minna for 2016.

Months	Average Monthly irradiance on horizontal surface (W/m^2)	Average Monthly irradiance on inclined surface (W/m^2)
January	572309.29	621420.367
February	1929507.867	2022046.272
March	1983035.774	2037889.438
April	2124562.122	2129083.729
May	3968731.605	3952049.795
June	1579640.027	1557237.022
July	1509437.87	1492545.028
August	1436164.192	1406217.726
September	1636778.128	1608536.342
October	1939684.816	1945794.993
November	1831945.636	1914577.737
December	1722697.223	1807836.045

Table 2 - The Monthly mean average global solar irradiation on horizontal and inclined surfaces in Minna for 2017.

Months	Average Monthly Irradiance on Horizontal Surface (W/m^2)	Average Monthly irradiance on inclined surface (W/m^2)
January	1690827.252	1761093.146
Feb	1962933.849	2012733.577
March	2239990.012	2190104.516
April	1871756.983	1810488.776
May	1962363.017	1901066.135
June	1768379.139	1695427.665
July	1510517.207	1465559.771
August	1251658.208	1225246.148
September	1703477.707	1686010.24
October	1858754.217	1920882.676
November	1877673.93	1995026.85
December	1639256.003	1748087.149

Table 3 - The Monthly mean average global solar irradiation on horizontal and inclined surfaces in Minna for 2018

Months	Average irradiance on horizontal surface (W/m²)	Average irradiance on inclined surface (W/m²)
January	1819711.55	1919312
February	1720898.65	1794248.36
March	2020344.1	2080221.75
April	1828281.25	1834007.93
May	1759546.028	1734743.668
June	1510211.044	1488622.69
July	1368448.754	1364919.104
August	1289781.98	1284023.372
September	1542683.417	1555275.084
October	1835633.419	1925928.408
November	1803669.292	1948744.807
December	1271368.5	1343995.35

3.4. Analysis of hourly global solar energy dynamics on inclined surface

The average hourly global solar irradiance on an inclined surface is illustrated in Figure 4. As shown, the average solar irradiance on inclined surface varies during the years. These variations are because of the weather variation accompanying the rotation and revolution round the sun. Also, Minna is characterized by two distinct seasons. Namely, The wet season and dry season [9].

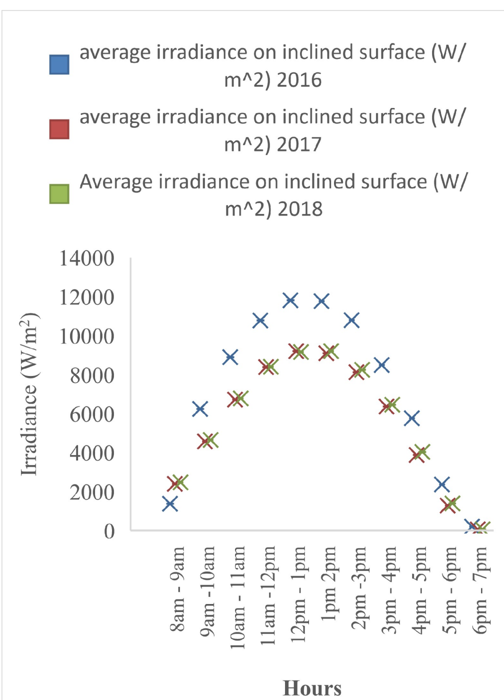


Fig. 4 - Hourly Mean variation of global solar energy dynamics on inclined plane. (2016 to 2017)

In 2016, the minimum value was in the hour of 12 Noon to 1 pm with an average of about 11800.0 W/m² and the minimum value were in the hour of 6 pm to 7 pm with an average of about 196.5 W/m². Also, in 2017, the maximum value was in the hour of 12 Noon to 1 pm with an average of about 9198.8 W/m² while the minimum value was in the hour of 6 pm to 7 pm with an average of about 58.9 W/m². Also, in 2018, the maximum value was in the hour of 1 pm to 2 pm with an average of about 9199.3 W/m² and minimum value was in the hour of 6 pm to 7 pm with an average of about 65.9 W/m².

3.5. Analysis of daily global solar energy dynamics on an inclined plane

The daily global solar energy irradiance on inclined surface in Minna, is illustrated in Figure 5. As shown, the average energy irradiance varies in the years. These variations are because of the weather variation accompanying the rotation and revolution round the sun.

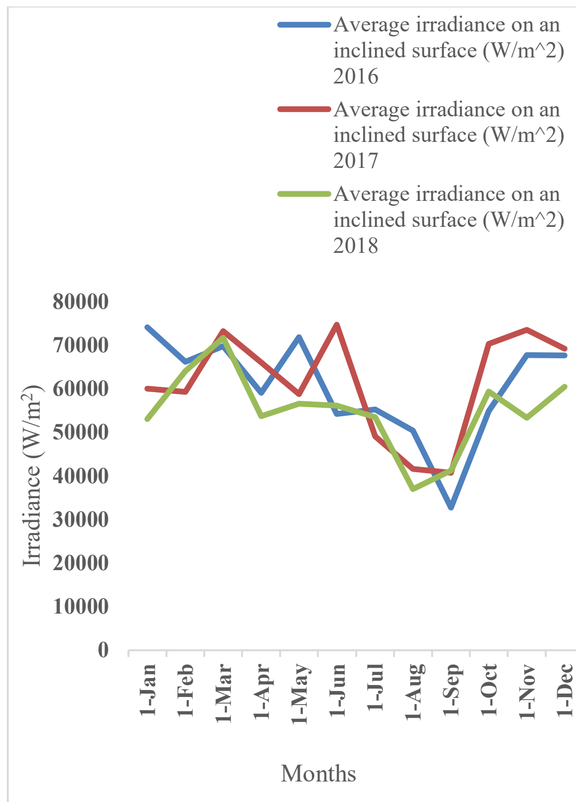


Fig. 5 - Daily mean variation of global solar energy dynamics on inclined plane for 2016.

In 2016, the daily average has maximum value on February 10 with an average value of about 83978.2 W/m² and minimum value on August 15, with an average value of about 12695.3 W/m². Also, in 2017, the maximum value was on February 13 with an average value of about 148876.4 W/m² and minimum value on August 17 with an average value of about 12341.0 W/m². In 2018, the maximum value was March 3 with an average value of about 82378.5 W/m² and minimum value was August 23 with an average of about 13779.8 W/m².

3.6. Analysis of Monthly Global solar energy dynamics on an inclined plane

The average global monthly solar energy irradiance on inclined surface is illustrated in Figure 6. As shown, the average energy irradiance varies from month to month. In 2016, the maximum value was in May with an average of about 3952049.775 W/m^2 and minimum value was in January with an average of about 621420.367 W/m^2. Also, in 2017, the maximum value was in March with an average value of about 2190104.516 W/m^2 and minimum value was in August with an average value of about 1225246.148 W/m^2.

Also, in 2018, the maximum value was in March with an average value of about 2080221.750 W/m^2 and minimum value was in December with an average value of about 1284023.372 W/m^2.

Tables 4 to 6 illustrate the monthly average global solar energy dynamics on inclined surface for 2016 to 2018.

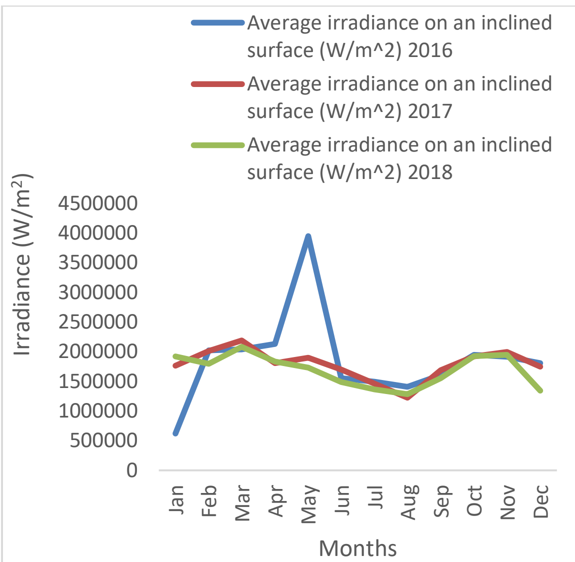


Fig. 6 - Monthly mean variation of global solar energy dynamics on inclined plane in Minna for 2016

3.7. Analysis of yearly global energy dynamics on inclined and horizontal planes

The yearly mean of hourly global solar energy dynamics on horizontal and inclined surfaces have been summarized in Table 4. The data covers from 2016 to 2018. Also, as shown in Figure 7, the average global yearly solar irradiance on horizontal and inclined surfaces has been summarized with 2016 having the best performance.

Table 4 - The yearly mean average of global solar irradiation on Horizontal and inclined surfaces in Minna for 2016 to 2018.

Years	Average irradiance on horizontal surface (W/m^2)	Average irradiance on inclined surface (W/m^2)
2016	22234495	22495234
2017	21337588	21411727
2018	19770578	20274043

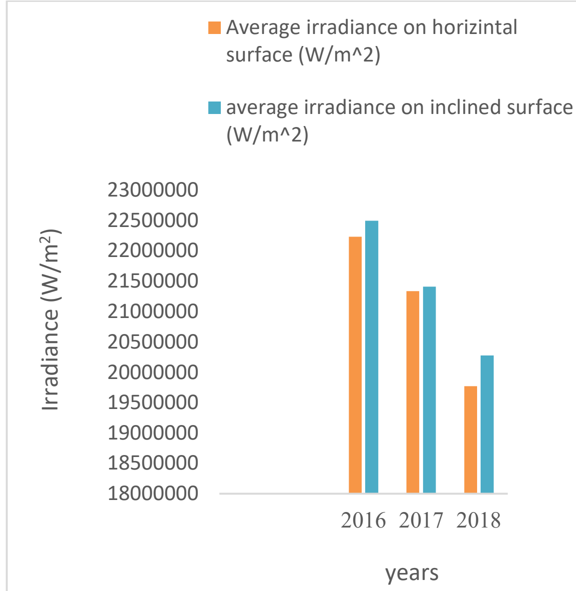
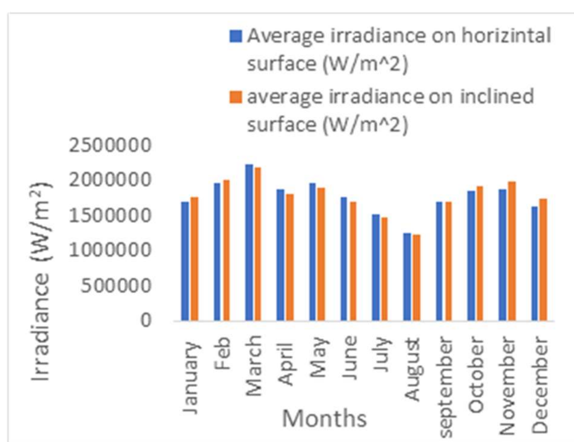


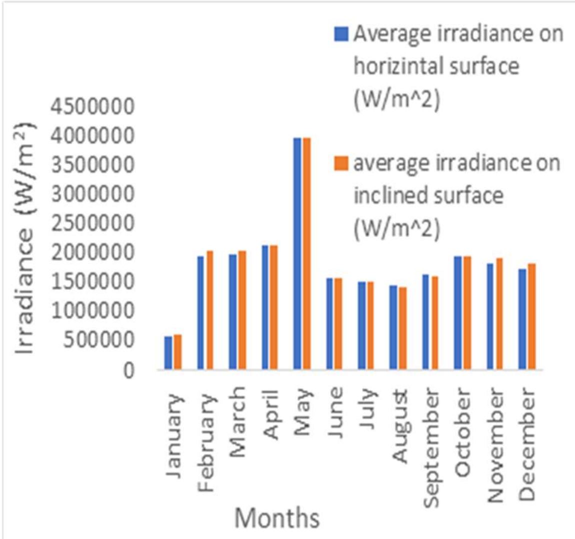
Fig. 7 - Yearly mean variation of global solar energy dynamics on horizontal plane in Minna for 2016, 2017 and 2018.

3.8. Comparison of solar energy on horizontal and inclined surface

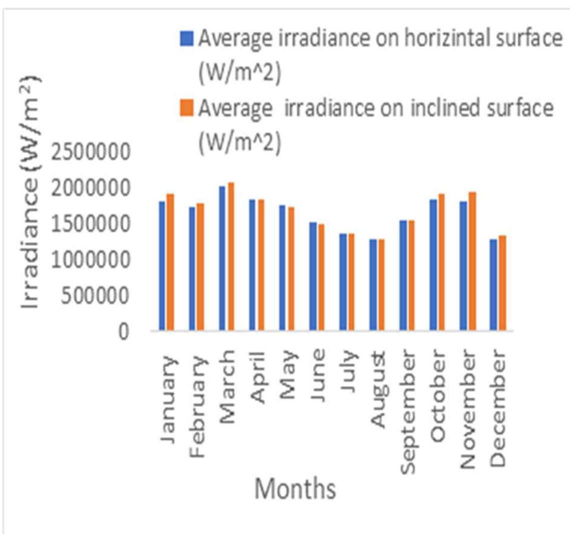
The comparison between the average monthly global solar energy irradiation on horizontal and inclined surface is illustrated in Figures 8a to 8c. As shown the difference between the average solar irradiance between the two surfaces vary during the year. Tables 1 to 3, presents the summary of the average values of monthly mean global solar energy dynamics on the two different surfaces under consideration. One on horizontal surface and the other on inclined surface for 2016 to 2018. As shown, in Figures 8a to 8c, In the months of January to April during the dry season when the humidity is high, global solar irradiance is higher on inclined surface than the horizontal surface while in the months of July to October, during the wet season, irradiance is higher on horizontal surface than that on inclined surface. Considering the months of November to December, irradiance is higher on inclined surface than that on horizontal surface.



(a)



(b)



(c)

Fig. 8 - comparison of global solar energy dynamics on horizontal and inclined plane in Minna. (a) 2016 (b) 2017 (c) 2018.

4. CONCLUSION

The analysis of solar energy on horizontal surface has been achieved in terms of hourly, daily, monthly, and yearly global solar energy dynamics throughout the seasons in Minna.

Also, the analysis of solar energy on inclined surface has been achieved in terms of hourly, daily, monthly, and yearly global solar energy dynamics throughout the seasons in Minna.

In comparison, the quantity of solar energy on inclined surface is greater than that on horizontal surface based on yearly average but not for all seasons of year because there are instances where the reverse is the case during the wet season.

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Author contributions

"F. U. Uruakpa conceived the idea and conducted the analysis and findings."

"J. A. Ezenwora conducted the experiment and did the major supervision."

"A.G. Ibrahim did the co-supervision."

Conflict of interest

The authors declare no conflict of interest.