Using ArcGIS for Optimal Location of Small Hydropower Sites in Nigeria for Sustainable Development

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***Abstract*- This paper focuses on the prospects of small hydropower plants (SHP) in Nigeria and utilizes ArcGIS software for analysing the country's hydropower energy potential. The analysis conducted using ArcGIS reveals the significant SHP potential in various states across Nigeria. By overlaying water areas and waterline data on maps, potential sites for SHP are identified, particularly in states such as Borno, Niger, Edo, Anambra, and Jigawa. Further analysis was done using data for water lines in Nigeria converted into shaped files for the six geopolitical zones of Nigeria, with the various states and local government areas, to provide expanded views for different possible schemes for SHP. Data set were built up for the different geopolitical zones and statistical analyses were done for SHP potentials. Inverse Distance Weighting (IDW) tool on ArcGIS was used for interpolations to indicate places that are good for locating dam schemes for hydropower production as well as other schemes that require less water storage for small hydropower production. Additionally, it was determined which zones in which each state excelled in terms of availability of inland waters and lands susceptible to inundation. There were also some significant difficulties and potential in evaluating Nigeria's small hydropower projects using ArcGIS.**

Keywords: Small hydropower; flow rate; power potential; renewable energy; ArcGIS.

1. INTRODUCTION

Hydropower technology is used in more than 160 countries across the globe to generate electricity, making up more than 16% of all energy production. This adaptable technology provides quick reaction to grid variations in poor nations, in particular [1-6]. Nigeria's energy sector is in disarray, mostly as a result of corrupt government officials and power industry players. Nigeria's estimated 400 million population by 2050 will result in an increase in energy usage. Nigeria's hydropower potential is limited, and not well harnessed till date [7].

Nigeria's crude oil and natural gas reserves, with an estimated 11,756MW capacity, generate only 0.03 kW per person, primarily using hydropower as the primary electricity source [8-10]. Because of the switch to fossil fuels, particularly because of Nigeria's substantial reserves, the hydropower sector's growth declined. However, worldwide interest in small-scale hydro projects has grown, with China leading the way with over 58,000 plants and 1,200 facilities. 1,360 GW of hydroelectric capacity was installed globally in 2021, which was a 26 GW increase compared to previous years [11-15].

The various rivers and dams in Nigeria provide tremendous hydroelectric potential for long-term development. However, just three of the federation's states use hydropower operating programs, indicating that modest hydropower technology is not widely used. Studies have examined suitability assessments utilizing Geographical Information System (GIS) and Multi Criteria Decision Making (MCDM) methodologies, as well as hydropower potential in the Niger State. In Nigeria, viable hydropower sites are selected and mapped using spatial and statistical modelling techniques [16-24].

This study uses ArcGIS to evaluate small hydropower sites in Nigeria, highlighting potential in Borno, Niger, Edo, Anambra, and Jigawa. The data was extracted from six geopolitical zones and used for statistical analysis. The study aims to increase hydroelectricity in Nigeria's energy mix, benefiting the economy, society, and environment. The findings will help the Nigerian government, stakeholders, and energy policymakers in proposing potential sites for small hydropower schemes for sustainable development.

2. OVERVIEW OF THE CURRENT STATUS OF SMALL HYDROPOWER IN NIGERIA

Small hydropower plants (SHPs) are categorized and described using the labels micro, mini, and small. The definition of SHP and the estimation of capacity are dynamic and dependent on regional economic growth. Olayinka et al. (2010) claim that SHP has existed in Nigeria since 1923, or 45 years before Kainji, the nation's first significant hydropower project, was put into operation [10]. The Nigerian Electricity Supply Corporation (NESCO) was also able to harness hydropower from the Kurra falls to supply energy to the former Benue-Plateau region from the middle of the 1940s until the 1980s.

According to Table 1, Nigeria has a sizable but modest hydropower potential [25]. Table 1 shows that by harnessing the modest hydro power potentials in just 277 locations, the nation's energy portfolio could generate 734.2 MW of electricity. It is impossible to emphasize the immense potential of small hydro power in Nigeria's 36 states, particularly in light of the fact that just twelve of the federation's states are represented in Table 1. This is one of the targets of this paper.

TABLE I SMALL HYDRO POTENTIAL IN NIGERIA'S SURVEYED STATES

River Basin	State	Capacity (MW)	Unit Location
Lower Benue	Benue	69.2	19
Chad	Borno	20.8	28
Upper Benue	Bauchi	42.6	20
Upper Benue	Gongola	162.7	38
Lower Benue	Plateau	110.4	32
Niger	Kaduna	59.2	19
Niger	Niger	117.6	30
Cross River	Rivers	258.1	18
Hadeija-Jamaare	Kano	46.2	28
Niger	Kwara	38.8	12
Sokoto-Rima	Katsina	8.0	11
Sokoto Rima	Sokoto	30.6	22
Total		**734.2**	**277**

3. NIGERIA'S HYDROPOWER POLICY

In order to utilize Nigeria's tremendous small hydropower potential, a dynamic renewable energy portfolio standard was developed along the lines of the following for hydropower projects [26, 27]:

Policy:
The nation is committed to focusing on small and micro hydropower projects, utilizing all hydroelectric capacity for electricity production, using hydrological resources ecologically, and actively promoting private sector and indigenous participation in hydropower development.

Objectives:
The plan aims to increase hydroelectricity's role in the energy mix, utilize mini- and micro-hydropower for remote and rural areas, reduce non-renewable resource usage, minimize environmental impact of large-scale hydropower development, and encourage private sector investment.

This study tends to provide analysis that align with the policies and objective listed above in line with the United Nations sustainable development goals.

4. ARCGIS SOFTWARE ENVIRONMENT

The Environmental Systems Research Institute (ESRI) developed ArcGIS, a Geographic Information System (GIS) software that allows users to organize, analyze, and present geographic data for various applications. It integrates data from various sources, enhancing data organization and efficient administration [28].

Research on ArcGIS has demonstrated its effectiveness in various industries, including urban planning, where it efficiently handles geographic analytic problems and provides valuable data for decision-making processes [29]. Researchers have also employed ArcGIS for transportation planning, assessing accessibility, and optimizing transportation networks [30].

Due to its customisable symbology and 3D visualization tools, ArcGIS thrives in producing aesthetically appealing maps and 3D representations of geographic features.

5. ASSESSING SMALL HYDRO POTENTIALS IN NIGERIA USING ARCGIS

In order to locate possible small hydropower sources in Nigeria, the study employed ArcGIS to evaluate the country's geography while taking six geopolitical zones into account. Understanding the appropriateness of water regions for the production of hydropower was obtained from the analysis. Figure 1 shows a Nigerian water region shape file superimposed over state and map data. Data from ring buffers ranging from 200 meters to 5 kilometers is overlayed to identify accessible water bodies for modest hydro power generation in Nigeria, identifying areas accessible by road.

The analysis finds great potential for run-off river and small dam systems in states including Borno, Niger, Edo, Anambra, Jigawa, Lagos, Taraba, Adamawa, and Yobe. Shaped files for six geographical zones were created using data from water lines in Nigeria converted from XY-data from UN-FAO and overlayed on the map, allowing for broader views of small hydropower potentials across the country [31].

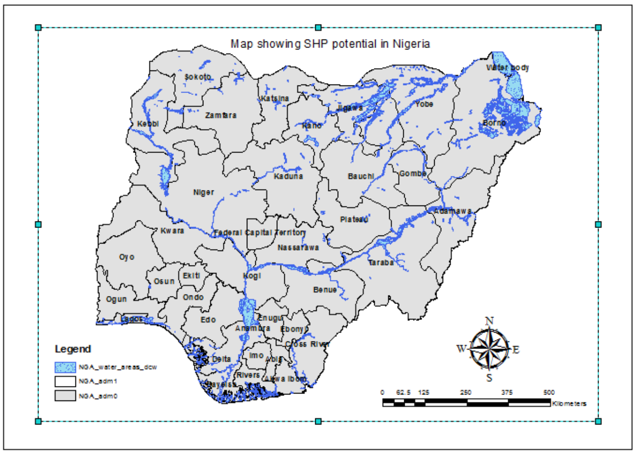

Figure 1 ArcGIS map showing water areas in Nigeria.

An enlarged perspective of rivers and other significant water bodies was provided for minor hydropower generation by overlaying characteristics like water areas and water lines on a map of South East in Nigeria shown in Fig. 2a. A simulation of a multiple-ring waterline buffer showed potential locations for modest hydropower installations. The lack of data on land use and land cover was one of the drawbacks of this work. The investigation showed that places like Anambra East and West, Idemili South, and Ekwusigo local government areas have great potential for modest hydropower.

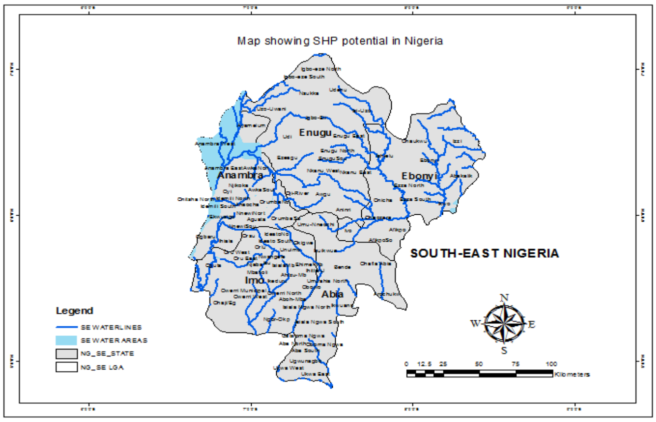

Figure 2a Waterlines and water areas in south eastern Nigeria.

The NGA_adm2 shape file was used to extract the map for South-South Nigeria in Fig. 2b, and spatial analysis tools were used to overlay data for water regions and lines to highlight probable locations for SHP. Etsako Central, Esan North Local Government Areas, Oshimil South in Delta, and Obubra in Cross River were all determined by the analysis to be viable places.

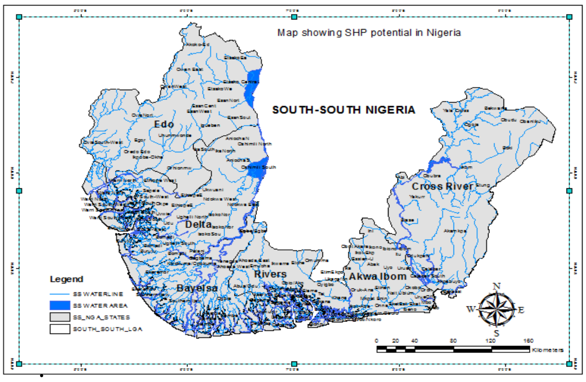

Figure 2b Waterlines and water areas in south south Nigeria.

Lagos and Ogun state have potential for hydro-power stations (SHP) in the South West of Nigeria, with Lagos Island, Eti-osa, and Epe as good locations. Ogun waterside and buffer distances are also suitable. Further analysis using extracted shaped files for North Central Nigeria in Fig. 3 shows significant hydropower potential, especially in areas near River Niger, Benue, and Lokoja, including Ibaji, Idah, Lokoja, Igalamela in Kogi state, and Agatu, Guma, Borgu, Agwara, in Benue state.

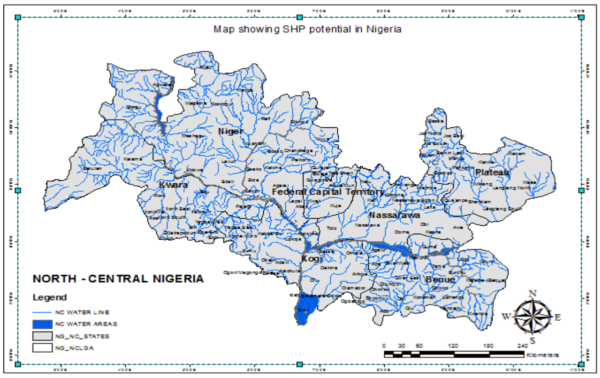

Figure 3 Waterlines and water areas in north central Nigeria.

In the North-West, there are hydropower suitability areas in Kebbi, Kano and Jigawa states. From the analysis of this study, the following areas has comparatively high-water availability; Ngaski (Kebbi), Tudun Wada (Kano), Hadeja, Guri, Kinkasa and Auyo (Jigawa). There are however other areas with lower availability of water for small head and flow turbines suitable for run-of-the river hydropower scheme.

ArcGIS analysis in Nigeria's North Eastern region shows hydropower potential in Borno, Yobe, Gombe, Taraba, and Adamawa states, but lower water availability in Numan, Adamawa.

6. RESULTS AND DISCUSSIONS

The study examines water regions and water bodies in Nigeria, revealing inland waterways and inundation-prone terrain. The Inverse Distance Weighting (IDW) tool on ArcGIS is used to identify suitable locations for dam schemes for hydropower production and schemes requiring less water storage. However, if additional information on site elevation and flow rate is not provided, the judgment for suitability areas will be incomplete.

The inverse distance weighting interpolation method is calculated using the Shepard's method (Shepard 1968) and expressed as

$$f(x,y) = \sum_{i=2}^{n} wifi \qquad (1)$$

Where; n is the number of scatter points in the set, f_i is the prescribed function values at the scatter points (e.g. the dataset values), and w_i is the weight functions assigned to each scatter point.

In order to aid in decision-making and direct future feasibility studies, the study analyzes possible hydropower sites in six geographical zones of Nigeria, identifying the states with the highest and lowest potentials for hydropower schemes using weighted scores assigned to various locations on the admin 2 data provided.

Deep inland seas and waterlogged plains in Nigeria are depicted in Figure 4a, showing potential locations for sizable hydroelectric projects. While low-capacity regions like Delta, Rivers, and Cross River may be viable for small hydro power projects, high-capacity states like Yobe, Jigawa, Bauchi, Sokoto, Adamawa, and Niger are among them.

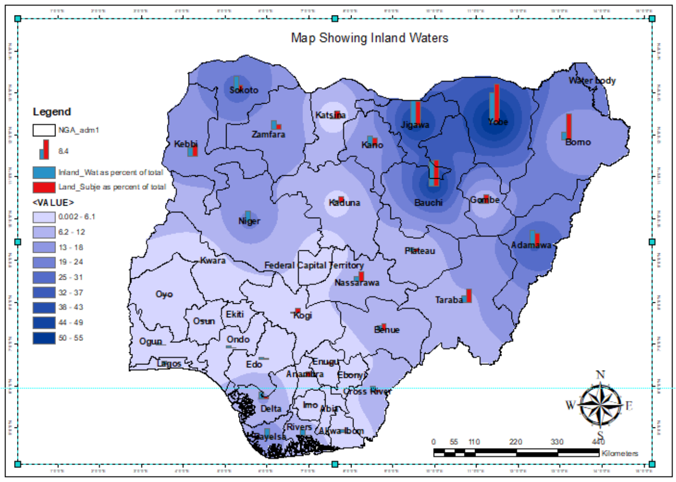

Figure 4a Map of Nigeria showing inland waters.

Figure 4b highlights the sites in deep red where water is readily available from overflowing water bodies and lands submerged under water. It demonstrates that Borno, Kebbi, Bauchi, Yobe, Taraba, Kogi, and other regions have shallow waterways caused by floods and other water that overflows from deep waters, seas, and oceans.

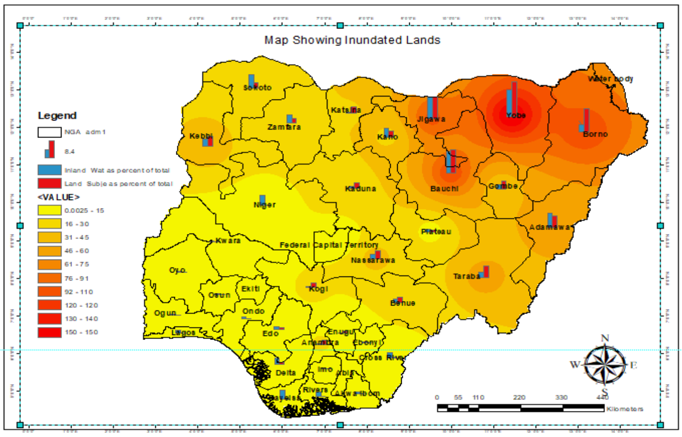

Figure 4b Map of Nigeria showing lands subject to inundation.

Figure 5a demonstrates that Anambra state, when compared to Abia, has the greatest water area for SHP. This information may be used to inform policy decisions and further research in the Anambra-Imo River basin. While Abia lacks sufficient water, Anambra state has the highest water resource and potential for SHP. For existing SHP initiatives in the Anambra-Imo River basin to be strengthened, more research is required. In Fig. 5b, Delta has the greatest water-takeover areas in the South South, whereas, Bayelsa, Delta, Cross River, and Rivers states have more inland water for dam plans and transit lines.

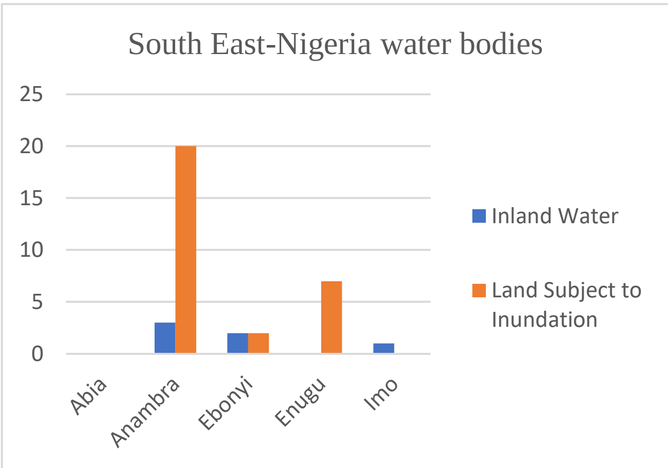

Figure 5a Types and capacity of water bodies in south east Nigeria.

The South West has inland waters from Lekki, Lagos, and Ologe Lagoons, suitable for sea ports and hydropower studies as seen in Fig. 5c. Yobe state has the highest potential for hydropower in the North East, with 58 inland water locations and 151 inundated land sites, offering potential for irrigation and hydropower technology applications as shown in Fig. 6a.

Nigeria's North-Western region has the largest inland waterways and inundated land areas, with Jigawa, Sokoto, Kano, and Zamfara having the highest sites in Fig. 6b.

Niger, Benue, Nasarawa, and Plateau have the highest inland water sites, with potential for SHP in Nassarawa and Kogi states as shown in Fig. 6c.

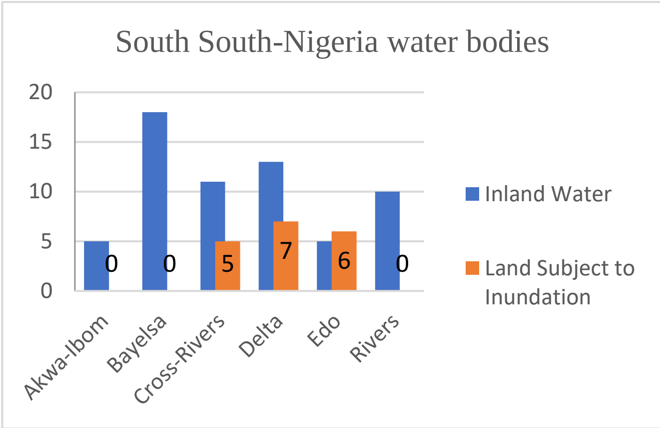

Figure 5b Types and capacity of water bodies in south south Nigeria.

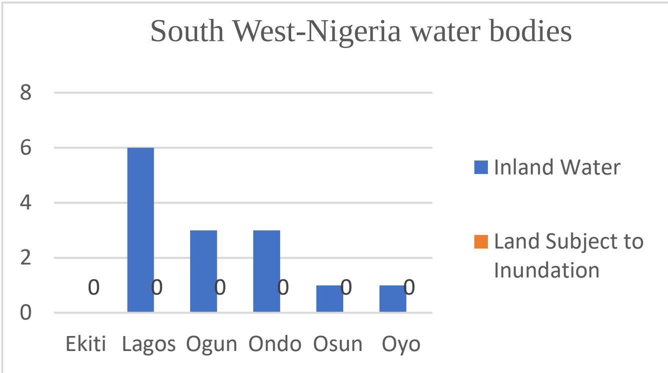

Figure 5c Types and capacity of water bodies in South West Nigeria.

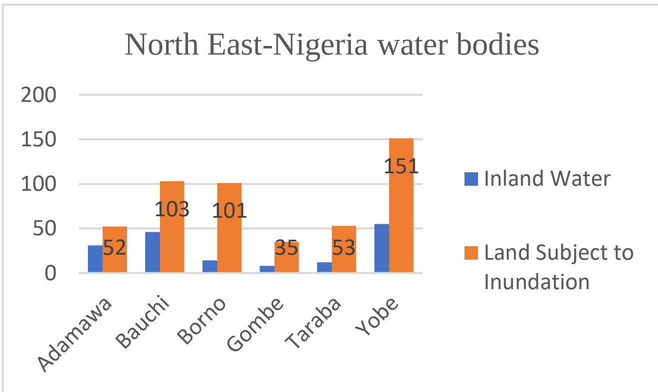

Figure 6a Types and capacity of water bodies in north east Nigeria.

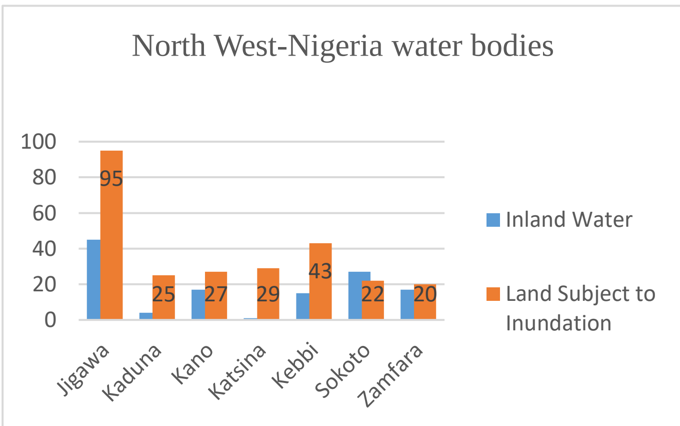

Figure 6b Types and capacity of water bodies in north west Nigeria.

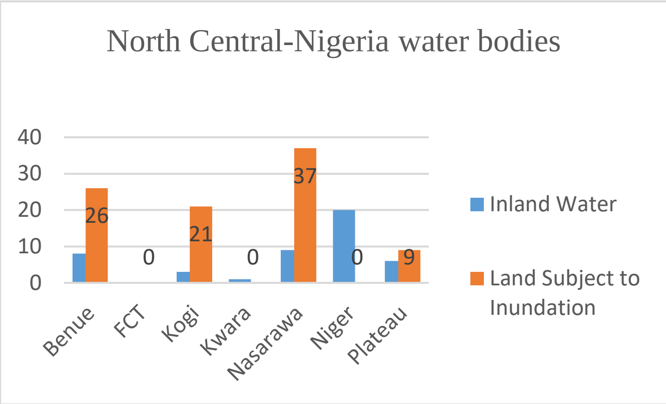

Figure 6c Types and capacity of water bodies in north central Nigeria.

7. CHALLENGES AND OPPORTUNITIES OF ASSESSING HYDROPOWER SITES IN NIGERIA USING ARCGIS

This section explores the challenges and opportunities of using ArcGIS to evaluate potential hydropower sites in Nigeria, highlighting the country's abundant water resources.

The assessment of hydropower sites in Nigeria faces challenges due to limited data availability, insufficient technical expertise, and environmental considerations. Comprehensive data is needed for accurate assessments, but Nigeria lacks the necessary expertise. Additionally, the lack of expertise in hydrology, geospatial analysis, and GIS makes ArcGIS ineffective. The environmental impact of hydropower development is also a concern. When deciding where to locate hydropower plants, infrastructure requirements and accessibility are taken into account. In particular in distant areas, the availability of adequate roads, transmission lines, and other infrastructure has a significant impact on the viability of hydropower development.

A suitable regulatory and policy framework, with defined standards and rules for site selection, licensing, and environmental impact studies, is needed for the evaluation of hydropower sites in Nigeria.

ArcGIS offers opportunities for geospatial analysis and visualization, integrating remote sensing data to improve site discovery and assessment. It also offers Multi-Criteria Decision Analysis (MCDA) features to identify ideal hydropower locations based on factors like environmental, technical, and socioeconomic concerns. ArcGIS also allows for climate change adaptation, assessing resilience of sites and adaptation to changing climatic patterns. It also supports stakeholder engagement and participatory mapping, promoting transparency and inclusive decision-making in hydropower site selection.

8. CONCLUSIONS AND RECOMMENDATIONS

Data accessibility, technical competency, environmental issues, infrastructure, and regulatory frameworks are just a few of the difficulties facing ArcGIS evaluations of Nigeria's hydropower facilities. The potential for hydropower in Nigeria may be realized by employing ArcGIS's capabilities for geospatial analysis. Considering six geopolitical zones and natural settings, Nigeria has tremendous potential for Sustainable Hydropower Projects (SHP). The country's megawatts can be increased, and its energy mix can be improved, by implementing a dynamic renewable energy strategy with SHP development. This study shows a methodology for assessing these potentials and recommends a dynamic approach for renewable energy that prioritizes mini- and micro-hydropower projects, eco-friendly practices, private sector and indigenous engagement. These steps would definitely increase the proportion of hydroelectricity in the country's energy mix. This strategy can expand access to energy, decrease environmental impact and conserve non-renewable resources.

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