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Developing a Geographic Information System (GIS) Based Multicriteria Evaluation Framework for Identifying Optimal Locations for Renewable Energy Deployment in Edo State, Nigeria

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A B S T R A C T

This study presents a comprehensive assessment of the renewable energy potential in Edo State, Nigeria, focusing on solar and wind energy resources. The methodology integrates data acquisition, image classification, ALOS PALSAR processing, and Analytical Hierarchy Process (AHP) to identify suitable sites for renewable energy development. Data acquisition involved the collection of primary datasets through field visits and the procurement of secondary datasets from various sources. These datasets included ground truth data, satellite imagery, DEM data, and meteorological data, among others. Image classification techniques were employed to extract land cover/land use information from Landsat 8 OLI imagery, while ALOS PALSAR processing techniques were applied to enhance the accuracy of terrain analysis. The results reveal promising findings regarding the renewable energy potential in Edo State. For solar energy, 12 out of 18 Local Government Areas (LGAs) were identified as suitable for development, with Esan South-East exhibiting the highest coverage area of 777.65 square kilometers. Regarding wind energy, 15 LGAs were deemed suitable, with Ovia South-West showcasing the largest coverage area of 1189.97 square kilometers. The AHP methodology facilitated the systematic evaluation and prioritization of decision criteria, enabling the identification of optimal sites for renewable energy projects. The integration of spatial analysis techniques and decision support tools provides valuable insights for policymakers, investors, and stakeholders involved in renewable energy planning and development initiatives in Edo State. This study contributes to the sustainable utilization of renewable energy resources, aligning with global efforts towards mitigating climate change and promoting energy security.

Keywords: Analytical Hierarchy Process (AHP), Edo State, GIS, Renewable Energy,

Introduction

Renewable energy represents a critical avenue for sustainable development, particularly in regions striving to meet growing energy demands while mitigating environmental impacts. In Edo State, Nigeria, the exploration of renewable energy sources has gained considerable momentum in recent years due to their potential to address both energy security and climate change concerns (Oyewo et al., 2019; Adu-Gyamfi et al., 2020). However, identifying suitable sites for renewable energy projects presents a complex challenge influenced by various factors such as geographical features, environmental constraints, and socio-economic considerations (Ogbomo et al., 2018; Adenikinju et al., 2021).

To address this challenge, Geographic Information Systems (GIS) offer a powerful toolset for integrating spatial data and conducting spatial analysis to support decision-making processes (Oladokun et al., 2017; Ajala et al., 2020). Multicriteria evaluation (MCE) systems within GIS frameworks enable the simultaneous consideration of multiple criteria and constraints, facilitating the identification of optimal sites for renewable energy deployment (Oladele et al., 2019; Aborisade et al., 2021).

This study aims to develop and implement a GIS-based Multicriteria Evaluation System tailored to the context of Edo State, Nigeria, for selecting suitable sites for renewable energy projects. By leveraging spatial data on factors such as solar irradiation, wind speed, land use, proximity to infrastructure, and environmental sensitivity, this framework seeks to provide valuable insights for decision-makers in the energy sector (Oyebode et al., 2018; Oluwadare et al., 2020).

The integration of GIS technology with multicriteria evaluation methodologies offers a systematic approach to site selection, enhancing the efficiency and effectiveness of renewable energy planning and development efforts in Edo State (Adeniran et al., 2018; Olaniyan et al., 2021). Through the synthesis of diverse datasets and the application of spatial analysis techniques, this research endeavors to contribute to the sustainable transition towards renewable energy utilization in the region, aligning with global efforts towards climate resilience and energy sustainability (Ajibade et al., 2019; Odusola et al., 2020).

Study Area

Edo State is located in southern Nigeria, nestled within the Niger Delta region. It covers an area of approximately 17,802 square kilometers and is bordered by four other Nigerian states: Delta to the west, Ondo to the northwest, Kogi to the northeast, and Anambra to the east. To the south, it is bounded by the Atlantic Ocean, providing access to coastal resources and trade routes.

The state capital is Benin City, a historically significant urban center renowned for its rich cultural heritage, including the ancient Benin Kingdom. Benin City serves as the administrative, economic, and cultural hub of Edo State, boasting vibrant markets, museums, and landmarks reflecting its storied past.

Edo State is characterized by diverse landscapes, ranging from lush rainforests in the south to rolling plains and plateaus in the north. The state's topography contributes to its agricultural productivity, supporting cultivation of crops such as oil palm, rubber, cocoa, and cassava. Additionally, the presence of rivers and creeks facilitates fishing activities and provides water resources for irrigation and transportation.

The state is inhabited by a diverse population representing various ethnic groups, with the Edo people forming the majority. Traditional festivals, art, and craftsmanship are integral to the cultural identity of the state, attracting tourists and scholars interested in exploring its cultural heritage.

Economically, Edo State is endowed with natural resources such as crude oil and natural gas, contributing to its status as a key player in Nigeria's petroleum industry. In recent years, there has been a growing focus on diversifying the economy, with initiatives aimed at promoting sectors such as agriculture, manufacturing, tourism, and renewable energy.

Despite its potential for economic growth, Edo State faces challenges such as infrastructure development, environmental degradation, and socio-economic disparities. Efforts by the state government and various stakeholders are underway to address these issues and harness the state's resources for sustainable development and improved quality of life for its residents.

Materials and Methods

Methodology

The achievement of the study's objectives relied on a multifaceted methodology, incorporating several key stages:

Data Acquisition

Acquisition of Primary Datasets

The primary datasets essential for this research were gathered through meticulous fieldwork, tailored to the specific requirements of the study. This involved:

i. Collection of Ground Truth Data: Coordinates of sample points representing land cover/land use features were meticulously captured on-site using handheld GPS devices. These coordinates served as reference points for accuracy assessment in subsequent analyses.

ii. Gathering of Non-Spatial Data: Detailed attribute data describing the characteristics of land cover/land use features observed during field surveys were systematically documented. This comprehensive dataset enriched the understanding of the study area's landscape composition and dynamics.

Acquisition of Secondary Datasets

In addition to primary data collection, secondary datasets were sourced from various existing repositories:

i. Shapefile of Nigeria: A comprehensive shapefile delineating administrative boundaries, including the Delta and Edo States, as well as Local Government Areas (LGAs), was sourced.

ii. Landsat 8 OLI Imagery: High-resolution satellite imagery from Landsat 8 OLI was obtained from reputable sources such as www.earthexplorer.usgs.gov, providing valuable spectral information for image classification and analysis.

iii. ALOS Palsar DEM Image: Digital Elevation Model (DEM) data derived from ALOS Palsar satellite imagery was acquired from authoritative sources to facilitate terrain analysis and suitability assessment.

iv. Wind Speed Data: Meteorological data pertaining to wind speed was sourced from reliable sources like www.ncdc.noaa.gov, aiding in the evaluation of wind energy potential within the study area.

v. Road and Transmission Data: Geospatial data concerning road networks and transmission infrastructure were procured from the Department of Surveying & Geoinformatics, Nnamdi Azikiwe University Awka, enhancing the accuracy of spatial analyses.

vi. Solar Irradiance and Top of the Atmosphere Data: Solar irradiance data and top-of-the-atmosphere reflectance data were obtained from reputable sources such as www.earthexplorer.usgs.gov and www.ncdc.noaa.gov, facilitating solar energy potential assessment.

Image Classification

Digital image classification techniques were employed to extract land cover/land use information from satellite imagery. Utilizing the supervised classification method, spectral signatures derived from Landsat 8 OLI imagery were utilized to categorize individual pixels into distinct land cover classes, enhancing the understanding of spatial patterns and distribution within the study area.

ALOS PALSAR Processing

To address data errors and enhance the accuracy of terrain analysis, ALOS PALSAR DEM data underwent preprocessing steps. Sink filling techniques were applied using ArcGIS 10.5 software to mitigate depressions in the DEM dataset, followed by the generation of elevation, slope, and aspect layers. These derived terrain parameters served as critical constraints and factors for suitability analysis, aiding in the identification of optimal locations for renewable energy development.

Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) methodology was employed to systematically evaluate and prioritize decision criteria relevant to renewable energy site selection. By assigning numerical weights to each criterion based on its relative importance, the AHP facilitated the comprehensive assessment of both subjective and objective factors influencing site suitability. This systematic approach enabled the identification of projects with the highest overall value, considering both benefits and risks associated with renewable energy development initiatives.

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)

Results

The comprehensive analysis conducted on the renewable energy potential of Edo State has yielded promising findings, indicating favorable conditions for both solar and wind energy development across various Local Government Areas (LGAs).

In terms of solar energy suitability, the assessment identified 12 out of the 18 LGAs as conducive for solar energy projects. Notably, Esan South-East emerged as the LGA with the highest solar energy potential, boasting an extensive coverage area of 777.65 square kilometers. Following closely behind is Ovia North-East, with a substantial coverage area of 629.07 square kilometers. These findings underscore the considerable scope for solar energy exploitation within Edo State, particularly in the identified regions.

Similarly, the examination of wind energy suitability revealed promising prospects, with 15 out of the 18 LGAs demonstrating favorable conditions for wind energy development. Ovia South-West emerged as the top contender in terms of wind energy potential, with an expansive coverage area spanning 1189.97 square kilometers. Additionally, Ovia North-East and Etsako Central showcased significant wind energy suitability, with coverage areas of 779.99 square kilometers and 508.31 square kilometers, respectively. While some LGAs exhibited lower coverage areas, ranging from 1.55 square kilometers in Esan Central to 251.41 square kilometers in Ikpoba-Okha, the overall findings highlight the distributed potential for wind energy harnessing across Edo State.

These results signify a promising outlook for renewable energy development in Edo State, with ample opportunities for both solar and wind energy projects. The identification of suitable sites within the LGAs lays the groundwork for strategic planning and investment in renewable energy infrastructure, paving the way for sustainable energy production and contributing to the state's energy security and environmental objectives.

Conclusion

The comprehensive assessment of renewable energy potential in Edo State has provided valuable insights into the suitability of various Local Government Areas for solar and wind energy development. With 12 out of 18 LGAs identified as suitable for solar energy projects and 15 LGAs showing potential for wind energy, the findings underscore the significant opportunities for renewable energy exploitation within the state.

The extensive coverage areas identified in LGAs such as Esan South-East, Ovia North-East, and Ovia South-West highlight key regions with abundant renewable energy resources, laying a strong foundation for strategic investment and development initiatives. Moreover, the distributed potential across multiple LGAs signifies a decentralized approach to renewable energy deployment, fostering resilience and diversity in the state's energy landscape.

Moving forward, it is imperative for policymakers, investors, and stakeholders to capitalize on these findings and embark on targeted efforts to harness Edo State's renewable energy potential. By leveraging appropriate technologies, implementing supportive policies, and fostering partnerships, the state can unlock its renewable energy resources to meet growing energy demands sustainably while contributing to climate change mitigation and economic development objectives.

Furthermore, continued research and monitoring efforts are essential to refine our understanding of Edo State's renewable energy landscape and adapt strategies to evolving environmental, technological, and socio-economic factors. Through collaborative efforts and innovative approaches, Edo State can chart a course towards a cleaner, more resilient energy future, benefiting both present and future generations.

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