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GIS-BASED APPROACH TO SMALL HYDROPOWER POTENTIAL ASSESSMENT ALONG RIVER OGUN, NIGERIA

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ABSTRACT

Electricity access is one of the challenges faced in Nigeria today; and this problem is more pronounced in the rural communities. Connecting rural communities to the national grid is always a problem due the financial and logistical constraints of extending power through difficult terrain. To meet the energy demands of this deprived vast rural population small hydropower plants are recommended to be built and installed. Small hydropower is a clean renewable and reliable energy alternative that meets the economic and environmental energy policy objectives. Improved technological development in GIS and remote sensing provides alternative methodologies for the assessment of theoretical hydropower potentials. This study provides a methodological pathway towards identifying small hydropower potentials for rural communities along the River Course. Input data for the study include Digital Elevation Model (DEM), precipitation and evaporation collected in raster, and population data. The study identified a total of 57 potential hydropower sites with a maximum energy potential of 5.80 mw site. Ogun River has 75380kW of potential energy distributed along the river course in Ogun State. The estimated energy potential is expected to support about 22,040, 16530, and 11020 households at 100% 75% and 50% performance respectively. The study concludes that small hydropower plants are viable option for reducing the energy deficit of the country and can also help in the attainment of sustainable development goals 7 (universal energy access for all). The study recommends that government must take advantage of emerging GIS and remote sensing technologies to identify, estimate, and develop small hydropower plants for rural electrification while pursing and encouraging energy democratisation and decentralization.

KEY WORDS Electricity, Small hydropower potential, GIS, and Rural Electrification

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1. INTRODUCTION

Electricity is one of the most important drivers of development in the world, particularly in the 19th century and beyond. However, according to International Energy Agency (IEA), 2022, about 770 million people live without access to electricity in the world today; mostly in Africa and Asia. Significant progress was recorded in access to electricity in the world between 2013-2019, but for the global pandemic (COVID-19), the number of people without access increased in 2020 for the first time since 2013. Hence, increasing the concerns of electricity access in the world and Africa in particular through sustainable means.

Hydropower is undoubtedly one of the most sustainable, reliable, clean, and renewable energy sources that serves both energy and national environmental policy objectives (Kusre *et al.*, 2009). It is a major renewable energy source for electricity production due to its reliability and it produces less greenhouse gas emission. Hydropower energy system comes with numerous advantages among which are low operation and maintenance cost, less greenhouse gas emission, high efficiency (above 60%), and longer life span (Hatata et al., 2019).

Small hydropower (SHP) is one of the numerous off-grid alternatives to electric grid extension that provides communities outside the grid network with electricity and usually serve as supplement in urban areas or large cities (Eshra et al., 2021). No universally acceptable definition of small hydropower exists, however, the smallness of hydropower ranges from 1-10MW in literature (Khare et al., 2019; Morales et al., 2014; Paish, 2002). According to Ghorbani et al. (2020) small hydropower is one of the most popular renewable energy sources with very little or no environmental and social implication compared to large scale hydropower system (Yadoo and Cruickshank, 2012). Despite the numerous advantages of small hydropower and abundant water resources in Nigeria; SHP potential remains relatively untapped (Adedeji, 2016).

has abundant hydropower Nigeria potentials yet has failed to utilise these resources maximally. About 12.4% of Nigeria's landmass is covered with water (Ita et al., 1985), yet only about 20% (IEA, 2014) of Nigeria's electricity generation comes from hydropower. which are mostly large hydropower plants (e.g., Kainji, Shiroro, and Jebba). In the face of abundant water resources, Nigeria, is facing serious crisis in electricity generation and this has serious implication on the level of electricity access in the country. According to the International Energy Agency (2016), electricity access in Nigeria stands at 55% in urban areas and 36% in rural areas, while about 134 million people (76 percent) rely on traditional fuelwood for energy. The increasing use of fuelwood as energy alternative increases the temperature of the environment leading to greenhouse effect thereby increasing climate change concerns.

Access to clean electricity is critical to the achievement of SDGs goal 7 (affordable and clean energy) and goal 13 (Climate Action) as well as the development of many sectors of a nation including education, water, industrialization, and health. Hence, meeting and achieving most of the SDGs, particularly goals 7 requires concerted efforts towards the generation and distribution of electricity to all citizens in the rural and urban areas of the country. Small hydropower according to Paish (2002), are now the greatest alternative, providing a considerable, long-lasting, and costeffective source of energy with minimal environmental impact.

In other to ensure energy access for all by year 2030, rigorous attempt towards energy decentralisation and adoption of programmes that promotes energy mix (on-grid and off grid energy solution) must be pursued (PPEO, 2017). The urban-rural dichotomy in energy access must in Nigeria must be balanced and this can be achieved through the use of off grid energy solutions, particularly small hydropower. According to Energy Commission of Nigeria (ECN, 2004), only twelve of the thirty-six states of the country has been surveyed for SHP potential; these states have a total SHP potential 734.2MW identified over 277 SHP potential sites. However only about 5% of the SHP potential has been harnessed in only four states in the country (ECN, 2004). The recent advancement of in technology and geographic information system (GIS) has provided a cost effective and fast approach to small hydropower survey and assessment using remote sensing data. This study is therefore an attempt to showcase a pathway towards effective survey and viability assessment of small hydropower potentials for electricity generation along Ogun River using GIS and remote sensing technology.

2. STUDY AREA

River is one of the most prominent rivers in Ogun State among which are River Ovan. Oshun. and Oni. The river runs from Osun state in the north to the south in Lagos state before emptying into the Atlantic Ocean. However, the focus of this study will be on the stretch of the river within Ogun State (Figure 1). River Ogun within Ogun State traverses five local government areas (LGAs) of the state; Abeokuta north, which is partly urban and partly rural, Abeokuta south (100% urban), Ifo, Obafemi-Owode and Odeda. River Ogun is a permanent river and its mostly recharged through rainfall. Ogun State experienced at least 9 months of rainy season from March to November and intermittent rain for the rest of the year (Azodo, 2014). It is also instructive to know that Ogun State is the home to many industries in Nigeria and hence there is high competition for residential and industrial energy use. The seemingly inadequate energy access for urban residential and industrial is likely accountable for the low or no level of energy access experienced in many rural communities in the State.





3. METHODOLOGY

3.1. Data Types and Sources

- Shuttle Radar Topographical Mission of 0.00083 by 0.00083 degrees resolution was downloaded form United States Geological Survey (www.usgs. com) (DEM)
- Shapefiles of communities within 2km radius of River Ogun was downloaded from OpenStreetMap (www.openstreetmap.com)
- The energy access level of the communities was determined through survey
- Per capita annual consumption in Ogun State in 2016 and 2017 was sourced from Ibadan electricity Distribution company (IBEDC)
- Monthly precipitation and evaporation dataset was downloaded from Dieulin et al. (2017)

3.2. Procedure for Spatial Analysis of SHP Potential Sites

The procedure for small hydropower potential sites identified in this study is depicted in Figure 2. The steps involved in the procedure is presented in the following order

- A DEM of 0.00083 by 0.00083 degrees resolution was loaded into ARCGIS 10.8 environment
- The DEM was masked with a 2km buffer vector shapefile of River Ogun

- The resulting DEM of the area was filled for void to derive a resulting DEM without sink
- The result of step three (DEM without sink) was used to estimate the flow direction of the area which is called FD
- The direct runoff data set was resampled according to the masked DEM using the resample function in ARCGIS
- The resampled data was converted to integer to aid processing
- The output of the flow direction (FD) and the direct runoff dataset (integer) were loaded as input data for the calculation of flow accumulation and the resulting raster was labelled "m"
- Focal statistics analysis function was carried out on the masked DEM of the study area to derive a DEM labelled Minimum neighbours (MN)
- The minimum neighbours (MN) were deducted from the initial Masked DEM of the area to derive the head "h" which is the difference in height of neighbouring cell
- The amount of runoff per raster (flow rate) labelled "m" was multiplied by the head (difference in height) to arrive at a raster called "mh"
- The result of step 10 labelled "mh" was multiplied by the value of gravity labelled "g" to derive to energy potential of the cells in kilojoules.
- The output in kilojoules was transformed to kWh and MW h by using the calculation factor $(1/3.6 * 10^{12})$

3.3. Method of Data Analysis

Spatial analysis and descriptive analysis were the analytical tools used for data analysis. The spatial analysis tools used include fill, flow direction, flow accumulation, resample, buffer analysis, focal statistics, and map algebra function in ARCGIS 10.8 environment. The spatial analytical techniques were used to identify small hydropower potential sites at various stages of the analysis. In addition, simple descriptive analytical tools such as frequency, minimum, maximum, and mean were also computed for easy understanding of the data. To estimate the energy potential of the potential sites in joules, the advanced energy equation advanced by Carroll et al. (2004) which is mathematically expressed in equation (1) was adopted.

$$E=m*g*h$$

equation (1)

Where E= "gravitational potential energy, measured in Joule J", m = mass (amount of runoff per raster); g = gravitational force (9.8); h= height (head/slope)

Note: The output dimension is in Joules which then has to be transformed to kWh and MW h by using the calculation factor (1/3.6 * 10^{12})

Figure 2: Flow Chart of the Research Methodology



Source: Adapted by the Author (2022)

3.4. Minimum Electricity Threshold Required to Meet SDG 7

reliability, affordability, Energy and sustainability are the key goals of Sustainable Development Goal 7. However, it does not set the minimum per capita energy threshold to be achieved to ensure energy access for both residential and non-residential sector. Hence, there is no universally electricity acceptable consumption threshold; electricity access threshold varies across countries and continents of the world.

For example, Moss et al. (2020) proposed a minimum energy benchmark of 1000kwh per capita per annum inclusive of residential (300 kWh) and non-residential (700 kwh) electricity consumption for the achievement of SDG 7. IEA (2015) also proposed a minimum threshold of 250 and 500 kWh/ year for rural and urban households be five persons) (assumed to respectively. Similarly, Brecha (2019) also argued that a minimum electricity threshold of at least 400kwh is closely to meeting the outcomes of SDG 7. Based on the economic dynamics and rural nature of most communities within twokilometre radius of the identified SHP potential sites in Ogun State, IEA (2015) minimum threshold value of 250kWh per household (5 persons) will be adopted as the minimum energy threshold for energy analysis in this study.

4. RESULTS AND DISCUSSION

4.1. Characteristics of River Ogun

River Ogun stretches for 118.1km from north to south within Ogun State boundary and it is the longest and biggest river in the State (Table 2). The minimum elevation along the river path is 1.003m and a maximum 103.9m above sea level. The vertical difference between the start point of the river in the north and the finish point is about 102.9m. This significant difference in vertical height along the river channel will provide good head (gradient) required for the development of hydropower plant. The maximum slope along the river channel is 7.020 which is also good for small hydropower development. The North-South profile of River Ogun is depicted in Figure 3. The Figure shows the undulating nature of the river channel and the flow direction of water from the north at (7° 24' 12.9605" N, 3° 30' 29.6205" E) to south (6° 38' 39.0696" N, 3° 22' 51.5256" E).

Table 2: Physical	Characteristics	of River	Ogun
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Characteristics	Value
Start Position:	7° 24' 12.9605" N, 3° 30' 29.6205" E
End Position:	6° 38' 39.0696" N, 3° 22' 51.5256" E
Minimum Elevation on Path:	1.003 m
Maximum Elevation on Path:	103.897 m
Vertical Difference (Start to Finish):	102.9 m
Path Length:	118.1 km
Straight-Line Distance:	85.153 km
Minimum Slope/Tilt:	-0.05°
Max Path Slope:	7.02° [104.13 km along path]
Flow direction	North to South





4.2. Quantity of Discharge and Slope along River Ogun

The quantity of discharge (flow rate) and the difference in vertical difference in elevation called "head" or "gradient" are the primary factors for energy potential estimation in run off river. The higher the vertical difference in elevation and quantity of discharge, the higher the potential energy generated. Table 3 shows the characteristics of discharge and head along River Ogun. The result shows that a minimum slope of 0.3 metre at Ifo LGA and a maximum slope of 24.3 metre was identified along the river at Abeokuta South LGA. The average annual discharge ranges from 82.8m3 in Odeda to 183.4m3 in Ifo. The quantity of discharge increases as the river flows towards the south in Ifo LGA. The analysis revealed that there is a wide variability in head and discharge distribution along the river course. Hence, the river can support the generation of varying level of electricity.

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River	Min head	Max head	Min Monthly Q/Discharge (m3)	Max Monthly Q/Discharge (m3)	Annual Mean Q/Discharge (m3)
Odeda	0.7	18.2	4.1	368	82.8
Abeokuta North	0.9	14.1	4.94	612	132.5
Abeokuta South	0.4	24.3	9.77	617	168.8
Obafemi-Owode	0.4	13.1	10.5	635	172.5
lfo	0.3	16.2	11.7	658	183.4

4.3. Distribution of Small Hydropower Potential Sites Along River Ogun

The study identified a total of 57 small potential hydropower (SHP) sites along River Ogun (Table 4). The small hydropower potential sites were distributed across five local government areas of Ogun State. Majority of the potential sites (21) were identified along the river channel in Odeda local government area (LGA) which is one of the adjoining LGA to the State Capital Abeokuta. Obafemi Owode LGA had 11 SHP sites and Ifo had 10 SHP sites along River Ogun. Abeokuta North and Abeokuta South had 6 and 9 SHP sites respectively; these two LGAs are the home to the State capital Abeokuta.

The energy potential available in the 57 potentials were also classified into three; namely 0.500-1.000mw, 1.001-3.000mw, and above 3.000mw. Table 4 shows that at least 15 potential sites can support 0.5000-1.001mw of electricity, 34 sites can support 1.001-3.000mw, while only 8 sites can support above 3.000mw of electricity. The distribution of the potential sites across five LGAs in Ogun state shows that communities from different LGAs are likely to benefit from the SHP sites when developed. It can also serve as a tool to stimulate development across different LGAs of the state. The distribution pattern of the SHP potential sites is presented in Figure 4.

Table 4: Characteris	tics of Stream	Network in	Ogun Wate	ershed
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LGAs	0.500-1.000 MW	1.001-3.000 MW	3.001-5.798 MW	No Hydropower Site
Abeokuta North	0	5	1	6 (10.5%)
Abeokuta South	4	5	0	9 (16%)
lfo	2	7	1	10 (17.5%)
Obafemi-Owode	0	8	3	11 (19%)
Odeda	9	9	3	21 (37%)
Total	15 (26%)	34 (60%)	8 (14%)	57 (100%)

Figure 4: Categories of SHP Potential Sites along River Ogun



4.4. Estimated Small Hydropower Potentials Identified Along River Ogun

The estimated electricity potentials estimated per sites along River Ogun ranges from 0.502mw in Ifo LGA to 5.798mw in Abeokuta North LGA (Table 5). The variability in the energy potential estimated across the sites is a function of the available head and the rate of flow at the discharge point. Table 5 shows that a total of 13.48mw of electricity potential can be generated from six potentials sites along the river in Abeokuta North, 9.94mw from nine (9) potential sites in Abeokuta South which is 100% urban and doubles as the state capital. The maximum electricity potential of 30.05mw was estimated along the river in Odeda LGA from twenty-one (21) potential sites. A total of 75.38mw what of energy was estimated from a total of 57 sites along the river course and across five LGAs.

River	Min Pwr (mw)	Max Pwr (mw)	Total SHP Potential (mw)
Abeokuta North	1.106	5.798	13.48
Abeokuta South	0.510	2.096	9.94
lfo	0.502	3.133	10.53
Obafemi-Owode	0.535	1.906	11.38
Odeda	0.513	3.284	30.05
Total			75.38

Table 5: Estimated Energy Potentials of the Identified SHP Sites

4.5. Energy Access Situation of Communities along River Ogun

The study examined the energy access situation of communities located along two kilometres radius of River Ogun in other to assess the viability of potential SHP sites. The study identified a total of fifty-seven rural communities and one urban centre (Abeokuta) the state capital of Ogun State (Table 6). The result shows there are at least 25 rural communities (hamlet/village) along 2 kilometres radius of River Ogun, 16 in Obafemi-Owode, 13 in Ifo, 3 in Abeokuta North and one town (Abeokuta) in Abeokuta South LGA. Interestingly, none of the rural communities located along the river within 2 kilometres distance are connected to the national grid or any off-grid electricity system, and hence had no access to public energy supply. Abeokuta on the other hand is connected to the national grid. The vast population of communities along the river course without access to electricity provides the requisite demand for the potential energy within reasonable distance. The distribution of the communities along the river course is depicted in Figure 5.

Table 6: Energy Situation of Communities along River Ogun

River	Communities	Development Status	Energy Access Status
Abeokuta North	3 (5%)	Rural	Not Connected
Abeokuta South	1 (2%)	Urban	Connected
lfo	13 (22%)	Rural	Not Connected
Obafemi-Owode	16 (28%)	Rural	Not Connected
Odeda	25 (43%)	Rural	Not Connected
Total	58 (100%)		





4.6. Projected Household Population to be Serviced with Electricity

The study provides an insight into the possible number of households (average of five members) that can be provided with a minimum energy threshold of 250kWh per anum. This is equivalent to an average daily electricity access of 0.68kWh per capita and 3.4kWh per household per day. Based on this standard, the number of households to be served was estimated at 100%, 75% and 50% performance of the potentials identified. The result shows that at maximum performance capacity of 100% for a household of five, 22,040 households can be powered with electricity, 16531 households at 75% performance and 11020 households at 50% performance of the SHP potentials. This shows that a minimum of 11020 households can be lifted out of energy poverty with a minimum access to 250Kwh per annum per household. This can also serve as an inclusive approach towards connecting communities (mostly rural) far away from national grid due to topographical or logistical constraints into public energy system through off-grid system using SHP.

Table 7: Projected Household Population to be Serviced with Electricity	
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Biyor		No of Households to be served			
River	Energy Potential (kWh)	100%	75%	50%	
Abeokuta North	13480	3942	2956	1971	
Abeokuta South	9940	2906	2180	1453	
lfo	10530	3079	2309	1539	
Obafemi-Owode	11380	3327	2496	1664	
Odeda	30050	8786	6590	4393	
Total	75380	22040	16530	11020	

5. DISCUSSION OF RESULT

The purpose of this research was to determine uniformly the best places in Ogun State to set up small-scale hydropower facilities, broken down by local government area, and estimated maximum capacity available. Planning for the electrification of rural areas could benefit greatly from a better understanding of the location and size of small-scale hydro potential. In a GIS setting, it's possible to combine many different kinds of information. This makes them useful for analyzing a region from multiple angles. Unfortunately, because of the nature of the input geospatial data, spatial imperfections cannot be totally eliminated. Our investigation made an effort to reduce potential error by making use of recently collected, properly organized, and recorded data that was made available to the public. However, it is important to keep in mind that the results may have been impacted by the fact that multiple datasets were combined, each of which has its own inherent flaws and imprecisions due to differences in spatial or temporal resolutions and geographical projections.

5.1. Conclusion

The results have shown that GIS and remote sensing data can provide the requisite technology needed to identify potential sites in a cost-effective manner and within a reasonable period of time. This is a much better approach to the traditional water resources assessment approach using discharged data at outlet of watershed. Therefore, spatial identification and quantification of smallscale hydropower potential is expected to be an important addition to the field of spatial electrification planning. The available small hydropower potentials estimated are enough to stimulate efforts towards identifying small hydropower potentials in the country with a view to harnessing same for electrification, particularly in rural areas off the national grid. These will ensure equitable provision of electricity all irrespective of location and level of development. Small hydropower has become more important

than ever in many countries of the world including China, Germany, Spain, and India among others particularly with its attendant low carbon footprint.

It is also evident that small hydropower can be used to reduce the level of energy poverty for a minimum of 11020 households as well as reducing the carbon footprint of the communities. Harnessing the small hydropower potential across the country provides a huge prospect for the attainment of SDGs 7 and 13 and facilitate the achievement in education, health, and production, thereby leading to increase wellbeing of the population and higher gross domestic product for the country. This study therefore concludes that achieving inclusive energy access in Ogun State and the country at large requires the promotion of energy mix through ongrid and off-grid approach of which small hydropower is one. Hence, energy democratisation and decentralisation must be pursued vigorously to provide the requisite environment for the promotion of off-grid energy systems, particularly SHP.

5.2. Recommendations

The following recommendations were evolved from the findings of the study;

- The government must also take advantage of the technological advancement, particularly in GIS and remote sensing for small hydropower assessment in order to facilitate the identification and estimation of small hydropower potentials in a cost effective and sustainable manner.
 - The government must also provide policies that will drive the decentralization of electricity generation in the country through diverse sustainable pathways.

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Areas of requisite electricity potential in the country should be mapped and advertised to encourage investment in that direction.

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