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Assessing Optimal Sites for Renewable Energy Development in Delta State, Nigeria: A Geospatial Multicriteria Evaluation Approach

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Abstract
This study presents a Geographic Information Systems (GIS)-based multicriteria evaluation (MCE) approach for identifying suitable sites for renewable energy development in Delta State, Nigeria. The research focuses on assessing the potential for solar and wind energy across the state by analyzing various spatial factors and criteria. Utilizing GIS techniques, data on land use, topography, proximity to infrastructure, and environmental sensitivity were integrated to evaluate the suitability of different locations for renewable energy projects. The results of the study revealed promising opportunities for both solar and wind energy development in Delta State. For solar energy, 13 out of the 24 Local Government Areas (LGAs) were identified as suitable, with Ndokwa East and Oshimili South LGAs exhibiting the highest area coverage of 225.16 and 293.71 square kilometers, respectively. In terms of wind energy, 16 LGAs were found to be suitable, with Ndokwa East, Isoko South, and Warri North LGAs presenting the most favorable conditions, covering 1359.50, 380.30, and 285.89 square kilometers, respectively. Even LGAs with lower area coverage still offer viable opportunities for renewable energy projects. These findings underscore the significant potential for renewable energy development in Delta State and highlight the importance of strategic planning and investment in the sector.
Keywords: *Renewable Energy; Energy; GIS, AHP*

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I. Introduction

The global pursuit of sustainable energy solutions has intensified in recent years, driven by mounting concerns over climate change, energy security, and economic development. In Nigeria, as in many other countries, there is a growing recognition of the imperative to transition towards renewable energy sources to meet energy demands while mitigating environmental impacts (IPCC, 2018; Abdullah & Hossain, 2017). Delta State, located in the southern region of Nigeria, presents a unique opportunity for the deployment of renewable energy technologies due to its abundant natural resources and increasing energy needs (Oseni & Awelewa, 2019). However, the selection of suitable sites for renewable energy projects in Delta State demands careful consideration of various socio-economic, environmental, and technical factors to ensure optimal outcomes (Ndulue & Nnabuchi, 2018).

Geographic Information Systems (GIS) offer powerful tools for analyzing spatial data and facilitating informed decision-making in site selection processes (Jia et al., 2017). By integrating multiple criteria, such as land use, topography, proximity to infrastructure, and environmental sensitivity, GIS-based multicriteria evaluation (MCE) systems enable stakeholders to identify and prioritize locations with the greatest potential for renewable energy development (Malczewski, 2006; Ghosh & Das, 2017). This study aims to develop and implement a GIS-based MCE system tailored to the context of Delta State, Nigeria, to assist decision-makers in identifying suitable sites for renewable energy projects.

To achieve this objective, a comprehensive review of relevant literature on renewable energy site selection, GIS applications, and multicriteria decision analysis will be conducted (Gevorgyan & El-Sayed, 2018). Drawing upon established methodologies and best practices, the study will develop a framework for integrating diverse criteria and spatial data layers within a GIS environment (Nwadinigwe & Orji, 2019). Through stakeholder engagement and expert consultations, the proposed MCE system will be refined and validated to ensure its relevance and effectiveness in the local context (Goumas & Lygerou, 2000).

This research contributes to the growing body of knowledge on renewable energy planning and GIS-based decision support systems by addressing the specific challenges and opportunities in Delta State, Nigeria. By providing a systematic approach to site selection, the developed MCE system will empower policymakers, investors, and other stakeholders to make informed decisions that promote sustainable energy development while safeguarding the region's socio-economic and environmental interests.

II. Study Area

Delta State, situated in the southern part of Nigeria, is one of the country's 36 states, covering an area of approximately 17,698 square kilometers. Bordered by the Niger River to the west and the Atlantic Ocean to the south, Delta State holds strategic importance due to its rich natural resources, diverse ecosystems, and significant economic activities.

Geographically, Delta State is characterized by a mix of coastal plains, mangrove swamps, and inland rainforests, providing a diverse habitat for flora and fauna. The state's topography ranges from low-lying coastal areas to rolling hills and plateaus in the northern regions, creating varied landscapes with distinct ecological features. The climate of Delta State is predominantly tropical, with high temperatures and humidity throughout the year. The region experiences two main seasons: the wet season, which lasts from April to October, characterized by heavy rainfall and occasional flooding, and the dry season, which occurs from November to March, marked by drier conditions and harmattan winds from the Sahara.

Delta State boasts abundant natural resources, including oil and gas deposits, which have historically contributed significantly to Nigeria's economy. The presence of oil refineries, petrochemical industries, and gas processing plants underscores the state's importance in the country's energy sector. Additionally, agriculture plays a crucial role in the state's economy, with crops such as oil palm, rubber, cassava, and rice cultivated across the fertile plains.

The population of Delta State is diverse, comprising various ethnic groups, including the Urhobo, Itsekiri, Ijaw, Isoko, and Igbo, each with its distinct cultural heritage and traditions. Urban centers such as Warri, Asaba, and Sapele serve as hubs of commerce, industry, and administration, while rural communities engage in farming, fishing, and small-scale businesses. Despite its natural wealth, Delta State faces numerous challenges, including environmental degradation, pollution from oil exploration activities, inadequate infrastructure, and socio-economic disparities. Efforts to promote sustainable development and address these challenges are underway, with initiatives focusing on renewable energy, environmental conservation, and community empowerment.

III. Material and methods

a. Methodology

The methodology adopted in achieving the desired goal included:

a. Data Acquisition
b. Image Classification
c. ALOS PALSAR Processing
d. Analytical Hierarchy Process

A. Data Acquisition

i. Acquisition of Primary Datasets

These data were obtained through field visits peculiar to the research at hand. They included.

a) The coordinates of sample points of land cover/land use on the ground to be used for accuracy assessment was obtained using handheld GPS.

b) Non-spatial (attribute) data describing the characteristics of Land cover/ land use identified on the scene were collected.

ii. Acquisition of Secondary Datasets

The secondary datasets were obtained from an already existing medium. They included:

a) Shapefile of Nigeria showing the Delta and Edo State States and LGA
b) Landsat 8 OLI imagery, downloaded from www.earthexplorer.usgs.gov.
c) ALOS Palsar DEM Image, downloaded from www.earthexplorer.usgs.gov.
d) Wind speed data gotten from www.ncdc.noaa.govc.
e) Road and Transmission data was gotten from the Department of Surveying & Geoinformatics, Nnamdi Azikiwe University Awka
f) Solar Irradiance and Top of the atmosphere data obtained from www.earthexplorer.usgs.gov and www.ncdc.noaa.govc

B. Image Classification

Digital image classification is a fundamental technique in remote sensing that leverages spectral information encoded within digital numbers across various spectral bands to categorize individual pixels according to their spectral signatures. Spectral bands capture electromagnetic radiation reflected or emitted from the Earth's surface, each band representing a specific range of wavelengths. By analyzing the unique spectral characteristics of different land cover types, image classification aims to assign each pixel to a predefined class or category, thus facilitating the extraction of meaningful information from remote sensing data.

In the context of this study, Landsat 8 OLI imagery, containing multiple spectral bands capturing different aspects of the electromagnetic spectrum, served as the primary data source for image classification. The supervised classification method was employed, wherein the classification process relies on the identification and labeling of training samples representing distinct land cover classes. These training samples, characterized by their spectral signatures, are used to train a classification algorithm to recognize similar patterns across the entire image.

During the supervised classification process, the algorithm compares the spectral signatures of pixels within the image to the spectral characteristics of the training samples, assigning each pixel to the class that best matches its spectral properties. This method enables the creation of thematic maps depicting the spatial distribution of various land cover types within the study area, providing valuable insights into land use patterns, vegetation cover, and other environmental features.

C. ALOS PALSAR Processing

Data errors in digital elevation models (DEMs) often arise due to limitations in resolution, both vertically and horizontally, as well as system errors incurred during the DEM generation process. These errors can significantly impact the accuracy and reliability of elevation data, thereby necessitating pre-processing steps to rectify discrepancies and enhance data quality. In this study, one prevalent issue encountered was the presence of depressions or "sinks" within the DEM data, which occur when low-lying areas are inaccurately represented as depressions or holes in the elevation surface.

To address this issue, a sink-filling process was undertaken using ArcGIS 10.5 software. Sink filling involves interpolating elevation values within depressions to ensure a continuous and realistic representation of the terrain. By systematically filling these depressions, the DEM data were refined to eliminate artifacts and improve the overall quality of elevation information.

Following the sink-filling process, additional derivative layers were generated from the DEM data to further characterize terrain attributes. Specifically, elevation, slope, and aspect layers were derived to provide valuable insights into the topographic characteristics of the study area. Elevation data represent the vertical height above sea level at each point, offering a comprehensive depiction of the terrain's relief. Slope layers quantify the steepness of terrain surfaces, while aspect layers indicate the direction in which slopes face, providing information on solar exposure and drainage patterns.

D. Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) serves as a robust decision-making tool by facilitating the comprehensive evaluation of both subjective and objective factors influencing a decision. It offers a structured framework for systematically weighing the relative importance of various criteria, allowing decision-makers to consider multiple dimensions, including benefits and risks, in a quantitative manner.

One of the key strengths of the AHP lies in its ability to accommodate both qualitative and quantitative inputs, enabling decision-makers to incorporate subjective judgments alongside objective data. By assigning numerical values to each criterion based on its perceived importance, decision-makers can effectively prioritize factors according to their relative significance in achieving the desired objectives.

Moreover, the AHP enables the consideration of both benefits and risks associated with different alternatives or courses of action. Decision-makers can assign weights to each criterion, reflecting the perceived magnitude of benefits or risks involved. Criteria deemed more critical or influential in achieving project objectives receive higher weightings, signifying their greater importance in the decision-making process.

Through pairwise comparisons and the use of preference scales, decision-makers can systematically rank alternatives based on their overall value or desirability. The AHP facilitates the aggregation of criteria weights and preference scores to determine the relative merits of different options, helping identify projects with the highest overall value or the most favorable combination of benefits and least risks, (Table 3.1).

Table 3.1: Relative Importance in Pairwise Comparison

Judgment value	Description
1	Equal importance
3	Moderately importance
5	Strongly Importance
7	Very strongly important
9	Extremely important

Source: (Saaty, 1980)

IV. Results and discussion

The findings of the study unveiled promising opportunities for renewable energy development in Delta State, Nigeria. Specifically, the analysis revealed that 13 out of the 24 Local Government Areas (LGAs) exhibit favorable conditions for solar energy deployment. Among these, Ndokwa East emerges as particularly conducive, boasting a substantial area coverage of 225.16 square kilometers suitable for solar energy projects. Following closely is Oshimili South LGA, with an expansive area of 293.71 square kilometers identified as suitable for solar energy harnessing.

Moreover, the results underscore the substantial potential for wind energy generation across the state. Out of the 24 LGAs, a total of 16 showcase suitability for wind energy projects. Notably, Ndokwa East emerges once again as a key area, presenting an extensive coverage of 1359.50 square kilometers suitable for wind energy development. Additionally, Isoko South and Warri North LGAs exhibit significant potential, with respective area coverages of 380.30 and 285.89 square kilometers identified as suitable for wind energy initiatives. Although these LGAs dominate in terms of area coverage, it is noteworthy that the remaining ten LGAs also offer viable opportunities for wind energy, albeit on a relatively smaller scale. For instance, Ika South LGA presents a modest yet still noteworthy area coverage of 0.31 square kilometers, while Patani LGA offers a substantial area of 146.24 square kilometers conducive to wind energy ventures (figure 4.1).

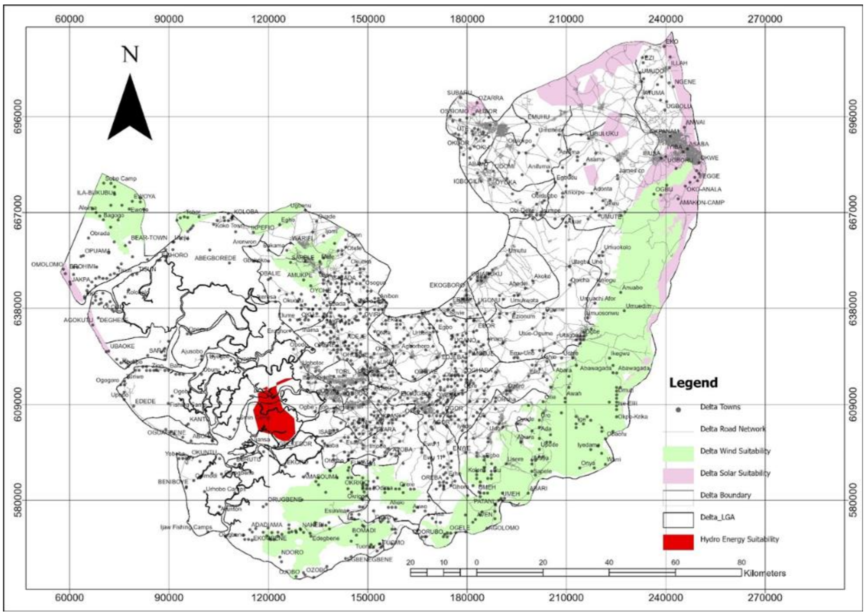

Figure 4.1: Wind, Hydro and Solar suitability in Delta State

These findings not only highlight the diverse renewable energy potential within Delta State but also emphasize the need for strategic planning and investment in both solar and wind energy sectors. By capitalizing on the identified favorable areas, Delta State can significantly enhance its renewable energy portfolio, contributing to sustainable development goals while reducing reliance on traditional fossil fuels. Additionally, such initiatives have the potential to foster economic growth, create employment opportunities, and mitigate the adverse effects of climate change. Thus, the results of this study serve as a valuable resource for policymakers, investors, and stakeholders seeking to promote renewable energy development in Delta State and beyond.

V. Conclusion

The findings of this study hold profound implications for Delta State's quest for alternative energy sources. The comprehensive assessment has delineated areas suitable for wind, solar, and hydro energy power plants, providing crucial insights for strategic decision-making in renewable energy infrastructure development. These results furnish decision-makers with valuable information to pinpoint optimal locations for the installation of renewable energy sources, factoring in a myriad of criteria such as land cover/land use, slope, wind speed, solar radiation, road network, stream network, settlement patterns, DEM data, power transmission infrastructure, and flow accumulation.

By leveraging this data-driven approach and prioritizing areas exhibiting high suitability, Delta State stands to unlock the full potential of renewable energy generation while diminishing reliance on non-renewable energy sources. This proactive stance not only aligns with global efforts towards mitigating climate change and promoting environmental sustainability but also lays the groundwork for fostering a resilient and self-sustaining energy ecosystem. Ultimately, the adoption of renewable energy solutions holds the promise of bolstering Delta State's energy security, driving economic prosperity, and fostering social well-being, thus catalyzing the transition towards a more sustainable and prosperous future.

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