Geo-spatial Assessment of Small Hydro Potential in Abia State, South-Eastern Nigeria

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Abstract- Incentives and policies aimed at diversifying Nigeria's energy mix for sustainable development, has made small hydropower (SHP) technology to become more popular in the country's energy and power industry. Despite the presence of water bodies and waterlines in Nigeria, the South-Eastern part of the country has not prioritized the use of these resources by using SHP potentials in policy creation and execution. In order to undertake a spatial analysis utilizing map data overlayed by shapefiles of water bodies, waterlines, road networks, and land use and land cover (LULC) data, the ArcGIS software was used in this paper to focus on the potentials of small hydropower in Abia State, located in the South Eastern part of Nigeria. After the map data was reclassified, multiple ring buffers were made for different proximities around the waterbodies and waterlines, and Normalized Difference Vegetation Index (NDVI) calculations were done to find the regions that would be suitable for small hydropower projects. A weighted score between 33 and 66, with an NDVI range of -0.018 to 0.015, indicated the presence of water bodies and built-up areas surrounding them, and an NDVI range of 0.015 to 0.14, with a weighted score within the range of 11-16, were found to be suitable areas in Osisioma Ngwa and Obingwa Local Government Areas respectively, with suitable elevations and hydraulic data for run-off the river schemes. The siting of hydropower plants was recommended to be within a multiple ring buffer distance of 200m and 5km from the waterlines and roads. This discovery also promotes the hybridization of renewable energy technologies with pumped hydro storage to reduce the capital costs for mini-grids and dependability on the national grid in Abia state.

Keywords: Abia state; energy potential; geo-spatial assessment; renewable energy; small hydropower

1. Introduction

The South-East, one of Nigeria's six geographical zones, is well known for its vibrant economy, entrepreneurial energy, and rich cultural past. The area is composed of five states: Abia, Anambra, Ebonyi, Enugu, and Imo. Among the important economic activities in the area are trade and commerce, manufacturing, agriculture, banking services, healthcare and education, entrepreneurship, entertainment, transportation, innovation and technology [1].

The South-East is frequently called the "Igbo land" because of the prevalence of the Igbo ethnic group, which is well-known for its robust commercial and trade skills. Two well-known commercial centres where a wide range of goods are bought and sold are Onitsha and Aba [2]. These locations have flourishing markets that attract traders from all around Nigeria and its neighbouring countries.

The South-East is home to a large concentration of industry and manufacturing, particularly in areas like Aba. Small and medium-sized companies in the area produce a wide range of commodities, such as electronics, plastics, leather goods, textiles, and footwear [3] The "Aba Made" logo is always connected to high-quality products. In the South-East, the economy is mostly reliant on agriculture and industries. The region is well-known for producing a wide variety of fruits and vegetables, as well as crops including yam, cassava, and oil palm. Additionally growing in popularity are commercial farming and agribusiness [4].

The financial sector is growing in the South-East due to the presence of several banks, microfinance institutions, and

other financial services companies in the area. Major financial and commercial hubs are emerging in cities like Owerri and Enugu [5]. The South-East is home to several hospitals, universities, and polytechnics, among other medical and educational establishments. These sectors produce money and open up work opportunities. Because of the Igbo people's entrepreneurial drive, many small and medium-sized enterprises (SMEs) have emerged in a range of industries, significantly increasing regional economic activity [6].

In the South-East, the building and real estate sectors have grown significantly as a result of urbanization and population growth [7]. This expansion includes the building of residential and commercial constructions [8]. Nigeria's entertainment business, particularly the film industry known as Nollywood, is booming in this area. The South-East has produced several notable actors, directors, and filmmakers. The South-East of Nigeria is a key hub for logistics and transportation because of its strategic position, vast road network, and proximity to neighbouring countries [9]. There are a lot of transport firms, commodity distribution marketplaces, and logistics companies in the area. Startups and tech hubs are booming across the South-East, and interest in innovation and technology is growing. This indicates the area's commitment to diversifying its economy outside well-established sectors [10].

It's crucial to remember that despite this business activity, the region continues to confront challenges including poor power supplies, gaps in the infrastructure, security threats, and political unrest [11]. Overcoming these challenges and improving the electrical supply that drives these commercial activities are essential to the region's economic success.

With a focus on the utilization of the state's small hydropower potential, this paper aims to provide the much-needed background and understanding of alternative and renewable sources of electricity generation in Abia state in order to meet the enormous current demand for electricity without reliance on the national grid. It explores the possibilities for a convergence and intersection between waterlines, road networks and built-up areas in the available Land Use Land Cover (LULC) map datasets through geo-spatial interpolations to show areas suitable for siting small hydropower plants. The built-up areas are identified within the ArcGIS platform to have a Normalized Difference Vegetation Index (NDVI) within the range of 0.015 – 0.14 and with a Rose Quartz coloration. Likewise, water bodies a NDVI range -0.018 –0.015 and with a Lapiz Lazuli Blue coloration. The area suitable for a small hydropower project is characterized by the availability of these water bodies, land suitable for building constructions and accessibility by road.

2. Power Supply in Abia State

Like many other Nigerian states, Abia State has difficulties in constant power supply. Due to a number of problems, such as limited financing, mismanagement in the power industry, and poor infrastructure, Nigeria has generally suffered with an inconsistent and insufficient power supply [12]. Like other regions of Nigeria, Abia State had regular power outages and load shedding in the power supply scenario [13]. In order to deal with the inconsistent power supply, several parts of the state depend on backup generators and inverters [14]. An overview of the situation of the various power sector value chains in Abia state is provided below;

a. Power Generation: The only source of electricity for Abia State is the national power grid [15]. Power plants in Nigeria produce the majority of the country's electricity, and then they distribute it to other states, including Abia [16, 17]. Some of the power generation projects in Abia state include the following:

- Aba Integrated Power Project (Aba IPP): As part of the Aba Integrated Power Project, Geometric Power Limited is in charge of constructing and operating a power plant in Aba, Abia State. In order to meet the energy demands of the commercial and industrial sectors in Aba and its environs, the power plant is designed to generate electricity, which might be provided to the Aba Ring-Fenced Industrial and Export Processing Zone, a designated region in Aba, Abia State, Nigeria [18]. Increasing exports, promoting industrialization, and advancing economic growth in a certain region are the objectives of this industrial and export processing zone.
- Alaoji Power Plant: The Alaoji power plant is a functional power plant with a number of units, some of which aren't running right now. It can hold 1068 megawatts (MW) at least. March 2015 saw the completion and activation of the first 540 MW phase [15].

b. **Power Distribution:** The residential, commercial, and industrial users in the state of Abia are served by the Enugu Energy Distribution Company (EEDC), which oversees the distribution of energy in South-East of Nigeria [19]. In order to meet their energy needs, Abia State companies and residents are looking more into alternative energy sources like solar energy and wind generators due to the unpredictability of the national grid's power supply [20]. The electrical business in Abia State has challenges similar to those faced by the rest of the nation, such as inadequate infrastructure, power theft, considerable losses in transmission and distribution, and financial constraints. The inconsistency and low quality of power supply have been influenced by these issues.

3. Available Renewable Energy Resources in Abia State

The utilization of renewable energy is driven by the need to supply sustainable and reliable energy sources, diversify the energy mix, and reduce greenhouse gas emissions in Abia State and other regions of Nigeria [21]. Numerous renewable energy projects and sources are under investigation in Abia State as highlighted below:

I. Solar Energy: With a specific PV power output (*PVOUT*) of 1342.5kWh/kWp and a Global Horizontal

Irradiation (*GHI*) of 1684.6 kWh/m^2/yr, Abia State receives a lot of sunlight throughout the year, according to the Global Solar Atlas [22], making solar energy a viable source of renewable energy. Both on and off the grid, solar electricity may be used to power structures including homes, businesses, and public organizations.

II. **Biomass Energy:** In Abia State, biomass energy, particularly from organic and agricultural waste, is another type of renewable energy. Biomass may be used for electricity generation, cooking, and heating [23]. The United Nations Food and Agricultural Organization (UN-FAO) reports that Abia state can produce 28.604 billion tons of energy crops yearly [24].

III. **Waste-to-Energy:** There are programs aimed at converting organic waste into power through anaerobic digestion and the production of biogas [25]. Together with helping with waste management, this can provide renewable energy. In 2017, Tosin and colleagues conducted a state-level evaluation of Municipal Solid Waste (MSW) in Nigeria. According to the literature, the potential power generating capacity of Nigeria's states varied from 31 to 205 MW, contingent upon the level of waste production in each state. The country's yearly potential to produce electricity from MSW was estimated to be 26,744 GWh, with 89% of the states having sufficient ability to produce at the required minimum of 50 MW [26]. According to different research carried out in the Umuahia Metropolis, Abia state has a lot of potential to produce power from household garbage, with an average of 0.53 kg per family per day [27].

IV. **Hydropower:** Abia State's topography and river system present opportunities for small hydropower projects. These initiatives use the flow of water in rivers and streams to generate electricity [28]. A recent analysis found that the state's ability to implement hydropower schemes is limited by the lack of inland water and flooded land areas. Nonetheless, the research suggested using run-off-river systems to generate electricity in places like these using micro and pico turbines [29, 30].

V. **Wind Energy**: In Abia State, solar and hydroelectric energy are frequently more common than wind energy because of the erratic wind patterns. According to the literature, there are still prospects for small-scale investments at around 108 viable sites in Abia south, which span a distance of 270 km^2, despite the poor potential for wind energy in Abia state due to low height and wind speed [31]. Nonetheless, wind resource assessments and evaluations might be done to identify appropriate locations for wind energy projects.

4. Overview of the Potentials of Small Hydropower in Abia state

The reported limited hydropower potential of Abia State as found in various literature is a result of the state's topography, even with the presence of several rivers and streams [32]. Small hydropower plants may be powered by the flow of water in rivers and streams, and Abia State has a number of characteristics that make such projects possible. Studies indicate that the following places; Arochukwu, Umuahia, Obingwa, Osisioma-Ngwa, Ohafia, Bende, and Isiukwuato local government may have qualities that make them suitable sites for modest hydro projects. These presumptions are supported by the topography and the numerous streams and rivers that are present in these regions. The map of Abia state with rivers and waterlines is displayed in the image below.

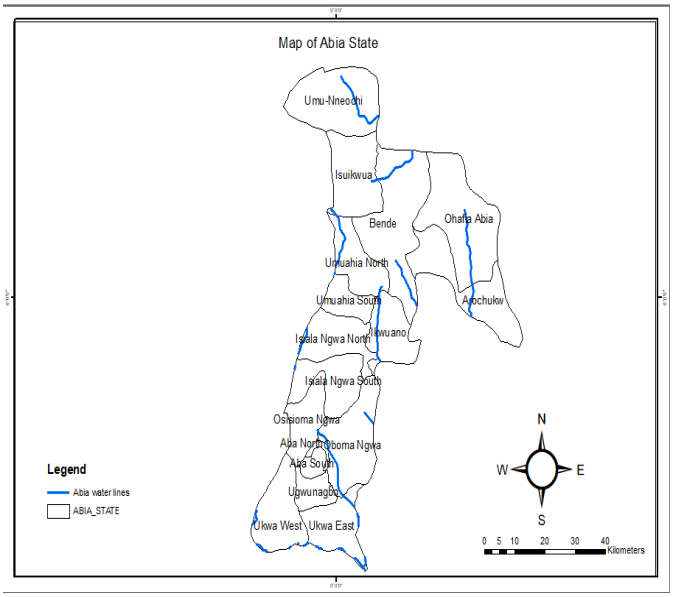

Fig.1 Map of Abia state showing waterlines. Source: (ESRI, 2020).

5. Methodology

In order to meet the energy demands of the various consumers in Abia state for sustainable development, as stated in the 2019 report of the United Nations Development Organization (UNIDO) [33], this study evaluates these potentials using a geospatial tool to determine the suitability areas within these locations mentioned above for small hydro generating plants for run-off-river schemes and the potentials for these schemes to support the hybridization of other renewable energy conversion technologies with small hydro or pumped hydro schemes.

Geographic data may be arranged, analysed, and displayed for a multitude of uses with the help of the ArcGIS program, which was created by the Environmental Systems Research Institute (ESRI) [30]. Using a clip tool to extract *NGA_adm0, 1, 2* map files from ESRI map datasets, the study uses two spatial analytical methods: NDVI calculations and Weighted Overlay analysis to analyse map files containing LULC, Water bodies and water areas raster data overlaid on a map shape file (*ABIA.shp*).

The Normalized Difference Vegetation Index (NDVI): The normalized difference vegetation index, or NDVI, is a tool used to quantify vegetations by measuring the amount of vegetation that is absorbed (RED) and strongly reflected (near-infrared, or NIR) [34]. Its value ranges from -1 to +1, with negative values indicating a high likelihood of water

and positive values indicating a high likelihood of dense green leaves, which are indicative of high temperatures and areas of tropical rain forests. Values between 0.015 and 0.14 indicate built-up area, and -0.018 and 0.015 indicate areas characterized by water. The formula for NDVI calculation is shown below.

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad . \qquad (1)$$

Weighted overlay calculation: On a scale of 1 to 9, low-to-high potential regions are displayed using the weighted overlay analysis tool [35]. To display the locations in Abia state that are suitable for small hydropower plants, *LULC* raster files are reclassified and superimposed with *road_r* and *water_r* raster files in specified percentages up to 100%.

The weighted score is determined using the formula below;

$$W_{score} = \sum_m^n C_i * W_i \; . \qquad (2)$$

Where;
i = (roadlines, waterlines, multiple ring buffer with distances from road etc);
Wscore is overall weighted overlay score;
C_i is criteria score of i;
W_i is weight value of criteria i.

Suitability analysis: The following equation represents the Map algebra, a spatial analytic tool that is used to do raster computations to calculate suitability area (S_A):

$$S_A = LULC * Wi. \qquad (3)$$

Where *LULC* is the reclassified Land Use Land Cover raster data.

Flow chart: The following procedures are used to conduct spatial analysis using the ArcGIS platform in order to identify potential sites for small hydropower projects in the state of Abia

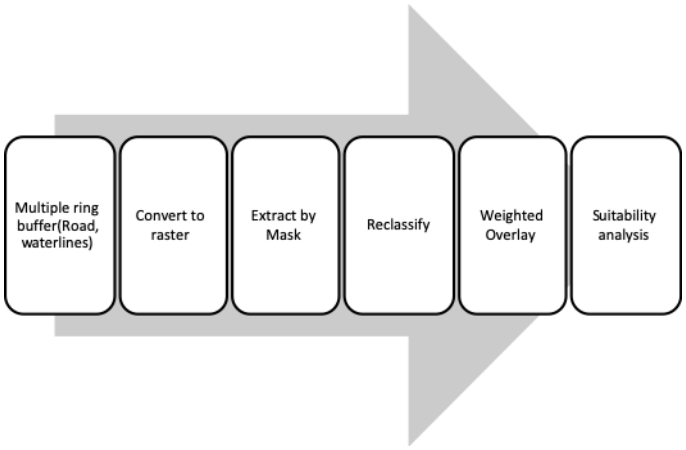

Fig. 2 ArcGIS geospatial analysis flow chart

6. Geospatial Assessment of Small Hydropower Potentials in Abia State

The ESRI website was used to get the map datasets for *NGA_roads* and *NGA_waterlines* [36]. With the aid of the ArcGIS spatial analyst tool clip, the road and waterlines on the map of the state of Abia were extracted from the *NGA_0, 1, 2* shape files showing Nigerian map, states and Local Government Areas.

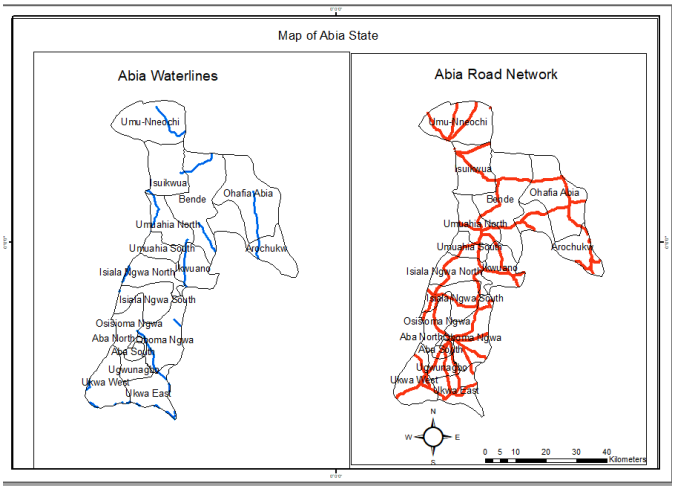

Fig. 3 Abia state map showing waterlines and road network

Multiple ring buffers were created for distances, 200m to 5km for road and waterlines. These were converted to raster files (*road_r* and *Waterline_r*), extracted by mask and reclassified as follows;

Table 1, Classification of road and waterline raster data with output colors.

Classification	**Distance[m]**	**Colors (*Road_r*)**	**Colors (*waterlines_r*)**
9	200	Dark Umber	Ultra blue
7	200-700	Tuscan red	Yogo blue
5	700-1200	Pointsettia red	Cretan Blue
3	1200-3000	Medium coral light red	Lapiz Lazuli Blue
2	3000-5000	Rose Quartz	Sungilite sky blue

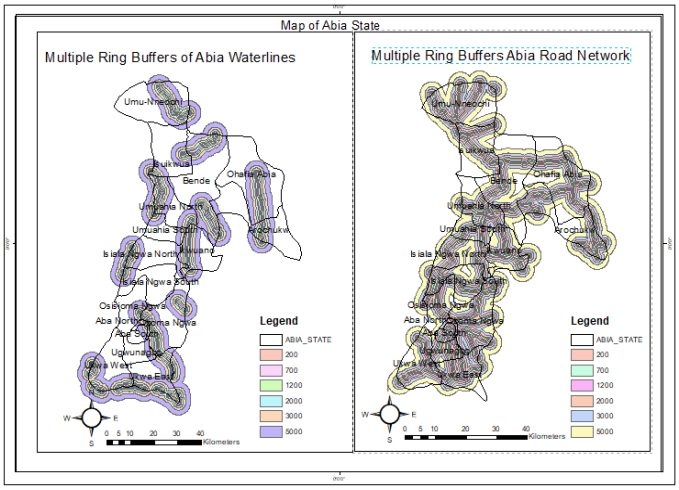

Fig 4 GIS Map showing multiple ring buffers for Abia state waterlines and roads

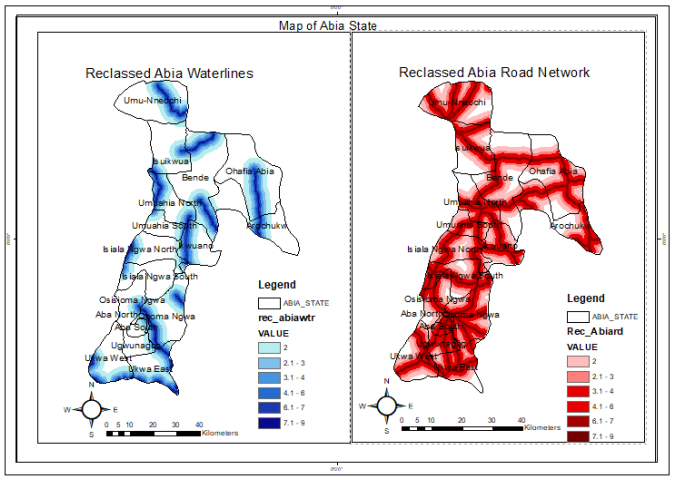

Fig 5 GIS Map of Abia state showing reclassified waterlines and road raster

The *NGA_adm 0* map shape file was overlaid with NDVI data for Nigeria that was taken from ESRI databases. To acquire *LULC* raster data, the map of the state of Abia was derived from the superimposed raster data [37]. This was given a new classification:

Table 2, Reclassification of Land use Land Cover (*LULC*) raster with output colors shown

Classification	**Label**	**NDVI Range**	**Colors**
9	Water body	-0.018 – 0.015	Lapiz Lazuli Blue
7	Built up area	0.015 – 0.14	Rose Quartz
5	Barren land	0.14 – 0.18	Sahara sand
3	Shrub and grass land	0.18 – 0.27	Lemongrass yellow
2	Sparse vegetation (Crop area)	0.27 – 0.36	Leaf green
1	Dense vegetation (Forest area)	0.36 – 0.70	Fir green

Weighted overlay calculation: Weighted scores of 40%, 30%, and 30%, respectively, were used to overlay the reclassified maps for *LULC*, *road_r*, and *Waterline_r*, totaling 100%.

Suitability analysis: To identify locations that are suitable for small hydro power generation, the weighted overlay calculation map is multiplied by the *LULC* map using Map algebra in accordance with Eq. 3 which is aimed at finding an intersection between the various datasets. While other colors indicate the different land cover designations for built-up regions suggesting prospective development sites or liveable areas, the deep blue hue indicates water bodies and potential locations.

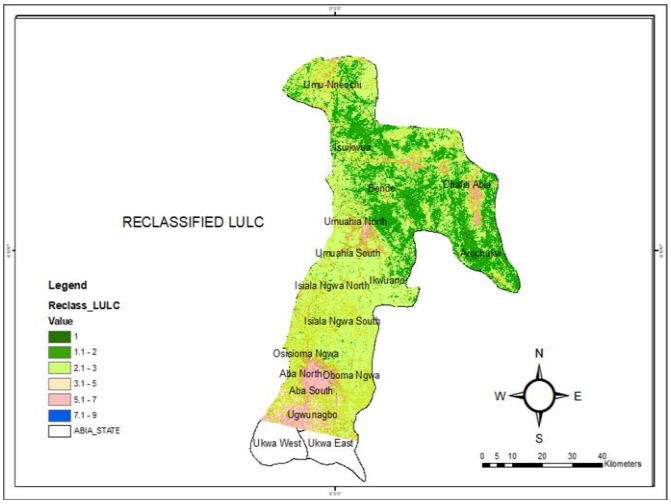

Fig 6 Reclassified Land Use Land Cover Map for Abia State

7. Results and Discussions

The weighted overlay and map algebra calculations performed using the ArcGIS platform to identify appropriate locations for small hydropower project siting in Abia state are displayed in the figures below.

The results of the weighted overlay for the different raster data in the 4:3:3 ratio is displayed in Fig. 7, with colors changing from amber to green as you go closer to a possible site.

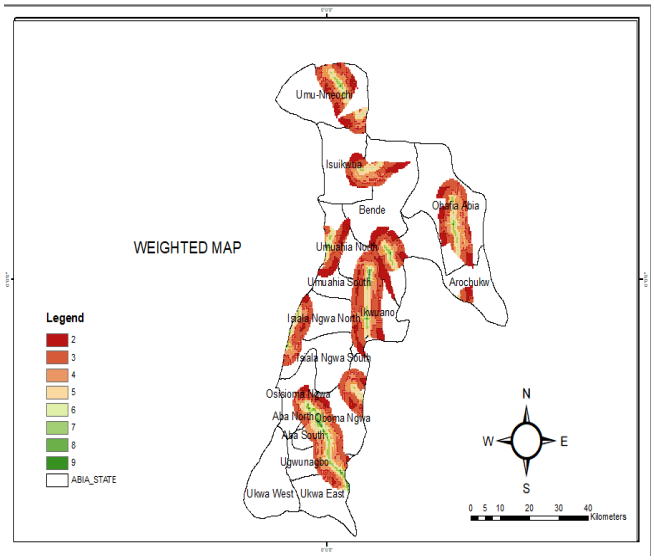

Fig 7, Weighted overlay map with Abia road, waterlines and *LULC*

The suitability study results are displayed in Fig. 8 below, which highlights possible locations in four local government areas: Obingwa, Aba North, Aba South, and Osisioma-Ngwa. The lapiz lazuli blue tint for water bodies with a class weight between 36 and 63 makes local government regions evident. Umuahia North L.G.A. and Ohafia are two other possible locations. The orange, lemongrass, and red colorations indicate the possibilities of placing these schemes in places that are accessible by road and inside populated regions. There may be habitations along the waterlines in other places like Umunneochi, Umuahia South, Ikwuano, and Isiala Ngwa North, but there aren't many waterbodies in these regions, thus investing in power generating there isn't practical.

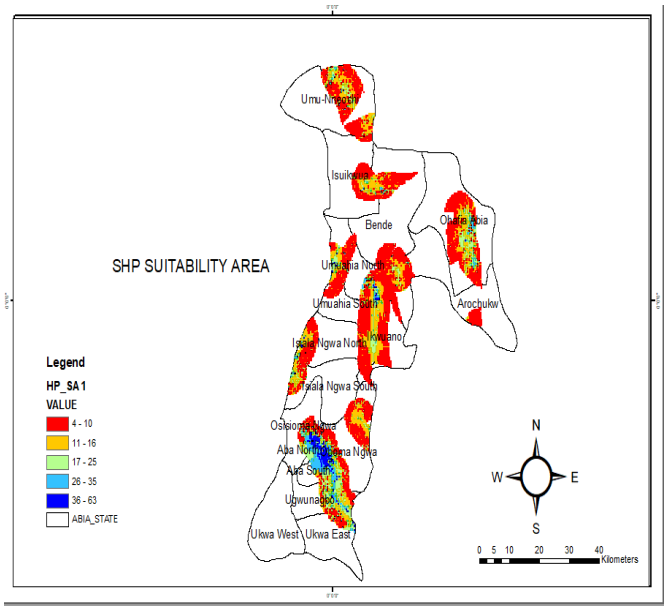

Fig. 8, Map of Abia state showing suitability areas for small hydropower generation

8. Conclusions and Recommendations

This analysis shows that small hydropower potential in the senatorial districts of Abia South and Abia Central may be used for irrigation and power generation. The presence of water bodies and built-up areas surrounding them, with an NDVI range of 0.015 – 0.14 and a weighted score of 11-16, is indicated by the availability of suitability areas in Osisioma Ngwa and Obingwa Local Government Areas, which have a weighted score between 33-66 and an NDVI range of -0.018 – 0.015. These unrealized potentials might be used to supply water for large-scale agricultural as well as fulfil the energy needs of the industrial clusters, small, and medium-sized businesses, and the city of Aba. This study provides insights into optimal locations for small hydropower projects to improve energy access in Abia state, and a framework for further feasibility studies by mini-grid developers and government agencies.

In order to provide backup storage for planned mini-grid projects by the Rural Electrification Agency through the Nigerian Electrification project, the study also suggests building pumped hydro storage facilities in Osisioma-Ngwa and Obingwa the local government areas. It is advised that project developers look at this option in order to reduce total capital expense. reduced energy prices and enabled low-income communities in the state of Abia to receive mini-grid power. Additionally, since these factors determine the type of hydro turbines to install and the necessary civil works, the government should endeavour to conduct feasibility studies in these areas to ascertain the potential capacity of small hydropower plants and the scheme that will be suitable for these locations based on available hydrological and hydraulic data, such as head, *H* (m) and volumetric flow rate of the water *Q(m3/s)*.

References

[[1] Profile of South-Eastern Nigeria and Description of the Study Area Profile of south-eastern Nigeria. (2001).

[2] D. C. Ohadike,, Igbo Culture and History.pdf. Preprint at (1960).

[3] P. Chinwuba, Determinants of Participation in Nonfarm Economic Activities in South East Nigeria: A Tobit Analysis Approach. 5, 102–109 (2015).

[4] World Bank. Nigeria Socio Economic Assessment 1. World Bank 3–17 (2011).

[5] C. Umezinwa, Health and economic growth in South East, Nigeria. African Research Review 10, 111 (2016).

[6] N. E. Odoh, & S. U. Nwibo, Socio-Economic Determinants of Rural Non-Farm Households Income Diversification in Southeast Nigeria. International Research Journal of Finance and Economics-Issue 164, 116–128 (2017).

[7] C. M. Amaechi, & O. U. Muoh, Women and development in Africa: Urbanization and the role of Umuada

in Igboland, Southeast Nigeria. Asian Women 34, 85–107 (2018).

[8] N. A. Obi-Ani, & M. C. Isiani, Urbanization in Nigeria: The Onitsha experience. Cities 104, 102744 (2020).

[9] G. Jelilov, & H. Iheoma, The Impact of Industrialization on Economic Growth: The Nigeria Experience (2000-2013) Entrepreneurial Trade Fair (Turkmenistan) 2012 View project Entrepreneurial Trade Fair (Turkmenistan) 2010 View project The Nigeria Experience (2000-2013). British Journal of Advance Academic Research 5, 11–20 (2016).

[10] Unizik journal of business. 1, 81–92 (2018).

[11] U. Idika, Factors that Hinder Effective Domestic Energy Management Practices within Households of Urban and Rural Areas of Abia State. 5, 1–16 (2018).

[12] D. A. Diji, Critical Review of the Nigerian Energy Scenario. IOSR Journal of Electrical and Electronics Engineering 5, 55–67 (2013).

[13] J. C. Onwumere, C. A. Amaghionyeodiwe, & E. C. Ndukwe, Effect of epileptic power supply on the investment and performance of bakeries in Abia State, Nigeria. Nigeria Agricultural Journal 50, 92–99 (2019).

[14] REA. Nigeria Electrification Project (NEP). (2023).

[15] K. E. Okedu, K. Sarah, I. Kayoade, & U. Roland, Impact of the Independent Power Producers and National Integrated Power. 20, 147–170 (2018).

[16] B. Facts, The Profile of Energy Generation and Consumption in Nigeria Department of Pure and Industrial Chemistry , Nnamdi Azikiwe Department of Chemical Engineering , Nnamdi Azikiwe University ,. 194–201 (2016).

[17] E. Elizondo, M. Enskat, R. Golumbeanu, M. Hirsch, M. Hurls, U. Laumanns, S. Maia, I. Nakiwu, A. Ouedraogo, D. Rysankova & W. Steel, Productive Use of Energy – PRODUSE Measuring Impacts of Electrification on Small and Micro-Enterprises.

[18] K. Ukoima, & E. O. Agwu, Review of the Impact of Electricity Supply on Economic Growth: A Nigerian Case Study Review of the Impact of Electricity Supply on Economic Growth: A Nigerian Case Study. IOSR Journal of Electrical and Electronics Engineering 14, 28–34 (2019).

[19] H. O. Amuji,, C.C. Nwachi, N. Nicholas, J. C. Mbachu, & W. T. Owolabi, Correlation Analysis of Enugu Electricity Distribution Company' s Electricity Bill. 10–19 (2023) doi:10.5281/zenodo.7765101.

[20] D. Clinton, & A. B. Chinago, State of power supply in Nigeria, the way out. International Journal of Development and Sustainability 7, 435–447 (2018).

[21] F. Igbinovia, An overview of Renewable energy potential in Nigeria: Prospects, Challenge and the Way forward. Energetika Journal 46, 570–579 (2014).

[22] M. C. Njoku, F.I. Ugonwafor, C. H. Ogbaji, R. C. Owunna, Global Solar Radiation Utilization In South-East Of Nigeria. 1141–1152 (2022).

[23] G. Ramanjaneyulu, &B. R. Reddy, Emerging trends of microorganism in the production of alternative energy. Recent Developments in Applied Microbiology and Biochemistry 275–305 (2018) doi:10.1016/B978-0-12-816328-3.00021-0.

[24] M. O. Ukoba, E. O. Diemuodeke, T. A. Briggs, M. Imran, K. Owebor, C.O. Nwachukwu, Geographic information systems (GIS) approach for assessing the biomass energy potential and identification of appropriate biomass conversion technologies in Nigeria. Biomass Bioenergy 170, 106726 (2023).

[25] M. U. H Joardder, P. K. Halder, M. A. Rahim. & M. H. Masud, Solar pyrolysis: Converting waste into asset using solar energy. Clean Energy for Sustainable Development: Comparisons and Contrasts of New Approaches 213–235 (2017) doi:10.1016/B978-0-12-805423-9.00008-9.

[26] T. O. Somorin, S. Adesola, & A. Kolawole, State-level assessment of the waste-to-energy potential (via incineration) of municipal solid wastes in Nigeria. J Clean Prod 164, 804–815 (2017).

[27] I. K. Chima, & V. Nwabinye, Economic Analysis of Household Waste Generation, Disposal and Management in Umuahia Metropolis, Abia State, Nigeria. International Journal of Health Economics and Policy 2, 47 (2017).

[28] O. S. Ohunakin., S. J. Ojolo, & O. O. Ajayi, Small hydropower (SHP) development in Nigeria: An assessment. Renewable and Sustainable Energy Reviews 15, 2006–2013 (2011).

[29] C. Odiji, M. Adepoju, I. Ibrahim, O. Adedeji, I. Nnaemeka, O. Aderoju, Small hydropower dam site suitability modelling in upper Benue River watershed, Nigeria. Appl Water Sci 11, (2021).

[30] B. Oyinna, K. E. Okedu, O. E. Diemuodeke, L. E. David, I. O. Negedu, E. A. Osemudiamen, I. Colak & A. Kalam. Assessing small hydropower sites in Nigeria for sustainable development using ArcGIS. Energy Reports 10, 2889–2898 (2023).

[31] N. E. Chiemelu, U. Nkwunonwo, F. I. Okeke, & O. C. Ojinnaka, Geospatial Evaluation of Wind Energy Potential in the South-East and South-South Sections of Nigeria. International Journal of Environment and Geoinformatics 6, 244–253 (2019).

[32] V. U. Nkemdirim,, G. C. Alozie, & I. Felix, Spatial Analysis of the Quality of Groundwater Supply : Evidence from Abia State. American Journal of Water Resources 4, 83–90 (2016).

[33] UNIDO. Incentive Policies for Small Hydropower Development. 1–8 (2019).

[34] M. O. Ukoba, E.O. Diemuodeke, T.A. Briggs, M. Imran, M. M. Ojapah, K. Owebor, C. Nwachukwu, M.D. Aminu, K.E. Okedu, A. Kalam, & I. Colak, Optimal sites for agricultural and forest residues energy conversion plant using geographic information system. Heliyon 9, e19660 (2023).

[35] M. Asadi., K. Pourhossein, & B. Mohammadi-Ivatloo, GIS-assisted modelling of wind farm site selection

based on support vector regression. J Clean Prod 390, (2023).

[36] ESRI Geographical Information System, 2020.

[37] B. C. Oyinna, M. O. Ukoba, "Geographical Information System Based assessment of small hydropower potential in South-Eastern Nigeria; A case study of Abia state.," Proceedings from Africa International Conference on Clean Energy and Energy Storage, 2023.

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