Site Selection for Wind Energy as an Alternative Source of Energy in Bonny, Nigeria

Abstract

Wind energy is one of the most attractive renewable energy sources because of its low operating, maintenance, production costs, as well as its low environmental impact. This study is aimed at exploring geospatial techniques in the development of a wind farm at Bonny Island, Nigeria and the objectives are to provide data and a map of the spatial distribution of wind in Bonny Island, to determine the weight of each of the factors needed for developing a wind farm in Bonny Island, to produce a wind energy suitability map of Bonny Island. This study applied the Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) methodologies to examine the five important parameters upon which the suitability of locations is highly dependent. The analysis revealed that Bonny Island has potential for wind farm installation, with 3,549.8ha, 10,219.6ha and 424.6ha classified as being highly suitable, suitable, and not suitable. It was also determined that wind speed, land use/land cover, distance from the road, distance from the river and land slope each has high priority weight of 50%, 25% 10%, 10%, and 5% respectively and was used to produce wind energy suitability map of the study area. This research recommends amongst other things the investment and installation of a wind energy farm in Bonny Island, owing to the comparative advantage over other sources of energy in Nigeria.

***Keywords*: Wind Energy, Geospatial Techniques, GIS, Analytical Hierarchy Process, Suitability Map**

1.0 Introduction

The increasing demand for the need for clean and affordable energy in Nigeria has necessitated the need for renewable energy resource assessment and subsequent determination of suitable sites within the country. One of the promising renewable energy resources with good potential to meet the energy requirements is wind energy (Ayodele et al., 2018). The growing global energy demand and the possible depletion of fossil fuel reserves and the environmental problems associated with the use of fossil fuel necessitate that green and sustainable source of energy be sought for.

Globally, energy demand is increasing due to surges in population. It is estimated that the global energy demand is gaining momentum with an annual growth of about 2% (Grob, 2010). This population growth affects the standard of life directly as it causes a steady increase in fossil fuels consumption. The consumption of fossil fuels has a negative impact on the environment as they are a major cause of global warming (Aydin et al., 2010). The utilisation of fossil fuels in larger quantities increase the concentration of greenhouse gases. This concentration has been on a steady rise in the last 250 years as opined by (Janke, 2010). Increasing population growth rate, limited economic opportunities and the burden of high energy demand are creating pressure on the Organisation of the Petroleum Exporting Countries (OPEC) (BP, 2014).

As a result, there became a paradigm shift in the energy sector towards renewable generation sources globally due to the environmental concerns associated with both nuclear power and fossil fuels. The idea and process of generating electricity from renewable sources is fast becoming popular as the largest alternative source of energy. The increase in the cost and environmental challenges for large-scale power generation has forced the world to get electricity from alternative energy sources.

In Europe and America, wind as renewable energy has stood out as the most valuable and promising choice of alternative potential green energy source as reported by (Sambo, 2006). Though wind as a source of energy varies from one location to another, it is noted that wind energy by nature is clean,

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abundant, affordable, inexhaustible and environmentally sustainable. Due to these advantages, it has become the fastest-growing renewable source of energy in both developed and some developing countries. In Africa, Egypt, Morocco and Tunisia are the leading countries with installed capacities of 550MW, 291MW and 114MW respectively as of the end of 2011(Muyiwa et al., 2012).

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For instance, Agbele (2009) asserts that offshore areas from Lagos State through Ondo, Delta, Rivers, Bayelsa, and Akwa-Ibom States have the potential for harvesting strong wind energy throughout the year. However, all these propositions have not been verified with statistical measurements and model tests with existing state-of-the-art wind turbines to quantify the derivable wind power available. It is noted that wind power could be less available on land when compared with offshore. This is because of the presence of some structures and features that retard the movement of air on land.

The need for an alternative source of energy in Bonny Island and its environs owing to its comparative advantage of abundant wind around its coastline has been brought to the fore in several for in recent times. The energy needs of Bonny Island are being supplied by operating companies such as Nigeria Liquefied Natural Gas Limited (NLNG) and Shell Petroleum Development Company (SPDC). NLNG has an installed generation capacity of 320MW. The company uses an average of 250 MW and has an installed feeder of 10 MW, and exports power to Bonny Town and its neighbouring areas as opined by Bonny Utility Company report, (BUC, 2019). Similarly, the SPDC has an installed generation capacity of 96 MW and has the capability of exporting 10 MW to the community as well. The exported power is being managed and distributed by Bonny Utility Company (BUC, 2019). The power from NLNG and SPDC is generated from hydrocarbon (Gas and diesel). Presently, the collective electrical power limit of NLNG and SPDC to Bonny Island is 20 MW. This power is generated from hydrocarbon fuel which causes a lot of carbon emission and pollution to the environment. Bonny Island being an industrial town is expected to have population growth and power demand is anticipated to rise to 30 MW in the next five years predominantly from the influx of industrial workers as a result of the introduction of Train-7 at the NLNG plant and the construction of access road from Port Harcourt mainland to Bonny Town (Adebayo & Chuks, 2019). Besides, owing to its proximity to the coastline given the high amount of wind, it has high comparative advantage in the development of wind energy farm. Given the above, an assessment of the wind power potential of Bonny Island is necessary for a cleaner energy power supply to the town.

Comment [C4]: Bonny Utility Company (BUC, 2019) report,

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1.2 Statement of the Problem

Almost all the energy consumption is provided by the burning of fossil fuels in the last century. This persistent burning of fossil fuels is the cause of growing environmental concerns which results in the depletion of fossil fuels and increase of green-house effects. These concerns are the cause of exploring various alternative clean, renewable, and environmentally friendly sources of energy. Currently, wind energy is one of the most emerging renewables, sustainable, and commercially accepted sources of energy. Geospatial techniques have become an essential ally in identifying ideal locations for these inherently geographic solutions for energy production. Spatial analysis can reveal prime areas for renewable energy production by evaluating the energy potential of a given location based on geographic and cultural landscapes.

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Applying Geospatial Techniques in streamlining the site selection process, and the ability to add all influencing factors into a single map for developing a wind farm underscores the problem of this research.

1.3 Aim and Objectives

This study is aimed at exploring site suitability assessment for development of a wind farm at Bonny Island in Bonny, Nigeria.

The objectives are:

1) To provide data and a map of the spatial distribution of wind on Bonny Island,

2) To determine the weight of each of the factors needed for developing wind farm in Bonny Island,

3) To produce a wind farm suitability map of Bonny Island.

1.4 Study Area

Bonny is a Local Government Area located within Rivers State, South-South Nigeria. The headquarters of the area is in the town of Bonny which comprises several towns and villages. The population of Bonny LGA is estimated at 172,549 (NPC, 2006) inhabitants with Christianity and Paganism as the widely practiced religions in the area. The popular landmarks in the area include the Bonny Liquefied Natural Gas plant. Bonny LGA is an Island and lies within Latitude 4°25′09″ and Longitude 07°10′27″, it covers a total area of 646 square kilometres and features two distinct seasons which are the rainy and the dry seasons. The monthly historical peak power (MW) consumptions of Bonny Island from the year 2017 to 2019 were obtained from the Bonny Utility Company report 2019 to determine the wind power plant capacity to be modelled in the study area.

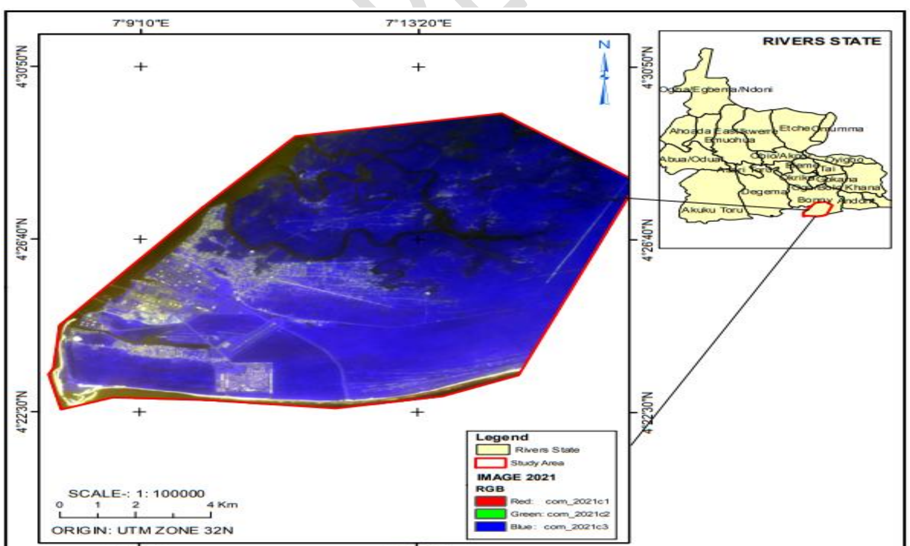

Figure 1: Map of the Study Area
Source: Office of the Surveyor General Rivers State, 2023

2.0 Materials and Methods

This research intends to develop a method that can categorize the land that is available for the construction of wind farm projects into different levels, based on the degree to which it is suitable for such endeavours. To accomplish this objective, several steps have been determined. Because of this analysis, particular weights are assigned to each factor to develop an index that can determine the suitability of land. The AHP was utilised to arrive at these final weights. The final suitability map is then produced with the help of GIS, a map which is used for spatial analysis and the integration of multiple factors into the proposed index to locate areas that are not suitable.

2.1 Parameters for Assessing Land Suitability

There are several factors considered in the assessment of the suitability of a location for wind energy farm. However, for this study five factors are considered which include wind speed, distance to settlements/roads, distance from rivers, slope, and land use/land cover.

2.1.1. Wind Speed

Wind speeds were the most crucial factor in deciding where to build a wind power plant. Most wind turbines start up with an efficiency of 3 m/s and stop at a speed of 25 m/s. Wind speeds of at least 3.5 m/s were considered good and appropriate for wind energy study. For this research, the wind speed data of Bonny Island was obtained from the Bonny weather station, and Finima airstrip records of Nigeria Liquefied Natural Gas.

2.1.2 Distance to Roads

The choice of wind farm sites requires consideration of the area's accessibility to major transportation networks (Gorsevski et al, 2012). The cost of building a wind farm will be reduced using already constructed roads. While existing roads make it easier to access the site, building new ones significantly increases the cost of production (Van & Fthenakis, 2011). For the transportation of the turbines and other equipment, it is necessary to confirm that road access exists or that it can be constructed at an affordable price. During this research, the road network data of the study area was obtained through maximum likelihood classification of the downloaded imagery of the study area.

Comment [C6]: Gorsevski *et al*., 2012

Comment [C7]: Van Haaren & Fthenakis,

2.1.3. Distance from Rivers

Rivers, lakes, and wetlands are examples of water bodies that have been deemed unsuitable for use as wind farm sites due to the ecological services they provide (Adaramola, et al 2015). The wind farms' distance from the riverbed will increase the safety of the facilities because the river routes are dynamic and constantly changing, and there is also a risk of flooding (Islam & Imran, 2022). Within 300 m of water bodies, renewable energy projects should not be constructed (Islam & Imran, 2022). A 0.6 km buffer was built around the water bodies in this study. IDRISI TAIGA 16.0 software was used for image classification.

Comment [C8]: Adaramola *et al*., 2015

2.1.4 Slope

The slope is a crucial technical factor that must be taken into consideration when selecting wind farms.

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Because these locations are difficult to access due to steep slopes. In the other hand, regions with a slope of more than 10% are excluded from the final suitability map. However, in this study, the slope factor was calculated using data from a digital elevation model (DEM) obtained from the office of the Surveyor General of Rivers State for proper analysis.

2.1.5 Land Use/Land Cover (LULC)

One of the key considerations for energy investments is land use. In areas where wind turbines barely impact current land use, wind energy should be installed. Land use has an impact on the choice of a wind farm because there are some locations where wind farms cannot be built even though there is sufficient wind speed, like in a forest, wetland, aviation zone, archaeological site. Therefore, it can be generally said that the most suitable types of land are agricultural land, grassland, barren land, and shrubland, while forest land is less suitable. IDRISI TAIGA 16.0 software was used for image classification.

2.2 Multi-Criteria Decision-Making

The Analytic Hierarchy Process (AHP) has received a lot of attention because it is thought to possess robust mathematical properties and has been applied in a wide range of fields (Noorollahi, *et al.,* 2015). The AHP has been used by researchers from a wide range of fields in numerous different contexts because of its ability to resolve issues involving the use of multiple criteria in decision-making (MCDM). In an MCDM problem, the AHP was used to specify the weights of the influencing factors to get closer to optimal solutions. The hierarchy was calculated once the problem's formation had been established. A pairwise comparison matrix was built based on the preference scale so that the criteria from one hierarchy level can be compared to the criteria from the next hierarchy level (Thomas & Doherty, 1980).

Comment [C9]: Noorollahi *et al.,* 2015).

2.2.1 Inverse Distance Weighting (IDW) Interpolation Method

One of the most frequently used deterministic models in spatial interpolation is the inverse-distance weighting (IDW) method. It is relatively fast and easy to compute, and straightforward to interpret. Its general idea assumes that the attribute value of an unsampled point is the weighted average of known values within the neighbourhood, and the weights are inversely related to the distances between the prediction location and the sampled locations.

The Inverse Distance Weighting (IDW) Interpolation Method was deployed to determine the various wind speeds around and within the study area.

3.1 Results and Discussion

3.1.1 Wind Speed

Wind speed is an important consideration when selecting the ideal site for new wind farms. Wind turbines' energy output rises as wind speeds increase till the nominal wind speed is reached, which refers to the speed that enhances power generation. However, in this case, the suitability of Bonny Island for the construction of wind farms was assessed using the criteria for wind speed evaluation. Depending on the frequency of the value and statistical data, land classes were divided into three degrees (Highly Suitable, Suitable, and Not suitable). According to the wind speed map, about 25% of

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the entire study area is highly suitable for the development of wind farms (Figure 2). 70% of the area is suitable while 5% is not suitable for wind farm development in the study area.

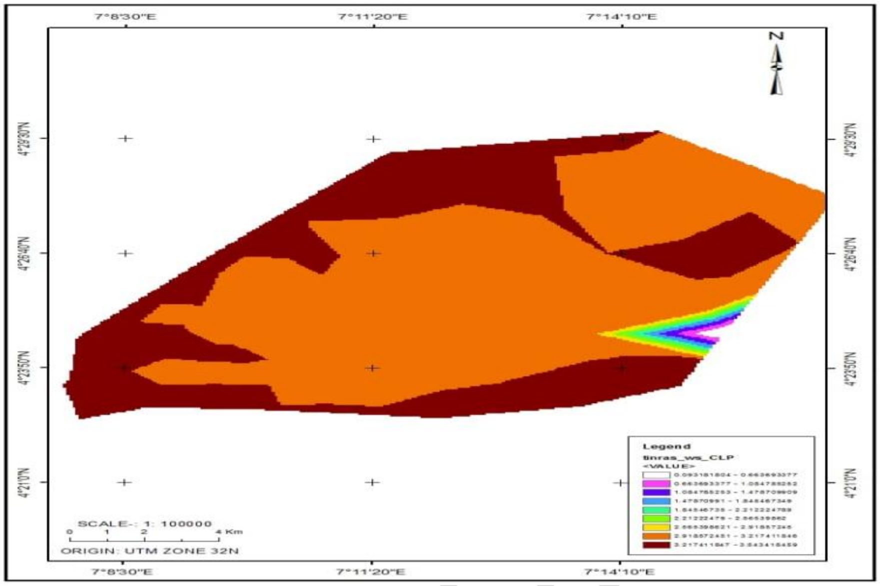

Figure 2: Map of Spatial Distribution of Wind Speed of Bonny Island

Source: Authors' Fieldwork, 2023

3.1.2 Distance to Roads

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Distance from roads was reclassified into four categories in this study using the Euclidean distance technique in the spatial analyst methods. Accordingly, the locations that are between 0 to 0.78km from the road were deemed to be highly suitable, while locations that were more than 3 km far were deemed to be unsuitable. Figure 2 depicts the road connectivity map, this map shows that 650% of the total area is less than 1.67 km from a road, making it the most likely location for wind farms. Furthermore, 20% of the total area is located between 1.67 and 2.5km from roads, making it moderately suitable for the development of wind energy. However, it is determined that 15% of the area is unsuitable for the construction of wind farms.

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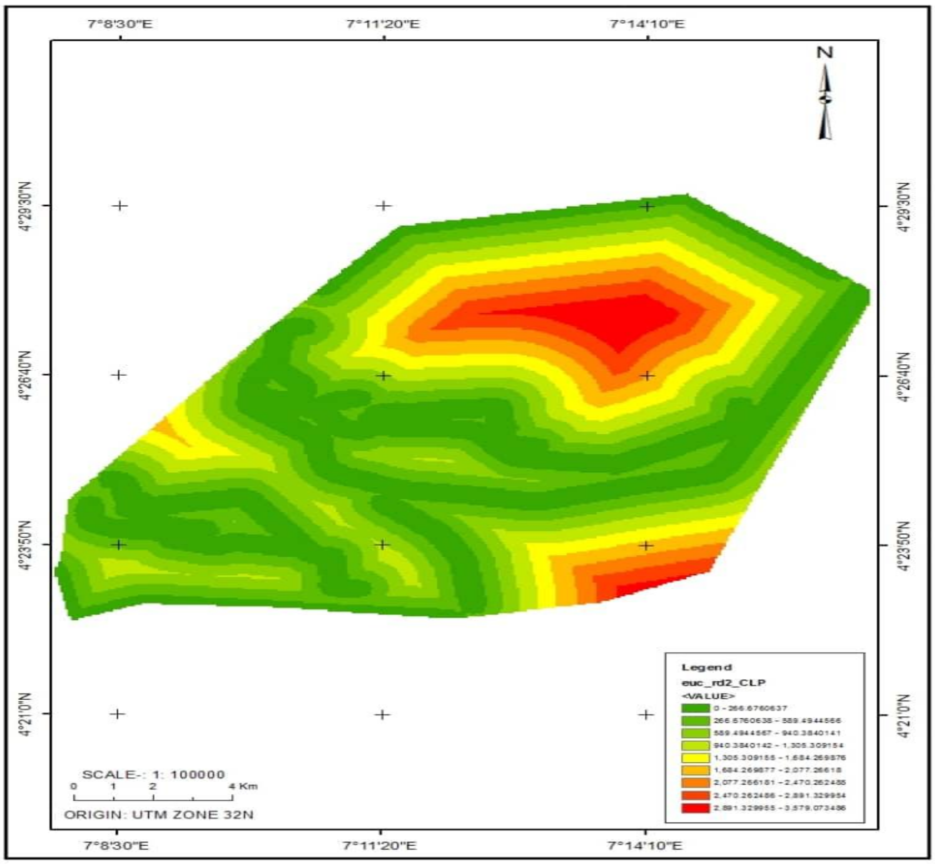

Figure 3: Euclidean Distance from Roads
Source: Authors' Fieldwork, 2023

3.1.3 Distance from Rivers

Water bodies are not suitable for wind farm sites, because of the ecological services they provide (Adaramola, *et al.*, 2015). Therefore, wind turbines must be located far away from bodies of water to ensure the safety of both the bodies of water and the turbines. Szurek, *et al.*, 2014, formed a minimum distance of 250m from the river and surface water (Szurek, *et al.*, 2014). In this study, a 1km buffer is created around the lake and a 200m buffer is created around the river. Therefore, areas greater than 600 m from a water body were deemed suitable for the construction of a wind farm. Figure 4 depicts a map of the distance from a water body. This map shows that more than 60% of the land area is greater than 600 m from a water body, making it an ideal location for wind farms.

Comment [C11]: Adaramola *et al.*, 2015

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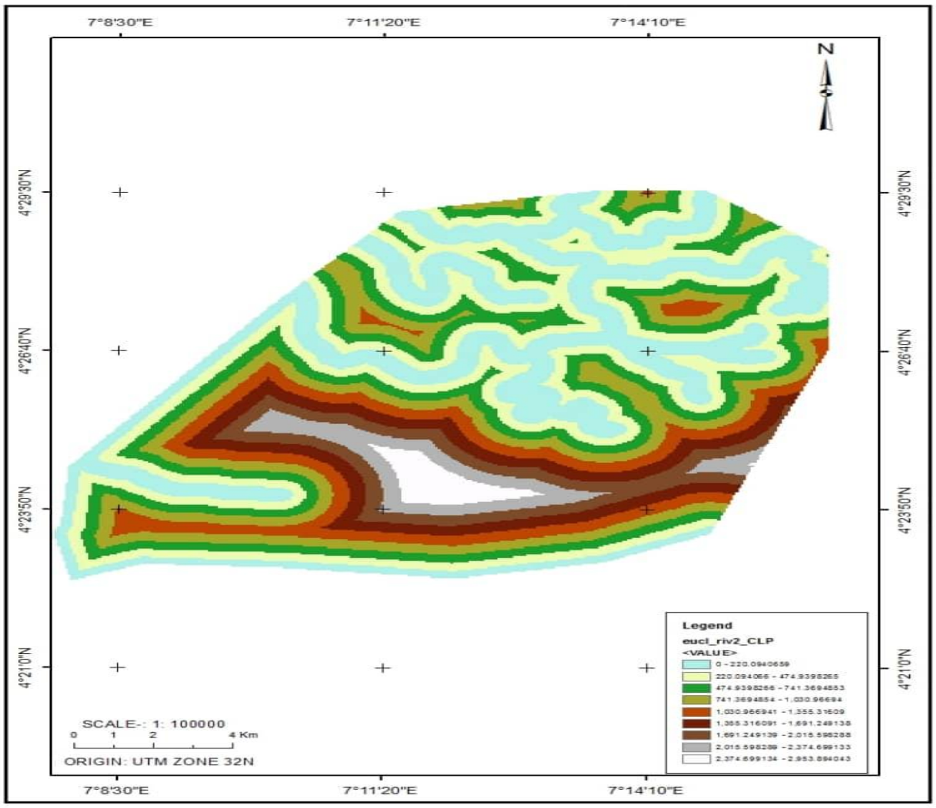

Figure 4: Euclidean Distance from Rivers
Source: Authors' Fieldwork, 2023

3.1.4 Slope

The terrain's slope has a serious influence on how easily wind turbines can be installed and maintained, so it is an important consideration when choosing a suitable site. Because wind turbine construction and maintenance are more difficult on steep terrain than they are on gentle slopes. In general, the digital elevation model of the Shuttle Radar Topography Mission (SRTM) with a resolution of 30m was used to generate a slope map in the GIS environment. In accordance with the degree of the slope, the slope raster was then split into four classes. In this instance, it was determined that a slope of less than 10˚ was highly suitable and that a slope of more than 10˚ was unsuitable. The slope map in Fig. 5 illustrates how most of the land in the study area is suitable.

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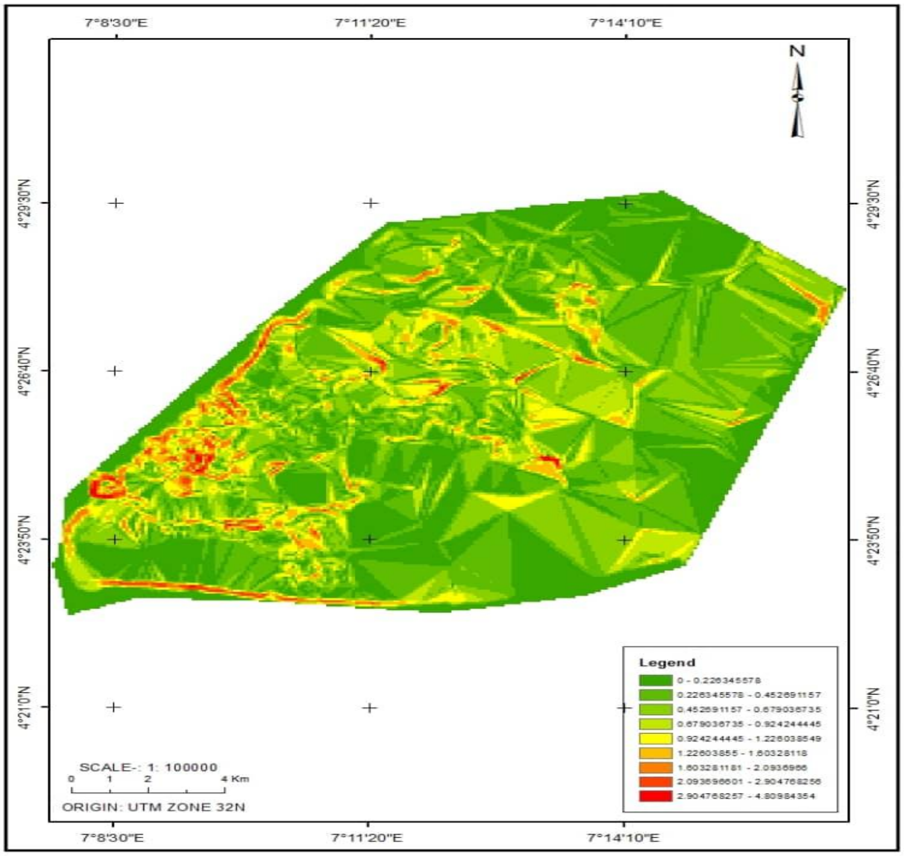

Figure 5: Slope Map of the Study Area
Source: Authors' Fieldwork, 2023

3.1.5 Land Use/Land Cover (LULC)

The current land use in an area with enough wind resources is crucial when choosing a location for a wind farm. For instance, some areas do not permit the construction of wind farms despite having adequate wind resources there. These places consist of wetlands, historical sites, aviation areas, and army areas (As a result, it can generally be said that agricultural land, grassland, barren land, and shrubland are the most suitable types of land, whereas forest land is thought to be less suitable. In this study area, 40% of the total area was Vegetation, 20% of the land was built up area while the remaining percentage is waterbodies, sand dunes and mangroves respectively (Van Haaren et al., 2012).

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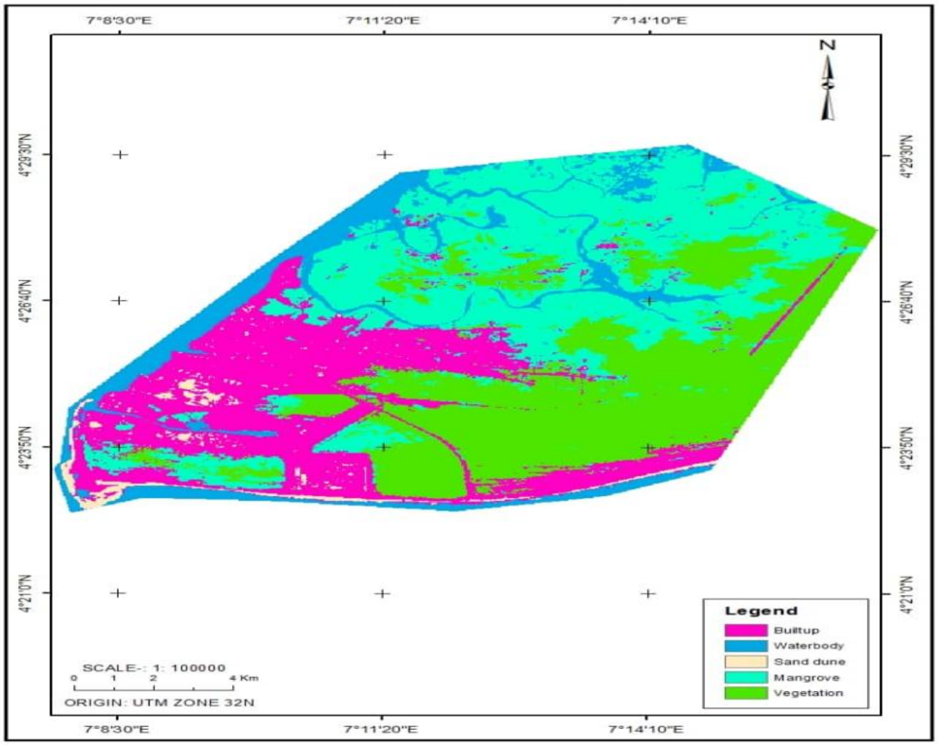

Figure 6: Land Use/Land Cover Classification Map
Source: Authors' Fieldwork, 2023

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3.2. Determining Weight Factors and Suitability Analysis

The overall weights of the wind energy suitability variables were determined using the ArcMap mapping program. Each factor was given a weight, signifying a priority or evaluation of the importance of one factor to the other. However, several criteria pairs may not be entirely consistent during comparison. The accuracy of the criteria comparison is therefore assessed using the consistency ratio (CR). Table 1 summarises the AHP weight result for each element. It was determined that the variable wind speed criteria had the highest priority weight (50%), land use/land cover had 25%, the proximity to settlement/road and river had 10% each while slope area had a minimal impact on wind farm establishment with 5% weight. The consistency ratio, according to the study's findings, is CR = 0.08, which is acceptable since it is less than 0.10.

Table 1: Suitability Score and Weight Used in Selecting Optimal Site for Wind Energy

S/N	Evaluation Factors	Range	Score	Suitability Class	Weight
1	Wind Speed (m/s)	2.853 – 3.543	5	Very High	50
		2.163 – 2.853	4	High	
		1.473 – 2.163	3	Moderate	
		0.783 – 1.473	2	Low	
		0.093 – 0.783	1	Very Low	
2	Slope (°)	0.00 – 0.962	5	Very High	5
		0.962– 1.924	4	High	
		1.924 – 2.886	3	Moderate	
		2.886 – 3.848	2	Low	
		3.848 – 4.810	1	Very Low	
3	Land Use/Cover	Vegetation	5	Very High	25
		Mangrove	4	High	
		Sand Dune	3	Moderate	
		Water body	2	Low	
		Built-up	1	Very Low	
4	Distance from River (m)	2363.12– 2953.89	5	Very High	10
		1772.34 – 2363.12	4	High	
		1181.56 – 1772.34	3	Moderate	
		590.78 – 1181.56	2	Low	
		0.00 – 590.78	1	Very Low	
5	Distance from Road (m)	0.00 – 715.82	5	Very High	10
		715.82 – 1431.63	4	High	
		1431.63 – 2147.44	3	Moderate	
		2147.44 – 2863.26	2	Low	
		2863.26 – 3579.07	1	Very Low	

Source: Authors' Fieldwork, 2023

3.2.1 Wind Farm Suitability Categories

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Using a weighted overlay on ArcMap, the full wind farm suitability map and table for the study area were generated. There are three classes in the final map which shows that 2.99% of the total area (424.6 Hectares) which is in red colour is not suitable for establishing wind farms, an area of 10,219.6 Hectares with 72% of the total land in yellow colour is moderately suitable while the remaining 25.01% (3,549.8 Hectares) of the total area in green colour is deemed highly suitable for sitting a wind farm within the study area.

Table 2: Total Area in Hectares and the Suitability Class for Wind Energy

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Class	Area (Ha)	% Area
Not Suitable	424.60	2.99
Suitable	10,219.60	72.00
Highly Suitable	3,549.80	25.01
Total	**14,194**	**100**

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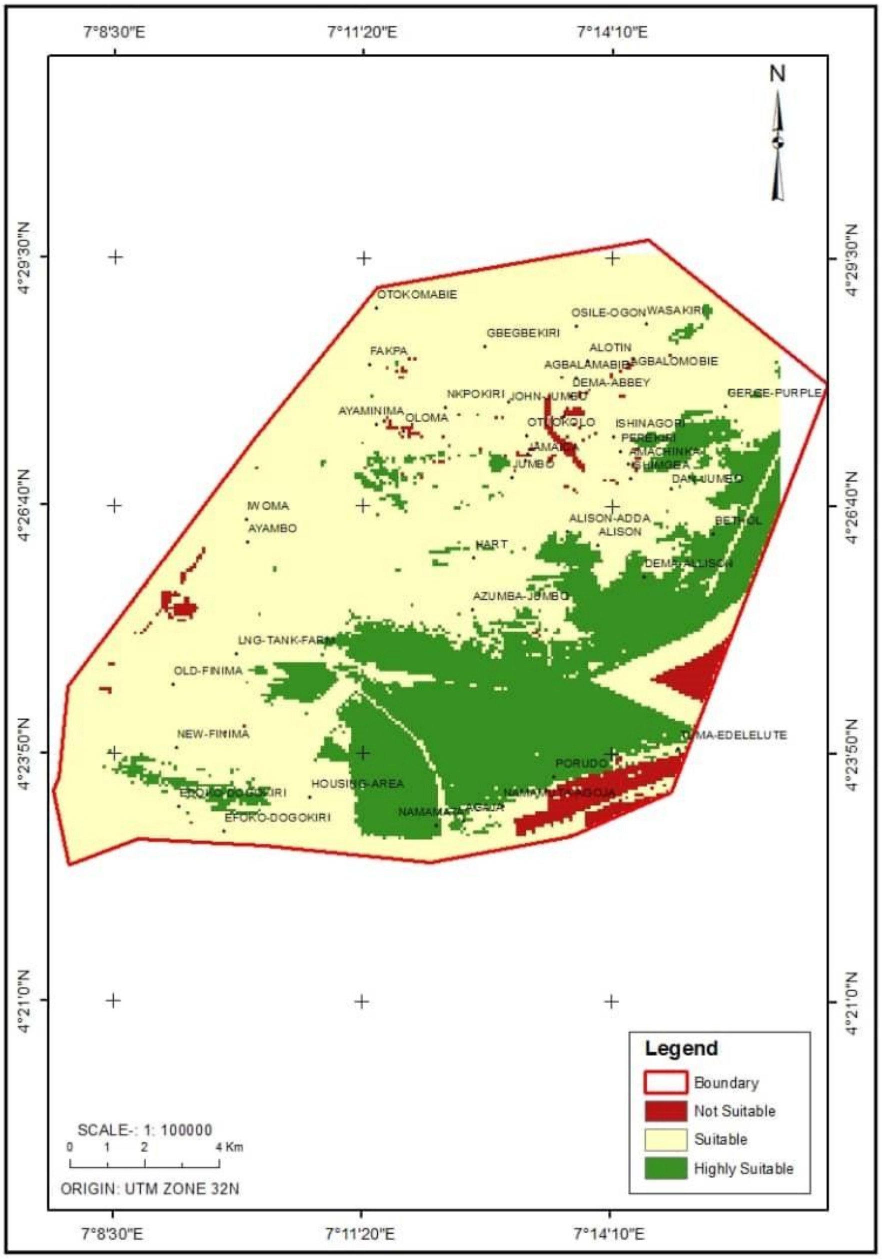

Figure 7: Suitability Map for Wind Energy Site Selection in Bonny Island
Source: Author's Fieldwork, 2023

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4.0 Conclusion and Recommendation

This study developed decision support models to identify potential wind farm locations in Bonny Island, Rivers State, Nigeria. Despite the barrier imposed by wind speed, substantial parts of Bonny Island still show great development potential for wind energy farms, given that a greater percentage of the entire study area satisfied the fundamental conditions under equal weights. This research has also validated the need for exploring Geospatial techniques for the development of wind energy that will engender a streamlined site selection process and provide the ability to add all influencing factors into a single map for wind farms.

This research recommends amongst other things the investment and installation of a wind energy farm in Bonny Island, the use of Geospatial techniques in further research on wind energy farms in Nigeria.

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