Multi-criteria Evaluation of sites for Small Hydropower Energy Potential in Eastern Nigeria Using Geospatial Technology.

Ndukwe E. CHIEMELU & Ugonna C. NKWUNONWO

Summary

Efforts at advancing the various ways of developing energies that are environmentally friendly have been a national and global concern. Small hydropower energy is one of such energies and its potential in Eastern region of Nigeria, is being explored. This study was aimed at employing the geospatial tools at evaluating sites with the potentials of small hydropower energy within the study area. The research adopted the Multi-Criteria Decision Making ModelBuilder - a geoprocessing research tool of ArcGIS 10.1 GIS software – for data processing, analysis and suitable sites selection. The datasets used are: the Advanced Spaceborne Thermal Emission and Reflection Radiometer- (ASTER) Digital Elevation Model (DEM) of 30m resolution, the National Forest Reserve shapefile of the study area and the Nigeria river map, which was acquired and re-sampled into one kilometer by one kilometer (1km x 1km) pixels in order to determine the 1km river reach. The combination of the slope factor map with the river reach produces the slope for every one kilometer of the river reach. The results showed the small hydropower energy potentials map of eastern Nigeria. The criteria for generation of Small Hydropower potential map were: river reach of 1km, slope ≥ 30% and forest reserve exclusion, with suitable areas lying more in Bayelsa and Rivers States over an area of 19,700 Ha or 0.2% or the entire area.

Keywords: Geospatial Technology, Modelbuilder, River Reach, Multi-criteria Decision, Eastern Nigeria

1.0 INTRODUCTION

Hydropower energy is the energy generated by harnessing the resources from the water bodies (made up of streams and rivers) as they flow along their courses usually from the regions of higher elevation to that of lower elevation as a result of gravitational pull. It is one of the very important sources of renewable energy. Before the discovery and adoption of small hydropower plants, the application of large hydropower plants required storage of stream water with its consequent occasional negative environmental impact. According to Fosnight et al (2010), small hydropower offer opportunity to provide off grid power in remote areas where the installation of power grids is often prohibitively expensive. From the small hydropower assessment studies carried out by SWERA in Guatemala and Ethiopia; reported in Fosnight et al (2010), the determination of the resource potential requires the calculation of the drop in elevation and the estimation of the potentially available stream flow.

1.1 Historical Background of Hydropower

Two thousand years ago, the Greeks began to employ the power of running water to turn the massive wheels that rotated the shafts of their wheat flour grinders. And in the hydropower heydays of the 18th century, thousands of towns and cities worldwide were located around small hydropower sites. Today, small hydropower projects offer emissions-free power solutions for many remote communities throughout the world such as those in Nepal, India, China, Iran and Peru as well as for highly industrialized countries, like the United States. In Nigeria, according to Sambo (2009), the potential of Small Hydropower is enormous but not yet harnessed. The simple fact is that what is presently obtainable in Nigeria is the large scale hydropower with all its' environmental consequences. In Nigeria, the long awaited solution to the lingering rural electrification project issues was propounded by Sambo A.S. when he posited in Sambo (2005) that with the large network of rivers in the country, renewable energy potentials of the small hydropower system could be harnessed and converted to electrical energy. At present, the high hydropower potential of Nigeria makes it to account for about 29% of the total electrical power supply. (Sambo, 2005) together with (Aliyu and Elegba, 1990) agreed that the overall hydropower resources potentially exploited in Nigeria is in excess of 11,000MW. While writing on the viability of small hydropower development in Nigeria, Sambo (2009), posited that SHP potential sites exist in virtually all parts of Nigeria with an estimated capacity of 3,500MW. Findings from the studies carried out in 12 states and 4 river basins, according to him, identified over 278 unexploited SHP sites with total potential of 734.3MV.

1.2 GIS and site selection

According to Chiemelu et al (2021) the ability to identify where things are located has been a very important tool in the hands of planners and policymakers. This is so because adequate knowledge of the resources available within an area of interest is very vital in decision-making, especially with regards to decisions to either harness it or not. Geospatial technologies such as GIS and Remote Sensing have globally proved relevant in the evaluation of renewable energy resources. GIS applications have been used to provide crucial information for decision-making, which support site selection procedures in various research areas such as natural resources management, environmental pollution and hazard control, regional planning, urban development, and utilities management (Aydin, 2009). The deployment of geospatial techniques for environmental modelling such as site selection usually involves the integration of various environmental variables (factors) (Ebistu, et al, 2013). Geoprocessing tool such as ArcGIS Model Builder is commonly used to integrate various variables used in Multi Criteria Analysis. Hence, we used this method to develop the geospatial-based SHP energy decision support system in the study. According to Zeleny 1982, the term "multiple criteria decision making" (MCDM) indicates a concern with the general class of problems that involve multiple attributes, objectives, and goals. Attributes are the characteristics of objects in the real world. These attributes can be specified "in relative independence from the decision maker's needs or desires." MCDSS can be broadly categorized into the following: data-oriented MCDSS, utilizing multi-attribute decision making models; and model-oriented MCDSS, utilizing multiple objective decision making models (Chiemelu, et al 2021)

In this research, we aim to use key geospatial techniques (GIS and remote sensing) to identify suitable sites for small hydropower (SHP) energy generation in the Eastern Nigeria. The objectives of the study include the: i.) production of the 1km river reach within the study area – as the major potential from Nigeria river map; ii), development of a geospatial model that would deploy the major potential and other environmental variables such as slope and forest reserve exclusion to determine SHP energy potentials in the region; and iii), production of maps of SHP energy potentials in the region.

2.0 HYDROPOWER MODELS

In the SWERA model, the hydropower potential of the stream was assessed using the synthetic stream flow data and elevation drops estimated from the DEM. Stream flow estimates for every 1-km river segment was used for the assessment of the hydropower. The hydropower for the river segments was then estimated as:

$$P = (H_{ij})(q_{ij})(p)(g10^{-6}) \quad \ldots \quad (1.0)$$

Where q_{ij} is the stream flow of the segment of interest (m^3/sec) gotten from

$$q_{ij} = (FACC_{ij} / FACC_i)\ Q_i \quad \ldots \quad (2)$$

$FACC_{ij}$ is the area of the contributing watershed above the segment, $FACC_i$ the flow accumulation of the basin outlet, Q_i basin simulated stream flow (m^3/sec).
P = hydropower potential (MW), H is hydraulic head (m) of the stream segment,
p is the water density of 1000 kg/m3, and g is gravitational acceleration of 9.81m/s^2 (Fosnight et al., 2010).
According to Meijer (2013), the definition of hydropower is the generation of electricity by means of a turbine, derived from the energy of water (m^3/s) over a certain Head difference (m). The general Formula for hydropower that applies here is;

$$\text{Hydropower (kW)} = \eta(\%)\ g\left(\frac{m}{s^2}\right)\ Q\left(\frac{m^3}{s}\right)\ \Delta H\ (m) \quad \ldots \quad (3)$$

Source: (Meijer, 2013)
Where η = Turbine Efficiency, which is a variable depending on many Parameters. The highest efficiency is obtained when a turbine is used in an optimal configuration.
g = Gravity Acceleration
Q = Discharge (m^3/s)
ΔH = Head difference (m)
Remote sensing and GIS have been applied in the selection of sites suitable for installing small hydropower plants. They have utilized to arrive at various alternative sites available in the study area as well as to select the most technically suitable site. This view was further buttressed by some other authors (Kumar, et al., 2002; Chakrabarti, 2002), who opined that RS and GIS can play a vital role in scientific assessment of the suitable sites in inaccessible mountainous areas, which no other method can provide. Buehler, 2011 in his study titles "Analyzing the Potential for Small

Hydroelectric Power Installment in the Dominican Republic", applied the combination of both the remote sensing and GIS tools to locate the potential of small hydropower with his study area. In his work, the GIS spatial analysis tool was used to generate the rivers, the watershed and the slope. Using the ModelBuilder to add up these factors through raster calculations, the locations of high small hydro-power potentials were extracted. Meijer, (2013) in her work on World Hydropower Capacity Evaluation, was aimed at giving insight in the potential of hydropower for a specific region and distinguishes micro, small and large hydropower. In order to evaluate the global hydropower potential a systematical method was developed to simulate input data and check whether there is hydropower at a specific location. Ballance et al, (2000) in their work titled "A geographic information systems analysis of hydro power potential in South Africa" used GIS analysis to determine the steep gradient.

3.0 MATERIALS AND METHODS

3.1 Study Area

The study area, which is the Eastern region of Nigeria is shown in the figure below. Geographical location: by latitudes 4°15'N and 7°10'N and longitudes 5°25'E and 9°30'E. It measures about 88,812 sq. km and has a population of around 30 million people. The states that fall within this region are: Abia, Akwa-Ibom, Anambra, Bayelsa, Cross-River, Ebonyi, Enugu, Imo and Rivers. The climate is Tropical rainforest or the Equatorial monson with a very small temperature range. It is imperative to note that the southern border of the region is the Atlantic Ocean into which the major river tributaries flowing through the region enter.

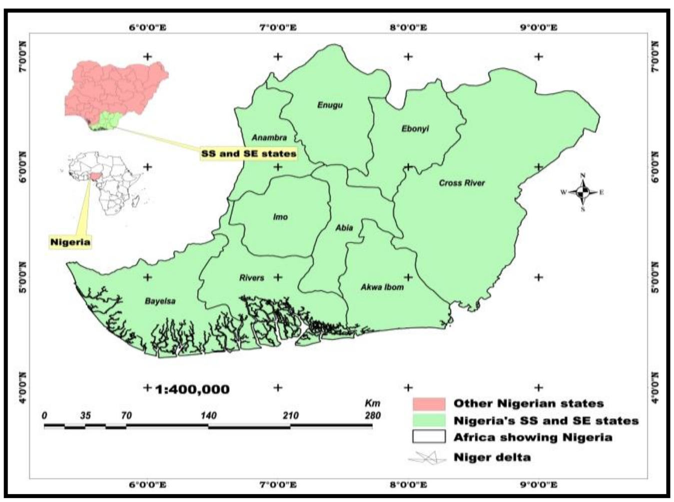

Figure 1. Map of the study area showing the various states. Maps of Africa and Nigeria are inset. (source: Chiemelu, et al. 2021)

3.2 Materials

3.2.1 Basic SHP Potential

The basic requirement for determining suitable locations for harnessing small hydropower resources is the flow velocity of a non-seasonal flowing river. The velocity of flow is a factor closely bond with the slope of the flow line. When water is flowing from a region of high elevation to that of low elevation, there is usually an increase in the velocity of flow at that point.
The approach adopted was to look for the combination of sustainable high flow rates and steep gradients with which to create the necessary head for micro-hydro power generation. The low flow characteristics of the river or stream were also investigated to ensure sites had reliable dry season flows, in order to provide power all year round. The next step was to calculate energy potential, using Equation (7). In engineering designs, flow values are often determined per 1,000m of river reach. As the data had been supplied at 400 m intervals, it was re-sampled to 1,000 m intervals using inherent GIS functions:

$$AEPL(kWh\ yr^{-1}) = 9.8(ms^{-2}) \times \tan(\Theta) \times Reach \times MAFV\ (m^3)/3,600\ (s) \quad \ldots (7)$$

Source: (Ballance et al, 2000)

where: AEPL = Local Annual Energy Potential, in kilowatt hours per year
9.8 = acceleration due to gravity, in meters per second squared
Θ = river gradient in radians
Reach = river reach length (1,000 m)
MAFV = mean annual flow volume per km^2 of catchment, in meters cubed
3,600 = the number of seconds per hour.

3.2.2 Other Environmental Conditions

Other environmental conditions that are taken into account when locating optimal sites for small hydropower energy include, the slope of the river flow, the volume of flow, exclusion of forest reserve and built-up areas.

Major site selection criteria considered for this study are as shown in Table 1 below:

Renewable Energy Resources	**Considered Factors**	**Selection Criteria**	**Sources**
Small Hydropower	Rivers/ Water bodies (Major)	1km Reach	Balance et al., 2000; Punys et al., 2011; Fosnight et al., 2010
	Slope	>= 30%	Meijer, 2013; Balance et al., 2000; Boustani, 2009. Santasmita et al, 2006
	Forest Reserve	Exclusion	Tanutpongpalin et al, 2004

(Source: From Literatures)

3.3 Methods

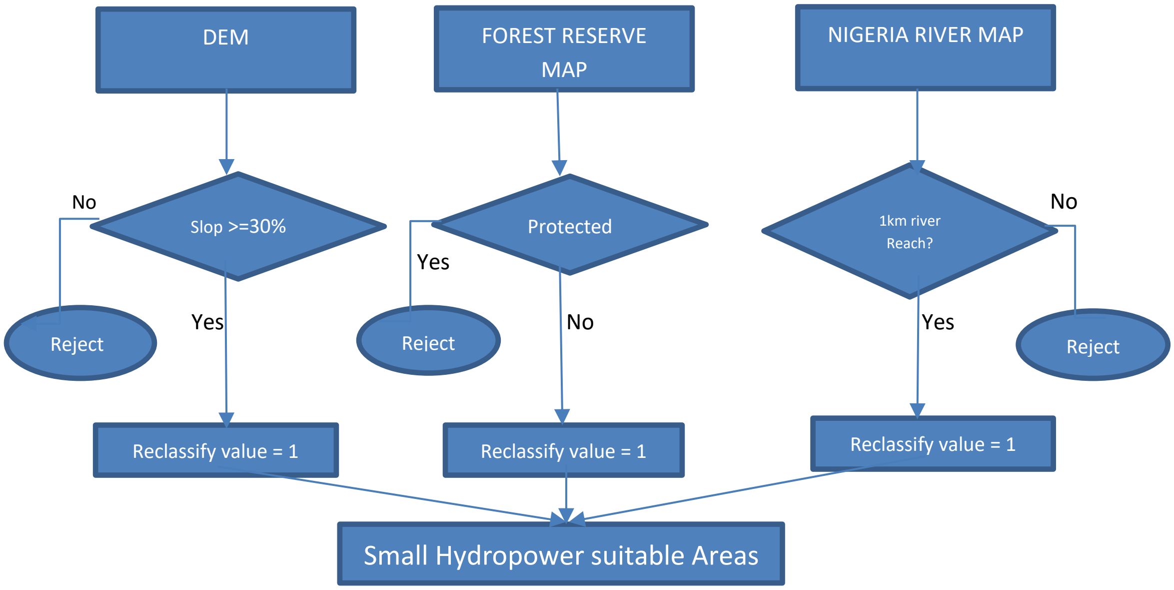

Figure 2 Flowchart summarizing key steps of the methodology

3.3.1 Implementing MCDSS Using ModelBuilder

ArcGIS 10.1 software geoprocessing tool known as modelbuilder was employed for integrating various multiple criteria elements in an overlay function. It was used to develop the multi-criteria decision support system used in the study. A Multi-Criteria Decision Support System (MCDSS) can be defined as a Multi-Criteria Decision Making (MCDM) model embedded in a Decision Support System (DSS) to solve various semi-structured and unstructured decisions involving multiple attributes or multiple objectives or both. According to Zeleny, the term “multiple criteria decision making” (MCDM) indicates a concern with the general class of problems that involve multiple attributes, objectives, and goals. Attributes are the characteristics of objects in the real world. These attributes can be specified “in relative independence from the decision maker’s needs or desires.” MCDSS can be broadly categorized into the following: data-oriented MCDSS utilizing multi-attribute decision making models; model-oriented MCDSS utilizing multiple objective decision making models (Eom et al., 1987; Zeleny, 1982; Eom, 2011)

ModelBuilder is a GIS graphical programming system available in ArcGIS series. This system can be used to string together data, ArcGIS tools, scripts, and external programs into a single application. ModelBuilder can be used to create elaborate GIS applications in a fraction of the time that it would have taken using older programming systems. Its capability of combining multi-criteria factors in arriving at a decision is very valuable to decision makers.

Small hydropower energy potential site suitability was determined through the combination of major criterion factor – the river reach – with other environmental factor maps. Basically small hydropower derives good potential in areas where there are waterfalls, i.e. in rivers with continuous flow where water flows from high to low platform. For small hydropower project, no water reservoir tank or water storage or dam is needed, which is usually the case with big hydropower projects. In order to determine the suitable sites in this study, Nigerian river map was acquired and re-sampled into one kilometer by one kilometer (1km x 1km) pixels in order to determine the 1km river reach. The combination of the slope factor map with the river reach produces the slope for every one kilometer of the river reach.

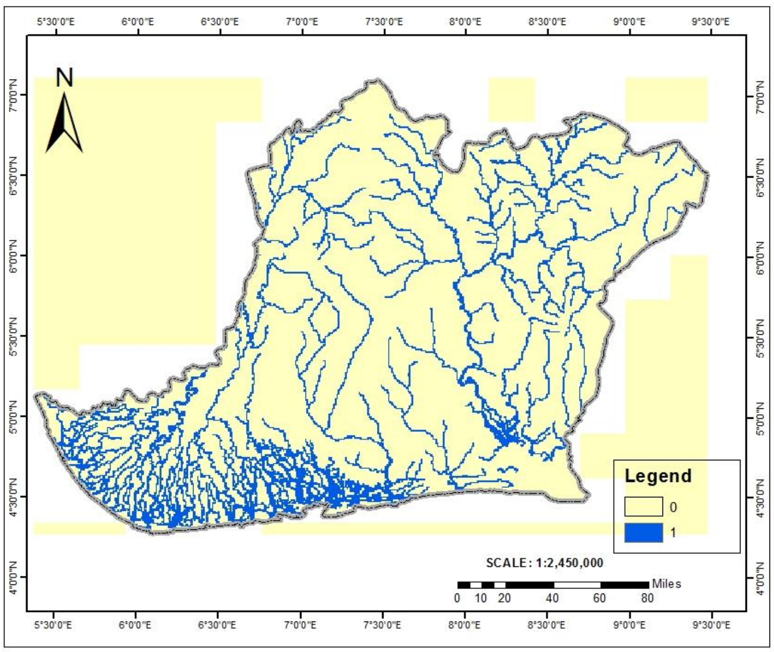

Figure 3 Eastern Nigerian Rivers (Source: DEM; GIS lab, UNEC)

3.3.2 Model Simulation for suitable river

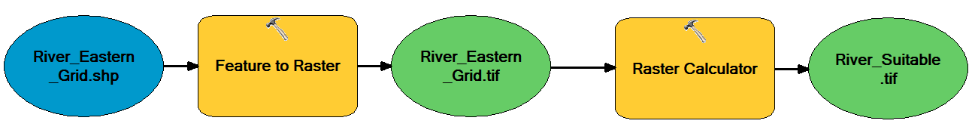

Figure 4: The geoprocessing model used to derive the River suitability factor map

Model for river suitability is shown in figure 4 above. In this model, the input data is represented as River_Eastern_Grid.shp, which is the shapefile of the rivers within the study area after it had been grided using 1km by 1km grid. Feature to raster tool was used to convert it to raster before carrying out the raster calculation. This statement was used in the raster calculation:

"%River_Eastern_Grid.tif%" == 1 … (8)

This statement turns all the river suitable areas to 1 meaning acceptance, while the rest becomes zero which means rejection. The result or output is the river suitability factor map shown in the figure 9 below. In other words, the 1km river reach was thus generated

3.3.3 Model Hydro slope suitability

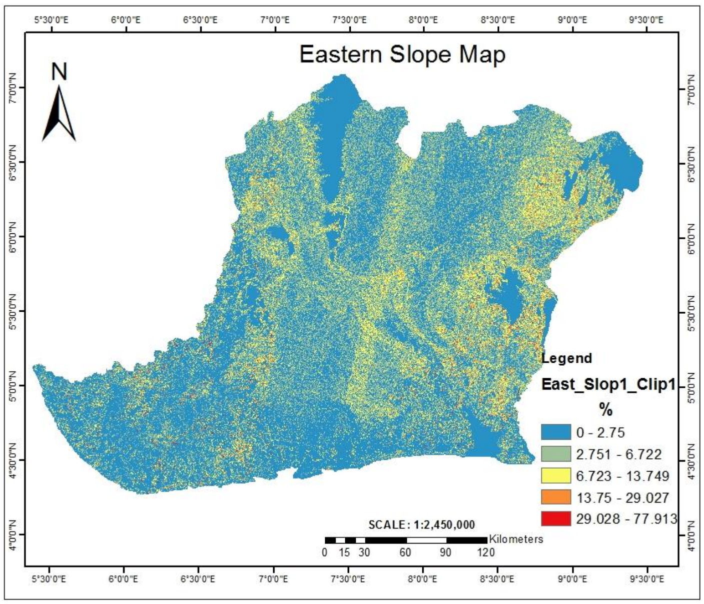

Figure 5: Slope map of the study area generated from ASTER DEM.

The model shown in figure 6 is the model for determining slope suitability factor map for small hydropower resource potential site evaluation. Similar to other slope operations, the input data is the same with others, but the difference is with the value of the acceptable slope. In the case of small

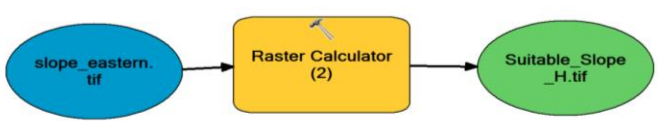

Figure 6 Model for Hydro slope suitability

hydro, the slope condition is equal to or greater than 30%. Hence the raster calculation statement is as thus stated:

"%slope_eastern.tif%" >= 30 (9)

The output or the result of this process is the slope suitability factor map for small hydropower energy. This is as shown in figure 10.

3.3.4 Model for Forest reserve Exclusion

The model for excluded forest reserve is as shown in figure 7 below

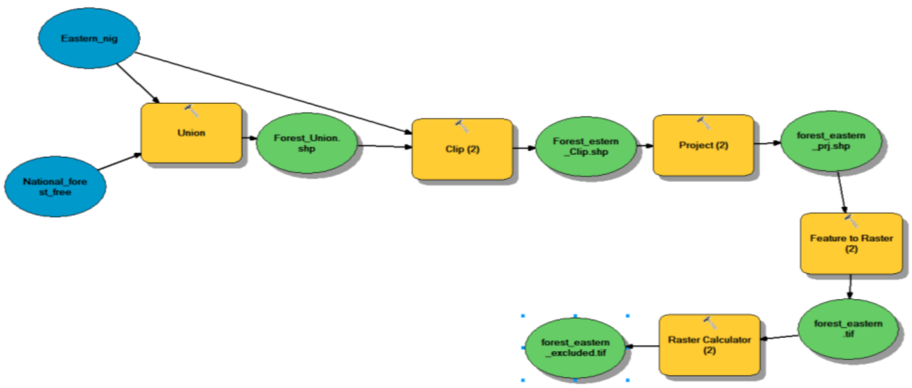

Figure 7. Model for the excluded forest reserve

3.3.5 Final Model for Small hydropower energy potential site suitability

The final model is shown in figure 8, which is the weighted summation of the three factor maps.

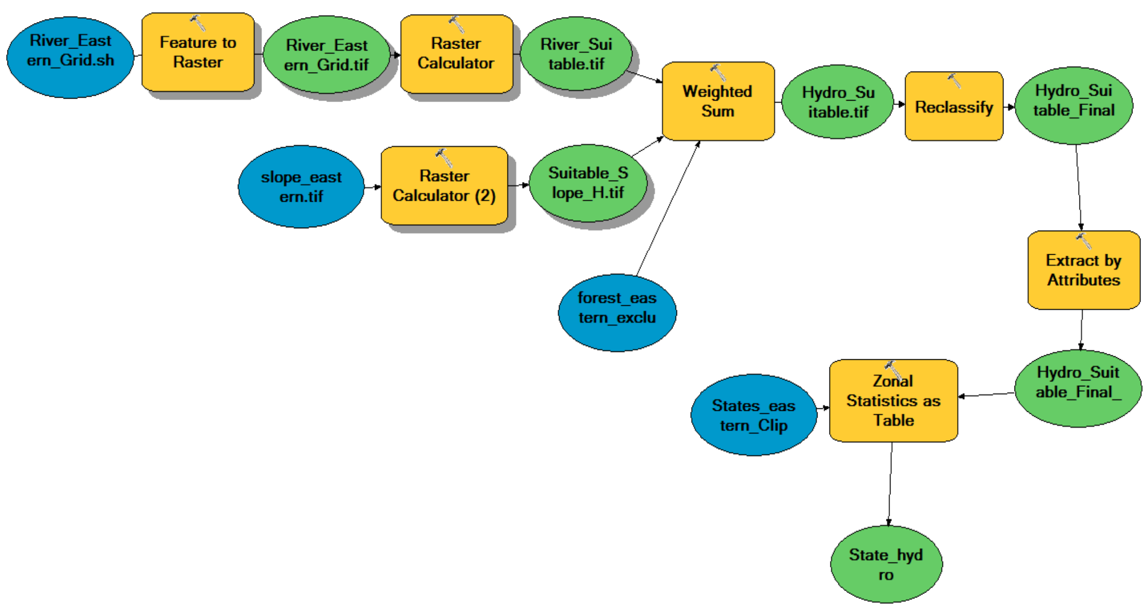

Figure 8: Final model for small hydropower energy potential site suitability and state by state comparison

4.0 RESULTS AND DISCUSSION

Key results from this study are presented in this section. Figure 9 shows the river reach suitability factor map. The areas depicted in blue are the areas with suitable 1km river reach for the region, while the areas depicted in yellow are the areas not within suitability region of river reach and hence were rejected. This rejection is based on the adopted crisp method, and not necessarily that they do not have some levels of the potentials. The fuzzy method, which we do not consider in this study, may have accepted some of those areas. The map shows that states with good cluster of suitable rivers are Bayelsa, Cross River, Rivers and Anambra, while Ebonyi, Enugu, etc, show low clusters values that may not be suitable for large-scale small hydropower energy projects.

Slope factor map shown in figure 10, is a major element in the determination of the small hydropower energy suitable sites, coming second to river reach in ranking. Implementing the model of figure 6 on the slope map of the study area, the suitable slope factor map was produced based on the threshold of equal to or greater than 30% slope.
Parts of the study area excluded because they are forest reserves or protected sites are shown in Figure 11. It could be seen from the map that many parts of Cross River state were excluded, however states such as Imo, Abia and Ebonyi had few exclusions.

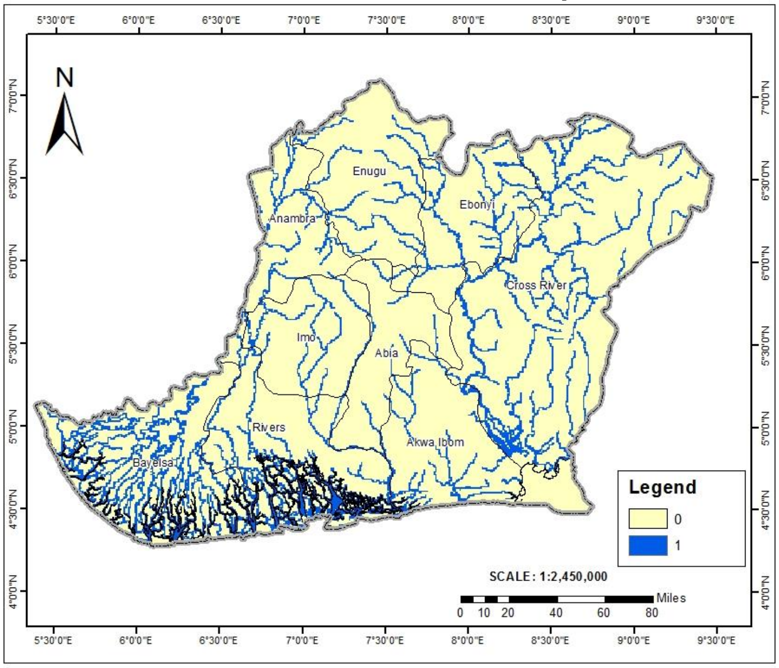

Figure 9: River Suitability Factor Map

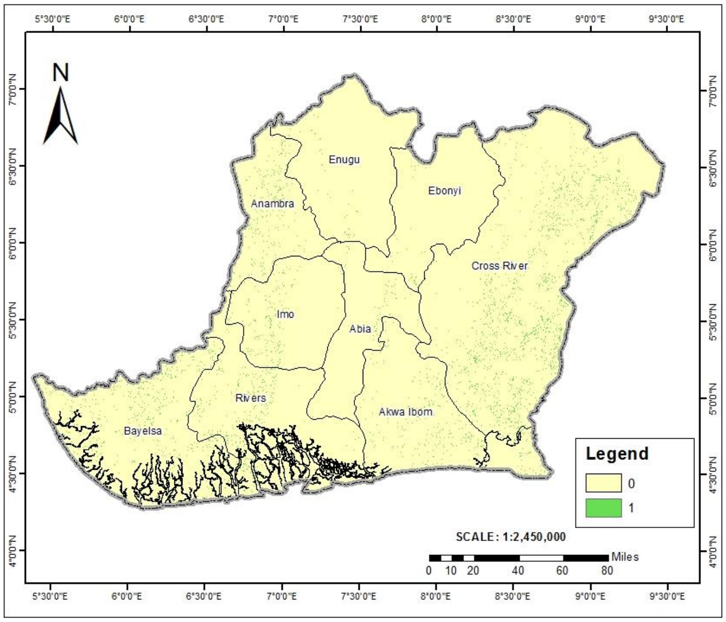

Figure 10: Showing Hydro Slope Suitability Factor Map

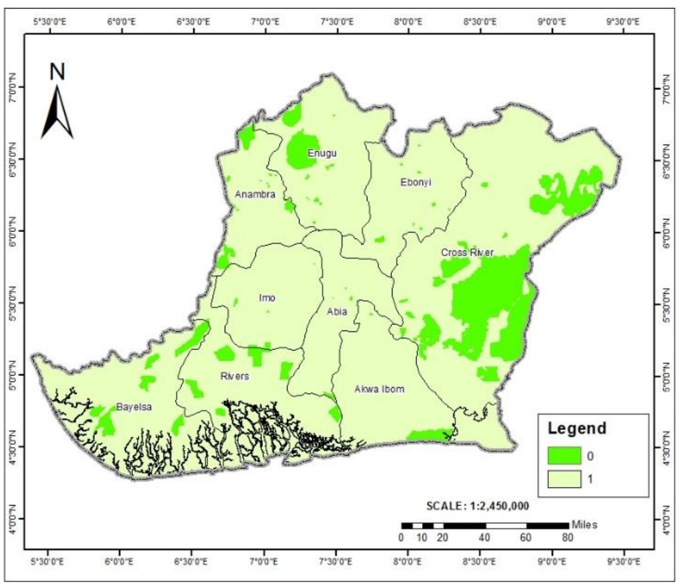

Figure 11 Excluded forest reserve factor map

The final results of the study were presented in graphics, which comprised of maps of the energy potential sites alongside their values in tabular form. This is usually the case with most GIS activities, with results shown in graphics. Graphics could be maps, graphs, tables, charts, etc.

4.1 Small hydropower Sites

From the aggregated model of figure 8, the research final result of the suitable sites for the potentials of small hydropower energy projects for the eastern part of Nigeria was produced. In addition, the states performance based on the suitable areas were also determined.

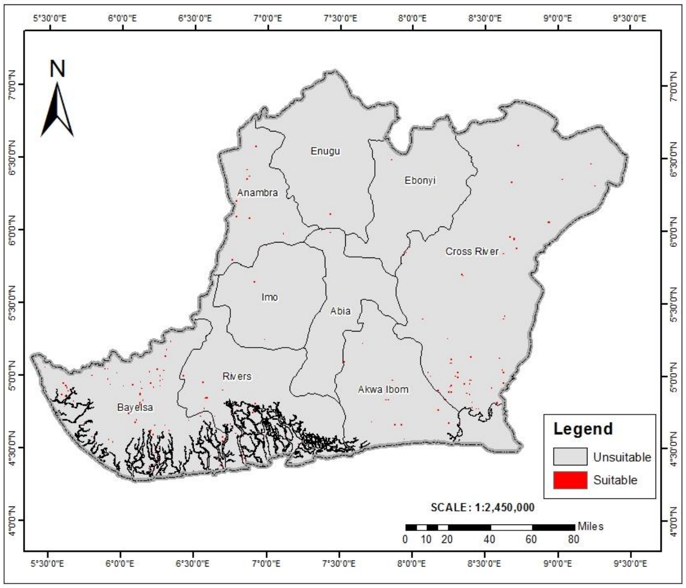

Figure 12 Small Hydropower Potential Map of the Eastern region of Nigeria

Table 2 Showing the Small Hydropower Potential Land Area Values

STATES	COUNT	AREA (Sq.m)
Abia	1	1000000
Akwa Ibom	16	16000000
Anambra	22	22000000
Bayelsa	78	78000000
Ebonyi	1	1000000
Enugu	1	1000000
Imo	3	3000000
Rivers	22	22000000
Cross River	53	53000000
Total		197000000

Source: Result Out-put Table from ArcGIS 10.1

From figure 12 titled ‘Small Hydropower Potential Map of Eastern Nigeria’, and the corresponding Table 2 showing the small hydropower potential land area values, it can easily be deduced that all the sections of the study area have share of the distribution of areas suitable for small hydropower resource exploration. Apart from the northern and the central sections of the study area, which have very few suitable sites, the remaining sections have fairly substantial amount of suitable sites. The states' positions with respect to the values of the areas with suitable potential for small hydropower are as follows: Bayelsa: 78,000,000sq.m or 7,800Ha, Cross-River: 53,000,000sq.m or 5,300Ha, Anambra: 22,000,000sq.m or 2,200Ha, Rivers: 22,000,000sq.m or 2,200Ha, Akwa-Ibom, 16,000,000sq.m or 1,600Ha, Imo: 3,000,000sq.m or 300Ha, Abia: 1,000,000sq.m or 100Ha, Ebonyi: 1,000,000sq.m or 100Ha and Enugu: 1,000,000sq.m or 100Ha. All these add up to bring the total area suitable for small hydropower exploration to 197,000,000sq.m or 19,700Ha. The criteria for generation of small hydropower potential site suitability map are as follows: river reach of 1km, slope of greater or equal to 30% and forest reserve exclusion.

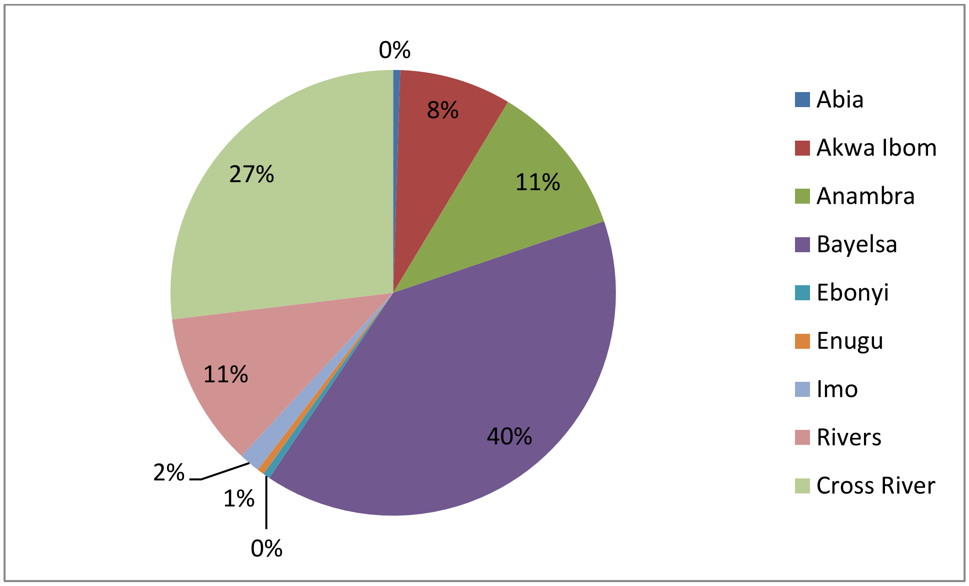

Figure 13 Percentage of Small Hydropower Potential sites in States

5.0 CONCLUSION AND RECOMMENDATION.

This research used geospatial techniques to assess the suitability of the areas within Eastern Nigeria to sustain the generation of small hydropower energy. Eastern Nigerian river map shape file was clipped out from the Nigerian river map, which was downloaded via internet. The Satellite-derived ASTER-DEM was processed in order to produce the slope map of the study area and together with other relevant environmental datasets were used to set up a geospatial multi-criteria model that was used to identify sites suitable for small hydropower energy projects. Many sites within the region exhibited characteristics suitable for small hydropower energy generation. Most of the suitable sites were located in the southern parts of the study area, which are closer to the Atlantic Ocean in the southern borders of the region or connected with the river Niger, which is the biggest river in Nigeria. A total land surface area of 197,000,000sq.m (19,700 hectares) were found to be suitable for small hydropower projects. Results from this study is recommended as a base for further research in these fields towards the development of renewable energy power sector. The outcome of this research is significant as it can motivate small hydropower energy investments in the region, especially as the Nigerian government is actively promoting the development of renewable energy sources to boost the energy security of the country and to reduce impacts of fossil energy on the environment and climate.

REFERENCES

1. Aliyu, U. O. and Elegba, S. B., 1990. 'Prospect for small hydropower develop- ment for rural applications in Nigeria', Nig. Journal of Renewable Energy, Vol.1,Pp.74 - 86
2. Aydin N.Y., 2009. GIS-Based Site Selection Approach for Wind and Solar Energy Systems: A case study from Western Turkey. http://etd.lib.metu.edu.tr/upload/12610774/index.pdf. Accessed 7/7/11
3. Ballance A., Stephenson D., Chapman R.A. and Muller J., 2000. A Geographic Information Systems Analysis of Hydropower Potential in South Africa. Journal of Hydroinformatics. IWA Publishing
4. Boustani, F., 2004. Small Hydropower In South Of Iran, *The 3rd International Conference On Fuel Conservation, 2004*
5. Buehler, D. Blake, 2011. Analyzing the Potential for small hydroelectric power installment in the Dominican Republic. M.Sc. Project. Brigham Young University
6. Chakrabarti.A.K., 2002. Site evaluation for ranking study of potential hydro-power projects: an Indian perspective using spatial technologies, Proceedings of Map India 2002, 6-8 Feb , New Delhi.2002.
7. Chiemelu, N.E., Anejionu, O.C.D., Ndukwu, R.I. & Okeke, F.I., 2021. Assessing the Potentials of Largescale Generation of Solar Energy in Eastern Nigeria with Geospatial Technologies. Scientific African/ Elsevier.
8. Ebistu, T.A and Minale, A.S., 2013 Solid waste dumping site suitability analysis using geographic information system (GIS) and remote sensing for Bahir Dar Town, North Western Ethiopia. African Journal of Environmental Science and Technology. Vol. 7(11), pp 976-989
9. Eom, S.B., 2011. Intellectual Structures of Decision Support Systems Research (1991-2004). In Decision Support an Examination of the DSS Discipline. Vol.14 Springer, USA
10. Eom, H. B., Lee, S. M., Snyder, C. A., and Ford, N. F., 1987. A Multiple Criteria Decision Support System for Global Financial Planning. Journal of Management Information Systems, 4(3), 94–113.
11. Fosnight E.A., Wood E., Gayar O.E., Renne D., Stackhouse P,. Anthony M., Artan G., Cowlin S. and Michels L., 2010. The Solar and Wind Energy Resource Assessment (SWERA) Decision Support System (DSS) Benchmark Report. http://appliedsciences.nasa.gov/pdf/projectreports10/CL-SWERA_benchmarking_report_29sep2010_finalWEB.pdf

12. Meijer L., 2013. WORLD HYDROPOWER CAPACITY EVALUATION_*'A Systematical estimation of the World's micro, small and large hydropower capacities based on a new modeling approach'* . M.Sc. Thesis. Deflt University of Technology.
13. Punys P., Dumbrauskas A., Kvaraciejus A. and Vyciene G., 2011. Tools for Small Hydropower Plant Resource Planning and Development: A Review of Technology and Applications. Energies
14. Sambo A.S., 2005. Renewable Energy for Rural Development: The Nigeria Perspective. ISESCO Science and Technology Vision. Vol.1
15. Sambo A.S., 2009. Strategic Development of Renewable Energy in Nigeria. International Association for Energy Economics.
16. Tanutpongpalin, N., & Chaisomphob, T. 2004. Proposed Methodology for Site Selection of Run-of-river Type Small Hydropower Project Based on Environmental Criteria. The Joint International Conference on "Sustainable Energy and Environment (SEE)", (s. 812-816). Hua Hin, Thailand.
17. Zeleny, M., 1982. Multiple Criteria Decision Making. New York, NY: McGraw-Hill.

Biographies

1. Name: **Ndukwe Emmanuel Chiemelu**

- B.Sc, M.Sc, & PhD
- emmanuel.chiemelu@unn.edu.ng
- Senior Lecturer
- Department of Geoinformatics and Surveying, University of Nigeria

My studies involve Geospatial Science applications in managing the environment and renewable energy potential site investigations.

Skills and expertise

Mapping, Geomatics, Geoinformation, ArcGIS, Spatial Analysis, Satellite ... Analysis, Digital Mapping, Geospatial Science, Satellite ... Processing, Spatial Statistics, Geostatistical Analysis, Geo-processing, Surveying, etc.

Membership of NIS, SURCON, GEOSON, NAGSL,

2. Ugonna Chinonyerem Nkwunonwo
B.Sc, M.Sc & PhD
ugonna.nkwunonwo@unn.edu.ng
Lecturer 1
Department of Geoinformatics & Surveying, University of Nigeria

Ugonna Nkwunonwo specializes in Flood risk management, Food modelling, Remote Sensing, Geographic Information System, Geoinformatics, Geodesy and Surveying. His current project is 'Investigating the Potential for Sustainable Urban Drainage System (SUDS) in the urban areas of Lagos Nigeria.'

Membership of NIS, GEOSON, NAGSL,