



Spatial Analysis of Site Suitability for Solar Photovoltaic Plants in Kaduna Metropolis, Kaduna State, Nigeria

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Received on: August, 2024

Revised and Accepted on: September, 2024

Published on: October, 2024

ABSTRACT

Nigeria is blessed with abundant natural source of renewable energy the; solar, wind, hydro and biomass. However, despite its strategic location near the equatorial region, the use of solar as a source of energy in the country is very insignificant. The current study focused on the spatial analysis of site suitability for solar photovoltaic (PV) power plant in the study area. Administrative map of the study area, Global Horizontal Irradiance (GHI), temperature, elevation, sentinel imagery, power line and road data were used for the study. Analysis was conducted using analytical hierarchical process (AHP) excel template and ArcGIS 10.8 software. Results on the suitability of economic factors revealed that, highly suitable area recorded the highest percentage for aspect (45.4%) and slope (99.1%), while unsuitable area for LULC (67.5%), road (53.1) and power line (59.01) recorded the highest percentage. Results for technical factors showed highly suitable with 66.4% and moderately suitable with 79.9% to be occupying more land area for GHI and temperature respectively. The result on the comparison matrix using AHP revealed GHI with 38.6% with high impact while road with only 4% with the lowest at 4% confidential level. Result on the site suitability index for the PV installation indicated moderately suitable area to has occupied the largest area with 73.7% while unsuitable with the lowest (0.9%) percent. Findings generally indicated that, there are five optimum sites for solar PV plant in the area with the capacity of PV output ranging from 1453.08 to 1459.37 kwh/m²/year. Based on these, it is concluded that, there are potential site for solar PV plant in Kaduna metropolis and these sites can provide the amount of energy required. Hence, the study recommends the provision of this type of plant in the area in order to reduce the much pressure on hydro power supply.

Keywords: Analysis, Suitability, Solar, Photovoltaic, Plants

1.0 INTRODUCTION

Energy becomes one of the most important components of human life and development, it affects the general living condition of humanity. There are various sources of energy which include natural gas, hydro, wind, fossil, biomass, solar and others. According to World Bank (2024) the Nigerian energy system depends mainly on hydro with the access rate of 52.50 percent as at 2015, this has increased to 59.50% in 2021, as a result of government's electrification project. Despite this effort, the reliance on hydroelectric power by many countries in the world and Nigeria in particular has been affected by population pressure and climate change which consequently leads to reduction in the level of water within the hydro dams. This has generally affected the living condition and economic viability of many people in developing countries such as Nigeria. Kaduna metropolis and the State at large were experiencing a significant power supply challenges due to a combination of several factors in addition to those stated above, the frequent grid collapses, vandalization of electric power transmission lines, and inadequate infrastructure are among others. These have resulted to limited electric supply which leads to the reliance of many people on the expensive and other un friendly sources such as the use of generators and fossil

fuels. Furthermore, the Nigerian economic transformation agenda to address developmental challenges and become an upper middle-income country, with the expected average real GDP growth rate of 7%, and nominal GDP of US\$11.7 trillion by 2050 (Okafor, 2024), would be difficult to achieve with the current power supply system.

The above-mentioned reasons and many other, calls for looking on other sources more especially renewable energy options. This is because, renewable energy sources become a viable option that will meet future demand of energy and toward sustainable environmental development (Colak, Memisoghi. and Gercek, 2020). In this regard the use of solar energy has been the best, because it stands as one of the clean, free, and abundant sources of energy. Opeyemi, Abayomi and Suara (2022) reported solar energy to have been more reliable, efficient as well as fast growing source of power generation globally.

The location of Kaduna State and Nigeria at large near the equatorial region resulted to its great potential for solar energy source. This is because, the region receives daily solar insolation of about 3 to 7 kwh/m² (Mohammed, 2019). Despite being abundant few people at individual

level and organization utilized the resource. Solar energy as a radiant light from the sun can be captured using a variety of technologies including photovoltaic, solar thermal energy, solar heating, and solar architecture.

A solar photovoltaic (PV) plant connected PV source of power supply that convert solar energy directly from its source to electric energy which easily be accessible to the consumer for daily activities. It is in this respect that solar energy is considered as the most essential source of energy to the teeming population of Kaduna metropolis. Assessing suitable sites for the installation of plants such as solar power plant required the use of various data and technology that looks into spatial extent. This is due to the fact that, development of the system depends not only on the amount of solar radiation received, rather many other processes and costs. According to Oguntoke and Adeyemi (2017) development of viable solar PV plant involved technical, economic, social and environmental processes such as topography and urban development. The most important factors include; solar irradiation, temperature, aspect, slope and Land Use – Land Cover of the location in to consideration.

In the context of these, the most appropriate technology required before development of Photovoltaic Power Plant systems, has been geospatial techniques (Kimunyi, 2021).

Despite the fact that, site suitability analysis for solar power generation has been previously conducted in Nigeria by researchers such as Omoloso, Alaigha, Aboyeji, Balogun and Akande (2020) in Osun State, and Opeyemi et al (2022) in the Federal Capital Territory (FCT). However, considering the distinct nature of Kaduna State, there is need for conducting similar study in the area. Based on these, the present study aims at analyzing suitable sites for solar photovoltaic plants in Kaduna metropolis. The study was achieved through assessing the optimum sites for the plant and the expected amount of energy to be obtained in the area.

2.0 MATERIAL AND METHODS

2.1 Study Area

Kaduna metropolis lie between Latitudes $10^{\circ} 26' 00''$ and $10^{\circ} 38' 00''$ North of the Equator and Longitudes $7^{\circ} 21' 00''$ and $7^{\circ} 33' 00''$ East of the Greenwich Meridian (Figure 1).

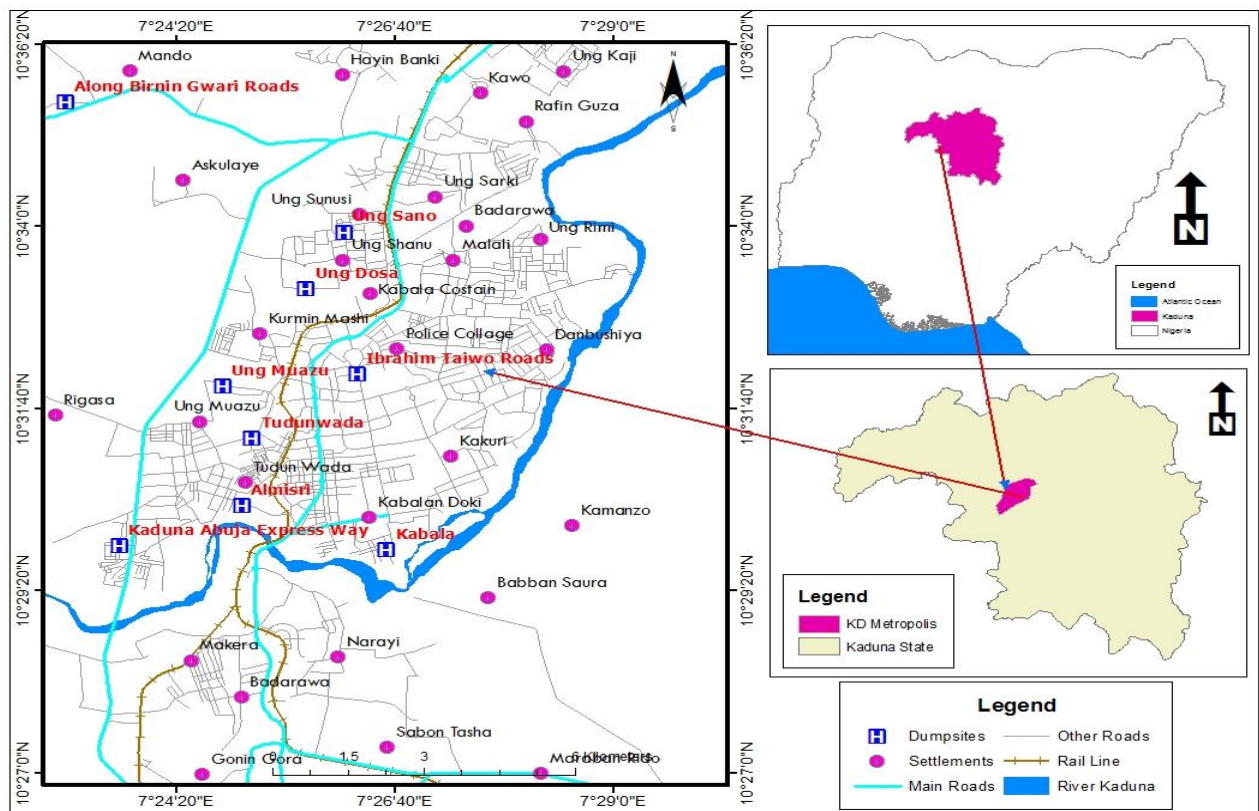


Figure 1: Map of Kaduna metropolis
Source: Adapted from Administrative Map of Kaduna State

Kaduna metropolis comprises four (4) Local Government Areas (LGAs), the Kaduna North, Kaduna South, parts of Igabi and Chikun with roughly around 355km² (Daful, Adewuyi, Dadan-Garba, Oluwole, Muhammad and Ezeamaka, 2020). The climatic condition of the area is tropical continental climate with distinct seasonal regimes, between cold to hot-dry and humid to wet climate (Jamila, Buhari and Iheoma, 2018). The temperature is high throughout the year attaining its peak in March and April (37°C). The morphology of the area comprises of a gentle undulating terrain at about 30.48 meters above sea level extending up to 50km outward but more to the north and south-east where it terminates at the foot of Jos Plateau.

2.2 Data Collection

As stated above according to Daful et al. (2020) Kaduna metropolis extended to about 355km². However, considering the fact that, there are areas which are very sparsely populated especially Igabi and Chikun LGAs, this study was restricted to only about 249km² instead of the supposed land mass.

The type and source of data used in this study was presented in Table 1, which include; Global Horizontal Irradiance (GHI) with a spatial resolution of 30 meters, elevation, sentinel imagery of 2023, path 189 row 053 with 10 meters resolution. Other data include temperature data in raster format, power line and road data in vector format. All the factors were considered as environmental factors, while Land Use-Land Cover (LULC), proximity to power line and road are social factors. However, specifically the study considered temperature and GHI to be technical parameters because they have direct impact on the

performance of the solar power plant at the place it was located. The other five factors aspect, slope, LULC, power line and road are the economic variables because they determine how the location of plant affects project costs.

Data processing was conducted in ArcGIS 10.8 environment. The road and all other data were transformed from Geographic Coordinate System (GCS) to Projected Coordinate System (PCS) as Minna UTM zone 32N. This is necessary for accurate measurement of the variables such as area and distance. In addition, all data were assigned a spatial resolution of the sentinel data at 10m resolution. Each data was processed based on its specific characteristics as follows:

The road and power line vector data were rasterized using Euclidian distance tool, the tool not only convert the data to raster format but classify the data based on distance from the actual location to other parts of the research area. Using of this tool enable the researchers to quantitatively assess the proximity of potential solar photovoltaic (PV) power plant sites to these networks. Furthermore, the elevation data in .GPX format was imported into the software and converted into shapefile, the data were then interpolated to produce continued surface raster imagery. This was used to generate digital elevation model (DEM), slope and aspect raster imagery. The administrative map of the study area was used to extract all relevant raster data using extract by mask tool. This enables the researchers to further reclassify the data into various suitability category as highly suitable, moderately suitable and unsuitable for overlay analysis.

Table 1: Type and Source of Data

S/N	DATA	SOURCE	Purpose
1.	Boundary of the research area	Ministry of Land and Survey	
2.	GHI	SolarGIS.com	Irradiance
3.	Elevation	Google Earth	Slope and aspect
4.	Temperature	SolarGIS.com	Temperature
5.	Road	OSM	Road data
6.	Power line	OSM	Power line data
7.	Sentinel	ESRI	LULC

2.3 Data Analysis

2.3.1 Land suitability index (LSI) determination

The criteria for the determination of highly suitable sites of the factors were adapted from the work of Rabiul-Islam, Tareq, Alauddin and Kader (2024) as; south, southeast and southwest oriented aspect, slope less than or equal to 5°, less than or equal to 500 meters away from road and power line, temperature of not more than 25.3°C, higher quantity of GHI and the LULC must be bare land, grassland or forest. After the generation of various suitability maps of the factors considered using various spatial analysis tools

such as interpolation, extract by mask and reclass in ArcGIS environment. The Analytical Hierarchy Process (AHP) Excel template was used to generate weight of each factor (GHI, temperature, slope, aspect, LULC, proximity to power line and proximity to road network). The process involves systematic comparison of the factors, using the Saaty (2013) scale (Figure 2), the scale was used to establish the relative importance of each. A pairwise comparison matrix was further developed as the basis for determining the influence level of each factor.

To determine Land Suitability Index (LSI) map for PV power plant in the area weighted overly tool was used to integrate all the seven factors based on the weight

generated in AHP. The reclass tool was used to classify the area into highly, moderately and unsuitable areas.

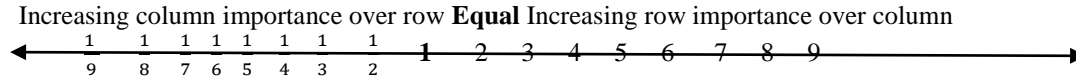


Figure 2 Comparison importance's between the factors

Source: Saaty (2013)

2.3.2 Optimum site determination

The resulting map of the LSI serve as a key input for the identification of the optimum site for PV power plants. The highly suitable sites were extracted from the main LSI map using reclassify tool. This map was vectorize to come up with the vector format map of the area. This enable the researchers to calculate the area of each location and extract sites with size of greater than or equal to 1000 acres as optimum sites Also, area solar radiation tool was used to generate compound site indexes of the potential energy output per unit area over a period of time in kwh/m²/year.

3.0 RESULTS AND DISCUSSION

3.1 Factors of Suitability Determination

The factors for the determination of suitable sites for solar PV power plant in Kaduna metropolis is divided into economic and technical factors as presented in Figure 3 to 6, and Table 2 and 3.

3.1.1 Economic Factors

Figure 3 to 5 and Table 2, presents results on the economic factors that determine site suitable for the installation of solar PV plant. The results on the aspect indicated that, highly suitable sites recorded the highest (45.4%) percentage while moderately suitable sites recorded 18.9%. This implies that south, southwest, and southeastern facing aspect are the optimal sites for solar PV installation in the research area. The results on the slope also revealed that highly suitable sites recorded the highest (99.1%) percentage while unsuitable sites recorded the lowest (0.04%) percent. The result clearly shows that in Kaduna metropolis areas with slope less than

or equals to 5% occupied more 99% of the area. This shows that Kaduna metropolis is mainly occupied by gentle and flat slope. Hence the possibility of recording low solar radiation, because higher elevated areas generally received more direct sunlight due to the reduction in obstacles. However, in term of economic benefit, the area is expected to be of higher suitability, due to the fact that flat terrain and somewhat steep slope's locations are usually chosen for large-scale PV projects since the system required flat topography. This corresponds to the findings of Ibrahim (2023) who identify areas with the slope less than or equal to 5% in Kaduna metropolis to have occupied about 99.7% of the area.

The Table 2 also revealed that, as per as LULC is concerned unsuitable sites recorded the highest (67.5%) percentage this was followed by highly suitable with 27%. This clearly indicated that the research area is densely populated which hinder the availability of bare land or grassland that could be used for siting the plant. Bare land and grassland areas are open space which absorb direct solar radiation without hindering while buildings especially story buildings which are among the major characteristics of cities hinder the direct absorption of solar radiation. In this case both economically and technically the LULC set up of the research area will not favor the construction of the plant despite the fact that, there is population that can patronize the project. This result is in line with that of Abdullahi (2018) who reported buildup areas to have been occupying more (37.3%) land area than other LULC classes in Kano metropolis.

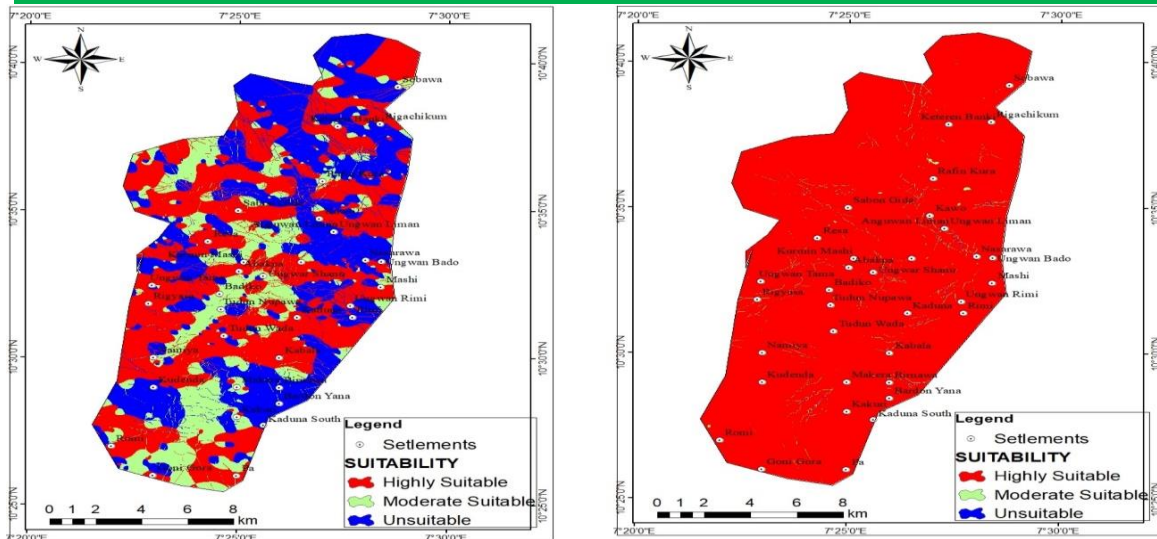


Figure 3: Aspect and Slope Factors

Table 2: Economic Factors

Classes	Aspect		Slope		LULC		Road		Power	
	Km ²	%	Km ²	%	Km ²	%	Km ²	%	Km ²	%
Highly suitable	113.2	45.4	247.05	99.11	67.27	27.0	50.84	20.4	43.3	17.4
Moderately suitable	47.18	18.9	2.1	0.84	13.63	5.5	65.49	26.3	58.86	23.6
Unsuitable	88.84	35.7	0.11	0.05	168.36	67.5	132.93	53.3	147.1	59.0
Total	249.26	100	249.26	100	249.26	100	249.26	100	249.26	100

The results on the suitability of distance from road shows that, unsuitable areas recorded the highest (53.3%) percentage while highly suitable sites recorded the lowest (20.4%) percentage. The results indicated that there is less concentration of roads in the research area due to the fact that, areas that are considered highly suitable are those less than or equal 500 meters from the major roads. This is quite possible as one of the major problems associated with the infrastructural development in Nigeria is inadequate road facility. Also, the results on the power line suitability indicated that unsuitable areas recorded the highest (59.0%) while the highly suitable areas recorded only 17.4%. Lower distribution of power line in the research area is an indication of high cost of the plant installation, because to attend maximum supply more lines are required.

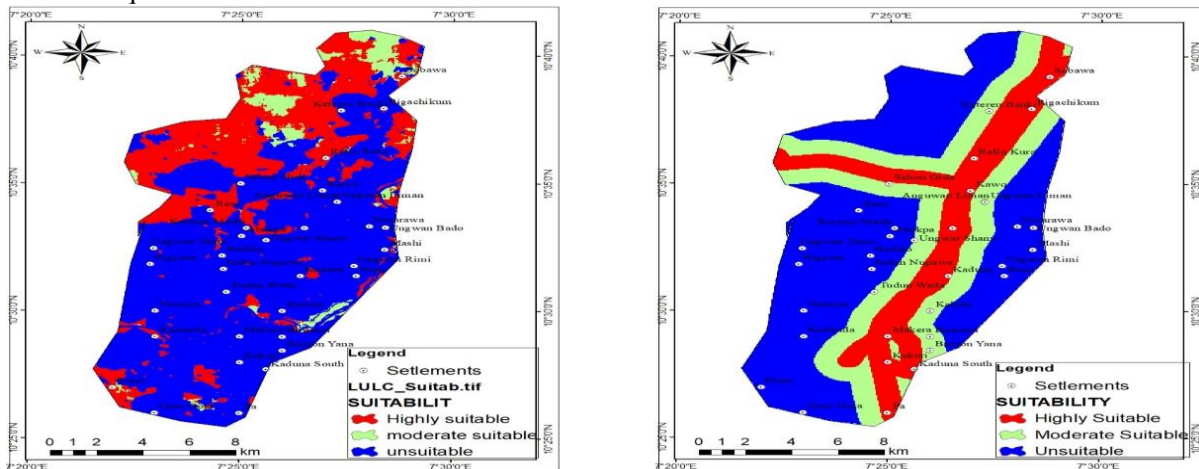


Figure 4: LULC and Road factors

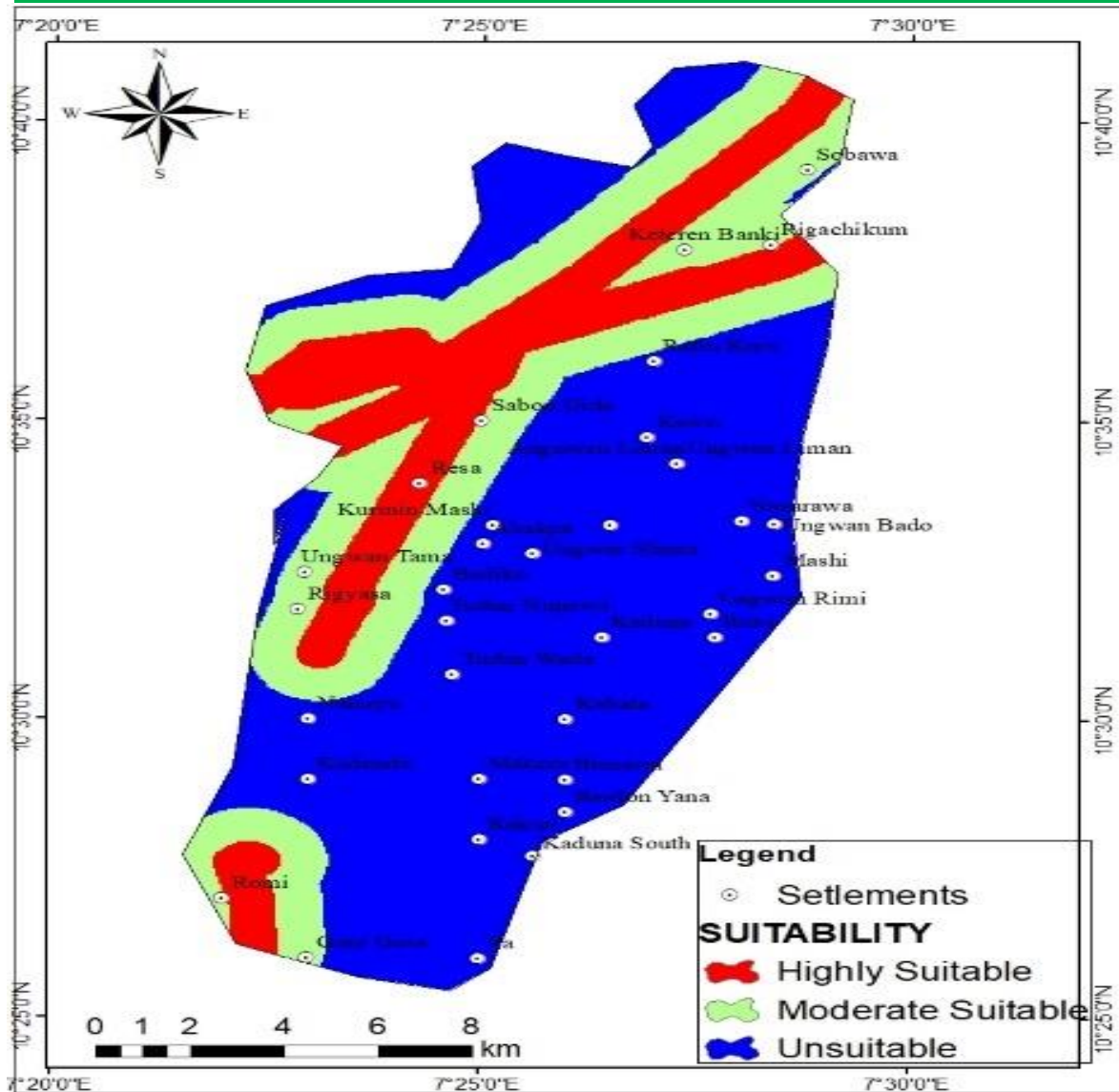


Figure 5: Power line factor

3.1.2 Technical factors

Table 3 and Figure 6, presents the results on the technical factors affecting solar PV installation. The result on air temperature indicated that moderately suitable sites recorded the highest (79.95%) percent while highly suitable sites recorded the lowest (3.98%). This result is very possible as the average annual temperature of the research area ranges between 25.1^oC to 25.6^oC. The temperature of solar depends on the air temperature of the surrounding environment in such a way that when the surrounding air temperature is high the solar panel will be too hot leading to week energy supply. This revealed that there are areas where energy required will be obtained. The Table 3 further indicated the suitability of GHI as areas with high suitability recorded the highest (66.36%)

percentage while the unsuitable areas recorded the lowest (2.28) percentage.

Table 3: Technical Factors

Classes	Temperature		GHI	
	Area [Km ²]	%	Area [Km ²]	%
Highly suitable	9.92	3.98	165.41	66.36
Moderately suitable	199.29	79.95	78.18	31.36
Unsuitable	40.04	16.07	5.68	2.28
Total	249.26	100	249.26	100

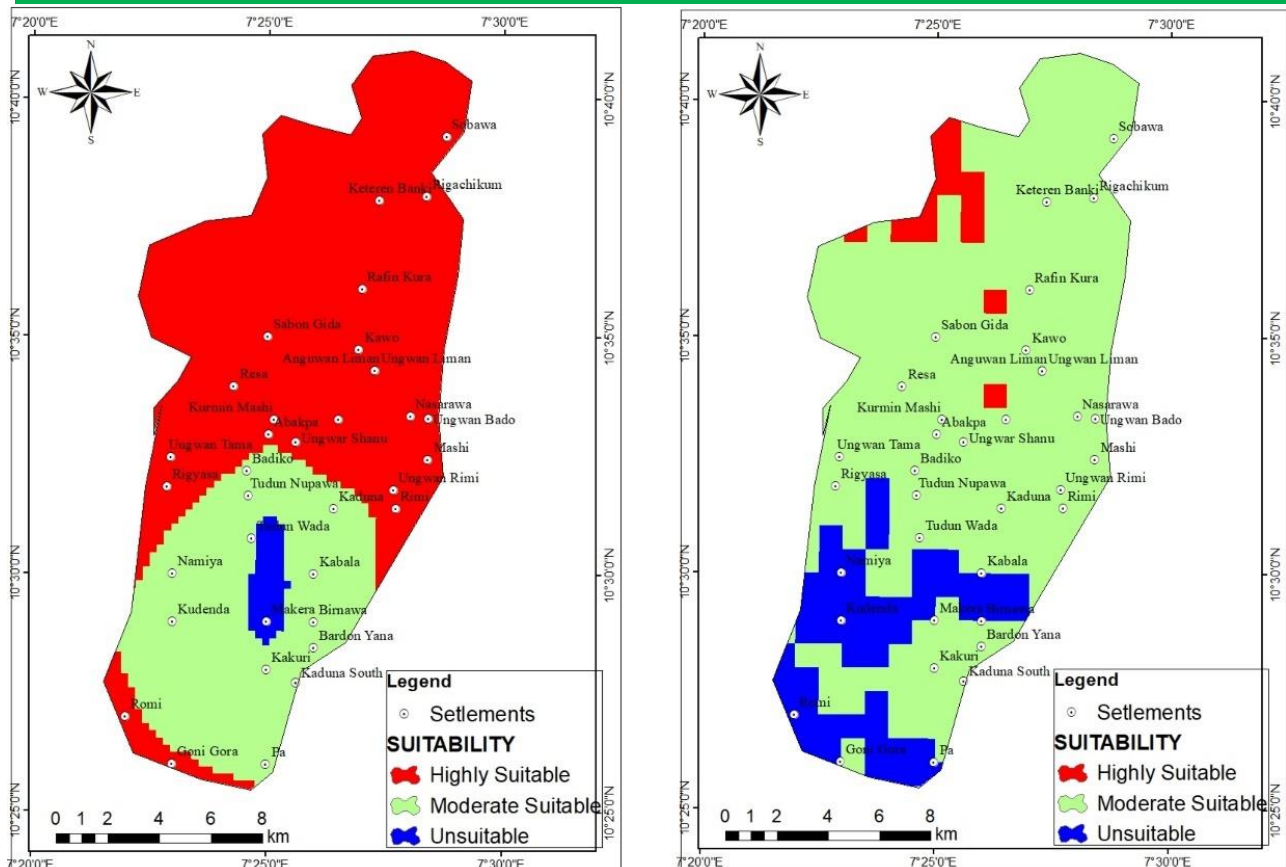


Figure 6: GHI and Temperature factors

The pattern of the result shows that, the area recorded higher solar radiation which is an important factor in the determination of PV potential sites. The study area is located in the tropical region and close to the line of equator where Sun is over head two times in a year which might lead to high recording of the solar irradiation. This result is in line with Komoto, Breyer, Cunow, Megherbi, Faiman and Vleuten (2014); Nabil and Mansour (2022) who stated that solar PV panels perform better at temperature below 25°C in such a way that when temperature rise by 1°C the performance decreases by 0.4–0.5%. The researchers also reported high suitability of GHI for solar PV installation in their respective research area.

3.2 Comparison Matrix for the Factors of Suitability Determination

Table 4 shows the result of the weight determination for the comparison matrix of the seven factors considered in determining optimum sites for solar PV plants in the study area. The result shows Lambda (λ) to be 7.28, Consistency

Index (CI) as 0.046 and consistency Ration (CR) to be 0.035, within the acceptance level of 0.4 which indicated 4% of consistency check and 96% confidence of the consistency, and therefore, the matrix computed is adequately satisfactorily. GHI is having the highest weight of 38.6%, this was followed by temperature with 22.5% while road recorded the lowest with 4%. Based on this, it is deduced that, factors with the higher weight are those with higher suitability.

3.3 Solar PV Plant Suitability Index

The result in Figure 7 serves as a key input for the identification of the optimum site for PV power plants. The statistical findings for each suitability class in Table 5 shows moderately suitable to have been recording the highest (73.65%) percent, the highly suitable with 25.44%, while unsuitable recorded only 0.9%. The highly suitable, estimated to be about 63,4 km² of the research area, were considered as the candidate zones for the determination of optimum sites.

Table 4: Comparison Matrix

Factors	GHI	Temperature	Aspect	Slope	LULC	Power	Road	AHP Normalized	
								Weight	%
GHI	1	2	3	4	5	6	7	0.386	38.6%
Temp.	1/2	1	2	3	4	5	6	0.225	22.5%
Aspect	1/3	1/2	1	2	3	4	5	0.140	14%
Slope	1/4	1/3	1/2	1	2	3	4	0.093	09.3%
LULC	1/5	1/4	1/3	1/2	1	2	3	0.066	06.6%
Power	1/6	1/5	1/4	1/3	1/2	1	2	0.050	05.0%
Road	1/7	1/6	1/5	1/4	1/3	1/2	1	0.040	04.0%

The identification of these locations as high suitable might be associated to the fact that, according to the LULC classification about 90% of the area is free from development. The slope of this area is less than 5%, and the area also recorded highest value of GHI, these characteristic of the area makes it more appropriate for solar PV installation. This result is similar with that of Rabiul-Islam et al (2024) in Bangladesh who discovered highly suitable area for solar PV farm to have occupied 18.51%. The result also corresponds with that of Rodrigues, Coelho and Cabral (2017) in Portugal who identify highly suitable area for installing solar farms to be about 21%.

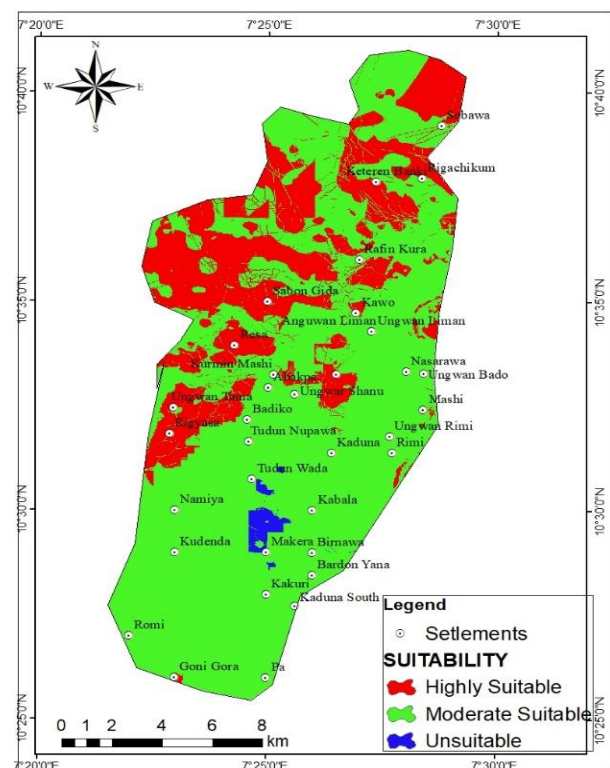
Table 5: Solar PV Suitability Sites

Suitability	Area [Km ²]	%
Highly suitable	63.42	25.44
Moderately suitable	183.59	73.65
Unsuitable	2.25	0.90
Total	249.26	100.00

3.4 Optimum Site for Solar PV Potential Sites

Table 6 and Figure 8 to 9 present the results of the optimum sites for the solar PV plants and expected energy output in the research area. The study identifies 5 optimum sites where by the largest (45%) site have been in the Northwestern part of the study area with 4924.6 acres, followed by site in the Northern part with 1777.2 acres,

while the lowest site with total land mass of 1272.2 acres was also found in the Northern part.

**Figure 7: Solar PV Suitability Index in Kaduna Metropolis****Table 6: Optimum PV Potential Sites**

Sites	Area (Acres)	%	PVOUT	Direction	Longitude (°E)	Latitude (°N)
1	4924.612645	45	1459.37	Northwest	7.401988982	10.5962722
2	1777.210926	16	1454.41	North	7.459145548	10.63417272
3	1690.675303	15	1451.2	West	7.386892512	10.53427785
4	1352.777787	12	1456.68	Northwest	7.421304921	10.62362763
5	1272.166516	12	1453.08	North	7.476953989	10.66647693
Total	11017.44318	100				

Based on the knowledge of the researchers about the physical characteristics of the study area and result from LULC map, the areas are deserved to be optimum. This is because, most of them fall within un develop, meaning there is no buildup, the slope of the areas is flat and low. The areas were also characterized with low air temperature when compare with other parts of the study area which enable the solar panels to capture and release required energy. The Table 6, also indicated the amount of potential solar energy expected from each optimum site, the site 1 which have the largest area for instant is expected to provide about 1459.4 kwh/m²/year.

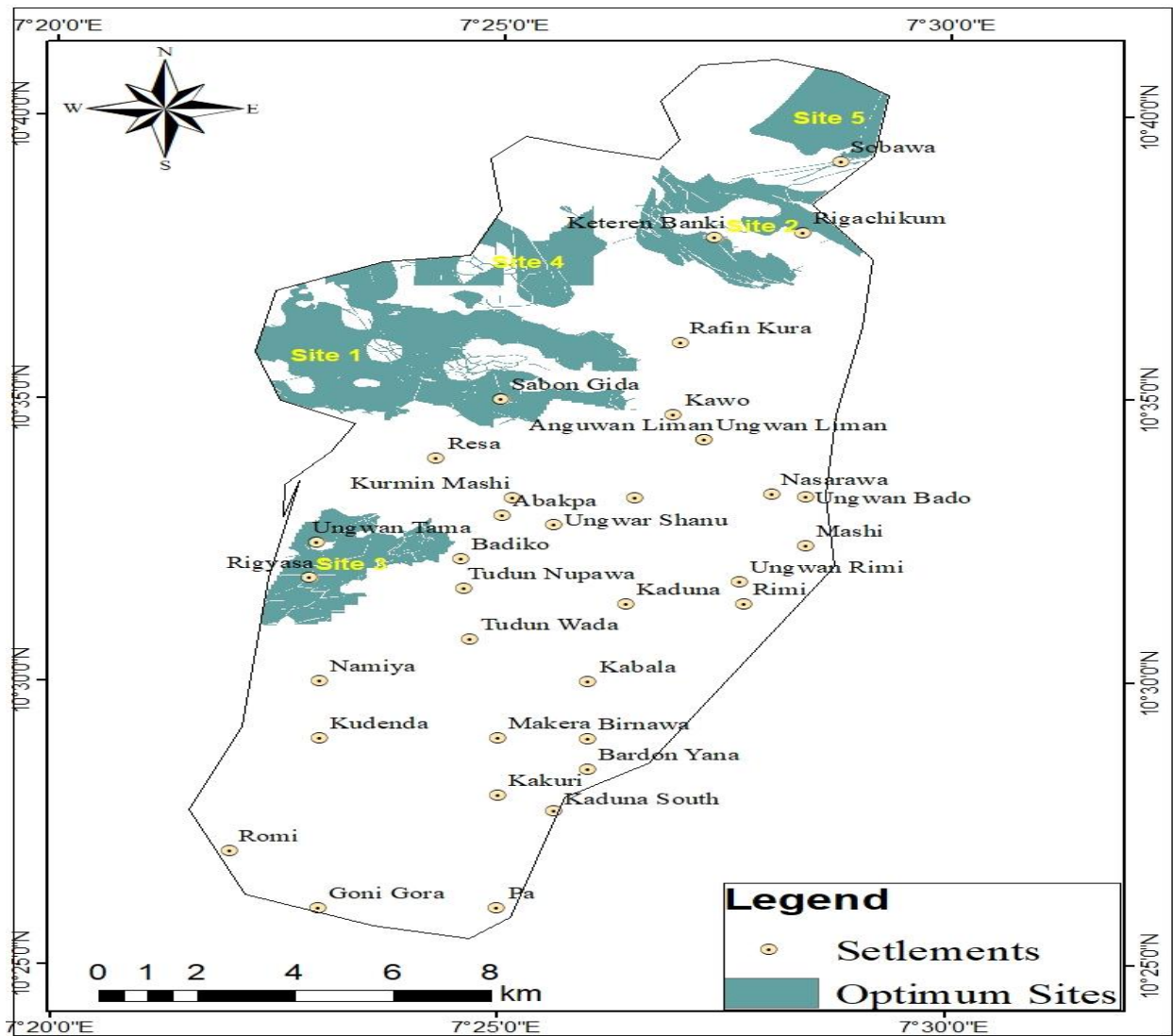


Figure 8: Optimum PV Potential Sites

This results therefore indicated that, the optimum sites identified has the capacity to produce the amount of solar energy required in the area, which will help in the cost of energy supply in the area This results support Mohammed (2019) that the potentiality of Nigeria to produce solar energy all year around is high due to its strategic location that receives about 3 to 7 kwh/m² daily solar insolation. The result is also in line with the

statement of Wu, Deng, Tao, Wang, Liu and Zhou (2021) that site selection for solar PV installation is crucial for energy output, investment costs, and efficiency. The findings also fulfilled the statement of Noorollahi, Fadai, Shirazi and Ghodsipour (2016) that PV systems require at least 4 kwh/m²/day of solar irradiance to be economically advantage among any given community.

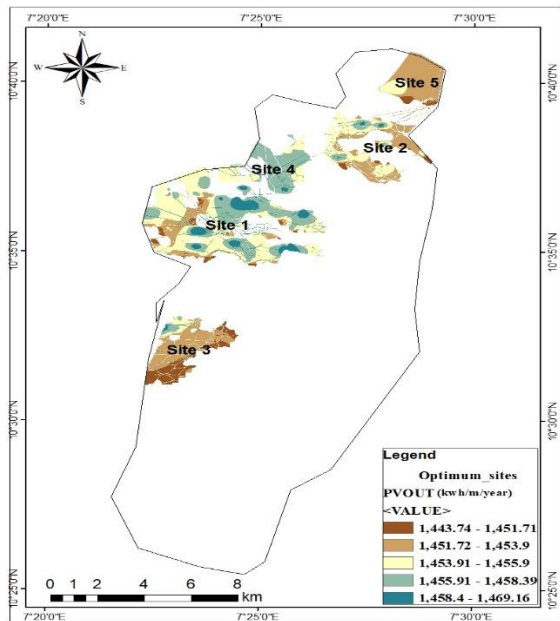


Figure 9: Expected Solar PV Energy Output (PVOUT)

4.0 CONCLUSION

The study concluded that GHI is the most important factor for the determination of solar PV plant in Kaduna metropolis, this was followed by air temperature. It was also observed that, there are more moderately suitable sites for solar PV plant in Kaduna metropolis than highly suitable and unsuitable areas. It was also concluded that, there are five major areas based on 1000 and above acres that fulfilled the requirement to be used for solar energy development in the area. In view of these, the study concluded that the area has the capacity to provide substantial solar energy for development of the area. Hence, it was recommended that government and other non-governmental organizations should joint hands in providing solar energy to the teeming population of the area.

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