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Geospatial Assessment Of Small Hydropower Potentials In Ogun Watershed For Rural Electrification

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ABSTRACT

Energy access is one of the challenges confronting Nigeria and many Sub-Saharan African countries. The energy poverty experienced in the country is even more pervasive in the rural communities where only about 36% of the population had access to electricity. With the current improvement in technological advancement in GIS and remote sensing, identifying small hydropower sites have become relatively easier, faster, and cost effective. Small hydropower is a clean renewable and reliable energy alternative that meets the economic and environmental energy policy objectives. This study therefore seeks to explore the viability of the SHP potentials for rural electrification.The quantitative research approach was employed.

The study analysed the small hydropower potentials in Ogun watershed using geospatial techniques (Hydrology, Neighbourhood analysis, Watershed analysis) and descriptive statistics to describe the population and energy dynamics of the study area. The study identified a total of 137 potential hydropower sites with a minimum energy potential of 502 kw and a maximum of 5.80 mw. Ogun watershed that has 202200 kW of potential energy is expected to support the electricity need of 59,471 rural households across ten local government areas in Ogun watershed.

The study concludes that with the abundant water resources available in the country, small hydropower plants are a viable option for reducing the energy deficit of the country and can also help in the attainment of sustainable development goal 7 (universal energy access for all). The study further posited that the development of small hydropower in Ogun Watershed reduces the level of energy poverty experienced in the rural communities and stimulates the growth and development of the communities across social, environmental, and economic dimension.This study was able to estimate the viability of the energy potential identified along Ogun Watershed for rural electrification of communities within 2 km radius of the potential site.

Index-words: *Electricity, GIS, Rural Electrification, Small hydropower potential.*

I. BACKGROUND

Access to electricity supply is fundamental to the achievement of any meaning development in a nation. However, over two billion people across the world lack access to electricity (International Energy Agency (IEA), 2018). More than 620 million people in Sub-Saharan Africa (SSA) are believed to be without power (IEA, 2014) and about 60% of Nigerians do not have access to electricity despite the abundant energy resources available in the country (IEA, 2019). Going by the current electricity deficit and population growth projections, the number of people worldwide without access to electricity may surpasses 2.5 billion people by 2030 if current electricity supply and distribution is not improved (IEA, 2017).

In Nigeria, there is the rural urban dichotomy on electricity access. According to the International Energy Agency (2016), electricity access in Nigeria is at 55 percent in urban areas and 36 percent in rural areas, while about 134 million people (76 percent) rely on traditional biomass for energy. Majority of the population without access to electricity are located in the country's rural areas, far away from existing and usually poor grid network. Extending electricity to these communities (rural communities) come with huge investments, structural, and technological changes in energy system (Barnes, 2005; Alexandros et al., 2018). Therefore, if these challenges must be overcome, a more flexible and sustainable electrification scheme must be developed in a cost-effective manner (Mentis, 2016).

Hydropower is among the most efficient technologies for production of renewable electrical energy, with a typical efficiency of 90% (Killingtveit, 2019). In 2015, 16.6% of electricity produced worldwide comes from hydropower. Currently, hydropower accounts for 17% of the electricity generation in Africa on average (IEA, 2020). Installed electricity capacity of hydropower as of 2017 was 30.4 GW in sub-Sahara Africa, yet 92% of the potential capacity of 300 GW remains untapped (Zhou et al., 2015). Similarly, only about 20% of Nigeria's electricity generation comes from hydropower, mostly large hydropower plants (Kainji, Shiroro, and Jebba hydropower dam). The development of large hydropower plant takes time, requires huge investment, and comes with social and environmental implications or dislocations (Nautiyal, 2012). The current economic challenges faced in the world in general and in Nigeria in particular make investment in large hydropower generation plants become difficult.

Opportunities to improve hydropower electricity generation in most remote areas abound in Africa, especially when developed in small and decentralized scale (Stockholm Environment Institute, 2016). In the presence of current hydrological conditions, small hydropower offers huge opportunities for electricity generation with less cost, time and little or no social and environmental implications (Yadoo and Cruickshank, 2012). Among all non-conventional renewable energy sources, small hydropower (SHP) has the highest density and ranks first in the generation of electricity from renewable sources around the world (Dudhani, et al., 2006). SHP can operate in both isolated and interconnected (connect to nation grid) mode (Yadoo and Cruickshank, 2012). In lieu of the numerous advantages of SHP, Szabo et al. (2011) argued that small-scale hydro is a very suitable option for rural electrification in Africa.

The identification and development of SHP sites have become much faster, cheaper, and cost effective with the advancement in technology, particularly Geographic Information System (GIS). The use of GIS and remote sensing data have been exemplified in local and international studies (Feizizadeh and Haslauer, 2012; Alaxandros et al., 2019, Fasipe and Izinyon, 2021). However, these studies reflect only on the availability of energy potential along river basins and watershed without matching it with energy demand of communities within a reasonable distance. Providing information on the viability of the energy potentials within the source area can stimulate private and government investment in small hydropower plant development. This study is therefore an attempt to showcase a pathway towards effective geospatial assessment of small hydropower potentials and viability for electricity generation in Ogun watershed. The objectives of the study are to:

1. Assess the characteristics of perennial rivers within the watershed;
2. Examine small hydropower potential sites;
3. Examine the energy situation of communities within 2 km radius of the SHP sites; and
4. Determine the viability of the potential SHP sites.

II. *LITERATURE REVIEW*

A. *Concept of Small Hydropower*

Water has been exploited as a source of energy by industry and a small number of utility providers for generations. The creation of hydroelectric electricity on a small scale to serve a local community or industrial operation is known as small hydro (Bhatia, 2014). The definition of a small hydro project varies, although it is widely considered that a producing capacity of up to 10 megawatts (MW) is the upper limit. This might be increased to 30 MW in the US and 50 MW in Canada (Khare et al., 2019). A hydropower plant can be further classified into a mini hydro, which is defined as a plant with an installed capacity of less than 1000 kW, and a micro hydro, which is defined as a plant with an installed capacity of less than 100 kW. A micro hydro is a type of hydroelectric electricity that is designed for a smaller town, single families, or small businesses.

B. *Application of GIS and Remote Sensing to SHP Survey*

Sammartano et al. (2019) identified potential locations of hydropower plants using GIS-based procedure in the Taw at Umberleigh catchment, Southwest England. River flows were used to estimate the river flows for flow duration curve assessment. In order to find suitable hydropower locations in the Mahanadi River basin, Goyal et al. (2015) employed a multi-criteria approach that combined an advanced methodology for geospatial raster/grid data preparation with the SWAT model (India). Kusre et al. (2010) used GIS technologies with the Soil and Water Assessment Tool (SWAT) hydrological model to assess the hydropower potential of a large basin in India, identifying a large number of possible hydropower sites. Pandey et al. (2015) also employed SWAT inside a GIS framework to analyze water availability for hydropower in India's Mat River basin. The SWAT model has been widely utilized to simulate hydrological processes in a variety of research, resulting in accurate river flow estimates in ungauged basins (Stehr et al., 2008; Memarian et al., 2014; Omani et al., 2017).

C. *Energy Consumption Pattern in Ogun State and Other Regions of the World*

According to IBEDC (2017), the average electricity consumption per annum in Ogun State is 7.5x107 kWh. This translates to an average of 27 kWh (Table 1) per capita per annum. The annual per capita energy consumption is only about 19% of the national average of 145 kWh. This is an indication of the level of energy poverty experienced in Ogun State, particularly in the rural areas beyond the reach of the poor electricity distribution network. The average electricity consumption in Sub-Saharan Africa is 487 kWh, 705 kWh in South Asia, 6022 kWh in European Union countries and 13254 in North America (IEA, 2014). According to IEA (2014), the world electricity consumption is estimated as 3128 kWh. Based on the foregoing analysis, it can be observed that only 5.7% of Sub-Saharan Africa's average electricity consumption is available to residents in Ogun state, 1.7% of European countries, 0.2% of North America, and 0.9% of the world electricity consumption average. Indeed, this poor performance in energy access has great implication on the social and economic development of the people, particularly the rural populace. There is need for improved electricity generation and distribution in Ogun State in particular and Nigeria at large if the sustainable development goal 7 (SDG 7) must be achieved before 2030.

TABLE I: AVERAGE REGIONAL ELECTRICITY CONSUMPTION PATTERN IN THE WORLD

Regions	Avg. Electricity Consumed per capita (kWh)	Source	Relative
Ogun State	27.6	Ibadan Electricity Distribution Company (IBEDC, 2017)	0
Nigeria	120-145	Worlddata.info; IEA, 2014	19.0
Sub-Sahara Africa (excluding South Africa)	180	African Development Bank Group (ADBG, 2022)	5.7
South Asia	705	IEA, 2014	3.9
East Asia and the Pacific	3665	IEA, 2014	0.8
North America	13254	IEA, 2014	0.2
Europe	1581	Eurostat, 2019	1.7
European Union	6022	IEA, 2014	0.5
World	3128	IEA, 2014	0.9

III. STUDY AREA AND METHODOLOGY

A. Study Area

Ogun State is one of the thirty-six states of Nigeria and it is located in the southwest region of the country (Figure 1). Ogun State is bordered by the former capital of Nigeria, Lagos state to the south, Oyo and Osun States to the North, Ondo State, and Republic of Benin to the west. Abeokuta is the administrative Capital of Ogun State and is the most populous city in the state. It has an estimated land area of 16,762 km2 and a projected population of 6.15 million people as at the end of 2021. Ogun State has high concentration of industries notable among which are Dangote cement and Coleman Cables among others.

The high population of people and industries imply high demand for energy for domestic and industrial use. The major rivers in Ogun state include Rivers Ogun, Osun, Oyan and Oni. Ogun State has a tropical climate in general. The average monthly temperature varies from 23°C in July to 32°C in February, with the wet season lasting from March to November and the dry season lasting from December to February (Azodo, 2014). Because of the high temperature in the area, electric fans and air conditioners are required for space cooling.

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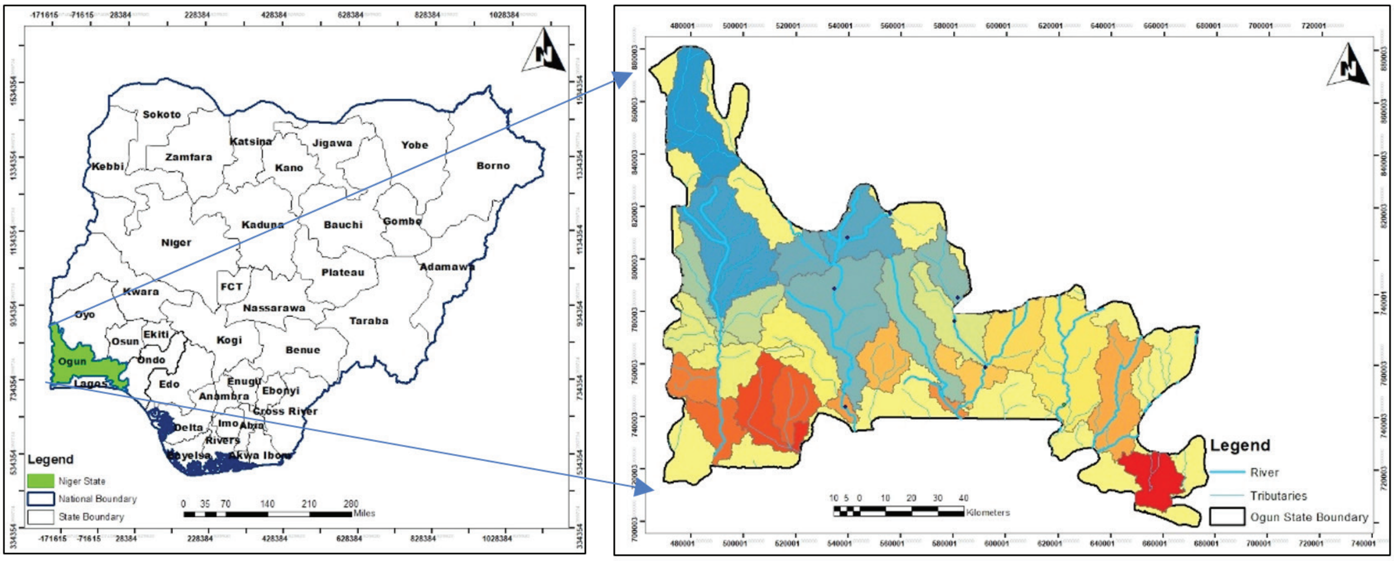

Fig. 1. Ogun State Watershed in the Context of Nigeria

B. Methodology

The concept of hydropower is predicated on the ability of water to be dropped from a high level to a low level, the pressure that emanates from this fall can be converted to mechanical energy which can be used to drive electric generator (Fraenkel et al., 1991). In this study, hydropower potential sites were identified using GIS and remote sensing approach. Shuttle Radar Topographic Mission (SRTM) was downloaded form United States Geological Survey (USGS) from which the Digital Elevation Model (DEM) of high spatial resolution of 0.00083 degrees was derived. The overall value of theoretical hydropower potential for that place is computed by adding up each individual hydropower value (based on equiareal raster cells). The DEM derived was masked with the administrative boundary of the study area. The DEM was load into ArcGIS 10.8 environment for spatial analysis. The spatial analyst tools used include hydrology, map algebra, neighbourhood, and conditional function tools. The DEM was subjected to fill, flow direction, and flow accumulation function under the hydrology tool to derive the amount of runoff per raster cell (m). Stream networks in elevation models are defined using the flow accumulation function. The accumulated flow is calculated using the weight of each cell flowing into each raster cell. Higher flow accumulation values represent sinks in a given location, and lower accumulation values represent peaks. In this example, the accumulation raster is weighted by the amount of potentially available water in the area under consideration, which is represented by the direct runoff data's integer dataset. The sum of water accumulated in each raster cell, which corresponds to the mass of water (m), is the output of the flow accumulation function (density of water x runoff).

Secondly, on the digital elevation data, a focal statistics function is used. This is a function that computes the necessary statistics (i.e., minimum, maximum, total of all values) for the cells that surround each particular cell. The minimal function in modern analysis is applied to a rectangle containing 3*3 cells around each cell which are used to find the minimum cells around each raster cell (lowest neighbouring cells). Consequently, the derive minimum neighbours were subtracted from the DEM to determine the drop in elevation of each cell to its minimum neighbours (gradient of fall). The output is called the "head" which is the height value and one of the variables required for the calculation of potential energy. Using the energy equation advanced by Carroll et al. (2004) which is mathematically expressed in equation (1), the energy potential of the identified site was derived.

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(1) $E= m * g * h$

*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 * 1012)*

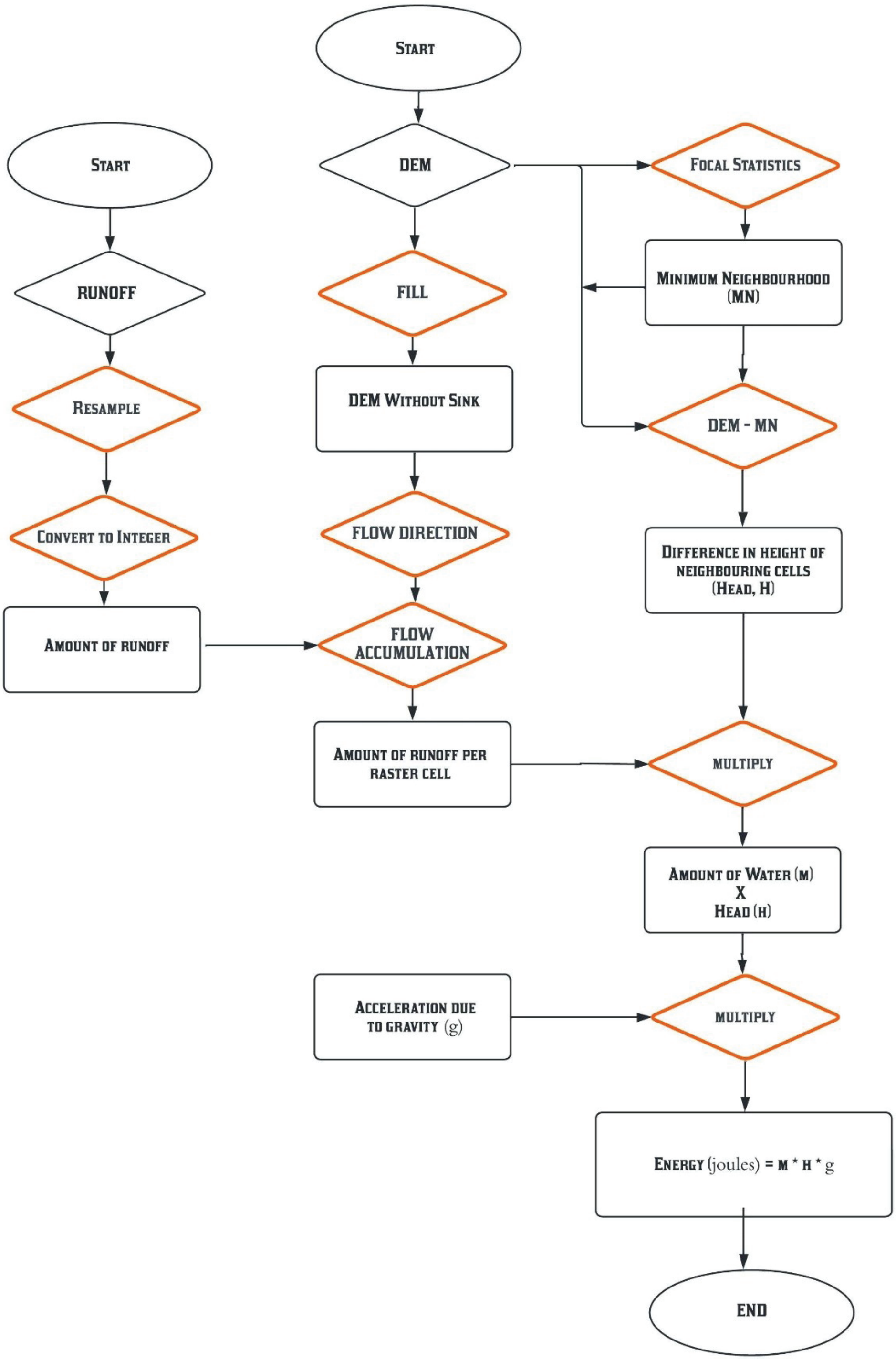

Fig. 2. Flow Chart of the Research Methodology
Source: Adapted from Feizizadeh and Haslauer (2012)

1. *Estimating Electricity Threshold Required to Meet SDG 7*

Energy reliability, affordability, 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 acceptable electricity 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

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a minimum threshold of 250 and 500 kWh/year for rural and urban households (assumed to be five persons), respectively. Similarly, Brecha (2019) also argued that a minimum electricity threshold of at least 400k Wh is close to meeting the outcomes of SDG 7. Based on the economic dynamics and rural nature of most communities within five-kilometre radius of the identified SHP potential sites in Ogun State, the IEA minimum threshold value of 250 kWh per household (five persons) will be adopted as the minimum energy threshold for energy analysis in Ogun Watershed.

IV. RESULTS AND DISCUSSION

A. Characteristics of the River Channel

The study identified and ground trothed six permanent and perennial rivers in Ogun State. These are Rivers Ogun, Oshun, Oyan, Oni, and two rivers with unknown name and hence were named unknown I, and unknown II. The length of the six Rivers ranges from 12.4km – 79km. The minimum elevation level along the six Rivers ranges from 3.4 m – 21.8 m, while a maximum elevation range of 74.0 m – 214.4 m (Table 2). The slope characteristics of the rivers in degrees ranges from 0.000804 - 0.001778. Based on the slope characteristics along the stream, a total of 137 potential small hydropower potential sites were identified. Fifty-five (55) of the potential sites were identified along River Ogun, 32 and 19 on River Oshun, and Oyan respectively. The “unknown” Rivers had 24 potential sites cumulatively, and 7 potential sites on River Oni. The results revealed that the development of small hydropower plant will be more viable on Rivers Ogun and Oshun owing to the large number of potential sites available along the water channel.

TABLE II: CHARACTERISTICS OF STREAM NETWORK IN OGUN WATERSHED

River	Stream length in km	Max Elev (m)	Min Elev (m)	No Hydropower Site	Average Bed Slope
OGUN	79	214.4	15.1	55	0.000804
OYAN	24.4	91	33.7	19	0.001554
Unknown I	17.6	76.1	16.8	8	0.001778
OSHUN	58.2	84.2	3.4	32	0.001256
Unknown II	36	74	14.8	16	0.001534
ONI	12.4	107.3	21.8	7	0.001464
Total				137	

Note: Elev= Elevation

B. Potential Small Hydropower Sites in Ogun Watershed

The potential small hydropower energy sites identified in Ogun watershed along the six primary streams identified in Ogun watershed is presented in Table III. The study established that about 224.7 MW of electricity can be generated from the watershed. The minimum energy potential along the river channels is 500 kW along river Ogun, and a maximum of 5.80 MW on the same stream. Ogun River had a potential energy of 75.4 MW, Oshun 67.5 MW, and 20.4 MW from River Oyan. These three Rivers accounted for about 81% of the potential energy estimated in the watershed. Potential energy identified along unknown River I and II are 5 MW and 26.3 MW respectively, while potential energy of 7.6 MW was estimated along Oni River. Table III further shows the average distance between the identified potential sites of the small hydropower plants. The average spacing between the potential sites ranges from a minimum of 1.61 km along River Oyan to a maximum of 2.2 km along Unknown River I. The spatial distribution of the potential small hydropower sites is depicted in Figure 3.

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TABLE III: DISTRIBUTION OF ENERGY POTENTIALS IN OGUN WATERSHED

River	MIN (MW)	MAX (MW)	PWR_(MW)	Ave. Spacing between plants
OGUN	0.502	5.798	75.4	1.74
OYAN	0.573	7.24	20.4	1.61
UNK River I	0.512	0.926	5.01	2.2
OSHUN	0.529	5.483	67.5	1.88
UNK River II	0.533	2.912	26.3	2.25
ONI	0.516	1.519	7.6	1.77
Total			**202.2**	

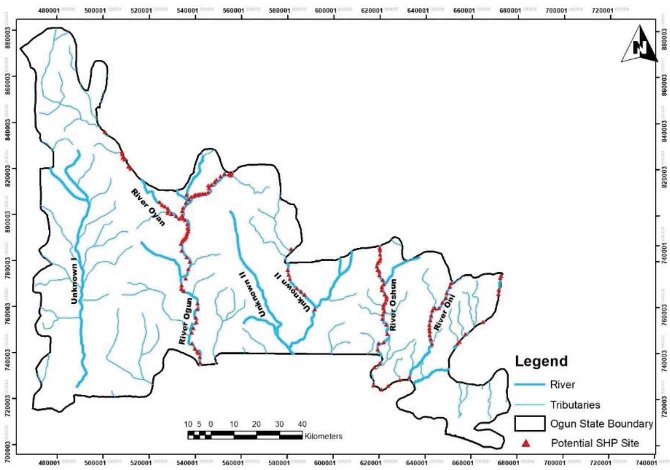

Fig.3. Spatial Distribution of Small Hydropower Potential Sites

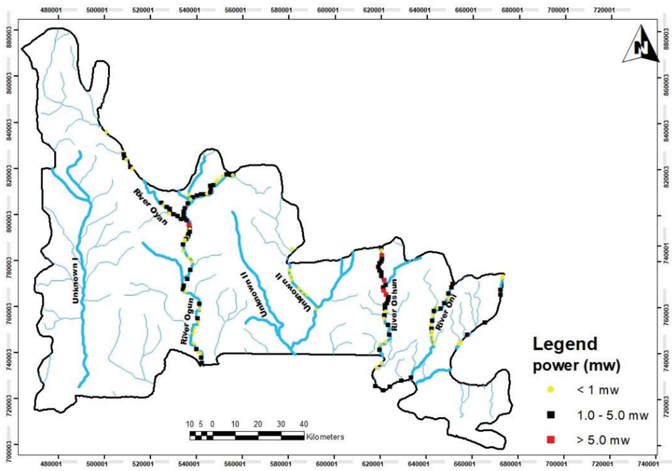

Fig 4. Classess of Small Hydropower Potential Sites in Ogun Watershed

The potential small hydropower sites identified were classified into three; less than 1 MW (1000 Kilowatts), 1-5 mw, and above 5 MW. Table IV shows the three classes of hydropower sites. A total of 59 sites had electricity potential of less than 1 MW (1000 kWh) with a cumulative energy potential of 39.5 MW, 73 SHP sites had between 1-5 MW electricity potential and cumulative energy potential of 136 MW, while only five SHP sites had electricity potential of more than 5 MW but less than 10 MW and a cumulative energy potential of 26.7 MW. Four of the five potential sites were located along river Oshun and one on river Ogun. The spatial distribution pattern of the potential hydropower site based on the three categories identified is depicted in Figure 4.

TABLE IV: NUMBER OF SMALL HYDROPOWER SITES BY CATEGORY OF ENERGY POTENTIALS

River	Frequency	Percent	Cumulative Energy Potential (MW)
Below 1 mw	59	43	39.5
1.0 – 5.0 mw	73	53	136
Above 5 mw <10mw	5	4	26.7
Total	**137**	**100**	**202.2**

C. Energy Access Situation of Communities along Rivers in Ogun Watershed

A total of 76 communities were identified within 2 km radius of the six rivers (Table V).. Therefore, the connection to grid and average daily electricity access of the communities were assessed. The result revealed that 73 of the total communities identified were rural, mostly hamlets and small villages, while three communities were urban. It is instructive to report that the 73 rural communities along the river course were not connected to the national grid and hence do not have access to public electricity. Only the urban communities along the river course were connected to the national grid. The study also established that only an average of 3-6 hours of electricity is enjoyed daily in the urban communities intermittently during the day. This shows that all the communities within two-kilometre radius of the potential SHP sites are energy poor. Therefore, demand for electricity within reasonable distance of the SHP sites is expected from the communities.

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TABLE V: ENERGY SITUATION OF COMMUNITIES ALONG THE RIVERS IN OGUN WATERSHED

River	Communities	E.A Status	Daily Duration of Electricity
Rural	73 (96%)	Not Connected	0
Urban	3 (17%)	Connected	3-6
Total	**76 (100%)**		

D. Estimated Rural Household Population that can be Connected in Ogun Watershed

Small hydropower potential sites are distributed across ten of the twenty Local Government Areas (LGAs) in Ogun State. 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 250 kWh on a daily basis. This is equivalent to an average daily electricity access of 0.68 kWh per capita and 3.4 kWh per household per day. The number of households that can be served with the electricity potentials estimated within the ten LGAs is provided in Table VI. The energy potentials estimated in Ogun watershed can support 59,471 households at 100% performance of the potential sites. In Ijebu east LGA, 20,059 households can be provided with minimum energy of 250 kWh and this population is equivalent to 59.8% of the projected household population in the LGA. The energy potentials in Ijebu North, Odeda, and Abeokuta North can support a minimum household population of 10,382, 9,265, and 7,206, respectively. The energy potentials available in Odogbolu LGA can support a minimum of 147 households which is equivalent to only about 0.4% of the projected household population. The energy potentials estimated in the LGAs can support a population of 297355 persons with minimum energy services like lighting, fan, phones, and television. This will no doubt provide opportunity for many households in the remote communities within the services radius of the potential sites to have access to electricity and hence reduce energy poverty within the LGAs, and Ogun watershed at large.

TABLE VI: ESTIMATED RURAL HOUSEHOLD POPULATION THAT CAN BE ELECTRIFIED

LGAs	Prj. HH POP	Energy Potential (kWh)	Est HH to be served	% HH POP
Abeokuta South	61047	9900	2,912	4.8
Abeokuta North	76862	24500	7,206	9.4
Odeda	33633	31500	9,265	27.5
Obafemi Owode	72187	11900	3,500	4.8
Ifo	165572	10500	3,088	1.9
Remo north	18349	1900	559	3.0
Ijebu North	86144	35300	10,382	12.1
Ijebu East	33571	68200	20,059	59.8
Imoko East	25473	8000	2,353	9.2
Odegbolu	38588	500	147	0.4
Total	**611425**	**202200.0**	**59, 471**	**9.7**

Prj = Projected; HH= Household; POP= Population

V. *CONCLUSION AND RECOMMENDATIONS*

The results have shown that GIS and remote sensing data can provide the requisite technology needed to identify potential sites in a cheaper and simpler 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 the outlet of watershed. The available small hydropower potentials estimated in Ogun Watershed is expected to stimulate efforts towards identifying small hydropower potentials in the country with a view to harnessing the same for rural electrification, especially with the increasing demand for clean and sustainable energy. Based on the current energy situation of the communities identified within 2 km radius of the site, the potential energy from the SHP sites are economically viable for development by government and private investors. The development of the small hydropower potentials is estimated to provide a minimum of 250 kWh for up to 59,471 households in Ogun Watershed. This implies that SHP within this area can serve as a tool for energy poverty and carbon footprint reduction in the communities identified. Harnessing the small hydropower potential across the country provides a huge prospect for the attainment of SDGs 7 and 13 and facilitates the achievement in education, health, and production, thereby leading to increase the wellbeing of the population and higher gross domestic product for the country. This study therefore recommends the decentralization of electricity generation in the country in order to allow for adequate investment in small hydropower potentials across the 36 states of Nigeria. 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.

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