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

Abstract

Power derived via the wind stands out as an appealing form of renewable energy due to its minimal operational, maintenance, and production expenses, coupled with its limited environmental footprint. This investigation focuses on employing geospatial methods to establish a wind farm on Bonny Island, Nigeria. The primary objectives include furnishing data and a spatial wind distribution map for Bonny Island, evaluating the significance of factors crucial for wind farm development in the area, and generating a wind energy suitability map. The study utilizes Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) methodologies to scrutinize five critical parameters influencing location suitability. The findings indicate that Bonny Island possesses potential for wind farm installation, with 3,549.8 hectares, 10,219.6 hectares, and 424.6 hectares categorized as highly suitable, suitable, and unsuitable, respectively. Moreover, wind speed, land use/land cover, distance from the road, distance from the river, and land slope each carry a substantial priority weight of 50%, 25%, 10%, 10%, and 5%, respectively. These weights contribute to the creation of a wind energy suitability map for 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 clean and cost-effective energy in Nigeria has prompted the assessment of renewable energy resources and the identification of suitable locations within the country. Wind energy emerges as a promising renewable resource with substantial potential to meet energy needs [5]. The global rise in energy demand, potential depletion of fossil fuel reserves, and associated environmental issues highlight the urgency of exploring green and sustainable energy sources.

On a worldwide scale, population growth contributes to a rising energy demand, estimated to increase by approximately 2% annually [9]. This growth directly affects the quality of life, leading to an ongoing surge in fossil fuel consumption. The adverse environmental impacts of fossil fuel use, particularly as a major contributor to global warming [4], emphasize the need to transition to cleaner and sustainable energy sources. The heightened use of fossil fuels has led to increased greenhouse gas concentrations over the past 250 years [11], placing pressure on the Organisation of the Petroleum Exporting Countries (OPEC) [6].

Consequently, there has been a global shift toward renewable energy sources due to environmental concerns associated with nuclear power and fossil fuels. The concept and implementation of generating electricity from renewable sources are gaining popularity as the primary alternative energy solution. Rising costs and environmental challenges associated with large-scale power generation have prompted exploration into alternative energy sources.

In Europe and America, wind power is recognized as a valuable and promising alternative green energy source [15]. While wind energy availability varies by location, its cleanliness, abundance, affordability, inexhaustibility, and environmental sustainability make it the fastest-growing renewable energy source in both developed and some developing nations. In Africa, Egypt, Morocco, and Tunisia lead in wind energy, with installed capacities of 550MW, 291MW, and 114MW, respectively, as of the end of 2011 [12].

For instance, coastal regions such as Delta, Lagos, Ondo, Rivers, Akwa-Ibom, and Bayelsa in Nigeria show significant potential for harnessing consistent wind energy throughout the year, according to [3]. However, these claims lack confirmation through empirical data, statistical measurements, and model tests using contemporary wind turbine technology to accurately assess obtainable wind power. It is acknowledged that wind power may be less abundant on land compared to offshore areas due to various structures and features impeding air movement over land.

The increasing demand for an alternative energy source in Bonny Island and its surrounding areas, driven by abundant wind resources along its coastline, has gained prominence in recent discussions. Bonny Island's energy needs are currently met by operating companies like Nigeria Liquefied Natural Gas Limited (NLNG) and Shell Petroleum Development Company (SPDC). NLNG, with a 320MW installed generations capacity, utilizes an average of 250 MW and exports power to Bonny Town and adjacent regions, according to a report by Bonny Utility Company [7]. Similarly, SPDC boasts a 96 MW generation capacity and the capability to export 10 MW to the community, with power management and distribution overseen by [7]. Both NLNG and SPDC generate power from hydrocarbon sources (gas and diesel), contributing to environmental concerns due to carbon emissions and pollution.

Currently, the combined electrical power supply from NLNG and SPDC to Bonny Island is limited to 20 MW. Given the industrial nature of Bonny Island, population growth is expected, and power demand is projected to reach 30 MW in the next five years. This surge is attributed to the influx of industrial workers following the introduction of Train-7 at the NLNG plant and the construction of an access road from Port Harcourt mainland to Bonny Town [2]. Additionally, due to its proximity to the coastline and the abundant wind resources available, Bonny Island holds an enormous comparative vintage point aiding development of a wind energy farm. Considering these factors, an evaluation of Bonny Island's wind power potential becomes crucial to facilitate a transition towards a cleaner and more sustainable energy supply for the town.

1.2 Statement of the Problem

The predominant energy source over the past century has been the combustion of fossil fuels, contributing significantly to environmental concerns such as the depletion of fossil fuel reserves and the escalation of greenhouse effects. These issues have prompted the exploration of alternative, cleaner, and sustainable energy sources. Wind energy has emerged as a prominent renewable and commercially viable option. Leveraging geospatial techniques has become crucial in identifying optimal locations for these geographically dependent energy solutions. Through spatial analysis, it is possible to pinpoint areas with high potential for renewable energy production by considering geographical and cultural landscapes.

The utilization of geospatial techniques streamlines the site selection process, integrating various influencing factors into a comprehensive map for wind farm development. This research emphasizes the significance of applying spatial analysis in assessing ideal locations for renewable energy projects.

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 measure the economic and environmental viability of wind energy development on Bonny Island,
3) To produce a wind farm suitability map of Bonny Island.

1.4 Study Area

Bonny is a jurisdictional area situated in Rivers State, South-South Nigeria, with its administrative centre located in the town of Bonny, comprising various towns and villages. The estimated population of Bonny Local Government Area (LGA) is 172,549 [13], with Christianity and Paganism being the predominant religions. Notable landmarks in the region include the Bonny Liquefied Natural Gas plant. Geographically, Bonny LGA is an island positioned at Latitude 4˚ 25′ 09″ and Longitude 07˚ 10′ 27″, covering a total land area of 646 square kilometres. The area experiences two distinct seasons, namely the rainy and dry seasons. To ascertain the wind power plant capacity for modeling in the study area, data on the monthly historical peak power (MW) consumption of Bonny Island from 2017 to 2019 was obtained from [7].

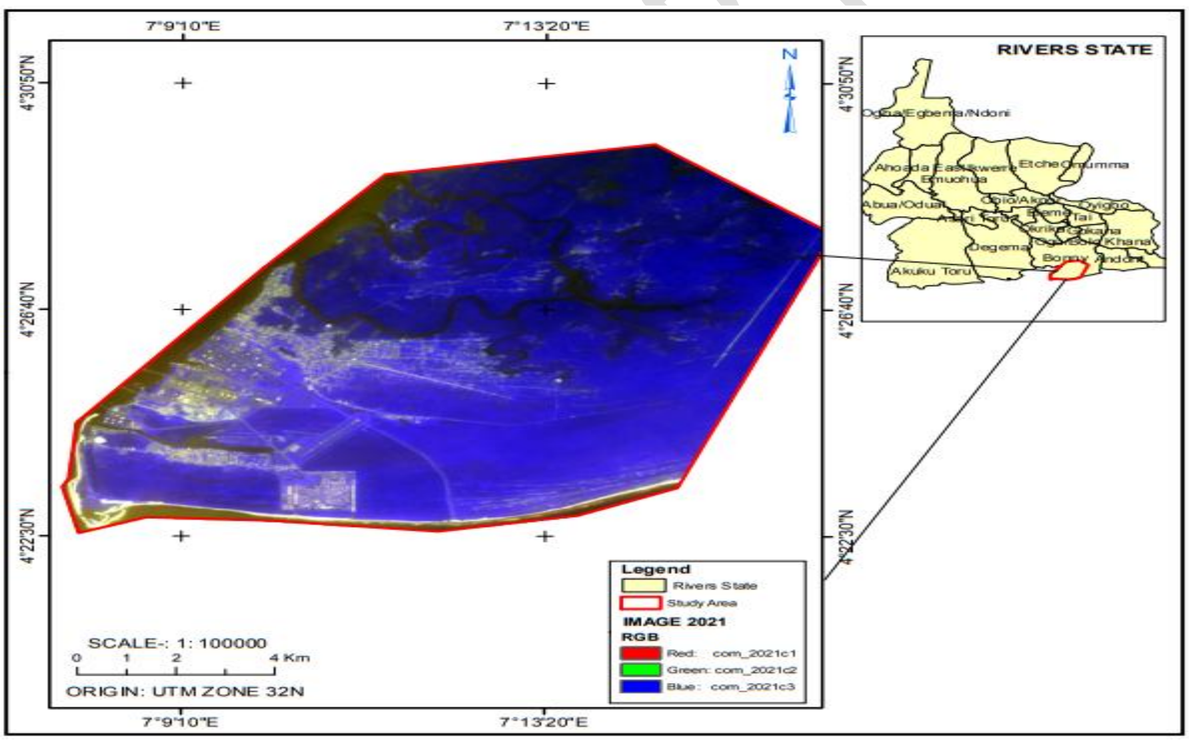

Figure 1: Map of the Study Area

Source: Office of the Surveyor General Rivers State, 2023

2.0 Materials and Methods

This study aims to devise a methodology for classifying land designated for wind farm construction into distinct tiers, contingent upon its suitability for such projects. To achieve this goal, a series of steps has been delineated, involving the assignment of specific weights to individual factors through analysis. The Analytic Hierarchy Process (AHP) was employed to derive these conclusive weights. Subsequently, a suitability index was formulated to assess land suitability. Utilizing Geographic Information System (GIS), a final suitability map was generated. This map serves as a tool for spatial analysis, integrating various factors into the proposed index to identify areas deemed unsuitable for wind farm development.

2.1 Parameters for Assessing Land Suitability

The evaluation of a site's appropriateness for a wind energy farm takes into account various factors. Nonetheless, this study specifically examines five key factors: wind speed, proximity to settlements/roads, distance from rivers, slope, and land use/land cover.

2.1.1. Wind Speed

The selection of an optimal location for a wind power plant heavily depended on wind speeds. Typically, wind turbines initiate operation at 3 m/s efficiency and cease at 25 m/s. Wind speeds surpassing 3.5 m/s were deemed favourable for the investigation of wind energy. In this study, wind speed information for Bonny Island was acquired from the Nigeria Meteorological Agency (NiMet).

2.1.2 Distance to Roads

Selecting suitable locations for wind farms involves assessing the user-friendliness of prime passage links [8]. Utilizing routes that already existed contributes to cost savings in the erection of wind farm. The admittance to site of work is enhanced when there are already-built routes, which contradicts the contemplation of edifying new roads thereby adding increase to cost of construction. [18]. It is imperative to ensure the availability of road access or the feasibility of constructing affordable routes for transporting turbines and other equipment. In the course of this study, road network data for the research area was acquired by employing maximum likelihood classification on downloaded imagery.

2.1.3. Distance from Rivers

Water bodies such as rivers, lakes, and wetlands are considered inappropriate for hosting wind farms due to the ecological functions they serve [1]. To enhance the safety of these facilities, it is recommended to maintain a considerable distance from riverbeds, as river routes are dynamic, subject to constant changes, and pose a potential risk of flooding [10]. Construction of renewable energy projects within 300 meters of water bodies is discouraged [10]. In the present study, a protective buffer of 0.6 kilometres was established around the water bodies. Image classification in this research was conducted using IDRISI TAIGA 16.0 software.

2.1.4 Slope

The incline plays a pivotal technical role that necessitates consideration in the choice of wind farm sites. This is due to the challenging accessibility of locations characterized by steep slopes. Conversely, areas featuring slopes exceeding 10% are omitted from the ultimate suitability map. Nevertheless, in this investigation, the slope variable was computed using data derived from a digital elevation model (DEM) sourced from the Shuttle Radar Topography Mission (SRTM), possessing a 30m resolution to facilitate thorough analysis.

2.1.5 Land Use/Land Cover (LULC)

The determination of suitable locations for energy investments is heavily influenced by land use, a critical factor. The ideal sites for installing wind energy involve minimal interference with existing land use by turbines. The choice of a suitable location for a wind farm considers land use factors, with certain areas like forests, wetlands, aviation zones, and archaeological sites posing constraints, despite having sufficient wind speed. Generally, agricultural land, grassland, barren land, and shrubland are considered more suitable, while forested areas are seen as less conducive. Image classification in this study utilized IDRISI TAIGA 16.0 software.

2.2 Multi-Criteria Decision-Making

The Analytic Hierarchy Process (AHP) has gained considerable attention due to its robust mathematical properties and widespread applications across various domains [14]. AHP is widely adopted by researchers from diverse fields in numerous contexts, capitalizing on its ability to address challenges associated with multiple criteria decision-making (MCDM). When faced with an MCDM problem, AHP proves invaluable in determining the weights of influential factors, facilitating the pursuit of optimal solutions. Once the problem's structure is defined, the hierarchy is computed. Using a pairwise comparison matrix based on a preference scale, criteria from one hierarchy level are systematically compared to those from the subsequent level [17].

2.2.1 Inverse Distance Weighting (IDW) Interpolation Method

The inverse-distance weighting (IDW) method is a frequently used deterministic model in spatial interpolation. Known for its speed, computational simplicity, and ease of interpretation, this method operates on the principle that the attribute value at an unsampled point is the weighted average of known values within its neighbourhood. These weights are inversely proportional to the distances between the prediction location and the sampled locations. In this study, the IDW interpolation method was applied to evaluate wind speeds both within and around the designated study area.

3.1 Results and Discussion

3.1.1 Wind Speed

Determining the ideal location for new wind farms necessitates careful consideration of wind speed. The energy production of wind turbines rises with increasing wind speeds until reaching the nominal wind speed, which optimizes power generation. In assessing the feasibility of constructing a wind farm on Bonny Island, wind speed evaluation criteria were applied. Land classes were classified into three degrees—Highly Suitable, Suitable, and Not Suitable—based on the frequency of values and statistical data. The wind speed map indicates that roughly 25% of the entire study area, highlighted in red in Figure 2, is highly suitable for wind farm development. Around 70% of the area, depicted in orange, is moderately suitable, while 5% is considered unsuitable for wind farm development in the study region.

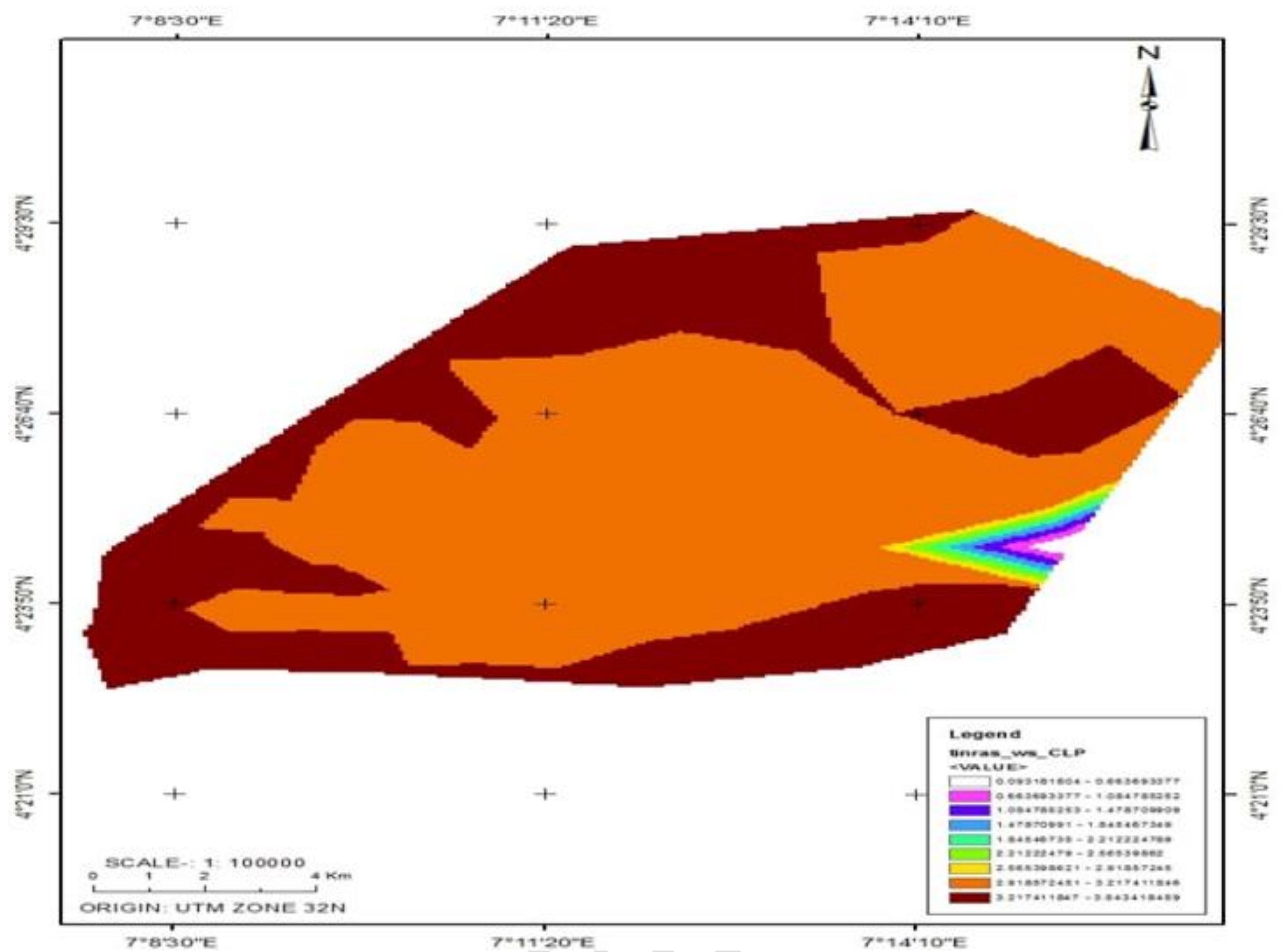

Figure 2: Map of Spatial Distribution of Wind Speed of Bonny Island
Source: Authors' Fieldwork, 2023

3.1.2 Distance to Roads

In this research, the spatial analyst methods utilized the Euclidean distance technique to categorize distances from roads into four groups. Areas within the range of 0 to 0.78 km from roads were classified as highly suitable, while those exceeding 3 km were considered unsuitable. The road connectivity map in Figure 3 demonstrates that 65% of the total area is located within 1.67 km from a road, indicating highly favourable conditions for wind farms. Additionally, 20% of the total area falls between 1.67 and 2.5 km from roads, suggesting moderate suitability for wind energy development. Moreover, 15% of the area is considered unsuitable for the construction of wind farms.

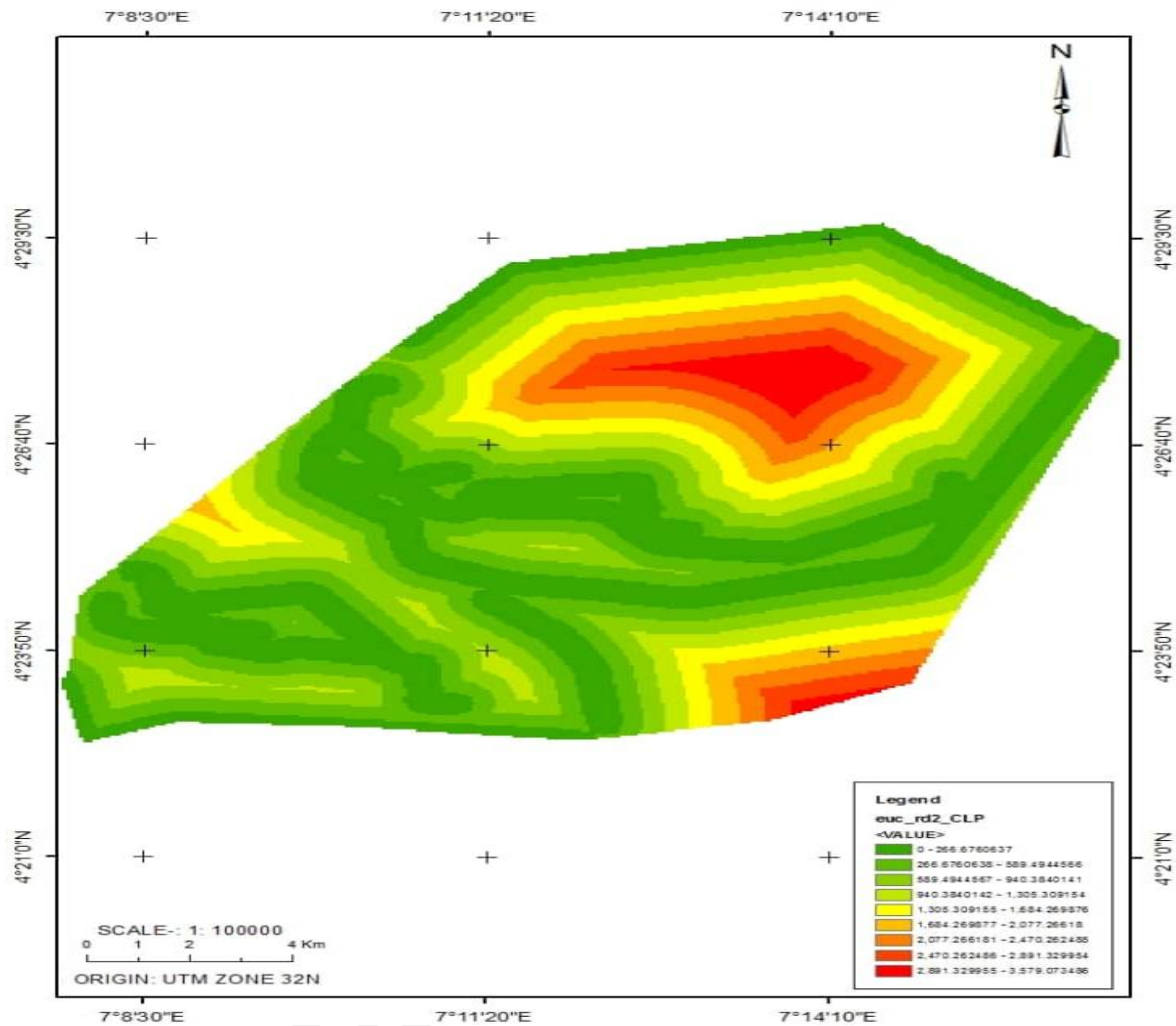

Figure 3: Euclidean Distance from Roads
Source: Authors' Fieldwork, 2023

3.1.3 Distance from Rivers

The area for wind farm sites should be situated at a significant distance from water bodies to safeguard the essential ecological functions they provide [1]. To ensure the welfare of both water bodies and wind turbines, it has been recommended to maintain a minimum distance of 250m from rivers and surface water [16]. In this investigation, we applied a 1km buffer around lakes and a 200m buffer around rivers. As a result, areas surpassing 600m from a water body were identified as suitable for constructing wind farms. The spatial distribution of distance locations from water bodies is depicted in Figure 4. The map indicates that more than 60% of the land area exceeds 600m from a water body, making it an optimal and secure location for wind energy development.

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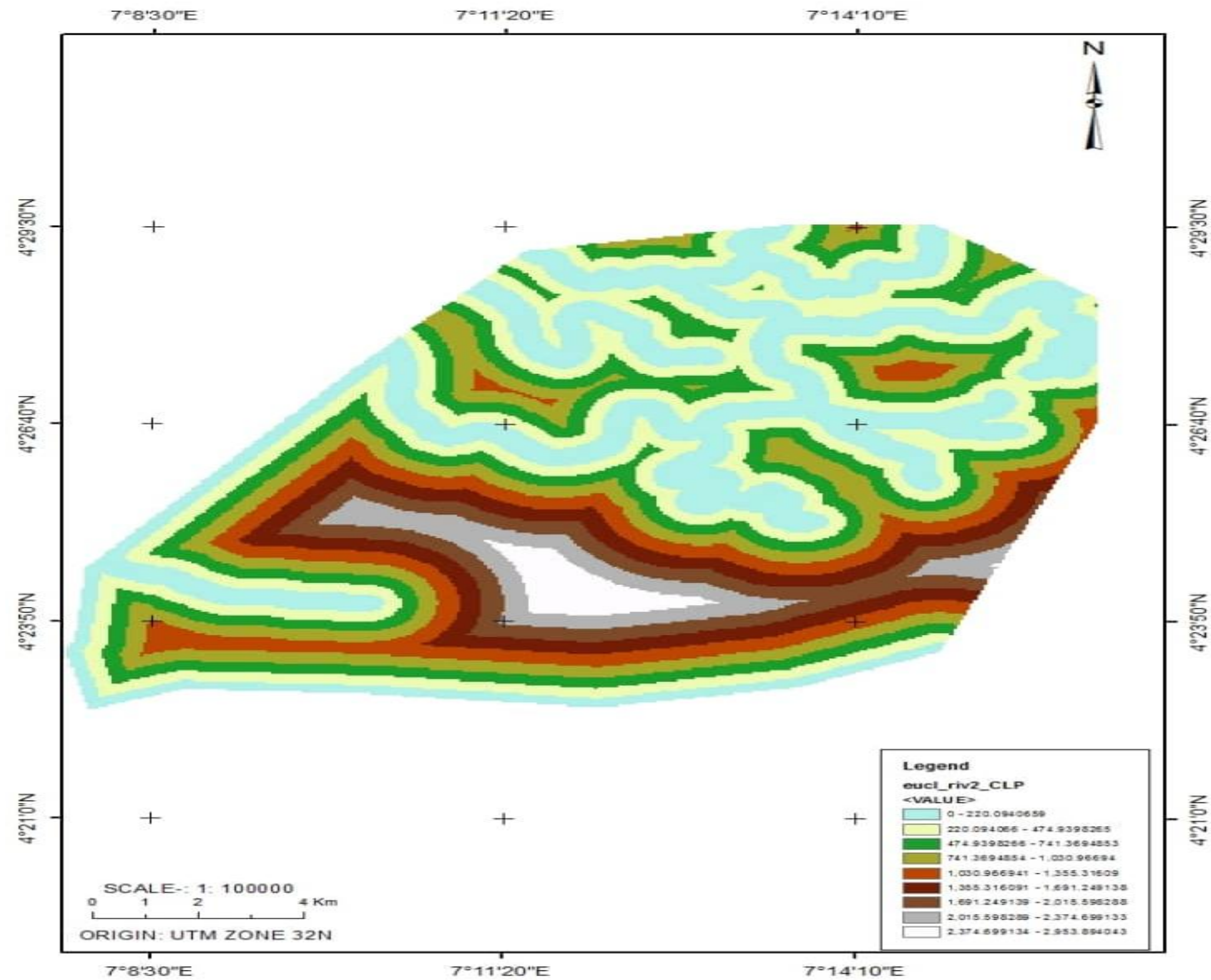

Figure 4: Euclidean Distance from Rivers
Source: Authors' Fieldwork, 2023

3.1.4 Slope

The gradient of the terrain plays a vital role in the installation and maintenance of wind turbines, making it a critical factor in site selection. More challenging conditions for the construction and upkeep of wind turbines are presented by steeper terrain compared to gentler slopes. Typically, the digital elevation model obtained from the Shuttle Radar Topography Mission (SRTM), with a resolution of 30 meters, was employed to generate a slope map using GIS tools. This map was then divided into four categories based on the degree of slope. Upon examination, areas with slopes less than 10 degrees were identified as highly suitable, while those exceeding 10 degrees were regarded as unsuitable. The slope map presented in Figure 5 visually illustrates that the majority of the study area consists of land suitable for the placement of wind turbines.

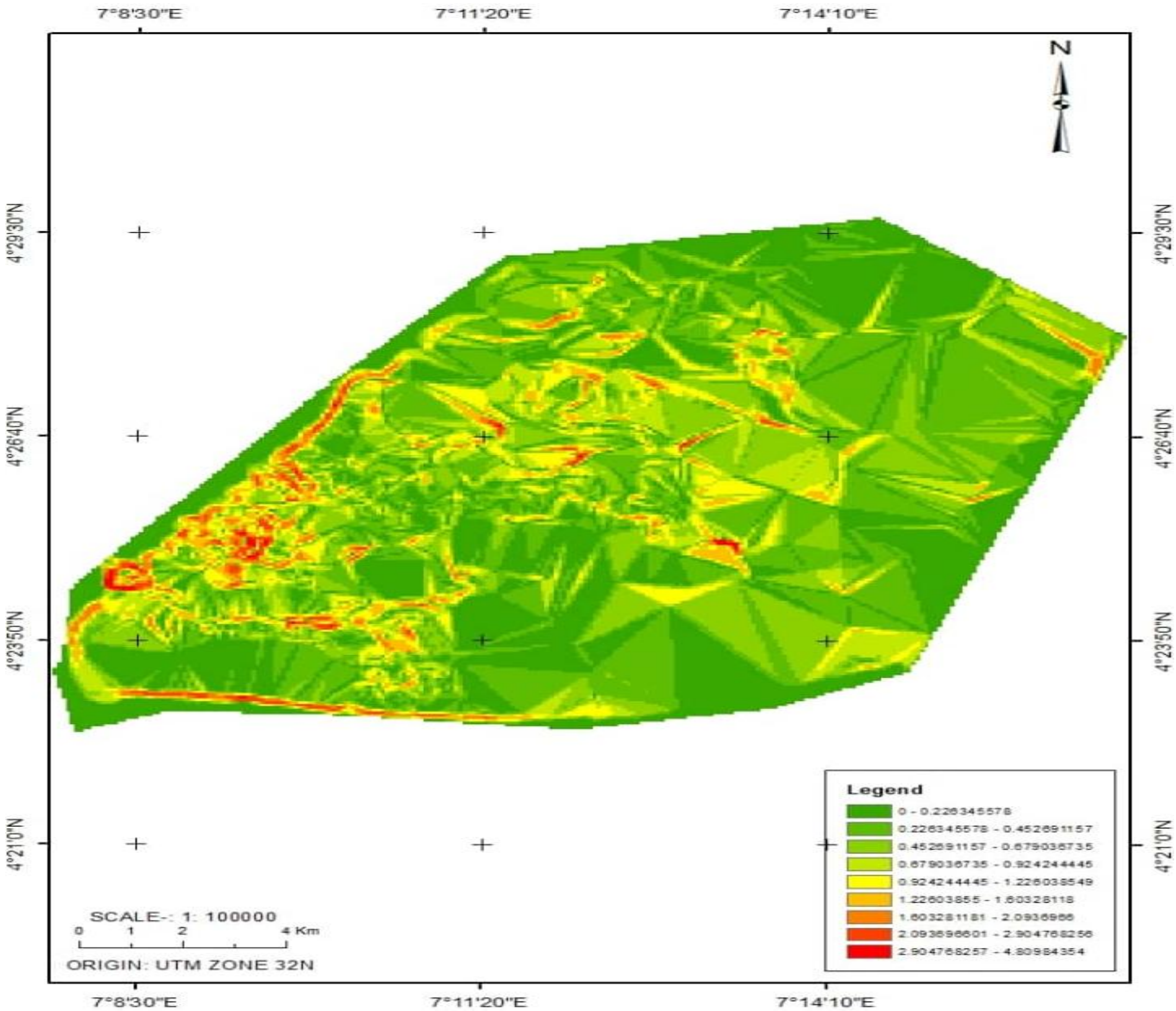

Figure 5: Slope Map of the Study Area
Source: Authors' Fieldwork, 2023

3.1.5 Land Use/Land Cover (LULC)

The identification of a suitable location for a wind farm is heavily dependent on the current land usage in an area that possesses abundant wind resources. Certain areas, including wetlands and historical sites as well as aviation zones but not limited to military areas, impose restrictions on the establishment of wind farms despite favourable wind conditions. As a result, it can be generally stated that agricultural land, grassland, barren land, and shrubland are considered highly appropriate for wind farm development, whereas forested areas are deemed less suitable. In the context of this research, 40% of the total area was covered by vegetation, 20% was designated as developed land, and the remaining percentage consisted of water bodies, sand dunes, and mangroves, respectively [18]. The findings of this study are visually represented in Figure 6 through the Land Use and Land Cover map.

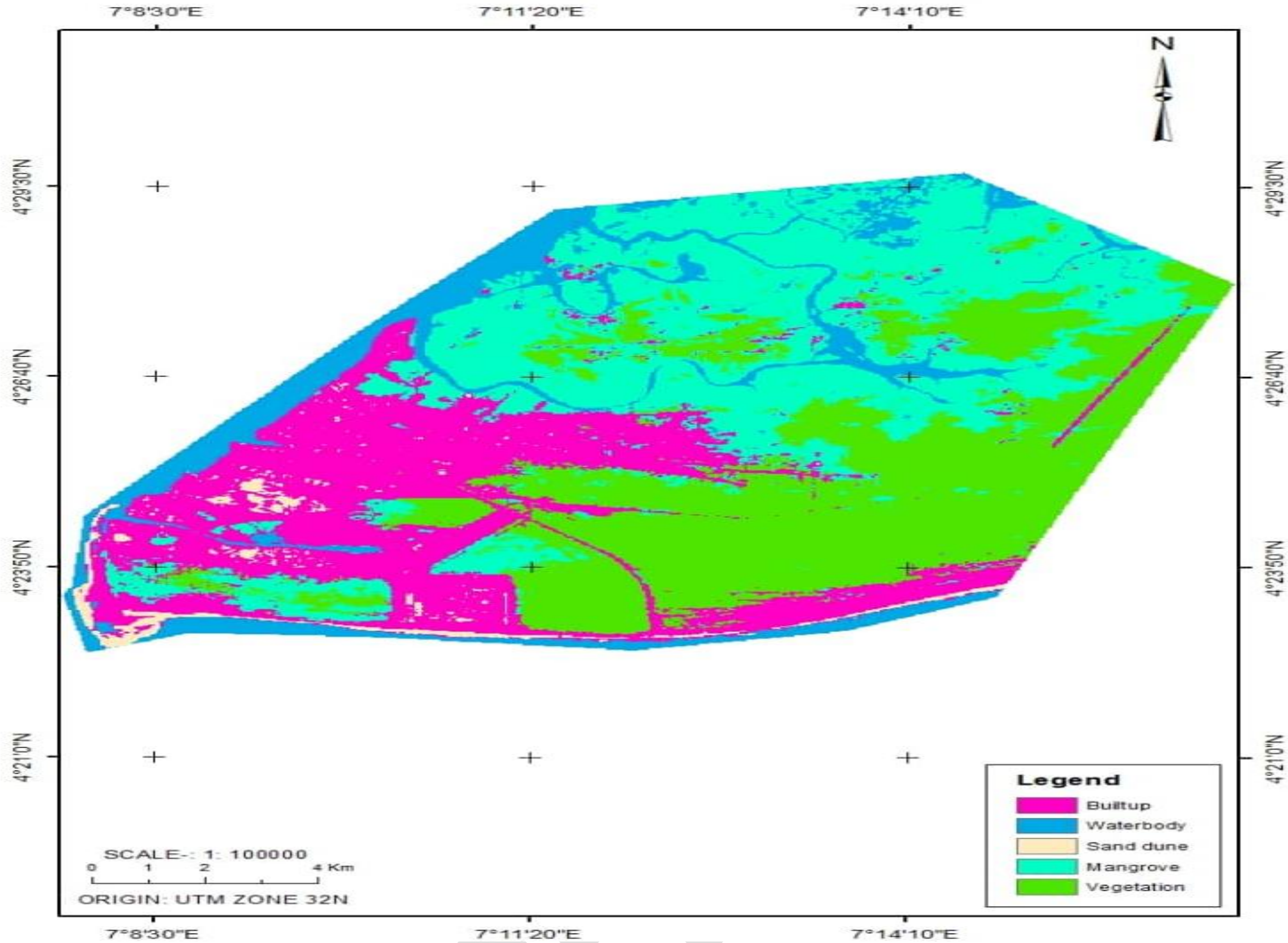

Figure 6: Land Use/Land Cover Classification Map
Source: Authors' Fieldwork, 2023

3.2. Determining Weight Factors and Suitability Analysis

The ArcMap mapping tool was utilized to determine the overall weights for various factors influencing wind energy suitability. Each factor was assigned a weight, indicating its importance relative to other factors. It's important to acknowledge that some pairs of criteria may display inconsistency during comparison. To assess the consistency of the criteria comparison, the study employed the consistency ratio (CR). Table 1 summarizes the Analytical Hierarchy Process (AHP) weight outcomes for each element. Obviously, wind speed standard received the highest priority weight at 50%, followed by land use/land cover at 25%, and proximity to settlement/road and river at 10% each. Slope area had a relatively little significant wind farm outlet, with a weight of 5%. The research work identified a consistency ratio (CR) of 0.08, which is considered acceptable as it is below the threshold of 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

By employing a weighted overlay technique in close-range to ArcMap, we generated an all-encompassing wind farm suitability map and corresponding table for the designated location where the research is being carried out. The final map delineates three distinct classes. Approximately 2.99% of the total area (424.6 hectares), represented in red, is deemed unsuitable for wind farm development. In contrast, an area encompassing 10,219.6 hectares, constituting 72% of the total land and depicted in yellow, is moderately suitable. The remaining 25.01% (3,549.8 hectares) of the total area, illustrated in green, is identified as highly suitable for establishing a wind farm within the study area. Table 2.0 and Figure 7 present the detailed results of the wind energy farm suitability assessment for Bonny and its surrounding areas.

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

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**

Source: Authors' Fieldwork, 2023

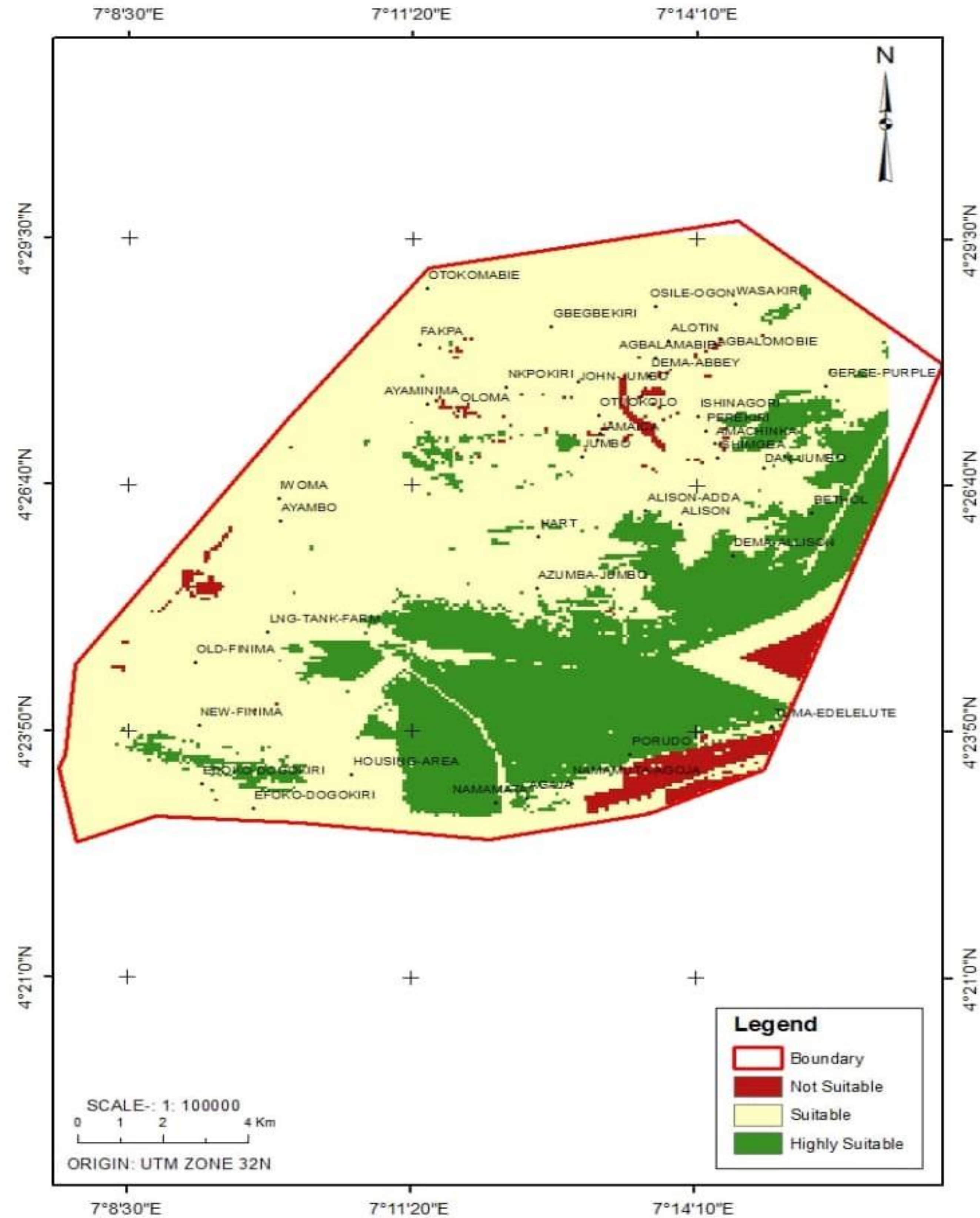

Figure 7: Suitability Map for Wind Energy Site Selection in Bonny Island
Source: Author's Fieldwork, 2023

4.0 Conclusion and Recommendation

This research created decision support models to identify suitable locations for wind farms in Bonny Island, Rivers State, Nigeria. Despite the challenge posed by wind speed variations, a significant portion of Bonny Island still exhibits considerable potential for the development of wind energy farms. This is attributed to the fact that a majority of the study area met the essential criteria when given equal importance. The study underscores the importance of leveraging Geospatial techniques to streamline the site selection process for wind energy projects. By incorporating all relevant factors into a single map, this approach enhances decision-making in the development of wind farms.

Among the recommendations arising from this study are the encouragement of investment and the establishment of a wind energy farm in Bonny Island. Furthermore, it advocates for the integration of Geospatial techniques in future research focused on wind energy farms in Nigeria. The study also suggests exploring the potential for offshore wind-energy farms, both off the coast of Bonny Island and along the coastline of Nigeria, as a subject for further investigation.

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