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GEOSPATIAL ESTIMATION OF ROOFTOP SOLAR PHOTOVOLTAIC POTENTIAL IN CALABAR MUNICIPAL, CROSS RIVER STATE, NIGERIA

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ABSTRACT

The availability of significant solar resource and the continuous hike in economic activities as well as an increased population in Calabar Municipal holds a substantial solar photovoltaic (PV) potential of rooftops in the city. This is as a result of the consequent increase in urban households. This Research work is aimed at estimating solar PV potential of rooftops in the study area using geospatial techniques. It adopted Geospatial techniques' approach in identifying rooftops available for PV deployment in Calabar Municipal. High resolution satellite imagery gotten from google Earth, Digital surface model (DSM)/ Digital elevation model (DEM) and ArcGIS 10.8 were employed in this study. In other to estimate the PV potential of rooftops, criteria such as Solar Radiation/ Irradiance, Total Roof Area (Building footprints), Slope (rooftop inclination angle) and Aspect (Buildings' orientation) were analyzed. The results gotten from these analyses were analyzed further and rooftops that fall below the acceptable range of the aforementioned criteria were excluded from the analysis. Results showed that the total roof area in Calabar Municipal was estimated as 5,965,916.44 m^2 (5.97 km^2) while the available roof area suitable for PV installations was evaluated as 5,964,966.42 m^2 (5.96 km^2). The findings of this research indicates that Calabar Municipal has good solar radiation as well as enough suitable rooftop area hence a very good place for solar PV deployments. Also, this study is accurate enough to be used as a guide in decision making on power (electricity) generation in Calabar Municipal of Cross River State.

Keywords: Rooftop Photovoltaic Potential, Solar Radiation, Calabar Municipal, Geospatial Techniques

INTRODUCTION

The demand for renewable energy sources in the world has been on the increase in order to reduce greenhouse gas emissions and to meet the global warming regulations (Fakhraian, Forment, Dalmau, Nameni and Guerrero, 2021). Renewable energy potential determination has a significant role to play in the development of energy policies and regulations (Izquierdo, Rodrigues and Fueyo, 2008). This according to Huang, Mendis and Xu (2009) is as a result of environmental degradation and energy crises. Although urban areas are the major consumers of energy supply, they are also considered as producers of high-potential energy (Fakhraian et al, 2021). Hence the need to promote the use of clean renewable energy sources (United States Energy Information & Administration, 2013). Nevertheless, the use of rooftop solar photovoltaics serves as an effective remedy for urban energy crises (Huang et al., 2009).

In locating suitable rooftops, attention have been given solely to urban areas as a result of the prevalence of high density of rooftops (Castellanos, Sunter and Kammen, 2017). In order to compute the available rooftop in an area, several considerations which influence built up such as population densities, the height and number of buildings as well as construction typologies must be made. Also, the location, shading, inclination orientation, historical considerations and other competing uses (elevators, pent houses or roof terraces etc.) determine relation between built-up and roof top available area (Izquierdo et al., 2008). Furthermore, the amount of solar radiation at a geographic location is of high relevance for solar energy utilization (Abdurrahman, Gambo, Musa, Sa'adu, Shehu & Dahiru, 2023).

The estimation of rooftop potential of solar PV does not require a specific approach as scholars have employed a variety of methods in the past to achieve this aim (Dioha and Kumar, 2018). Nevertheless, a detailed review of literature has revealed that solar PV estimation of rooftop can be achieved using three different techniques thus; the constant value, manual selection and GIS based techniques (Gagnon et al, 2016). With the emergence of Geographical Information Systems (GIS) which is now a matured technology, most researchers have employed it in carrying out renewable energy analysis (Khan & Arsalan, 2016). This is achieved by extracting suitable rooftops from satellite imageries and the use of further geospatial techniques for estimation of PV potentials. This methodology has been adopted in this study.

There are lots of energy resources in the world and Nigeria is yet to tap into the wealth of its renewable energy potential as the production of about only 3,000 megawatts of electricity presently in the country is grossly inadequate even for domestic consumption (FaithPraise et al., 2017). The generation capacity in Nigeria is mostly based on natural gas which is majorly sold out of the country and very little amount is left to cover the country and only 30% inhabitants of Calabar benefits from this left-over electricity (Edem, 2017). Edem, (2017), further posited that Calabar is solely dependent on the Odukpani power plant hence the electricity generated is usually poorly accessed and barely enough for household consumption and poses a great threat for industries striving in the city. Therefore, there is a dire need for the assessment and identification of suitable rooftops in the study area for PV deployment which could be utilized for effective and efficient generation of electricity for household consumption needs as well as boosting economic activities in the area.

Furthermore, Calabar, the capital of Cross River State experiences an abnormal supply of electricity which is grossly inadequate (Obafemi & Ifere, 2013). The insufficient and unreliable nature of electricity supply most times result in power failure experiences several times a day and may last for days and possibly weeks (Eronini, 2014). Hence the need for adoption of solar PV system in the city, which is a more reliable and cleaner source of energy (Ezugwu, 2015). This is crucial because Calabar possess an annual daily sunshine and an annual average daily radiation which when harnessed, is enough to produce energy with the deployment of Solar PV systems (Okafor & Uzuegbu, 2010).

Although, awareness of solar energy is gradually gaining cognizance in the city as most institutions and few private home owners are utilizing solar energy for power generation (Faithpraise et al., 2017), it is pertinent that an increased use of solar PV be employed for efficient and effective generation of electricity to meet household and industrial needs in the Municipal.

MATERIALS AND METHODS

Study Area

Calabar Municipal is located between latitudes 04º 54′ 15″ N and 05º 06′ 15″ N of the Equator and between longitudes 8º 20′ 15″ E and 8º 26′ 25″ E of the Meridian (See Figure 3.1) found in the southern part of Nigeria. The town is one of the two local government areas that make up the capital of Cross River State (Ibor & Atomode, 2014). It is flanked on its eastern border by the Great Kwa River and on its western border by the Calabar River (Antigha, Akor, Ayotamuno,Ologodien & Ogarekpe, 2014). According to the 2006 National population Census, Calabar Municipality has an estimated population of 371,022 people (Okaliwe, Nja, Ogunkola, Ejemot-Nwadiaro & Lucero-Prisno, 2021) and covers an area of 210,936 sq km (Ibor & Atomode, 2014).

Calabar municipal lies within the tropical equatorial climate which experiences high temperature, high relative humidity and heavy annual rainfall (Inyang, 1980). According to Okafor & Uzuegbu (2010), Calabar possess an annual daily sunshine of 6.25 hours which ranges between 3.5 hours in the coastal regions to 9.0 hours in the far northern areas. Also, it possesses an annual average daily radiation of about 5.25 kW/m2 per day in the coastal area and 7.0 kW/m2 in the northern region. This when harnessed, is enough to produce energy using Solar PV systems.

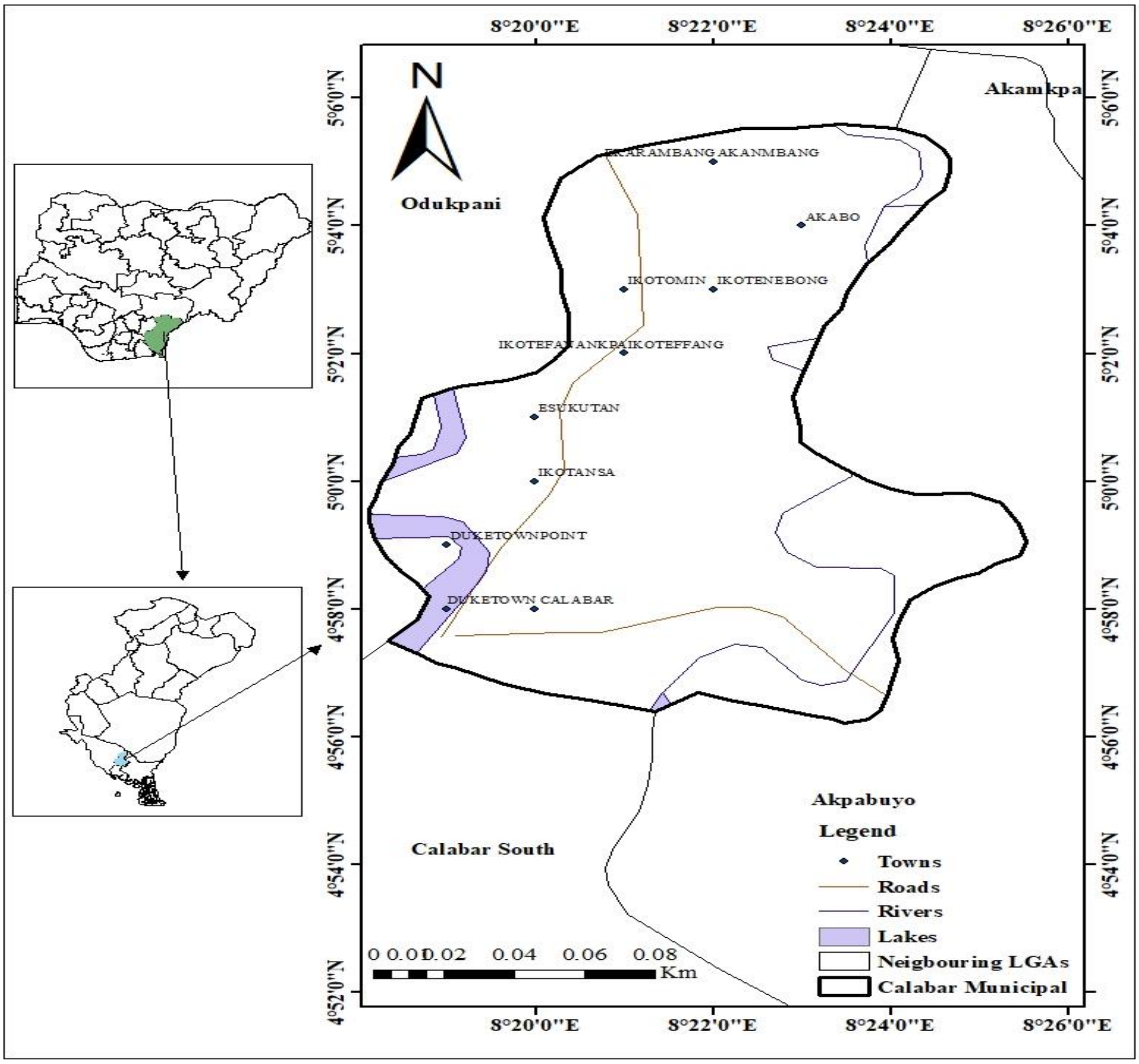

Figure 1: Calabar Municipal
Source: Author's Work

Data and Data Sources

The data that were used for this research are as presented in the table 1 below.

Table 1: Data Types and Sources

S/N	Data	Source	Purpose
1	High resolution satellite image.	Google earth	For extraction of building footprints and rooftops.
2.	Digital surface model (DSM)/Digital Elevation Model (DEM).	United States Geological Survey (USGS).	Extraction of rooftops exposed to solar radiation
3.	Base Map.	Office of the Surveyor general of CRS.	To clip out the study area boundary.

Source: Author's Compilation

Analysis

Examining the factors influencing PV potential of rooftops in the study area.

In order to achieve this objective, four (4) factors will be examined within the GIS framework as detailed below;

i. **Solar Radiation:** The Solar radiation was extracted from the Digital Surface Model (DSM) of the study area using area solar radiation tool of spatial analyst tool in ArcGIS. By default, the solar radiation raster was produced in watt hour per m^2 and was converted to the unit of kilowatt hour per m^2 for ease and meaningful reading using raster calculator under map algebra with the formula below;

ii. Solar radiation in watt hour per m2 = $\frac{Solar\ radiation\ raster}{1{,}000}$

iii. Rooftops that receive high radiation from the sun have higher potentiality than rooftops that receive low radiation from the sun. (Buffat *et al.* 2018; Ayodele *et al.* 2021).

iv. **Total Roof Area (Building footprints):** The rooftops in the study area were extracted from high resolution satellite image through on-screen manual digitization to form a layer. The total area covered by the rooftops was calculated through the attribute table of the layer using calculate geometry function of ArcGIS. The area was calculated in square meter, which will be copied into Microsoft Excel sheet to find the summation. The summation will give the estimation of total surface (roof) area available for installation of PV panels. Areas covered by shadow and other uses has lower potentiality while areas with direct contact with the sun has higher potentiality (Singh & Banerjee, 2015; Khan & Arsalan, 2016).

v. **Slope/ Rooftop Inclination Angle:** In this study, Digital Elevation Model (DEM) of the study area from Shuttle Radar Topography Mission (SRTM) acquired from United States Geological Survey (USGS) was imported into ArcGIS 10.8 to produce the slope map of the study area using the spatial analyst tool's function. The slope map produced in degree is easier to expunge areas that have higher slope (>10°) base on the study criteria evaluation (Mamun *et al.* 2022).

vi. **Aspect/ Building Orientation:** Aspect map was produced from the DEM of the study area in ArcGIS 10.8. Using the analyst tool's function. Under surface analysis, the aspect map was produced. It gave value range and cardinal direction. This helps to know the direction each building in the study area is facing. Building facing north normally receives less to no sunshine (Hafez et al., 2011; Latif *et al.*,2012; Maresova, 2014). So, these building were expunged from the analysis.

Determining rooftops that are suitable for solar PV installation

To achieve this objective, the solar radiation and available rooftops of the study area were subjected to series of conditions as outlined by the various criteria that influence the suitability of rooftops for solar PV installation. Since slope, amount of solar radiation, aspect and total roof area affects the suitability of rooftops for PV solar energy utilization; buildings that fall below accepted range of these criteria were excluded from the analysis to get the total rooftops that are suitable for solar PV installation.

RESULTS AND DISCUSSIONS

Factors influencing PV potential of rooftops in Calabar Municipal

Solar Radiation

The solar radiation of Calabar Municipal as presented in Figure 4.1 ranges between 1,669.21 kwh/m^2 and 1,798.8 kwh/m^2. The result further revealed that higher solar radiation is found around the western part of the study area trending from south to north (as indicated in red). This indicates that the western part of the study area is best fit for PV deployment while other parts in the study area (as indicated by colors other than red) are less fit for PV installation. This agrees with the works of Buffat *et al.* (2018) and Ayodele *et al.* (2021) which showed that high radiation determines high potentiality of rooftops in an area. It was also discovered that the solar radiation that falls on the rooftops ranges between 1,669.21kwh/m^2 and 1,798.8kwh/m^2.

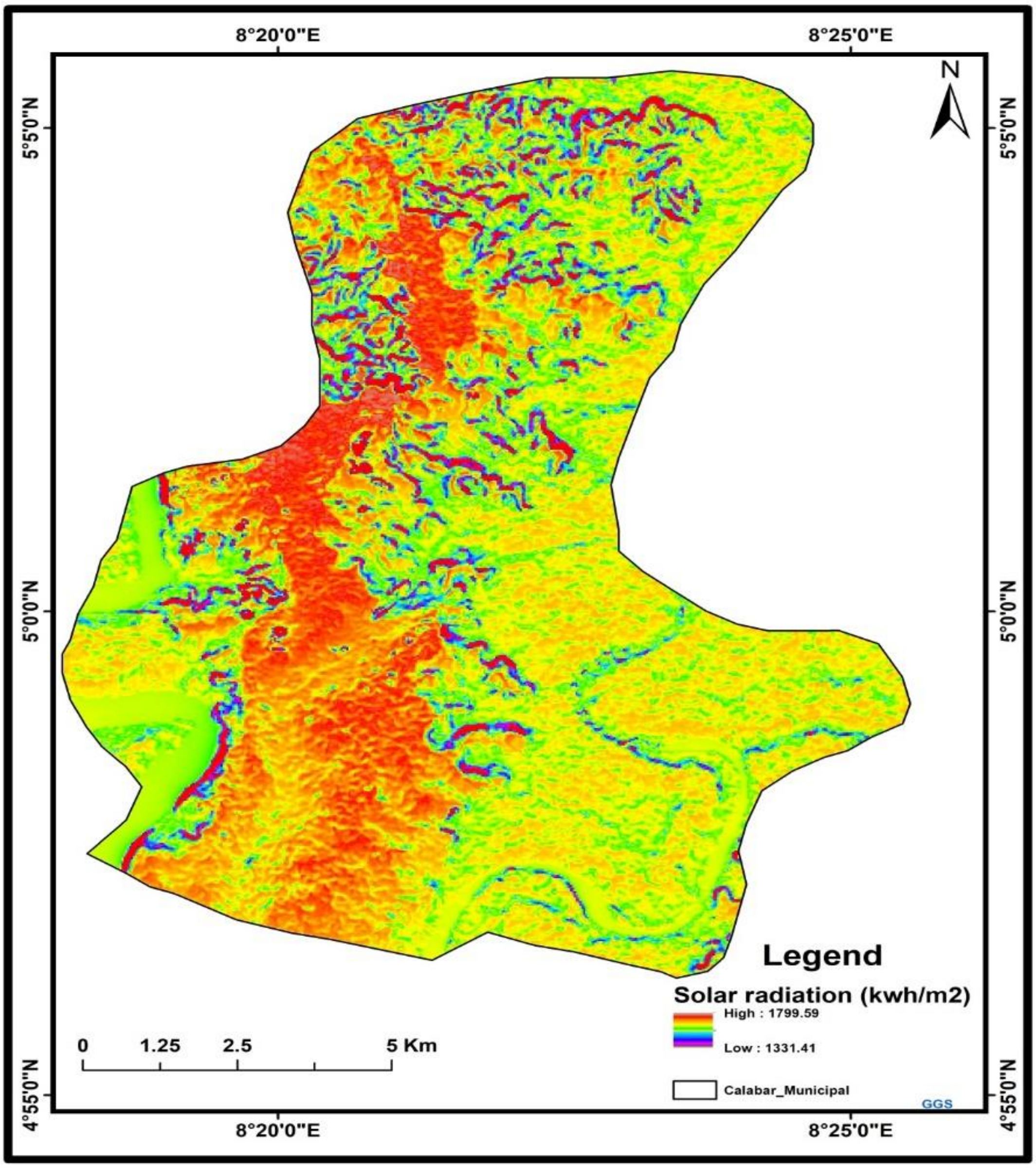

Figure 2: Solar Radiation in the Study Area
Source: Author's Analysis

Total Roof Area/ Building footprints

The result of the total roof area as shown on figure 4.2 and Table 4.1 indicates that most of the building footprints are found in the western part of Calabar Municipal trending from North to South. It can also be noticed that the building footprints are more concentrated in the central region of the study area. Building footprints are essential in getting the building rooftops which receives direct solar radiation and on which the PV panels will be installed. This is in agreement with Dioha and Kumar (2018), who opined that, areas with dense buildings has higher potentiality for rooftop PV deployment than areas with sparse buildings. In Calabar Municipal, the eastern part of the area which lack building footprints were excluded from the analysis since the attention of the subject matter of this study is on building rooftops.

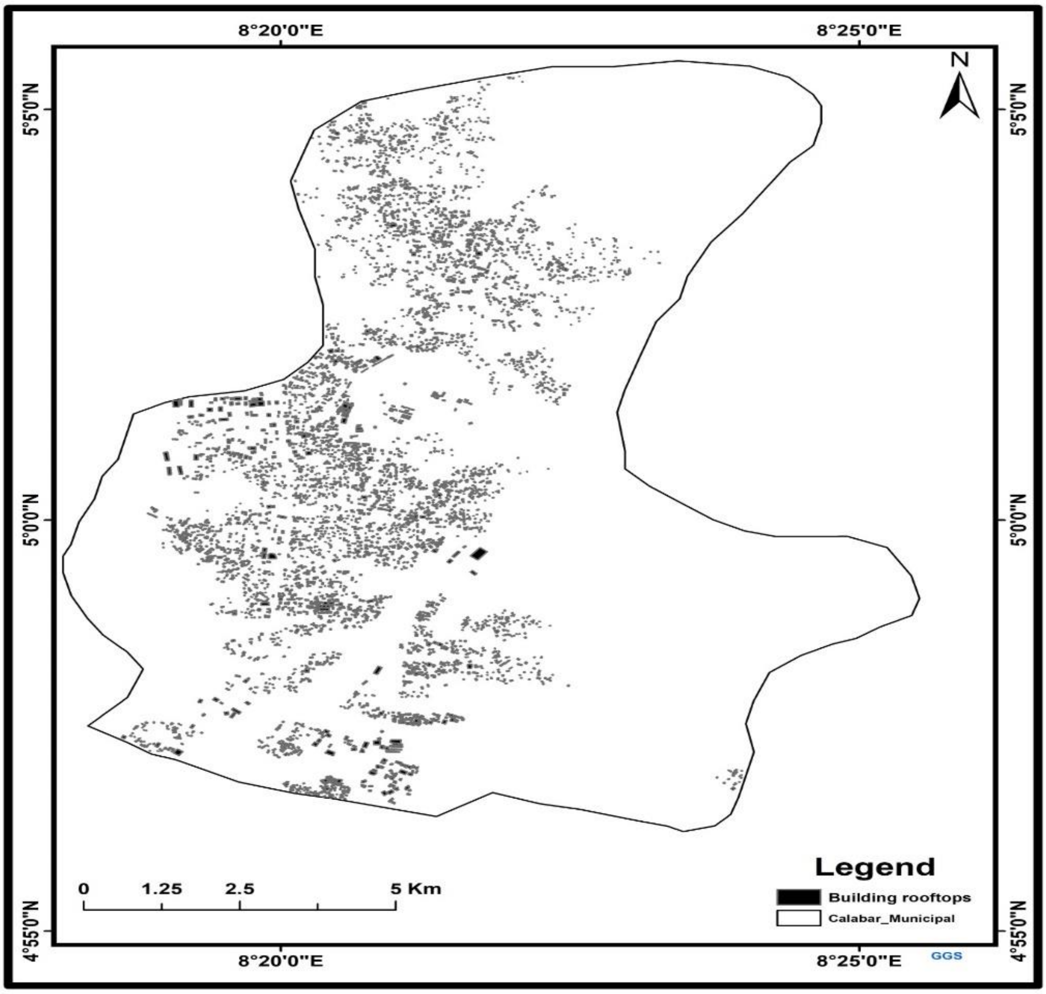

Figure 3: Building Footprints in the Study Area
Source: Author's Analysis

Table 2: Building footprints (Rooftops) statistics

S/N	Item	Value
1	Total buildings	5,191
2	Total roof area	5,965,916.44m^2
3	Mean	1,149.28
4	Standard deviation	888.3129

Source**:** Author's Compilation

As shown in Table 4.1 there are 5,191 building footprints (rooftops) in Calabar Municipal with a total area of 5,965,916.44m^2. It suffices to say that Calabar Municipal is a highly developed area in terms of buildings hence have high potential for solar PV deployment.

Slope/ Rooftop inclination angle.

The result of slope analysis ranges between 0 and 40.1 degrees as presented in figure 4.3. From the result of the slope of this study, it can be seen that the southern parts of the study area have gentle slopes ranging between 0^o to 8.8^o. Therefore, attention could be directed here for better solar yield required for PV installations with respect to slope.

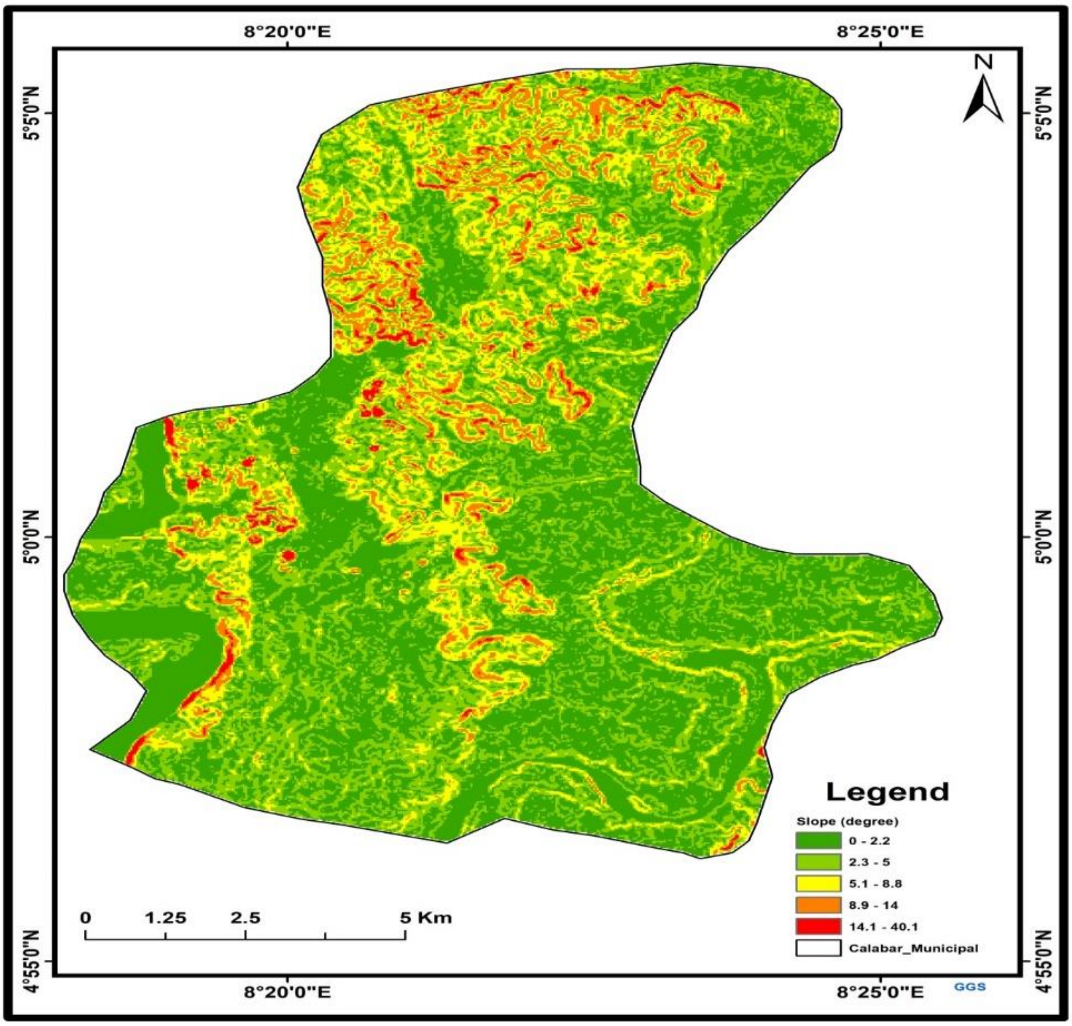

Figure 4: Slope Classes of the Study Area
Source: Author's Analysis

Aspect

The aspect result is presented in figure 4.4 below. It shows that the study area has an aspect that range from -1 (flat surface) to 360 (facing north). In the study area many buildings fall within this category (0-22.5 and 337.5-360 facing north). The implication of the buildings facing direct north is that they receive less sunshine as a result; less solar energy is available on such rooftops for utilization by PV. However, some buildings in the study area are oriented towards the south-east (112.5-157.5), south (157.5-202.5) and south-west (202.5-247.5) hence are better fit for PV installations. This agrees with the work of Maresova (2014) as well as Latif *et al.* (2012) which showed that buildings with true south orientation, found between south-east and south-west are most effective for PV deployment.

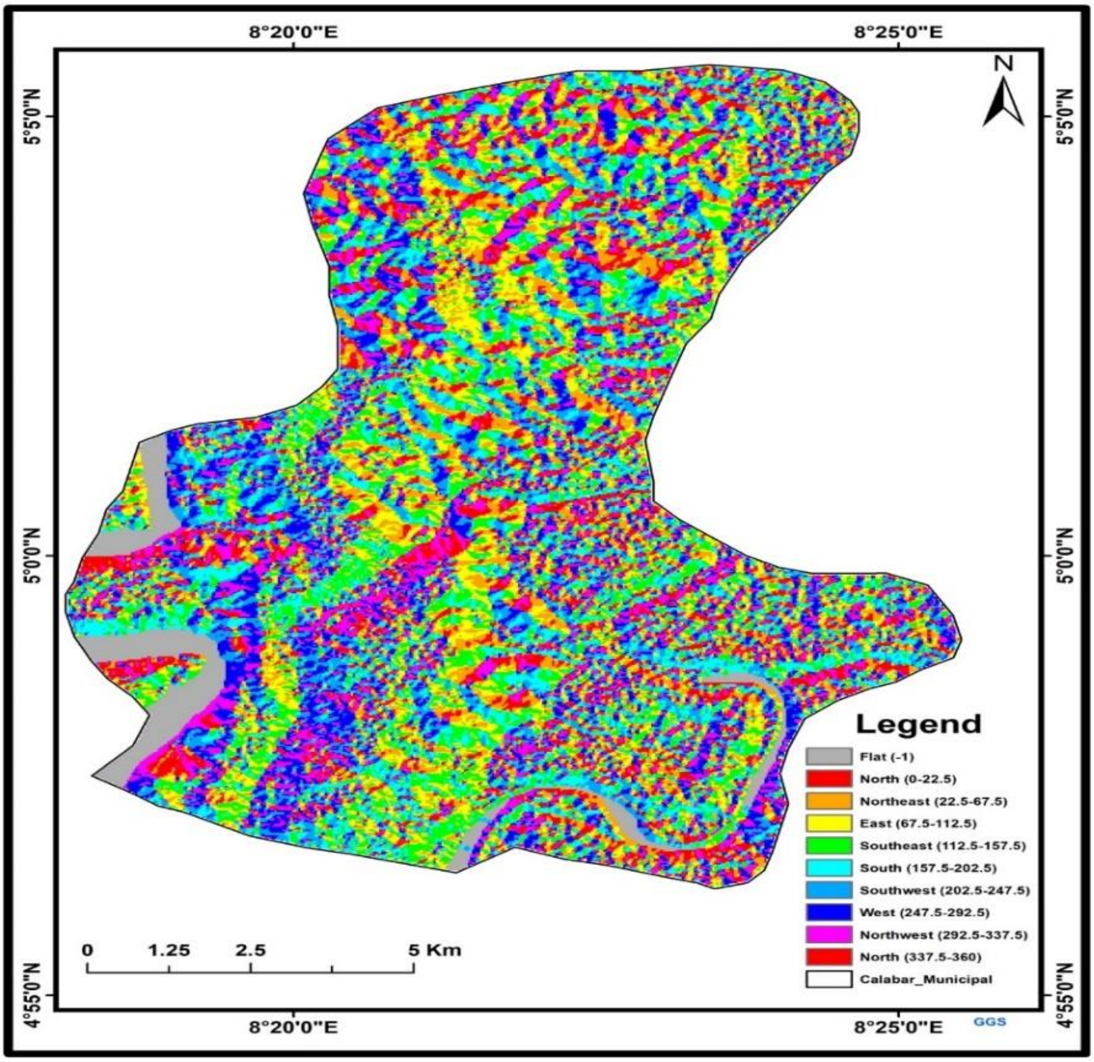

Figure 5: Aspect map of the Calabar Municipal.
Source: Author's Analysis

Rooftops suitable for solar PV installation in the study area

Out of 5,191 rooftops in the study area about 5,005 rooftops (96.4%) are found to fall under slope that are less than 10° and the associated solar radiation was found to be 1,669.21kwh/m^2 to 1,798.8kwh/m^2. This implies that about 186 buildings (3.6%) have been excluded since such rooftops receive less direct sunshine. Furthermore, buildings facing north and those with roof area less than 40m^2 were removed and the final suitable rooftops for PV solar installation is presented in figure 4.5. The final suitable rooftops in Calabar Municipal were found to be total of 4,857 rooftops with total roof area of 5,964,966.42m^2. While this agrees with *Song et al.* (2018), this is contrary to the work of Sakti *et al.* (2022) which showed that effective solar PV in Bandung ranges from 351.833 to 493.813 W/m^2, with a total of 37,688 building rooftops being at a high level of priority for solar PV development. This was as a result of the use of the analysis of meteorological effects integrated with the hill shade parameter to obtain the solar PV potential. However, the value of solar radiation for the final suitable rooftops in Calabar Municipal is found to still range between 1,669.21kwh/m^2 to 1,798.8kwh/m^2

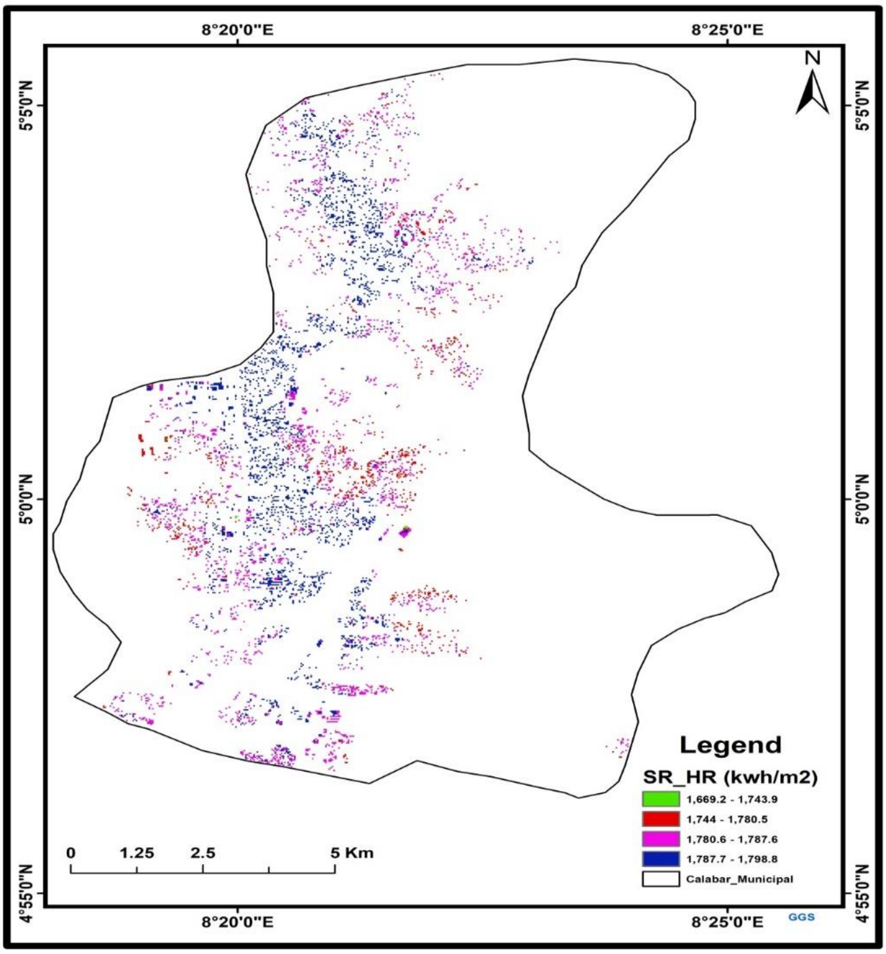

Figure 6: Final suitable rooftops and associated solar radiation in Calabar Municipal
Source: Author's Analysis

CONCLUSION

The rooftop solar photovoltaic potential in Calabar Municipal was estimated. High resolution satellite imagery gotten from Google earth, DSM/DEM and ArcGIS 10.8 were employed in determining the available rooftop suitable for PV deployments in the study area. Factors such as solar radiation/ irradiance, total roof area, slope and aspects were analyzed to see rooftops that fall within the acceptable limits for solar PV installations. Results from these analyses were further analyzed where rooftops that fell below acceptable limits were eliminated from the analysis. The total roof area in Calabar Municipal was estimated as 5,965,916.44 m^2 (ie 5.97 km^2) while the available roof area suitable for PV installations was evaluated as 5,964,966.42 m^2 (ie 5.96 km^2).

Conclusively, from the findings of this research, it suffices to say that Calabar Municipal has a good solar radiation as well as enough suitable rooftop area hence a very good place for solar PV deployments. Also, the solar PV suitability map of Calabar Municipal is accurate enough to be used as a guide in decision making on power (electricity) generation in Calabar Municipal of Cross River State.

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