Science World Journal Vol. 20(No 1) 2025 https://dx.doi.org/10.4314/swj.v20i1.35
www.scienceworldjournal.org
ISSN: 1597-6343 (Online), ISSN: 2756-391X (Print)
Published by Faculty of Science, Kaduna State University

Full Length Research Article

OPTIMAL SITE SELECTION FOR NUCLEAR POWER PLANTS IN NIGERIA USING GEOSPATIAL MULTI-CRITERIA-EVALUATION TECHNIQUES

*[1]Aliyu Jaafar Abubakar, [1]Yakubu Yunus Yakubu, [1]Habiba Ibrahim Muhammad, [1]Sa'adatu Umaru Baba & [2]Kabiru Shehu

[1]Department of Geography and Sustainability Studies, Kaduna State University, Kaduna, Nigeria
[2]Department of Environmental Management and Toxicology, Federal University, Dutse, Jigawa State, Nigeria

*Corresponding Author Email Address: aliyu.jaafar@kasu.edu.ng ; abusuhayl77@gmail.com

ABSTRACT:
To ensure safety, environmental sustainability, and operational efficiency, nuclear power plants must be meticulously planned and evaluated before they can be constructed. This study aims to determine whether nuclear power plants are suitable for construction in Nigeria based on a geospatial Multi-Criteria Evaluation (MCE) approach within a Geographic Information System (GIS). Nuclear power presents a practical alternative because of its significant efficiency and minimal greenhouse gas emissions. To determine the most viable locations for nuclear power plants, the research combines a range of spatial datasets, including Digital Elevation Models (DEM), population density maps, drainage networks, transportation networks, and geological fault maps. A spatial data processing method is employed using ArcGIS 10.4.1, which includes; map overlay operations, buffer analysis, geoprocessing, and map algebra. The criteria evaluated in the study include; relief areas with elevations above 700m to avoid flooding, lower population density areas to minimize risks exposure, areas with 20km proximity to water bodies for cooling nuclear reactors, and 20km minimum distance from fault zones for seismic stability and safety. Results based on the identified criteria indicates several states (13)- Kaduna, Katsina, Plateau, Gombe, Borno, Adamawa, Taraba, Benue, Cross River, Zamfara, Ondo, Kano, Nassarawa, and the Federal Capital Territory (FCT) - exhibit optimal conditions for the selection of nuclear power plant sites. The findings of this study are consistent with those of countries such as France, South Africa, and Canada, which use spatial evaluation techniques for site selection similar to those used in this study. Providing insights into the optimal site selection could contribute to energy security and Sustainable energy development in Nigeria.

Keywords: Nuclear power, Site selection, GIS, Multi-Criteria Evaluation, Nigeria

INTRODUCTION

Nuclear Energy provides a large-scale source of electricity that is reliably stable with minimum carbon emissions, which makes it a potential alternative, especially for countries facing daunting energy challenges. France and South Korea are nations that have effectively utilized nuclear power to enhance their industrial and economic growth (IAEA, 2022; World Nuclear Association, 2022). While devastating nuclear accidents in the past, such as that of Chernobyl in Ukraine, had raised serious safety concerns, recent technological advances in nuclear reactors, including Generation IV and Small Modular Reactors (SMRs), have significantly enhanced safety measures (Posiva Oy, 2023). Moreover, countries such as Finland and Canada have developed improved disposal techniques for nuclear waste to curtail environmental hazards (United Nations Environmental Program, 2023).

One of the major Challenges to the adoption of nuclear energy is the fear of nuclear proliferation, nonetheless, the global Treaty on Non-proliferation of Nuclear Weapons and the International Atomic Energy Agency (IAEA) oversight governs a strict distinction between peaceful and military nuclear programs. Germany and Japan are clear examples of how nuclear energy can be practically used for electric power while strictly conforming to safety measures (EDF Energy, 2021).

In Nigeria, a country bedeviled by epileptic and chronic power shortage, nuclear power could present an alternative, to reduce its reliance on fossil fuels. Investing in nuclear energy in Nigeria could attract foreign direct investment, enhance energy security, and create high-tech, skilled job opportunities. The use of the Geospatial MCE technique will ensure the mapping of potential nuclear plant locations thus mitigating possible risks and ensuring optimal efficiency (Eastman, 2001). Studies on site selection for nuclear plant locations are limited in Nigeria, despite the global interest in nuclear energy, most studies in Africa are aimed at hydro and solar energy (Okechukwu, 2021; Nwankwo, 2022). In countries such as Canada and France, they employ advanced techniques like GIS and Multi-Criteria Decision Analysis (MCDA) techniques for mapping optimal locations for nuclear power plants (Smith, 2021; Wang et al., 2022).

Site Selection for the optimal location of Nuclear Power Plants in Nigeria could be a strategic initiative focused on improving the nation's energy security while enhancing economic development due to nuclear energy adoption. Leveraging the application of a Geospatial Multi-criteria evaluation techniques to assess and delineate potential sites across the country for deployment of nuclear power plants will aid the decision-making process, especially in identifying locational characteristics related to environmental impacts, safety from possible disasters, and other socio-economic dynamics. This will contribute to achieving Nigeria's energy needs and development aims and objectives by 2030 (EDF Energy, 2021). Nuclear energy is projected to contribute about 8% with a capacity targeted at 29.7GW by 2030, as part of a broader effort towards diversifying the nation's energy portfolio which includes; gas, solar and hydropower. This research contributes to the body of knowledge on nuclear energy planning in Africa and provides a data-driven approach to support Nigeria's energy diversification agenda (World Nuclear Association, 2022; IAEA, 2023).

The present study aims to explore the optimal site selection for nuclear power plants in Nigeria using MCE within a Geographic

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Information System (GIS) framework. By incorporating factors such as elevation, population density, proximity to water bodies, and distance from geological fracture lines, this research seeks to provide a scientific basis for sustainable nuclear infrastructure development in Nigeria.

MATERIALS AND METHODS

Study Area

Nigeria is one of the most highly populated country-estimated at over 200 million, is located in West Africa. Occupying a total Area of about 923,768 km², thus the 14th largest African country by landmass. It is surrounded by the Niger Republic in the North, Republic of Chad in the Northeast, Cameroon in the East and Benin republic in the west. The country has about 853km of coastline along the Atlantic Ocean to the South.

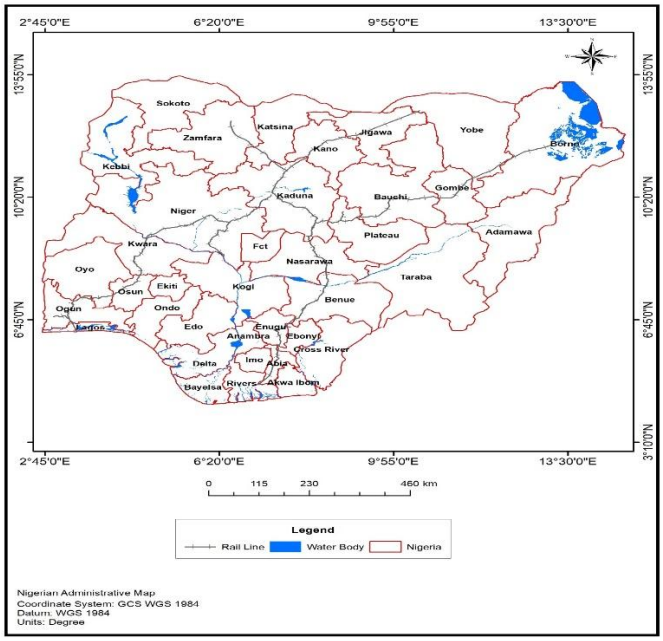
Climatic conditions are diverse in Nigeria Characterized by an arid condition in the Sahel North and a tropical rainforest in the south. Landscapes differ from the Niger and Benue River Basins to the Highlands of the Jos Plateau and the coastal Plains of the Niger Delta. The Country is economically endowed with rich natural resources including; petroleum, natural gas and solid minerals. Nigeria also faces significant challenges such as; environmental degradation, deforestation, desertification, and pollution. These factors make Nigeria a point of reference for research in environmental management, sustainability and socioeconomic development.

An administrative Map of Nigeria is shown in **Figure 1** as the Study Area. Additionally, administrative boundary data were incorporated to classify and analyze regional site suitability.

Data Processing

A combination of methods were employed to achieve the objectives of the study, these included; the use of Geospatial data sets and geoprocessing techniques to map and identify optimal locations for nuclear power plant deployment in Nigeria. Data sets used include; a Digital Elevation Model (DEM) for the assessment of terrain and relief, population density data for the analysis of settlement distribution, a drainage map for delineating proximities to water bodies, a transport network map to assess infrastructure accessibility, and a geological map to analyze fault lines and seismic risks.

The data processing and analysis involved several stages using ArcGIS 10.4.1. First, the DEM was processed to extract areas that met the minimum elevation requirement of 700 meters above sea level. This was achieved using the Raster Calculator tool in the Spatial Analyst extension, which allowed for the exclusion of low-lying, flood-prone areas. **(See Figure 2)**



Source: (Modified from Adegbite, et al., 2019).
Figure 1: Map of Nigeria Showing the 36 states

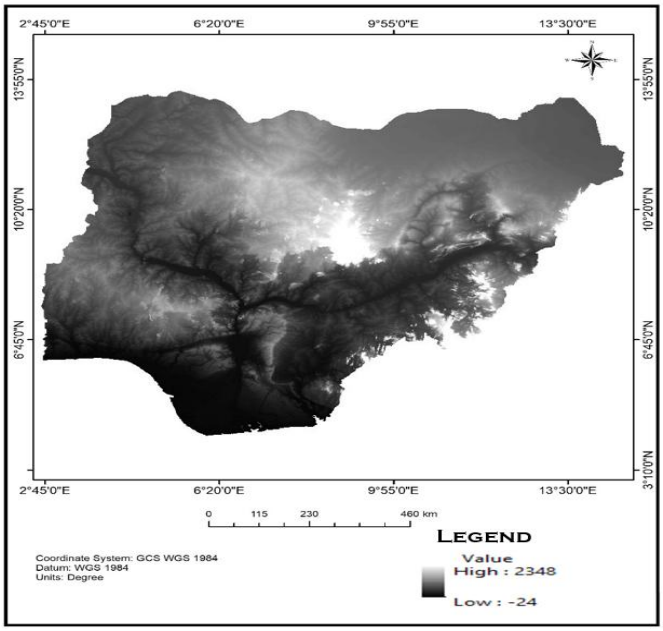


Figure 2: DEM Map Showing height above sea level used to extract areas over 700m

Next, the population density dataset was processed to filter out regions with high human settlements. Raster-to-polygon conversion was employed to segment population data, and selection queries were applied to extract areas with fewer than 500 persons per square kilometer. The resulting dataset was overlaid with the elevation dataset to further refine site suitability. **(See figure 3)**

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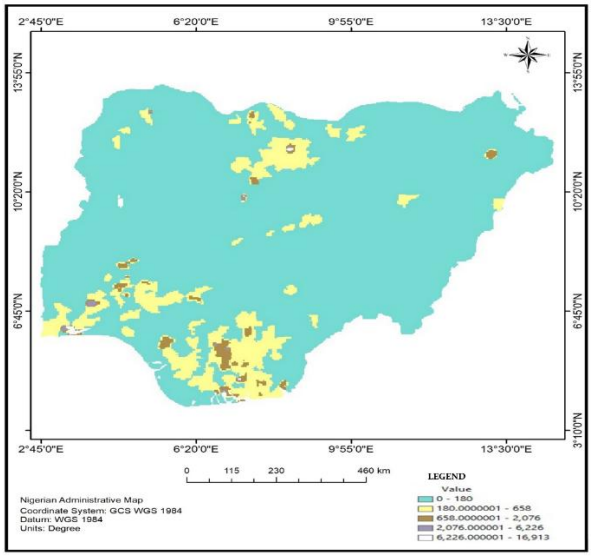

Figure 3: Population Map used to extract locations with less than 500 persons/km^2

The third phase involved water proximity analysis, where buffer zones of 20 kilometers were generated around major water bodies using the Buffer tool in ArcGIS. This step ensured that potential sites had access to a reliable water supply for cooling nuclear reactors. The buffer results were integrated with the existing site selection layers, retaining only those sites that met the water proximity criteria. **(See figure 4)**

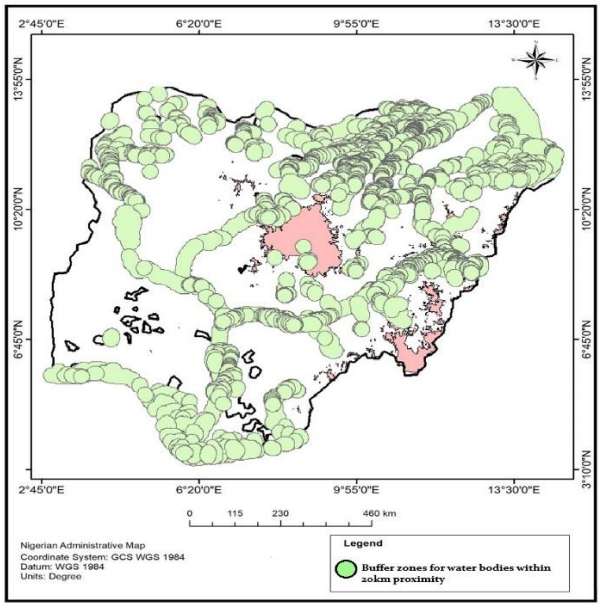

Figure 4: Map Showing Buffer Geoprocessing used to extract water bodies within 20km proximity for cooling

To ensure the exclusion of geologically unstable regions, the geological map was analyzed to eliminate areas within 20 kilometers of known fault lines. Using overlay analysis, all unsuitable areas near fault lines were masked out from the existing site selection layers. **(See figure 5)**

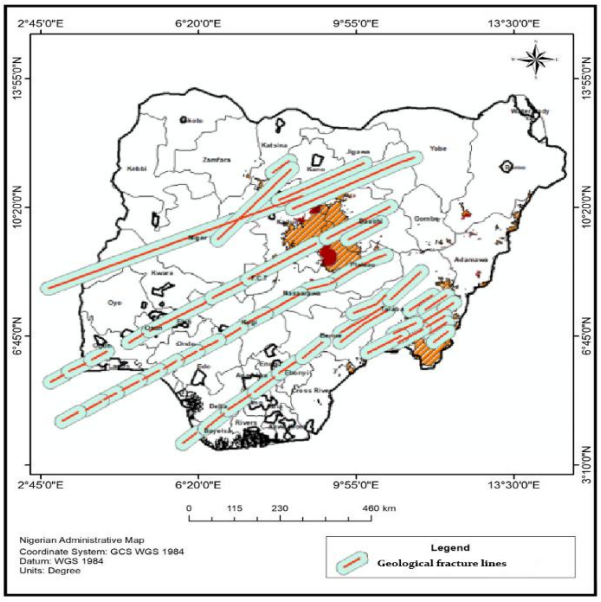

Figure 5: Map showing fracture lines used to extract locations 20km away from geologically unstable areas

A final overlay analysis was conducted by integrating all filtered datasets, using weighted suitability criteria for ranking potential sites. The final suitability map highlighted optimal locations across various states in Nigeria, including Kaduna, Katsina, Plateau, Gombe, Borno, Adamawa, Taraba, Benue, Cross River, Zamfara, Ondo, Kano, Nassarawa, and the Federal Capital Territory (FCT). This geospatial analysis ensured that the selected sites met environmental, infrastructural, and safety requirements necessary for developing a nuclear power plant. **(See figure 6)**

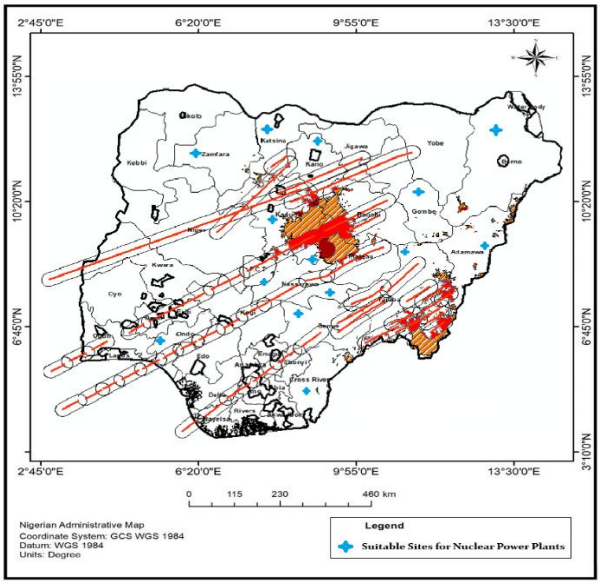

Figure 6: Suitability Map Showing States in Nigeria for Nuclear Power Plant Location

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RESULTS AND DISCUSSION

The results of the analysis indicated several suitable locations in Nigeria that could serve as candidates for the development of Nuclear Power Plants based on the Multi-criteria Evaluation results. States like Adamawa, Benue, Borno, Cross River, Gombe, Kaduna, Kano, Katsina, Nassarawa, Ondo, Plateau, Taraba, Zamfara, and the Federal Capital Territory (FCT-Abuja), satisfy the optimal conditions for siting nuclear power plants including; elevation, low population density, proximity to water bodies and geological stability as shown in the final suitability Map.

The findings as indicated in the suitability map in figure 6, shows that Nigeria has numerous regions that can safely and efficiently support nuclear power infrastructure. Analysis of the Digital Elevation delineated sites that are at least 700m above sea level, reducing the risks to flooding. Analysis of the population density ensured the exclusion of heavily populated regions, thus reducing the potential exposure to disasters in the event of accidents or operational failure. Proximity analysis to water bodies aided the mapping of areas that are at least within 20km of major water bodies to facilitate efficient reactor cooling. Finally, to ensure seismic stability, the analysis excluded all areas within a 20 km radius of known geological fault lines.

The results relate with studies by Alagbe et al. (2017), Nwilo et al. (2020), and Adegbite et al. (2019) which applied GIS-based Multi-Criteria Evaluation (MCE) to assess suitable sites for nuclear power plants in Nigeria, focusing on elevation, population density, geological stability, and water proximity. Similarly, the results relate with the findings carried out in other countries for nuclear energy exploration. For example, studies in South Africa's Koeberg Nuclear Power involved a detailed site selection analysis focused on; geological stability, access to water bodies, and safe buffering from populated areas (Eskom, 2022). France generates about 70% of its Power using nuclear sources and employs geospatial techniques and methods to ensure both infrastructural and environmental suitability of intended locations (EDF Energy, 2021). This comparison indicates that Nigeria is in line with global best practices for nuclear power plant site suitability selection, thus solidifying the feasibility for nuclear power inclusion in the country.

Moreover, the findings in this study further strengthens the growing belief that nuclear energy is the most consistently viable solution to large-scale power production. The fact that a 5kg uranium fuel is sufficient to power a submarine for 30 years of its life is a testament to this assertion (EDF Energy, 2021). Despite safety and waste management concerns to nuclear power exploitation, recent technological advances in reactors and nuclear waste containment methods have significantly reduced such risks. In countries like Sweden and Finland, effective geological repositories have been developed successfully to dispose of nuclear waste which could offer a solution for countries like Nigeria to replicate.

Ultimately, this study shows convincing evidence to support the need for the adoption of Nuclear Energy in Nigeria. Taking advantage of the versatility of geospatial analytics and Multicriteria evaluation, Nigeria can employ strategies for efficient and effective site selection to ensure the safety and sustainability of nuclear power deployment. Future research should however, focus on taking into consideration other important variables including especially; socio-economic and rigorous field investigations to further strengthen site suitability

Implications

This study has significant implications, especially environmental sustainability, energy security, economic growth, and the mitigation of risks associated with nuclear deployment. The major benefit of nuclear power is its ability to consistently supply continuous and stable power, unlike fossil fuels with their intermittent nature and supply disruptions. While integrating nuclear power in Nigeria could decrease reliance on fossil-based energy systems, promoting a diversified and dependable power supply for residential, commercial, and industrial needs while complementing renewable sources like solar and wind.

Nuclear power provides a reliable alternative to hydrocarbon-based fuels if viewed from an environmental perspective as it reduces the release of greenhouse gases. France, a country that generates 70% of its power from Nuclear, has significantly reduced its carbon foot print when compared with other nations that rely greatly on natural gas, coal and other fossil fuels. Nigeria being a party to several international climate pact and agreements, this reinforced the need for the adoption of nuclear electricity and to cement Nigeria's position as a leader in Africa's Green Energy Transition.

The Implementation of Nuclear power for electricity generation can also economically attract foreign direct investments and industrialization. This would ensure job creation and the need for technical expertise, skill acquisition, re-skilling and up-skilling to develop various sectors of the economy including; engineering, research and manufacturing. The availability of electric power will boost industrialization, manufacturing and the general economic growth of the country.

The rigorous site selection process as analyzed in this study ensures that nuclear power plants are sited far away from unsuitable locations to mitigate the risk associated with nuclear power adoption. Advancements in nuclear waste containment procedures including the use of deep geological repositories and reprocessing measures have enhanced safety measures, thus countries such as Sweden and Finland have effectively implemented long-term disposal methods that could serve as an acceptable and permissible standard for other countries to learn from.

Nigeria can significantly enhance its energy infrastructure by integrating nuclear electricity as part of its energy mix, this would aid its growing energy requirements. Despite the challenges in the adoption of Nuclear Power, particularly considering the strict regulatory conditions and international best practices, and the use of advanced modern technologies, the benefits far outweigh the risks. The creation of the Nigeria Nuclear Regulatory Authority (NNRA) and the Nigerian Atomic Energy Commission (NAEC), is indeed a step in the right direction and indicates the country's commitment to the eventual adoption of nuclear energy for peaceful purposes.

Conclusion

This study demonstrated the effectiveness and potential of geospatial-based multi-criteria evaluation methods for selecting suitable sites for nuclear power plants in Nigeria. This study demonstrated the effectiveness and potential of geospatial-based multi-criteria evaluation methods for selecting suitable sites for nuclear power plants in Nigeria. The techniques employed in the study ensure that the selected locations satisfy certain critical infrastructural and environmental criteria to promote sustainability in the development and deployment of nuclear energy. The research recommends further studies, particularly focusing on real-

world field investigations, statistical analysis, empirical data and socio-economic considerations, to complement prefeasibility assessments.

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