ORION SCHOLAR JOURNALS

International Journal of Multidisciplinary Research Updates

Journal homepage: https://orionjournals.com/ijmru/

ISSN: 2783-0179 (Online)

(RESEARCH ARTICLE)

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Developing a GIS-based multicriteria evaluation system for selecting suitable sites for solar energy power plants in Anambra state Nigeria

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International Journal of Multidisciplinary Research Updates, 2023, 06(02), 033–040

Publication history: Received on 19 October 2023; revised on 06 December 2023; accepted on 09 December 2023

Article DOI: https://doi.org/10.53430/ijmru.2023.6.2.0070

Abstract

The increasing demand for clean energy in society raises concerns about alternative energy sources, making it difficult to rely solely on one or two sources of electricity generation. This study aims to develop a GIS-based multicriteria evaluation system for identifying suitable solar energy power plants in Anambra State, Nigeria. Key criteria include solar irradiation, land use, proximity to transmission lines, accessibility, slope, and environmental constraints. GIS tools and satellite imagery data are used to analyze and visualize these criteria, enabling an efficient decision-making process. The methodology includes data collection, selecting and determining criteria for suitable site selection, constructing a hierarchical structure of site selection procedure, data acquisition, classification of acceptable criteria and factors into rank of suitability, determining the relative importance of each criterion using AHP (Analytical Hierarchy Process) based on pair-wise comparisons, assessing the consistency of judgments through a pair-wise comparisons method, and producing the final evaluation map. The results provide valuable insights into identifying suitable sites for solar power plants in Anambra State and are advised for use in other parts of the country. The GIS-based multicriteria evaluation system facilitates location decisions and increases efficiency in dealing with solar energy power plant siting. The study workflow model is suggested for smooth and quick appropriateness analysis and easy export as a python script.

Keywords: Anambra State; AHP; Energy; GIS; Solar

1. Introduction

The increasing consumption of fossil fuels and the environmental damage caused by increased CO_2 emissions have led to a growing global emphasis on renewable energy sources like solar, wind, hydropower, geothermal, tidal, and biomass energy. These renewable energy sources not only protect the environment but also lead to local and regional development and increased employment. They also reduce environmental pollution, greenhouse gas emissions, improve the quality of life, and increase population safety.

Energy has been and will continue to be the mainstay of an economy and plays a vital role in national development (Fagbenle, 1991). The use of renewable energy sources depends on local and regional characteristics and numerous parameters that need to be explored before power plant construction. Remote sensing and geographic information systems (GIS) are used to create spatial studies based on GIS for the construction of green power plants.

In Nigeria, energy development has faced challenges due to the country's short supply of electrical power, with only 40% of the nation's over 140 million having access to grid electricity (Abubakar, Ahmed, and Muneer 2013). Harnessing renewable energy potential such as solar and wind is necessary for reliable power supply in the country, as they contain enormous, largely untapped, and sustained opportunities for meeting the world's energy need.

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The creation of spatial studies and the application of geographic information systems began in the early 1990s, and their algorithms have been significantly modified over the last 20 years. Finding suitable locations for harnessing renewable energy is critical for economic success in terms of adopting renewable energy. GIS is a technological tool for comprehending geography and making intelligent decisions, providing functionalities for integrating a large spectrum of geospatial information into the decision-making process of renewable energy development. This research provides a comprehensive set of factors and conditions for geospatial analysis of site suitability location of renewable energy in Anambra State, Nigeria.

This study aims to create a GIS-Based Multicriteria evaluation system for selecting suitable solar energy sites in Anambra State, Nigeria. The objectives include establishing criteria and factors for locating solar power plants, classifying them based on suitability, applying a weighted linear combination of these criteria, and determining suitable model areas for solar energy power plants, resulting in a suitability index map.

1.1 Study Area

Anambra state, located in southeastern Nigeria, is bordered by Delta, Imo, Rivers, Enugu, and Kogi states. Its capital is Awka and covers an area of 4,593kmsq. The state has a population of 4.1 million according to 2006 national census and is predominantly inhabited by the Igbo ethnic group (98%). The economy is primarily based on farming, business, and oil refinery. The climate is tropical savanna, with an annual temperature of 27.0 ˚C. The state's ethnic groups include the Igbo and a small Igala population.

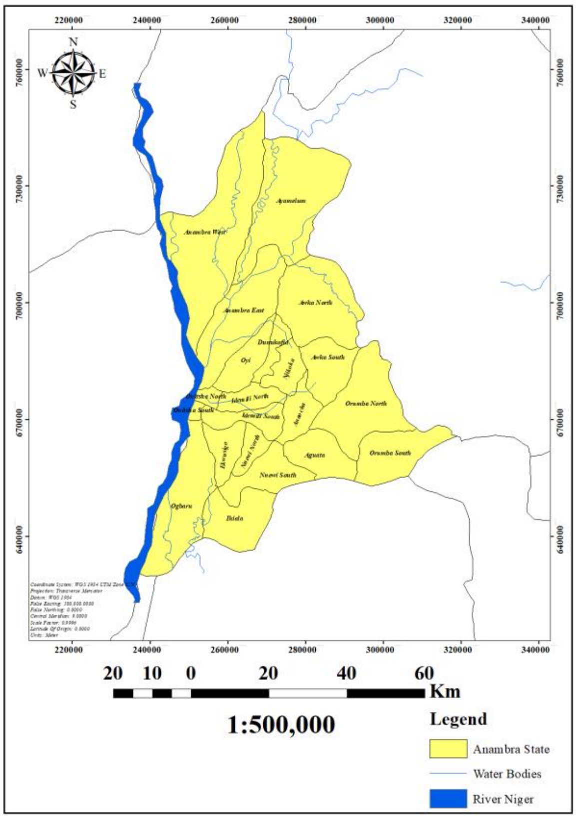

Figure 1 Map of Anambra States

2. Methodology and Techniques

The methodology includes data acquisition, verification, processing, database creation, standardization, analysis, pairwise comparison, buffering and weighted linear overlay. The selection standards for solar energy sites are based on climatic, geomorphological, environmental, and socioeconomic criteria.

Climate considerations include the use of raster maps to determine solar potential, which can be determined using Global Horizontal Irradiance. Geomorphological criteria include slope, elevation, and aspect, as these factors influence the performance of power plants. Proper alignment of solar panels can help capture sunlight for longer periods of the day. Environmental criteria involve distances from protected areas, preserving environmental resources, and considering land cover and land use to prevent potential environmental impacts.

Socioeconomic criteria include distance from roads, transmission lines, built-up areas, cities, and waterbodies. Access to transportation systems lowers installation costs of power plants, and road access is essential for minimizing energy waste. However, less emphasis is placed on the closeness of roads and transmission networks to ensure energy infrastructure can reach isolated locations.

Data used in this research includes ESRI Sentinel 2 10m LULC imagery, SRTM 1 Arc-Second DEM product, shape file of the administrative boundary of Nigeria showing Anambra State and LGA, waterbody data, solar irradiance data, road network data, and electricity transmission network data. Primary datasets were obtained through field visits, while secondary datasets were obtained from existing mediums such as the shape file of the administrative Nigeria showing Anambra State and LGA, ESRI Sentinel 2 10m LULC imagery, and SRTM 1 Arc-Second DEM Image.

The study used various datasets to analyze the solar potential, slope, elevation, and top of the atmosphere in Nigeria. These datasets were obtained from various sources such as the Department of Surveying & Geoinformatics at Nnamdi Azikiwe University Awka, Enugu Electricity Distribution Company, and www.earthexplorer.usgs.gov,globalsolaratlas.info, and www.ncdc.noaa.gov. The data types included Solar Potential (GHI), Slope Raster Digital Elevation Model, Elevation Raster Digital Elevation Model, Aspect Raster Digital Elevation Model, LULC Raster ESRI Sentinel 2 10m, Distance to Transmission Lines (11kV and 33kV), Distance to Roads, Distance to Built-Up Polygon Extract from LULC, and Distance from Waterbody.

Data processing involved techniques such as Image Sub-Mapping, Digital Image Classification, and SRTM Processing. Image sub-mapping is used to cut out the area of interest from the Solar Irradiance imagery, LULC Imagery, and SRTM using the shape file of the study area extracted from the administrative boundary of Nigeria. Digital image classification uses spectral information represented by digital numbers in one or more spectral bands, while SRTM processing includes elevation records for cells of a specific size.

3. Results

In this section, results of maps and data from spatial MCDA, supported by descriptive statistics. The outcomes are examined to ensure they meet study objectives. The data was compiled based on selected criteria, including land cover/landuse image, slope, distance to roads, medium-voltage transmission lines, aspect, solar radiation, populated regions, and waterbodies. Each conclusion is discussed based on the research question resolved during the process. Figure 2 to figure 8 display the data collected.

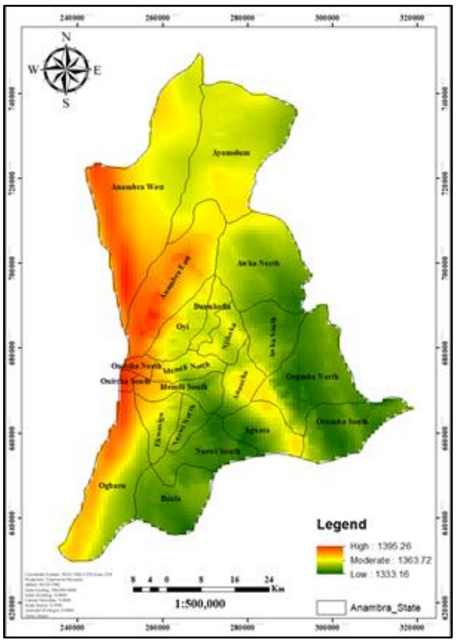

Figure 2 Solar Irradiance Data

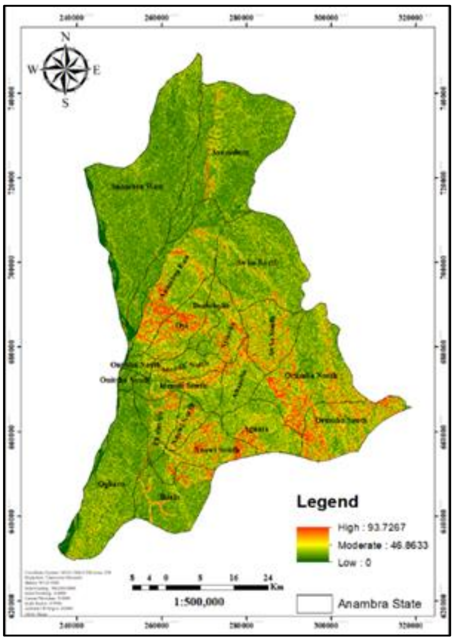

Figure 3 Slope Data

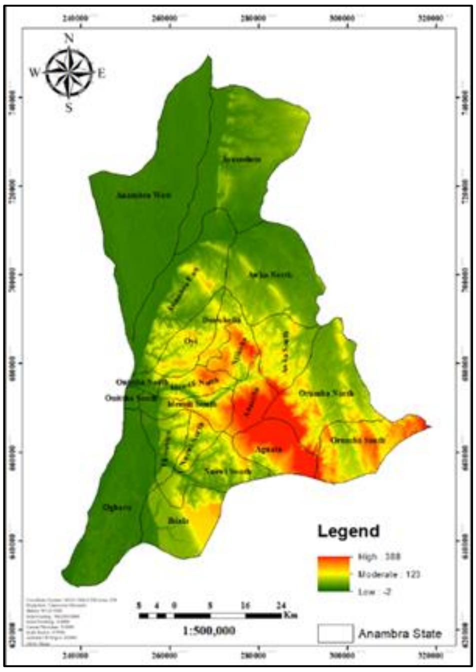

Figure 4 Digital Elevation Model Data

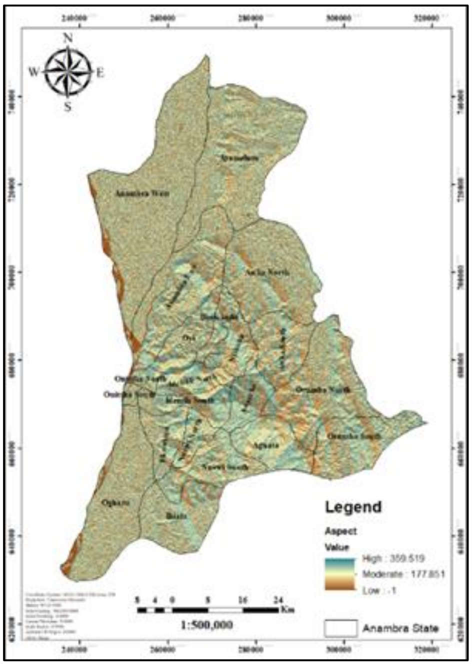

Figure 5 Aspect Data

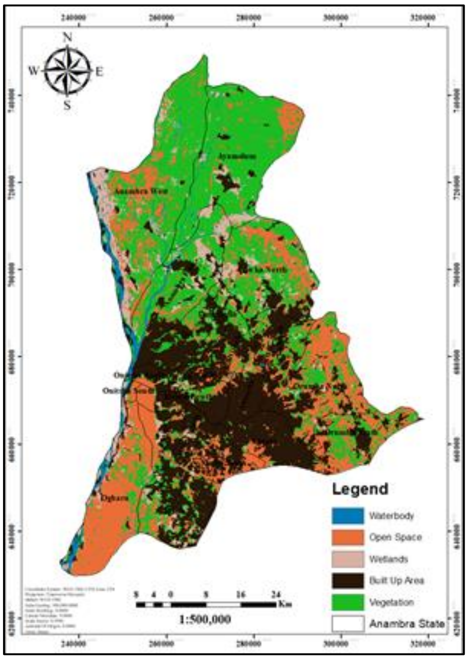

Figure 6 Land Use and Land Cover

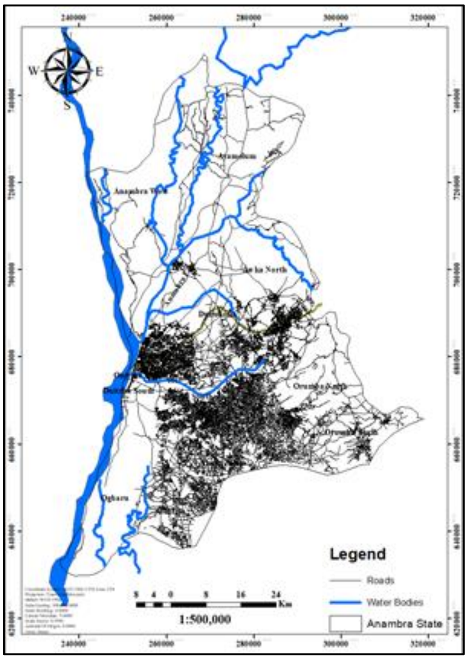

Figure 7 Road and Waterbodies Data

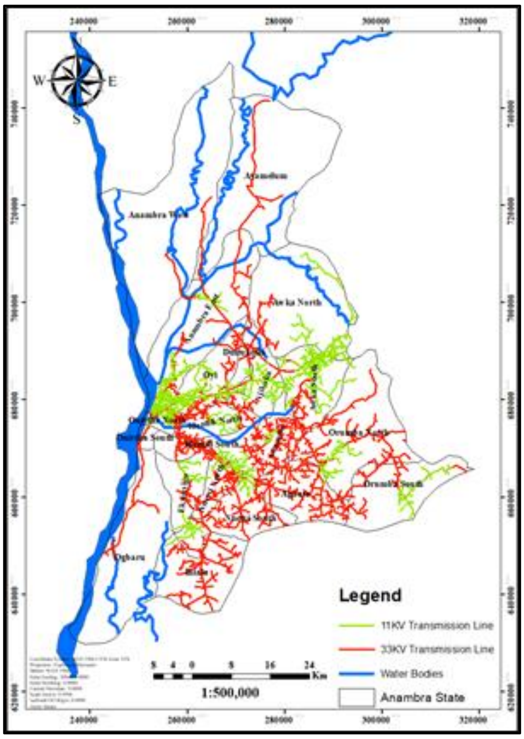

Figure 8 Electricity Transmission Data (Low Voltage)

3.1 Suitability Calculation

Table 1 Prioritization weight matrix

	F1	F2	F3	F4	F6	F6	F7	F8	F9	Total	Criteria weight (eign value)	Criteria weight (%)
F1	0.353	0.424	0.395	0.349	0.307	0.272	0.243	0.219	0.200	2.762	0.307	31 %
F2	0.177	0.212	0.263	0.262	0.246	0.226	0.208	0.192	0.178	1.963	0.218	22 %
F3	0.118	0.106	0.132	0.175	0.184	0.181	0.173	0.164	0.156	1.388	0.154	15 %
F4	0.088	0.071	0.066	0.087	0.123	0.136	0.139	0.137	0.133	0.979	0.109	11 %
F5	0.071	0.053	0.044	0.044	0.061	0.091	0.104	0.110	0.111	0.687	0.076	7 %
F6	0.059	0.042	0.033	0.029	0.031	0.045	0.069	0.082	0.089	0.479	0.053	5 %
F7	0.051	0.035	0.026	0.022	0.020	0.023	0.035	0.055	0.067	0.333	0.037	4 %
F8	0.044	0.030	0.022	0.017	0.015	0.015	0.017	0.027	0.044	0.233	0.026	3 %
F9	0.039	0.026	0.019	0.015	0.012	0.011	0.012	0.014	0.022	0.170	0.019	2 %
Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**9**	**1**	**100%**

The suitability index method in ArcGIS allows weights to be assigned and categorizes data into low, moderate, and high levels. The natural breaks reclassification method, used by ESRI, finds data break points between classes based on natural patterns in data clustering. These break points are set where there are significant jumps in data values. The solar renewable energy suitability can be calculated using the formula F = ((F1*31) + (F2*22) + (F3*15) + (F4*11) + (F5*7) + (F6*5) + (F7*4) + (F8*3) + (F9*2), as shown in Table 4.1.

The classifications revealed low suitability covered 3.86km2, moderate suitability 490.12 km2, and high suitability 74.20 km2, as seen in Fig. 9.

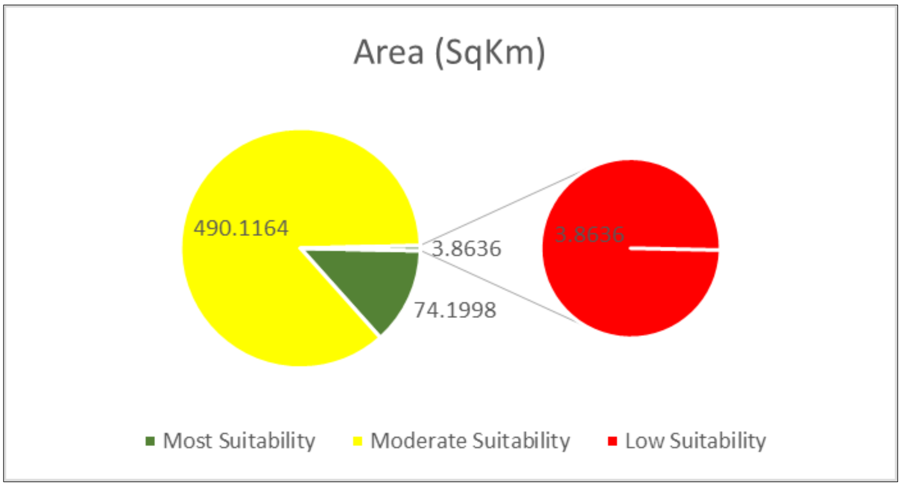

Figure 9 Solar energy Suitability Distribution Classification

The study reveals that a significant portion of a state, 1.62%, is highly suitable for solar exploration as seen in Fig. 10, with optimal conditions for establishing solar power plants. The remaining 10.671% is moderately suitable, with favorable conditions for solar power plants. However, 0.084% of the state is considered low suitability, suggesting the possibility of implementing solar energy initiatives with local adaptations. The majority of the land area, 87.629%, is deemed unsuitable for solar power plants, influenced by factors like weather trends, environmental concerns, disaster sensitivity, and protected zones.

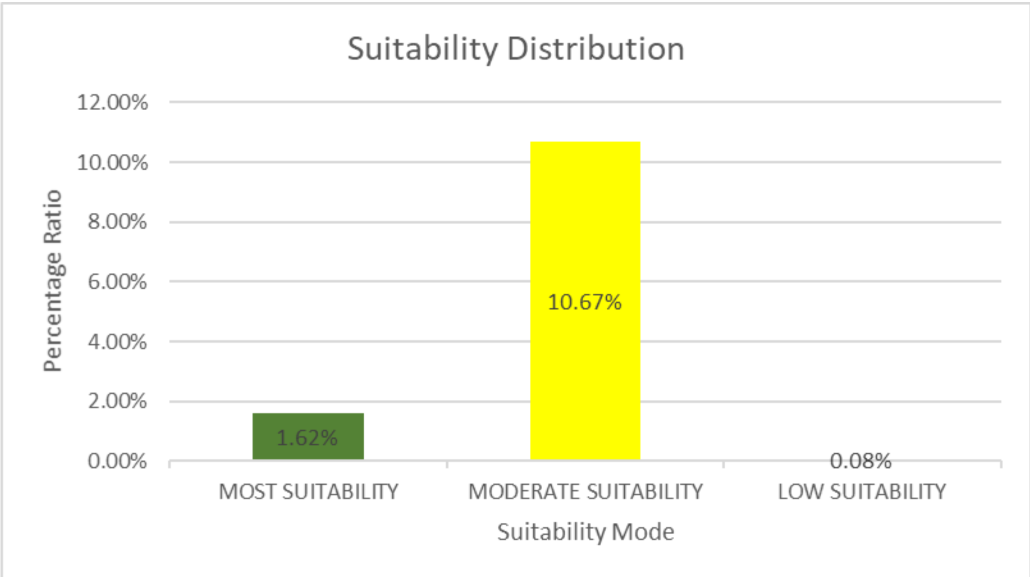

Figure 10 Solar energy Suitability Distribution (Percentage with respect to total area of Anambra State.)

The study suggests that while some regions may not be suitable for direct solar energy projects, complementary and alternative approaches could be explored to support the state's sustainability goals.

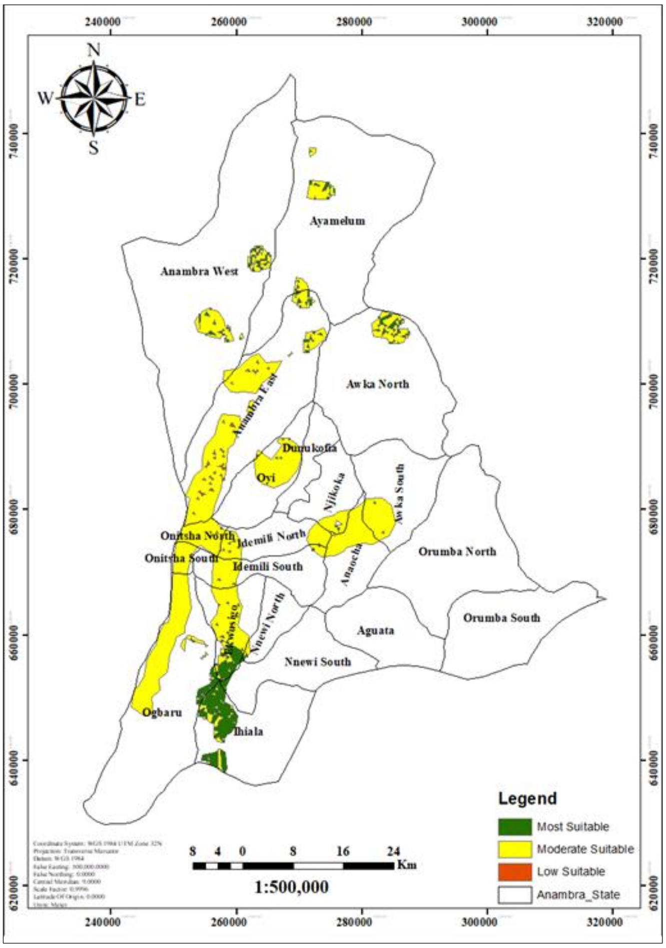

Figure 11 Solar energy power plant suitability

4. Conclusion

The project successfully integrated several information layers and conducted data analysis, providing more flexibility in the decision-making process. The study identified numerous sites that met all siting requirements for harnessing sun renewable energy, covering a total area of 568.18 km2. All sites displayed the optimal balance between all set criteria, demonstrating the usefulness of GIS in using remotely sensed data for site selection criteria. The project demonstrated the potential of GIS in enhancing the decision-making process in renewable energy projects.

Compliance with ethical standards

Acknowledgments

I sincerely appreciate the efforts of my Project Supervisor, Prof. J. I. Igbokwe. All authors read and approved this paper.

Disclosure of conflict of interest

There is no conflict of interest regarding the research, authorship and publication of this paper.

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