Global Journal of Engineering and Technology Advances, 2020, 05(02), 071–085

Global Journal of Engineering and Technology Advances

Cross Ref DOI: 10.30574/gjeta

Journal homepage: http://www.gjeta.com

(RESEARCH ARTICLE)

Selecting optimal site for solar photovoltaic plant in Ikwerre L.G.A., Rivers State, Nigeria

Jeremiah Uriah Richard [1, *] and Godwill Tamunobiekiri Pepple [2]

[1] *Head Business Development, Office of the Surveyor General, Moscow Road, Port Harcourt, Nigeria.*
[2] *Department of Surveying &Geoinformatics Rivers State University, Port Harcourt, Nigeria.*

Publication history: Received on 17 November 2020; revised on 26 November 2020; accepted on 28 November 2020

Article DOI: https://doi.org/10.30574/gjeta.2020.5.2.0102

Abstract

Erratic power supply is a serious problem to most part of Rivers State, Nigeria in general and Ikwerre Local Government Area in particular. This situation does not only halt social and economic development of the area but has also given birth to other social vices such as arm robbery, kidnapping, and other criminal activities. Renewable energy is an alternative form of energy aim at alleviating the problems of erratic power supply. It is generally considered as the cleanest form of energy. Solar photovoltaic is a type of renewable energy which derived its energy from the sun. The construction of solar plant requires the selection of suitable location for the generation of optimal energy. The purpose of the study is to determine suitable locations in Ikwerre Local Government Area, Rivers State to site solar photovoltaic plant using multi-criteria analysis (MCA) in ESRI's ArcGIS. The dataset used for the determination of the optimal sites include; solar radiation and slope map produced from digital terrain model (DTM), pipeline, road network, land use/ cover map, soil map, and settlement. The datasets were converted to raster and reclassed into six classes for the purpose of data integration. The datasets were weighted according to their relative importance in the weighted overlay tool. Solar radiation has the highest percentage influence 40, followed by proximity to pipeline and road network which are 15 each. The model produced four suitability classes ranging from poorly suitable to highly suitable class. Highly suitable class has an area of 10139.87ha with 548 polygons, representing 15.78% of the study area. Further analysis was carried out using highly suitable class and settlement layer, it was found that three (3) optimal sites were obtained as most suitable for sitting solar plant. The three polygons were located in the region with very high solar radiation, accessible to road and away from built-up areas. The above results suggest the usefulness of GIS in site selection, particularly in sitting solar photovoltaic plant. It is recommended that further study should include transmission line which was completely omitted in this analysis due to inability to get the shapefile from the ministry of power.

Keywords: Climate Change; Green House Gases; Multi-Criteria Analysis; Renewable Energy; Solar Photovoltaic; Slope Model; Solar Radiation.

1. Introduction

Renewable energy (RE) is an alternative form to the well known non-renewable energy such as fossil fuels and nuclear power. Renewable energy is energy derived from limitless sources [1], since supplies are continually replenished through natural processes. Also define as energy that comes from an inexhaustible source [2]. They include; hydropower, solar energy, wind energy, geothermal energy, biomass energy and ocean energy [3]. RE resources existence occur over large geographical space and are generally very efficient and cheaper. Renewable energy is directly or indirectly derived from sun. Its main functions are for power generation for industrial and commercial usage, air and water heating/ cooling, transportation and rural energy services [4]. The technologies are considered as the cleanest source of energy with little or no environmental impacts unlike the conventional energy sources. In addition, they provide the following benefits; energy security, climate change mitigation and energy economy. According to experts,

*Corresponding author: Richard J. U.
Head Business Development, Office of the Surveyor General, Moscow Road, Port Harcourt, Nigeria.

the greatest benefits of RE lies on its potential in mitigating climate change. Climate change is cause by the accumulation of greenhouse gases such as carbondioxide (CO_2),ozone (O_3), nitrous oxide (N_2O) and methane (CH_4) [5]and water vapour [6] in the atmosphere. Climate change main driver is the anthropogenically released carbon dioxide (CO_2) into the atmosphere [7] and is due to the combustion of fossil fuel [8]. Changing climate affected food security (FS) of a nation [9], causes poor crops productivity and frequent floods and droughts [10] and increase temperature [11].

About 14 percent global energy consumption comes from renewable energy [3]. As at 2014, RE provided an estimated 19.2 percent of global energy consumption with an estimated 147 gigawatts added in 2015 being the largest annual increase [4]. Investment in this sector has increase from 104 billion USD in 2007 to 150 billion USD in 2009 with China leading in renewable power development [12]. The investment in RE increase into this present date with more systems introduced for power generation.

Solar energy derives its power from sunlight. Of the sun's total power of 1.4 x 10^5 TW transmitted to the earth surface only 3.6 x 10^4 TW are utilized for electricity generation [13]. Going by the fraction utilized on earth, a square meter of land is exposed to sunlight that can produced 1,700 kWh of power per year [14]. Solar technology is beneficial to the environment through the provision of clean, reliable, scalable and affordable energy security [15]. Solar systems are classified into different types based on the absorbing mode of solar energy [16]; [17]. Of these categories, solar photovoltaic (PV) is mostly used to generate electricity [18]; [14]. The technology of current PV was invented in 1954 at Bell Telephone Laboratories [19]. PV industries are growing at an alarming rate, serving numerous world energy crises. Recent reports shows that global solar energy capacity was about 2.5 gigawatts [20] with China leading the production [21].Solar photovoltaic farm is an expensive project and as such efforts and time must be exhausted in selecting suitable location for optimal production. Renewable energy like solar photovoltaic is nature specific and will be strategically located to meet the energy needs of the people through remote sensing and GIS approach.

1.1. Statement of Research Problem

Affordable and steady electricity is paramount for the development of economy and all industries both small and big relied on electricity for its operations. Nigeria as a country is face with the challenges of poor power supply. It source of power supply since 1960 was based solely on hydropower plant [22] without any agenda to diversify the sector. The plant supplies electricity occasioned by erratic power supply to less than half of Nigeria's population [23]. The adverse effect was that power outage negatively affected our nation's economy with many industries shutdown [24] and others operating at low marginal profit [25]. Successive government in Nigeria has spent billions of dollars in the sector without any visible results. The recent revelation by the present administration that previous administration led by former President Olusengun Obasanjo spent 16 billion Dollars in power sector [26] without improvement in power generation in Nigeria. Many enterprises both small and big are being affected by the epileptic power supply. Small enterprise such as hair dressing saloon, steel fabrication, wedding, frozen food outfits, restaurant, supermarket, and small holding palm oil processing enterprise required regular power supply. Also big enterprises like banks, hotels, telecommunication industries, shop rites and supermarkets required adequate, steady power supply for their optimal performance. Most of these industries operate at high cost when the cost of operating generating set is added and the implication was that it will leads to inflation in the area [27]. Loss of farm produce and perishable food stuffs are common among farmers and household as a result of poor power generation. Crime rate is on the increase in rural and urban areas when people took the advantage of darkness enveloping the streets to commit crimes.

Erratic power supply has caused many homes to resort to using fire woods for cooking and big and small enterprises uses generators of various capacities for their daily operations. The greatest environmental consequence of these alternative energy sources is the problems of air pollution and climate change [28]. Greenhouse gases (GHGs) associated with climate change can leads to premature death, cardiovascular and respiratory disease and asthma [29]. It is responsible for global rainfall variation [30]; [31], menace of food security and water supply [32] and others social and agricultural problems. These problems will only be addressed if alternative power supply is available, hence, this study seek to select optimal location for solar power farm in the area through remote sensing and GIS approach.

1.2. Aim and Objectives of the Study

The aim of the study is to select optimal site for the installation of solar photovoltaic system that can arguments available power supply using multi-criteria analysis in ESRI's ArcGIS and remote sensing data.The study is structured to address the following objectives;

To model and determine the spatial variation of solar radiation using digital terrain model.

To determine optimal sites for locating solar photovoltaic system using multi-criteria analysis in the ArcGIS Spatial Analyst Tool.

2. Materials and Methods

2.1. Study Area

The study area is Ikwerre Local Governemnt Area, Rivers State, Nigeria. It is located between latitude 5° 00’ 00”mN – 5° 15’ 00”mN and longitude 6° 45’ 00”mE – 7° 00’ 00”mE in the UTM Zone 32N. It has a total area of 655.71sq.km and it is situated in the boundary between Rivers State and Imo State. Also has a total population of 189,726 [33]with its administrative and traditional headquarter’s in Isiokpo. The inhabitants of the area are predominantly farmers of various categories. The elevation of the area as obtained from the topographic data varies between 50m in the north to 18m in the south. This elevation is above the mean sea level.

The study area is made up of different land use and land cover types. Notable land use in the area include; buildings including both residential and industrial buildings, agricultural farmland and roads including dual carriage roads (Port Harcourt/ Owerri road, Igwuruta/ Rumuokwrushi road and Igwuruta/ Etche road), major roads, main paths and track roads. Land cover are earth’s surface features that exist naturally and they include; rivers, streams, swamps, topography and vegetation. It is in the freshwater swamps of Rivers State. FUGRO geological survey reports categorized the soil in the area into recent alluvium and undifferentiated basement complex soil. The soil is generally susceptible to river flooding. The annual rainfall ranges between 2100mm – 4600mm and mean temperature varies from 30.0°C - 33.0°C [34]. Two major seasons are observed and they are; the wet season started from March to October and dry season started from November to February every year [35]. Similarly, mean monthly and mean annual solar radiation in the area are 10.55mJm^{-2}/day and 9.2555mJm^{-2}/day [35].

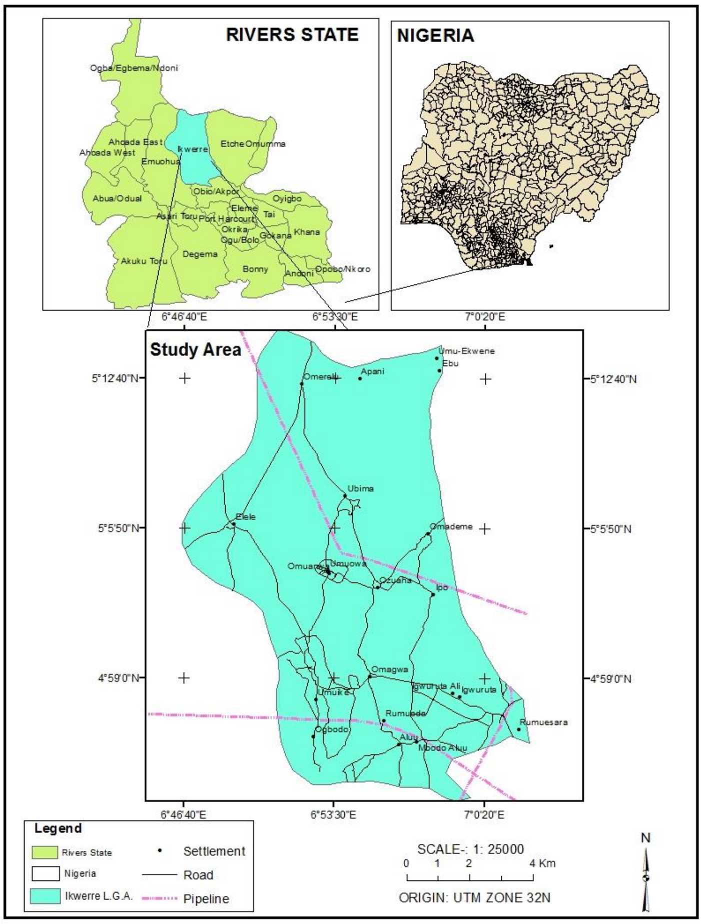

Figure 1 Study area location map.

2.2. Power Supply Stations

Nigeria generally has two power plants namely; hydro-electric and thermal power plants. Thermal power plant is equally divided into coal-fire and natural gas-fired systems. It is these power plants that supply Nigeria with energy for industrial and commercial usage. The study area has no station but derived its limited power supply from the stations in the state. The stations are Afam IV – V gas plant located on latitude 4° 51' 05"N and longitude 7° 15' 17"E with an installed capacity of 726MW. The plant was established and completed in 1982 with it gas supply source from Okoloma gas plant. The second station is the Afam VI station located on latitude 4° 50' 58"N and longitude 7° 15' 24"E with an installed capacity of 624MW. These two stations were owned by federal government of Nigeria. Other stations in the state are two stations in Omoku operated by IPP and NIPP with gas source from Obrikom gas plant. The area also complemented its energy supply from the Kainji power station located in Kainji Lake in the Niger River. The study area needed secure power supply to encourage economic development of the area and to meet the increase in population due to expansion of towns and influx of companies. The area was selected for the study due to the availability of land that will support establishment of solar power plant and also its strategic location in relation to others food producing local government areas like Etche, Emohua, Ahoada and Ogba/ Egbema/ Ndoni L.G.As that required steady power supply in their operations. The study area map is shown in figure 1.

2.3. Software

The study applied some geospatial analysis software and material relevant for the selection of suitable site for solar power. The material and software include;

ESRI's ArcGIS 10.3.1: The software strength is in vector processing. It was used to performed image clipping, multi-criteria analysisand for the compilation of maps. Multi-criteria evaluation (MCE) was implemented using overlay tool [36]; [37].

ENVI 5.0: ENVI (The Environment for Visualizing Images) software was used to convert Landsat image in TIFF to GeoTIFF such that the bands can be freely loaded in IDRISI software.

IDRISI TAIGA 16.0. The software strength is in raster operations [38]. The software was used to perform supervised image classification. This classification was carried out in other to extract land use/ land cover for the multi-criteria analysis.

GARMIN 76Sc Global Positioning System Receiver: Handheld Global Positioning System (GPS) receiver was used to capture the coordinates of roads, pipelines and other features needed for selecting optimum sites for solar power. [39] Used GPS for ground truthing in selecting suitable landfill site.

2.4. Dataset Used

The identification of suitable site for solar farm was carried out using the following datasets;

The satellite image used for the site selection of site for solar farm was Landsat data. The image was obtained from its website (http://glovis.usgs.gov/) after completing student registration. The image was downloaded in zip file using path 188 and row 57 covering the study area. The selected Landsat OLI data was precision orth-corrected product (LIT) which has been corrected for both radiometric and geometric distortions [40]. Landsat data was needed for the derivation of land use/ cover categories.

Table 3 Properties of Landsat satellite image used for selecting optimum site for solar power.

Sensor	Acqui. Date	Source	Band	Resolution (m)
Landsat OLI	27/12/2018	http://glovis.usgs.gov/	B432	30 x 30

Other datasets used in the analysis were summarized in table 2.

Table 3 Summary of datasets used in the study.

S/N	Data	Date	Source	Data Type
1	Landsat OLI 8	27/12/2018	http://glovis.usgs.gov/	Raster
2	DEM	2/11/2017	Google Earth	Vector
3	Soil Map	NA	FUGRO	Vector
4	Pipeline	NA	OSGRV	Vector
5	Solar Radiation map	2/11/2017	DEM	Raster
6	Road Network	NA	OSGRV	Vector
7	Settlement	NA	Field Observation	Vector

2.5. Data Processing

Determining suitable sites for solar power plant required the integration of datasets. These datasets must be processed in a GIS environment. The following are the data processing steps adopted in the study.

2.5.1. Image Classification

The Landsat satellite image used for the analysis was clipped band by band in ESRI's ArcGIS 10.1 using the study Area shape file. Image clipping limits the study to specific extent [41]. Image classification was performed on the composite image in IDRISI TAIGA from the RGB band combination module. The bands selected for the study are; red (band 4), green (band 3) and blue (band 2). These bands combination for the Landsat 8 is simply refers to as true colour composite. The bands were selected because composite of band 4 3 2 is ideal for natural land cover analysis.The image classification method adopted was maximum likelihood classification (MLC). The classification method was chosen base on its accuracy level [42]. [43] Obtain higher accuracy with MLC when compared the results with three others classifiers. The study adopted level 1 classification scheme as suggested by [44] to extracts land use/ land cover types. The land use/ cover types classified includes; water body, built-up, vegetation, wetland and sand dune. In the IDRISI software, MLC parameters selected are equal probability for each signature and 0.167 probability definition was used. The classification map was used as one of the raster data in ArcGIS 10.1 for the multi-criteria evaluation.

Classification accuracy assessment of remotely sensed image is crucial because of the infiltration of errors from various sources [45]. Error matrix is often used to represent accuracy assessment [46]. The matrix columns represent the reference data while the rows indicate the classification map categories. In this study, thematic map accuracy was computed using the training samples and the classification map in which overall accuracy and kappa statistics was produced.

2.5.2. Slope and Solar Radiation Map

Terrain elevation is an essential criteria considered in sitting solar power farm. It can be derived from conventional survey using total station, differential global positioning system (DGPS) and leveling instrument [47], photogrammetry method [48] and by LiDAR instrument [49]. Other methods of deriving DEM are Shuttle Rader Topography Mission [50], Advanced Spaceborne Thermal Emission and Reflection Radiometer [51] and Google Earth image [52]. The elevation data used for the derivation of slope was extracted from Google Earth image via GPS Visualizer applications from the link http://www.gpsvisualizer.com/convert_input. The extracted elevation was saved in excel spread sheet in x, y and z columns. Elevation data are used in the generation of digital terrain models (DTMs). DTMs can be as factor in selecting solar power station [53]; [54]; [55]. The DTM was used to produced slope and solar radiation map. The generated DTM and solar radiation models were reclassified into six (6) classes with equal interval.These classes were ranked according to suitability to solar power station.Solar radiation is defined as the amount of radiant energy emitted by the sun passing through a unit area in the horizontal in unit time [56]. It is a major determinant in selecting optimal location for solar farm.

2.5.3. Processing Other Datasets

These dataset include; soil map, road, pipeline, and settlement. The soil layer was converted to raster dataset. Similarly, Euclidian distance for the pipeline, settlement and road layers were computed. The Euclidian distances for these layers were produced with default ten (10) classes. It was reclassified from the default ten (10) classes to six (6) classes as needed in the weighted analysis.

Base on the conditions required to site solar power plant, which includes and not limited to sitting close to available access roads and away from existing pipeline. The reclassify Euclidian distance was ranked according to how a particular distance is suitable in the analysis. In each criteria used, ranges that are suitable for solar plant are rated 6, being the highest, while ranges that are least suitable assigned rating of 1. These factors and their ranges are shown in table 3.

Table 3 Criteria and requirements used in selecting optimum sites for solar power farm.

S/N	CRITERIA	RANGE		REQUIREMENT	% INFLUENCE
1	Solar Radiation	6	768804 – 769668	To site in locations with high solar radiation	40
		5	767941 – 768804		
		4	767078 – 767941		
		3	766214 – 767078		
		2	765351 – 766214		
		1	764487 - 765351		
2	Distance to Pipeline	6	12165 – 14598	To site Away from pipeline	15
		5	9732 – 12165		
		4	7299 – 9732		
		3	4866 – 7299		
		2	2433 – 4866		
		1	0 – 2433		
3	Distance to Road	6	0 – 1844	To site near access road	15
		5	1844 – 3688		
		4	3688 – 5533		
		3	5533 – 7377		
		2	7377 – 9222		
		1	9222 – 11066		
4	Slope	6	0.0001 – 0.3675	To site in flat terrain	5
		5	0.3675 – 0.7350		
		4	0.7350 – 1.1024		
		3	1.1024 – 1.4698		
		2	1.4698 – 1.8373		
		1	1.8373 – 2.2047		
5	Land Use/ Cover	6	Vegetation	Non built-up area is require	10
		5	Wetland		
		4	Water body		
		3	Built-up		
		2	Palm Tree		
		1	Void		
6	Soil	6	21c	Well drain soil required	5
		5	2a		
		4	15e		
		3	15d		
		2	22c		
		1	24b		

7	Distance to Settlement	6 5 4 3 2 1	5021 – 6025 4016 – 5021 3012 – 4016 2008 – 3012 1004 – 2008 0 – 1004	Not close to settlement	10

The criteria were weighted according to their relative importance in the selection of suitable site for the solar farm. A percentage influence for each factor was assigned. Solar radiation was assigned percentage influence of 40, pipeline 15, road 15, land use/ cover 10, soil 5, slope 5 and settlement 10. This resulted in total percentage influence of 100, as required for the model to work. [57] In their studies assigned weight of 38 and 3 to solar radiation and proximity to access road.

3. Results

The results of the multi-criteria analysis (MCA) adopted in investigating optimum site for solar power plant is presented using maps and graphs. The most important factor in the site selection analysis is the solar radiation map as shown in figure 4.1a. Maps of others factors used in selecting optimum site for solar plant are shown in figure 4.1b – 4.1g. From the maps produced value 6 indicates ranges of values in that factor considered more suitable while value of 1 implies ranges of values that are considered less suitable for sitting solar plant.

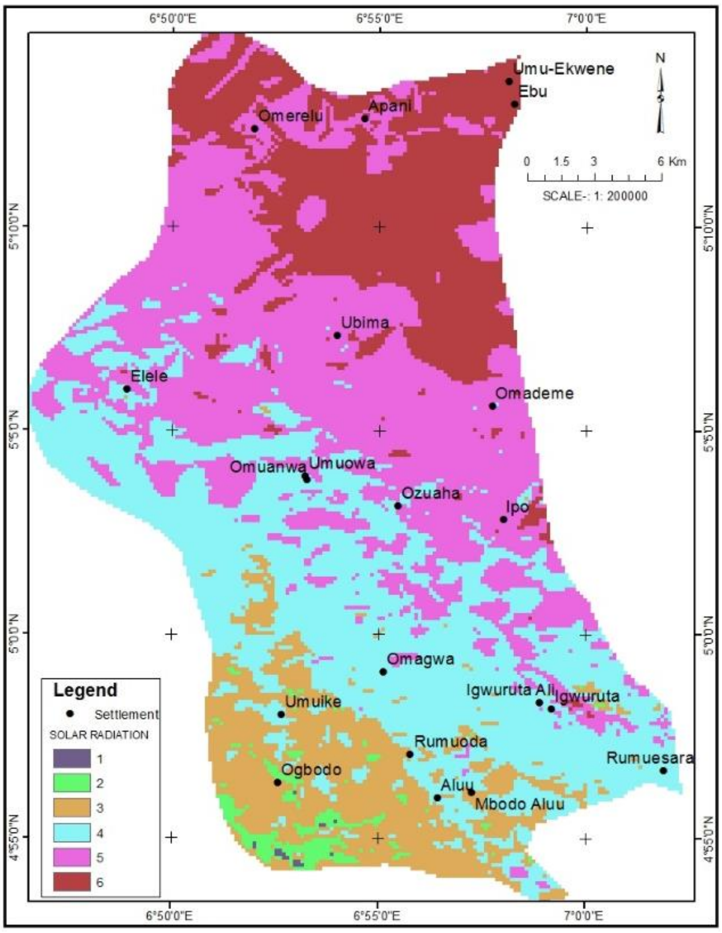

Figure 4 a. Solar radiation map

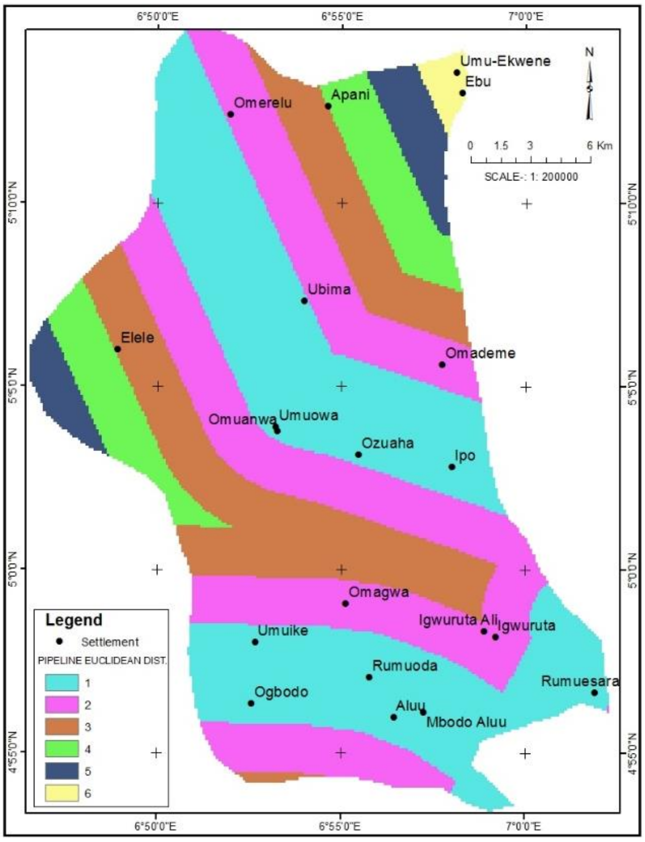

Figure 4 b. Distance from pipeline

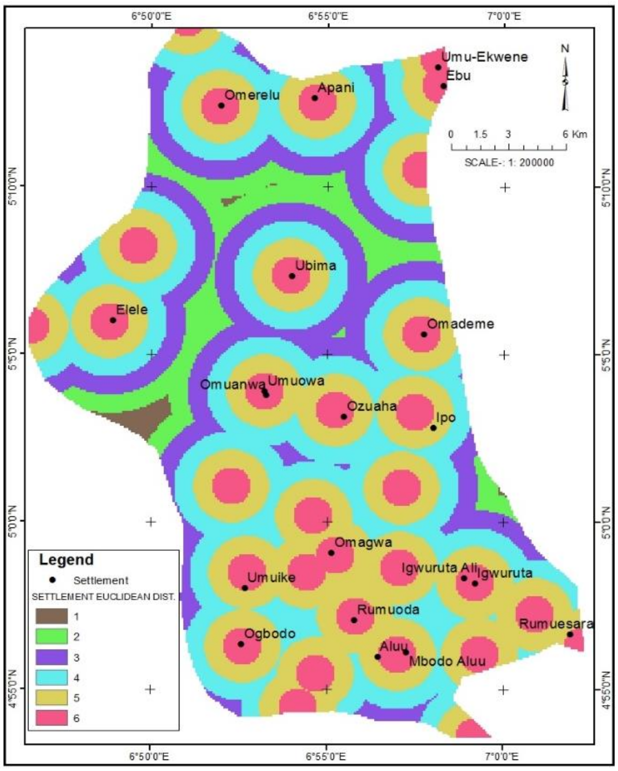

Figure 4 c. Distance from road

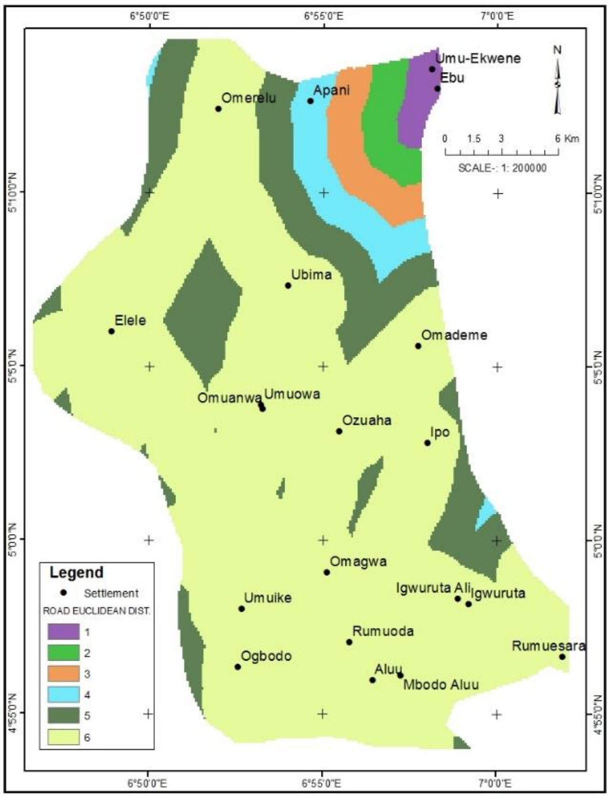

Figure 4 d. Distance from settlement

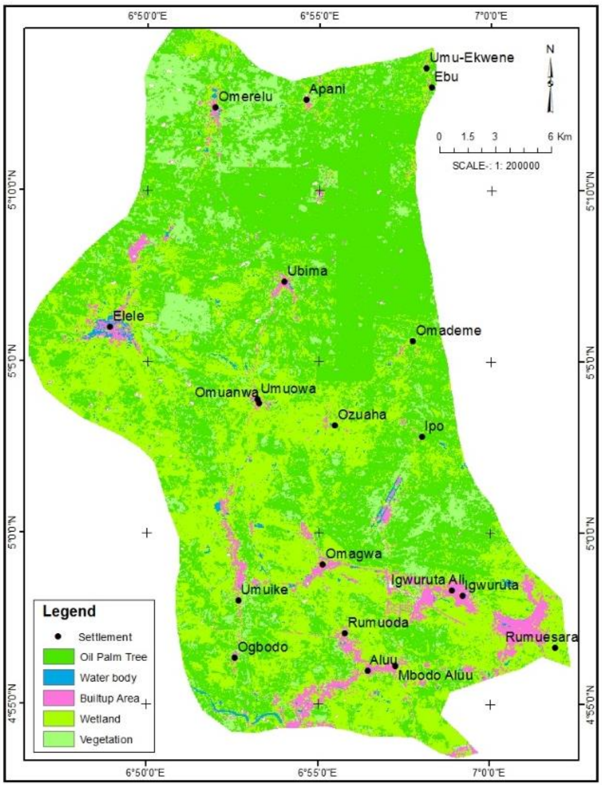

Figure 4 e. Land use/ cover map

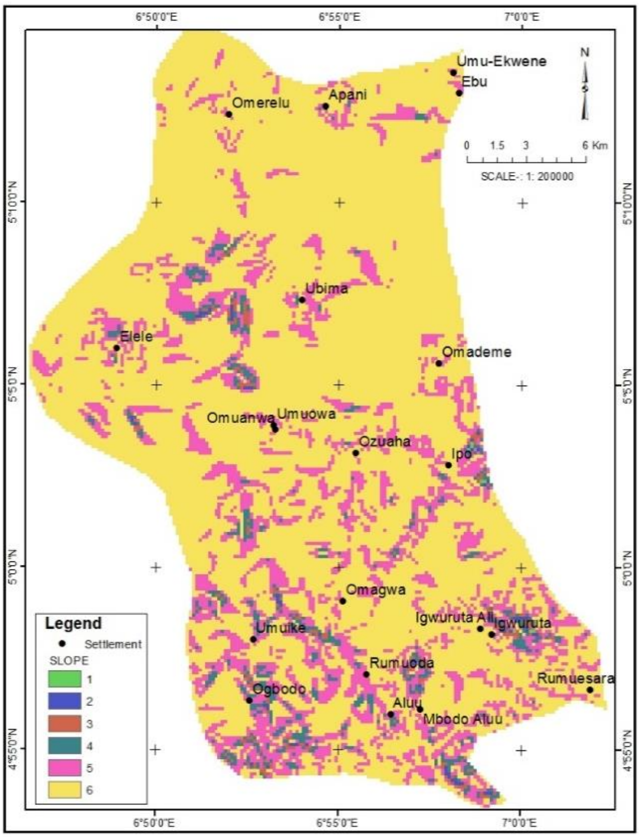

Figure 4 f. Slope map

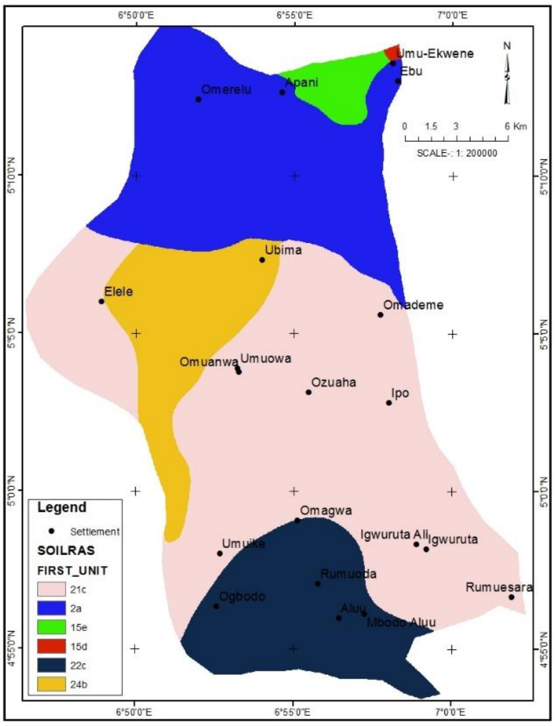

Figure 4 g. Soil map

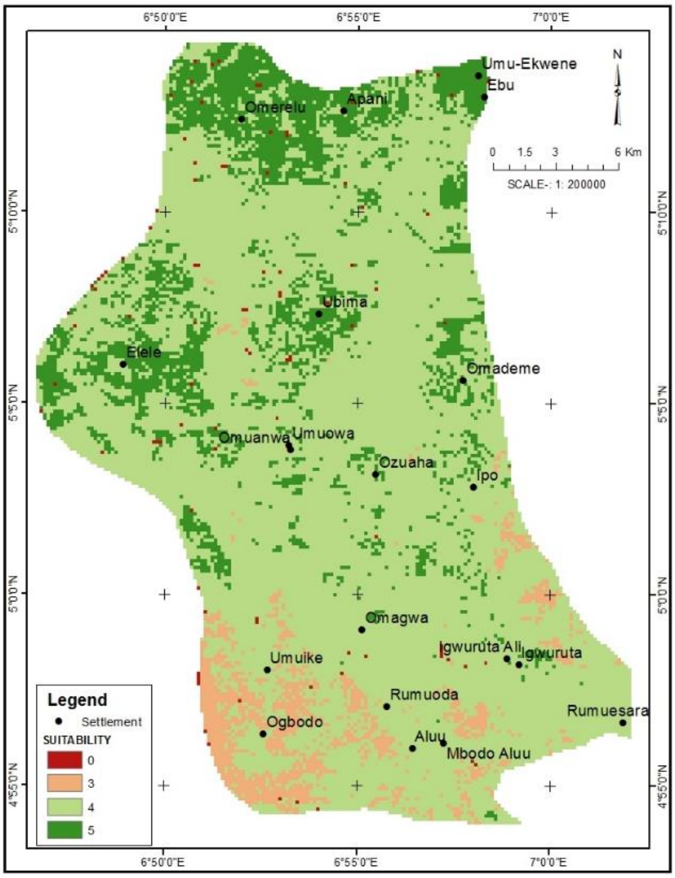

Figure 4 h. Suitability map of the area

The suitability map for solar power plant was produced by combining the factors and the map shown in figure 4.1h. The area in hectares of each class and their percentage are shown in table 4.1. The map was classified into four suitability classes. The first class is poorly suitable with an area of 178.07ha. This class is located in an isolated areas is the south. These areas are considered not suitable for sitting solar power plant. The second class is the moderately suitable with an area of 3724.79ha, located mostly in the built-up areas in the southern part of the map. The third is the suitable class for solar farm with an area of 50199.63ha. The forth class is the highly suitable with an area 10139.87ha, located mostly in the northern part of the map. It represents 15.78% of the study area. Highly suitable areas can be found around Elele, Omerelu, Apani and Ebu.

Table 4 Total area of each suitability class.

CLASS	MEANING	AREA (ha)	% AREA
0	Poorly Suitable	178.07	0.28
3	Moderately Suitable	3724.79	5.80
4	Suitable	50199.63	78.14
5	Highly Suitable	10139.87	15.78

A second analysis was performed using highly suitable polygons and settlements to select areas that are most suitable for solar plant. In doing so, buffer analysis was performed using the settlement layer and the highly suitable polygons. Buffer analysis of 2500m away from the settlement was performed; this is because, solar plant should be sited away from settlement. Selection by location analysis was used to select polygons that are at distance more than 2500m from settlements buffer radius. Three polygons were chosen as the most suitable locations for sitting solar photovoltaic plants. These locations were located in the region with very high solar radiation and free from built-up. The locations are also close to existing access roads which permits free access during construction and maintenance of the cells after built. Table 4.2 presents the areas of the most suitable sites for solar plant. These polygons have regular shapes for construction purposes. The selected polygons will provide enough space for solar plant and the associated facilities. It will also support any size of photovoltaic plants that will service the entire Local Government Area.

Table 4 Area of the three optimal locations for solar farm.

S/N	AREA (ha)	LOCATION
146	19.82	Northward
263	30.47	Northward
374	51.71	Eastward

4. Conclusion

Decision making is a complex process especially when many factors are considered. This is always the case in selecting optimal sites for solar power plant for efficient energy delivery. Solar power is that form of energy generated directly from the sun. It is climate change free energy unlike wood energy. Selecting sites for solar plant requires integration of factors in a GIS environment, hence, the utilization of multi-criteria analysis for the study. Seven datasets namely; solar radiation, slope, soil, pipeline, road, land use/ cover and settlement data were used in the selection of suitable sites for solar farm. The data were processed from vector file to raster and reclassified into six (6) classes as needed in the model. The classes were rated from one (1) being less suitable to six (6) being highly suitable condition for solar plant. In the case of road, farthest distance is considered suitable and was rated 6 in the reclassified data. Each factor was assigned percentage influence according to how importance the factor is in the model. The analysis reveals that the majority of the highly suitable locations are found in the northern part of the map were solar radiation is peak. Three (3) locations were selected from the highly suitable as the optimal sites for solar photovoltaic plant and these locations meet the requirements for solar plant. The locations selected are close to the access road and also away from built-up areas. This study establishes the fact that GIS can be use to make critical decisions relating to selecting optimal sites for solar energy and other forms of energy.

Compliance with ethical standards

Acknowledgments

We appreciate our beloved wives for their continual prayers towards our collective success. We also give special thanks to one of our great research pattern for giving us time to read this article. Finally, special thanks to the office of the Surveyor General Rivers State for providing some of the data free-of-charge.

Disclosure of conflict of interest

The authors whose name appeared on this article hereby declared that there is no conflict of interest with any organization.

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