GIS and RS Techniques for Identification of Hydropower Potential Sites in Benin-Owena River Basin in Nigeria

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Abstract- Nigeria's overall energy access is 60% with 86% urban and 34% rural rates, and over 20 million households without power in 2018; there is need for continuous investment in Nigeria's energy sector due to the epileptic supply nature. Sustainable way to alleviate poverty in rural communities is to establish clean and affordable energy initiatives. Reports indicated that hydropower is a feasible alternative in Nigeria's South-South geo-political region, with potential for Small Hydropower (SHP) development. In this study, the SHP potentials of Okhunwan river in the Benin-Owena drainage basin, Nigeria is investigated. Discharge was computed by the NRCS-CN model using 2018 monthly PERSIANN-CDR, slope, CN data, etc. as inputs and statistically compared with observed data from gauging station; indicating 0.75 as average correlation between simulated and observed. Validation between NIMET data from Benin City Synoptic station and PERSIANN datasets for Okhunwan sub-basin indicated average spatial correlation coefficients of 0.75. This study utilized GIS spatial data analysis and RS to obtain classification maps (DEM, CN, slope, etc.) where necessary data were extracted to evaluate SHP sites. Thirty-seven hydrometric points were mapped along the tributaries and main river courses of Okhunwan at 2km set points and considering the optimization criteria that a viable SHP site must have 2% minimum slope and 10m available head, 5 points were identified; with power ranging between 149.583 – 16,935.279 kW at 92% flow exceedance annually. The contribution of our study is that the identified SHP will provide electricity and enhance human development index of Benin-Owena river basin residents.

Keywords Hydropower potential, GIS, RS, available head, NRCS-CN model.

1. Introduction

All over the world, energy need and utilization is increasing [1]. Nonetheless, the continent of Africa has poor SHP development. It is expected that Africa's rising need for rural electrification programs can be addressed by incorporating SHP to the energy mix. However, in most developing countries in Sub-Saharan Africa (SSA) especially Nigeria most rivers are ungauged and their streams are not investigated. In the world, SSA has the lowest energy access rates. Only around 50% of the entire SSA populace has access to electricity, about 33% with access to clean cooking. Specifically, approximately 600 million people have no access to electricity and 890 million use traditional fuels with attendant problems for the environment for cooking [2].

Following the development of innovative approaches in satellite data and Remote Sensing (RS), and the ease with which their data can be processed due to the advancement in Geographic Information System (GIS) tools; new opportunities are emerging for hydropower potential assessment [3, 4]. RS and GIS are efficient techniques utilized in hydrological studies. For example, the digital elevation model (DEM) estimated from shuttle radar topography mission (SRTM) can be utilized for calculating the morphometric parameters viz basic linear and shape parameters. Morphometric analysis of a sub-basin may be obtained by the evaluation of linear, areal and relief aspects of the basin and slope contribution. Additionally, the hydrologic process of a basin can be correlated with such morphometric parameters like size, shape, drainage density and the shape of the tributaries.

In developing countries, one of the renewable energy sources feasible for rural electrification is Small Hydropower (SHP) and in fact Africa has a technical hydropower potential of 1,750 TWh, whose share of global capacity approximates 12%. [5, 6]. SHP has been proven to be a technology that is not only capable of contributing to the power needs of developing nations but also adaptable in a number of ways including stand-alone alternative, SHP-integrated central grid or a combination of stand-alone and irrigation system [7].

Renewable energy is now a central concept all over the world, considering its environmental benefits; especially its insignificant Greenhouse Gas Emission (GHG) [8, 9]. Renewable energy is an infinite source of energy, which may be sometimes discontinuous, with minimal pollution and near-zero environmental impacts [10]. The five basic renewable energy sources include: solar, wind, hydro (inclusive of ocean and tidal wave), biomass and geothermal. Many developing countries like Nigeria can meet their target of expanding access to affordable and dependable energy using renewable and sustainable energy technologies [11]. In accordance with the United Nations Sustainable Development Goal 7, articulating the expansion of access to clean, affordable, dependable energy and security; renewable energy-based production can provide sustainable solutions to achieving this set goal [12, 13]. Today, renewable energy has gone mainstream, justifying most of the additional capacities in power production in the world [14].

According to [15], in 2018; the world's power generation from renewable energy grew to about 2378 GW. Additions of renewable energy production outstripped the combination of nuclear power and fossil fuel installations for the fourth consecutive year in a row. The percentage contribution of hydropower, wind, and solar photovoltaics (PV) in the renewable power mix are respectively 11%, 28% and 55% with PV corresponding to approximately 100 GW. Generally, the share of renewable energy in the world's total installed capacity exceeds 33%, with hydropower Worldwide generation estimated at 4,210 TWh. There is low access to electric power supply in Nigeria due to epileptic supply from the National grid with Nigeria's electric power consumption per capita as of 2014 given as 145 kWh considering other countries like Canada, USA, France, South Africa with 15,588 kWh, 12,994 kWh, 6,940 kWh and 4,198kWh respectively [16]. The concept of harnessing Small hydropower (SHP) resources is feasible and can become an appropriate alternative for energy management in Nigeria's rural areas with reduced energy access through the use of off-grid systems owing to the huge potential of river systems which have not been investigated considering the fact that Nigeria SHP potential is around 3500 MW out of which only 64.2 MW has been developed [17].

Okhunwan sub-basin lacks electricity for small-scale industries and social services such as education and health care. Also, the level of agricultural production is poor which is contributing to household food insecurity. There is need to provide electricity for domestic applications which will, in turn, reduce indoor air pollution; and the search for fuelwood that contributes to deforestation rate. In this study, hydropower potentials of Okhunwan river in the Benin-Owena River Basin (Fig.1) in Nigeria is assessed using RS, GIS, and hydrological models-based Natural Resources Conservation Service – Curve Number (NRCS-CN) approaches for the purpose of determining the potential of harnessing SHP for the betterment of rural communities in a poorly gauged basin in order to increase energy access.

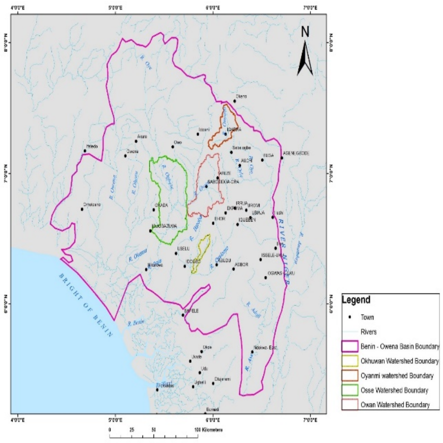

Fig. 1. Benin-Owena river basin map showing Okhunwan sub-basin.

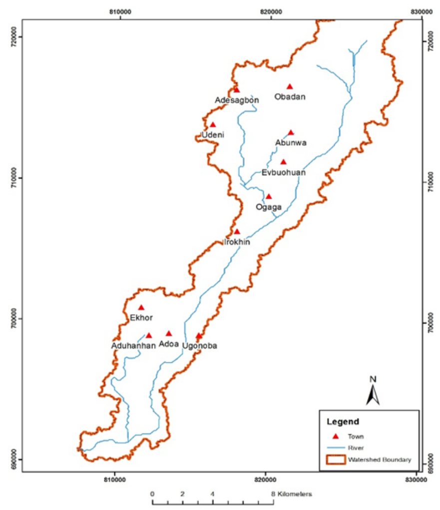

Fig. 2. Okhunwan sub-basin watershed map.

Table 1. Data, sources, purpose and softwares

S/N	Data	Purpose	Source
1.	Field measurement of streamflow for 2018	Evaluates the suitability of simulated streamflow for use in computing hydropower potential	Fieldwork, Benin-Owena River Basin Development Authority (BORBDA)
2.	Landsat 8 satellite imagery (30m Resolution)	Used to derive the land cover type within the basin and to generate the curve numbers	United States geological survey (USGS)
3.	SRTM Data (30m DEM resolution)	To determine the slope and topographical characteristics of the basin	USGS
4.	Harmonized world soil database (HWSD) v1.2	To determine the soil parameters which are required for runoff estimation	Food and agriculture organization of the United Nations (FAO) /United Nations educational, scientific and cultural organization (UNESCO)
5.	Precipitation data	Extraction/analysis of rainfall-runoff relationship	Precipitation estimation from remotely sensed information using artificial neural networks (PERSIANN)-Climate Data Record (CDR) Nigerian metrological agency (NIMET)
		Software used	
6.	ArcGIS 10.1	Generating development plans for the basin area in accordance with the production potential and limitation of terrain resources	ESRI (Environmental systems research institute)
7.	MS Excel 2016	For statistical analysis of data	Microsoft

2. Materials and Methods

The research study area is in Benin-Owena River Basin Catchment Area situated within the Western Littoral Hydrological Area HA-6 which is one of the eight hydrological areas into which Nigeria is subdivided. Okhunwan sub-basins (Fig.2) in the Benin-Owena River Basin Catchment is on 6°31'32.119" & 6°14'11.73" North Latitude and 5°58'42.373"& 5°45'56.915"East Longitude with sub-basin area of 195.75km^2, elevation variation which lies between 25 - 209 metres above sea level (masl); a general slope of 0% -20.66 with Land Use Land Cover (LULC) that varies from dense and mixed vegetation to build up areas characterized by loamy and sandy loam soil. Different data required for use in this study, source and purpose are listed in Table 1.

As the study was aimed at achieving spatial discharge and hydropower potential within the Okhunwan sub-basin, the sub-basin was mapped out along the main river course and tributaries at 2km interval. In all, 37 hydrometric points were identified at 2km interval and using RS & GIS necessary data needed for computation using NRSC-CN method such as CN, Slope, Elevation, Sub-basin area, River length and Rainfall intensity specific to each of the points were acquired. The Rainfall data for the year 2018 was collected from PERSIANN-CDR and the validity of the data was tested with the NIMET data from Benin city Synoptic station due to its proximity to study site before being used as an input data towards calculating the runoff depth (Q_d) and peak discharge (Q_p). The obtained monthly simulated peak discharge was also validated with the hydrometric measurement from the gauging station established at Abunwa town in the sub-basin for a period of 1 year (January to December, 2018) where hydrometric measurements were taken for the purpose of comparison with simulated data obtained using NRCS-CN method.

GIS and RS were used to generate required information on classification maps of LULC, hydrological soil group (HSG) type and ground surface condition. These data were integrated into a GIS environment, for a quick and accurate evaluation of the runoff curve number of each mapped out hydrometric points in the streams. Other classification maps generated via RS and GIS techniques include DEM to estimate change in elevation between points and establish flow direction, Slope for the purpose of knowing if the sub-basin can support hydropower development, rainfall for obtaining the monthly and annual rainfall and which area had more downpour than the others. From the CN map generated, CN values were obtained to calculate maximum potential retention (S) given by the relation [18].

$$S = \frac{2500}{CN} - 254 \qquad (1)$$

where S is potential maximum retention (mm); CN is Curve Number. Runoff depth values of the streams at 2 km points within the study area were evaluated for each rainfall event using the Natural resources conservation service curve number (NRCS-CN) method [18] in equation 2.

$$Q_d = \frac{(P - 0.2S)}{(P + 0.8S)} \qquad (2)$$

Q_d is runoff depth (mm); P is rainfall (mm) and S is the initial abstraction of rainfall by soil and vegetation (mm).

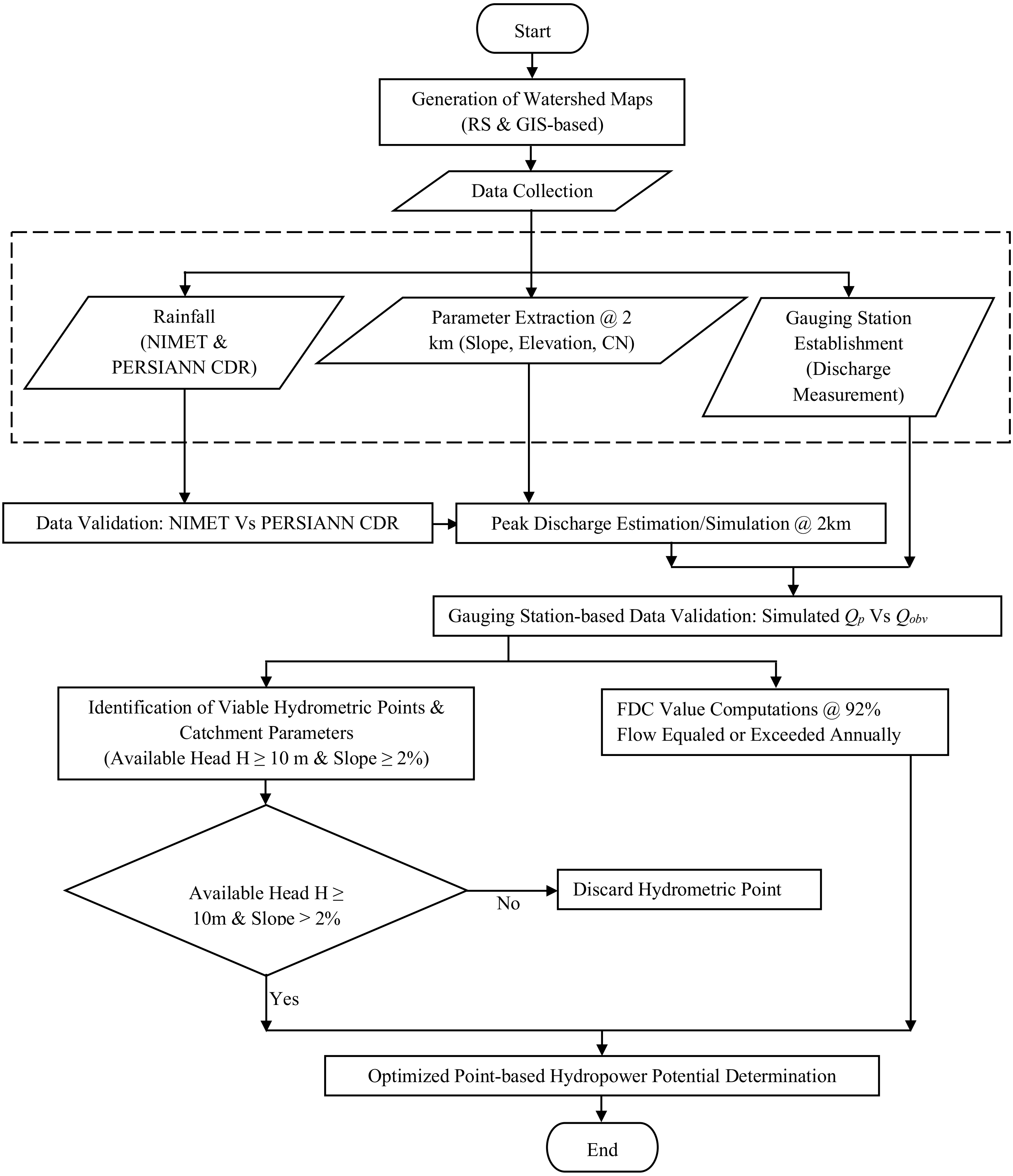

Fig. 3. Flow diagram of the methodology.

After generating Q_d, the next stage is to compute Peak discharge Q_p for the stream on yearly and monthly bases as presented in [19].

$$Q_p = \frac{(2.083AQ_d)}{t_p} \tag{3}$$

Q_p is peak runoff rate unit hydrograph (m^3/s), and t_p is time to peak runoff unit hydrograph (*h*). In equation 3, the only unknown variable is time to peak tp, and this was evaluated using the relationship between time of concentration tc and tp. The relationship between tp and tc is as given in equation 4 [20];

$$NRCS\ t_p = 0.6t_c \tag{4}$$

The value of t_c was obtained using equation 5 [21]:

$$t_c = 0.0526[(1000/CN - 9)]L^{0.8}S^{-0.5} \tag{5}$$

where t_c is time of concentration (hr), CN = curve number

L = flow length, (ft), S = average watershed slope, (%), which is equal to H/L, where H is the elevation difference between the basin's most remote point and the outlet. The variables to evaluate the time of concentration were obtained from the topographic maps. The values of tp and peak runoff rate Q_p were computed subsequently. On determination of flow exceedance or design discharge (Q) at each town which was adopted as Q_{92}, the run of river (RoR) hydropower potential was calculated using equation 6 [22] and Fig.3 shows the methodology flow diagram:

$$P(kW) = 7 \times Q_{92}(m^3) \times H(m) \tag{6}$$

3. Results and Discussion

3.1.1 Okhunwan Sub-Catchment Area Characteristics

The Sub-catchment area characteristics consisting of DEM classification map, Rainfall classification map, Soil classification map, Slope classification map, LULC classification map and CN classification map for Okhunwan sub-basin are presented in Fig.4., Fig.5., Fig.6, Fig.7., Fig.8. and Fig.9. respectively.

3.1.1.1 DEM Classification Map

The digital elevation map allows for rapid visual inspection of the DEM classes presented in Table 2 that show up and extraction of spot heights at 2 km points for this study. DEM also assists in identifying the direction of the maximum rate of change in elevation and determines the direction of water flow across a surface. DEM represents a very important geospatial data type in the analysis and modeling of different hydrological and ecological phenomenon which are required in preserving our immediate environment.

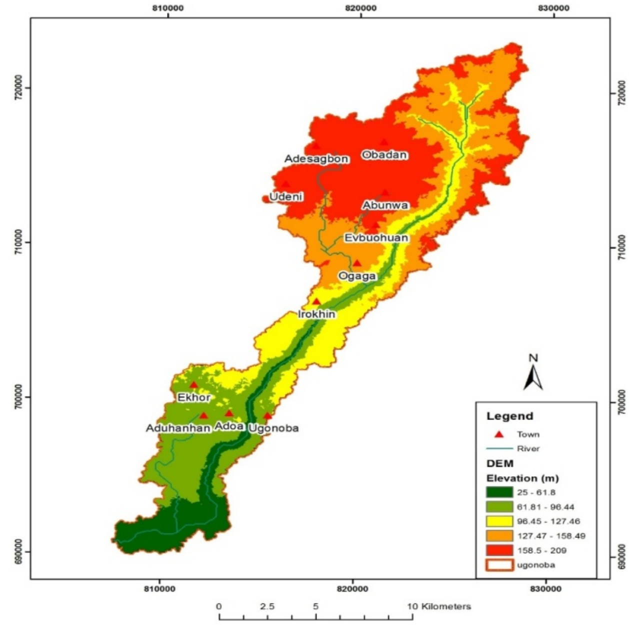

Fig. 4. Okhunwan sub-basin DEM classification map.

Table 2. Okhunwan catchment DEM characteristics parameters

DEM class size	Area covered (m^2)	Percentage (%)
25 - 61.8	18231300	9.90
61.81 - 96.44	38241900	20.76
96.45 - 127.46	30517200	16.56
127.47 - 158.49	45435600	24.66
158.5 - 209	51801300	28.12

Table 2 shows that a significant level of elevation which is a function of power potential exists in the sub-basin that can provide a minimum 10m gross hydropower head standard set for this research.

3.1.1.2 Rainfall Classification Map

The Rainfall classification map for Okhunwan sub-basin is presented in the map given in Fig.5. The rainfall classification map shows the range of average amount expected in a single rainfall event spatially over the sub-basin between 25.13 mm to 33.58 mm which can be classified on the average as moderately heavy rain [23] and this cumulated into annual rainfall range over the Okhunwan sub-basin as 2214 mm – 2452 mm. Rainfall data is one of the meteorological parameters that have a greater bearing on the livelihood of individual world over. Exact interpretation of the historical and spatial allocation of precipitation is a critical input parameter for hydrologic replication and validation. In this study, rainfall data were classified according to spatial variation over the sub-basin to show that some parts of the sub-basin had more rainfall than other parts considering the ranges displayed.

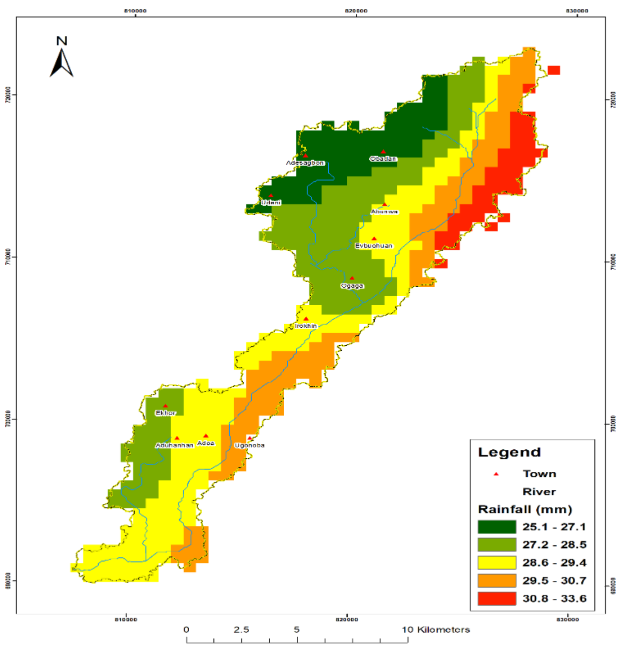

Fig. 5. Okhunwan sub-basin rainfall classification map.

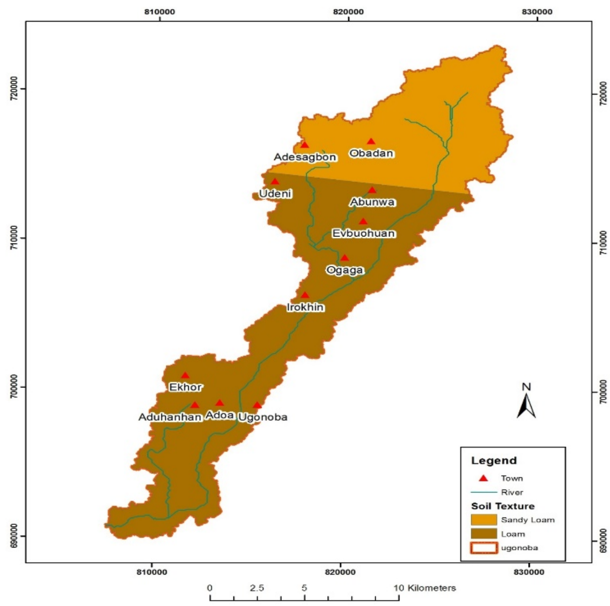

Fig. 6. Okhunwan sub-basin soil classification map.

3.1.1.3 Soil Classification Map

GIS-based soil information systems at different scales were of immense help in the characterization process of Okhunwan sub-basins soil profile and determination of geologic information for the study. Soil map of the study sub-basin was used to identify the hydrologic soil group (HSG) present in sub-catchment and the identified soil texture have direct influence on runoff volumes, infiltration and percolation. The identified soil texture for Okhunwan sub-basin are Loam and sandy loam as shown in Fig.6 while Table 3 shows the Hydrologic Soil Group (HSG) present in Okhunwan sub-basin.

Table 3. Classification of Okhunwan sub-basin HSG-based on USDA soil classification

HSG	Soil texture	Identified soil texture
A	Sand, loamy, or sandy loam	✓
B	Silt or loam	✓
C	Sandy clay loam	-
D	Clay loam, sit clay loam, sandy clay, silty clay	-

3.1.1.4 Slope Classification Map

Slopes maps and its configuration are commonly used to describe the hydrologic drainage structure of an area or a catchment. The shape, length and angle of a slope are connected with the velocity of runoff and to the water penetration into the soil. The slope is an indicator of energy gradient and impacts flow erosivity. Slope curvature is significant for soil mapping since it controls the flow direction of water in terms of convergence or divergence (tangential curvature) and it can accelerate or decelerate (profile shape). It applies an incredible impact on hillslope procedures, for example, soil and water redistribution, through stream, and vertical infiltration. Table 4 shows on average that the slope in the sub-basin can support hydropower development. Slope values extracted from the slope map produced for this research study serve as input data in the equation to determine time of concentration which helps in determination of real-time runoffs that leads to the conclusion that the lesser the slope value the flatter the topography; the complex or higher the slope value, the sharper the topography as well.

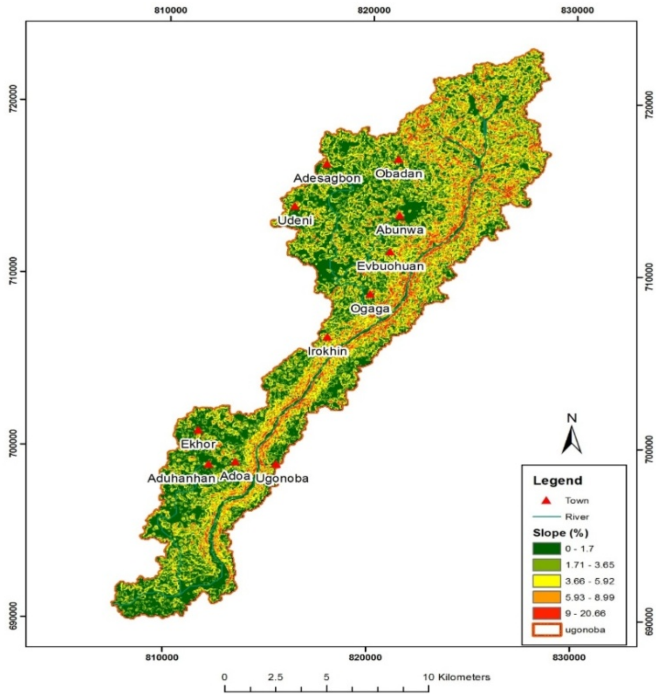

Fig. 7. Okhunwan sub-basin slope classification map.

Table 4. Okhunwan catchment slope characteristics parameters

Slope class size	Area covered (m^2)	Percentage (%)
0-1.7	58030200	31.6
1.71 -3.65	53674200	29.2
3.66 - 5.92	43455600	29.2
5.93 - 8.99	21348000	23.7
9 -20.66	7038900	11.6

3.1.1.5 LULC Classification Map

Figure 8 classified the sub-basin into 3 different categories of Built-up, Mixed and Dense vegetation with Table 5 showing shared percentages on the basis of land treatment practices. It also gives an indication of the geographical features present and factors that influence runoff, interception, time of concentration and CN values of each point generated at 2km interval.

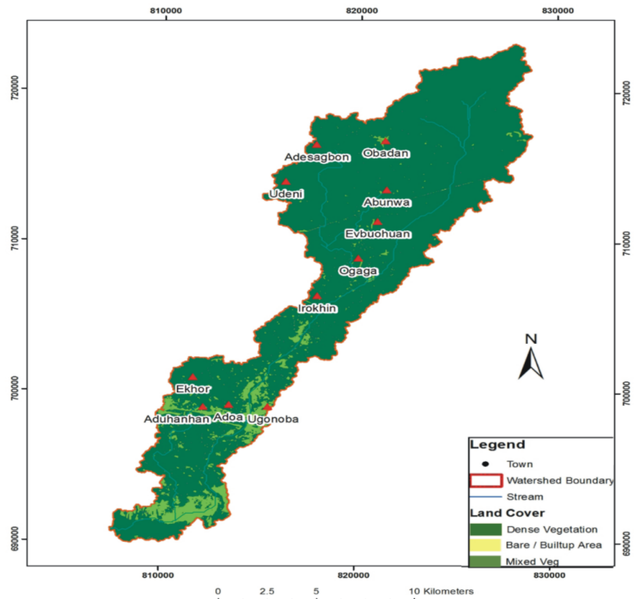

Fig. 8. Okhunwan sub-basin LULC classification map.

Table 5. Okhunwan catchment slope characteristics parameters

LULC class size	Area covered (m^2)	Percentage (%)
Mixed vegitation	15291000	6.90
Dense vegitation	162102600	73.19
Built-up	44100000	19.91

3.1.1.6 CN Classification Map

The CN is a crucial factor to consider for runoff estimation. From Fig.9 it can be seen that CN values of the sub-basin ranked between 26 – 95 with percentages of these parameters summarized in Table 6. Table 6 shows that the sub-basin runoff potentials are still on the low side considering that CN $\leq$ 48 is 83.89% for Okhunwan sub-basin and as a result of this categorization only 6.73% of the area under study fell on very high runoff potential, and 9.37% of study area fell under high runoff potential with moderate and low runoff potential classes occupying 22.15% and 61.74% of the study area respectively.

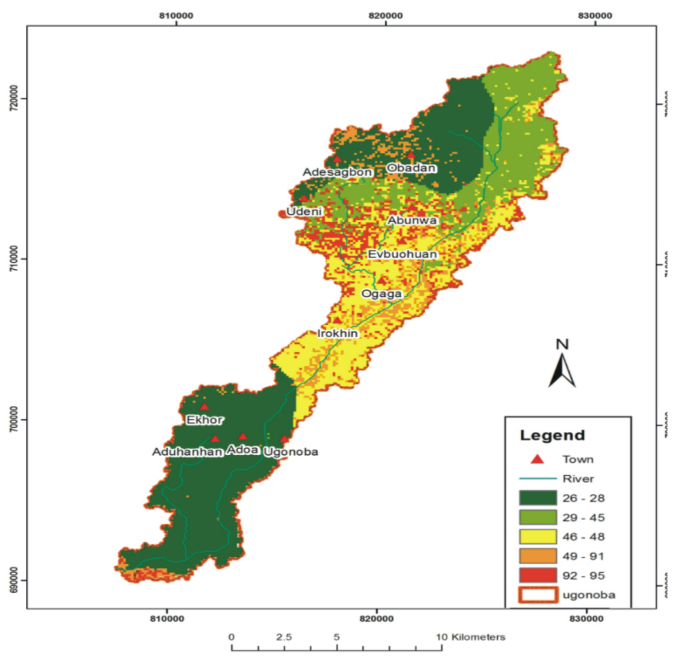

Fig. 9. Okhunwan sub-basin CN classification map.

Table 6. Okhunwan CN characteristics parameter

CN class size	Area covered (m^2)	Percentage (%)
26 - 28	4776300	41.98
29 - 45	2248200	19.76
46 - 48	2520000	22.15
49 - 91	1066500	9.37
92 - 95	765900	6.73

3.2 Result of Rainfall Estimation Comparability in Okhunwan Sub-basin

In this study, PERSIANN 0.25°×0.25° grid cell satellite-based rainfall data of 2018 were validated through comparison with the NIMET surface-based precipitation data from synoptic stations of Benin City as presented in Table 7 for Okhunwan sub-basin.

Table 7. Results of correlation between NIMET and PERSIANN rainfall dataset for Okhunwan sub-basin

Town	Multiple (R)	R^2	Adjusted (R^2)	P-value	Statistical relevance	Remark
Obandan	0.85496678	0.730968195	0.704065015	0.00039	Highly significant	Accepted
Adesagbon	0.861537	0.742246	0.71647	0.00032	Highly significant	Accepted
Abunwa	0.863598	0.745801	0.720381	0.00029	Highly significant	Accepted
Ogaga	0.866907	0.751528	0.726681	0.00026	Highly significant	Accepted
Evbuohuan	0.861977	0.743004	0.717304	0.00031	Highly significant	Accepted
Aduhanhan	0.878391	0.771571	0.748728	0.00071	Highly significant	Accepted
Irokhin	0.87001	0.756918	0.73261	0.00023	Highly significant	Accepted
Ugonoba	0.877127	0.769352	0.746287	0.00081	Highly significant	Accepted
Forest Reserve	0.881347	0.776772	0.754449	0.00015	Highly significant	Accepted

A 12 month precipitation data for year 2018 from NIMET was used to validate PERSIANN datasets in Okhunwan sub-basin using Pearson's product moment correlation statistical approach. On the Average, Okhunwan Sub-basin indicated spatial correlation coefficients of 0.75 to show that the PERSIANN-CDR is reliable with highly significant dependability status.

The results obtained indicated there is advancement in PERSIANN performance in recent years due to the cumulative number of training parameters and indicators of the artificial neural network which use polar-orbit satellite data in the PERSIANN algorithm hence, justifies the adoption of PERSIANN remotely sensed data for this study as against other satellite rainfall estimates such as the tropical rain measurement mission (TRMM), the climate hazards group infrared precipitation with station data (CHIRPS) datasets to mention a few [24].

3.3 Comparison of Measured Data with NRCS-CN Rainfall-Runoff Model in Okhunwan Sub-basin

Table 8 presents the result of the correlation between BORBDA observed data from gauging station for the year 2018 and estimated discharge (NRCS-CN method for Okhunwan sub-catchment) using Pearson's product-moment correlations. In specifics, an average of 75% correlation was registered at Okhunwan sub-basins which proves that the NRSC-CN model can be used to successfully simulate runoff for poorly gauged or ungauged basin. The results of the study show that the GIS and RS basin parameters determined from satellite images such as slope, LULC, are valuable in examining runoff response of ungauged basins. The study reveals there is a complementarity between calculated and observed runoff. The correlation results of estimated discharge across Okhunwan sub-basins are reasonably acceptable; considering statistical tests and p-values as outlined by [25, 26]; that P-values as ≥ 0.05 (not significant), < 0.05 (significant), < 0.02 (highly significant). For estimated discharge correlations; each town's entry p-value alongside the average p-value of the entire sub-basin is well below 2%; culminating into highly significant statistics results and thus the acceptance of the Null hypothesis.

Table 8. Result of correlation between BORBDA and estimated discharge data set for Okhunwan sub-basin

Town	Equation	Multiple R	R^2	Adjusted (R^2)	P-value	Statistical relevance	Remark
Obandan	NRCS-CN	0.85144	0.72494	0.69744	0.00044	Highly significant	Accepted
Adesagbon		0.858249	0.736591	0.71025	0.00035	Highly significant	Accepted
Abunwa		0.860501	0.740463	0.714509	0.00033	Highly significant	Accepted
Ogaga		0.863398	0.745455	0.720001	0..00030	Highly significant	Accepted
Evbuohuan		0.858879	0.737674	0.711441	0.00035	Highly significant	Accepted
Aduhanhan		0.875352	0.766241	0.742865	0.00019	Highly significant	Accepted
Irokhin		0.866387	0.750627	0.72569	0.00027	Highly significant	Accepted
Ugonoba		0.872188	0.760712	0.736783	0.00022	Highly significant	Accepted
Forest Reserve		0.876511	0.768272	0.745099	0.00018	Highly significant	Accepted

3.4. Okhunwan Descriptive Statistics of Runoff (Streamflow) Data

The descriptive statistics for streamflow in the Sub-basin of Okhunwan is displayed in Table 9. Streamflow statistics are necessary for evaluating the hydropower potential of a stream seasonally in order to ascertain the amount of water available for generating power. BORBDA data in the first roll represent the descriptive statistics of the observed discharged at the gauging town while spatial discharge calculated across all towns in the sub-basin with NRSC-CN method was also obtained. Essentially, a small standard deviation implies that the values in a statistical data collection are near the mean of the data set on the average, and a large standard deviation implies that the values in the set of data are more distant away from the mean on the average. From Table 9 a look at the standard deviation which measures how converged the set of data are around the mean shows an approximately normal data distribution ($\mu + \sigma$), one standard deviation of the mean values contained about 68% of the set; while two standard deviations represent 95% ($\mu + 2\sigma$); and within three standard deviations signifies about 99.7% ($\mu + 3\sigma$) where μ and σ represent mean and standard deviation correspondingly [26]. Okhunwan sub-catchments recorded the highest mean monthly value of 8093.374 m^3/s, in Adesagbon, while lowest mean monthly value of 265.375m^3/s, was obtained at Forest Reserve. Discharge range for all the town within Okhunwan sub-basins scope between lower and Upper value of 729.936 m^3/s (Forest Reserve) - 21768.505 m^3/s (Adesagbon). The most astounding total discharge was recorded in Adesagbon with a total discharge value of 97120.493 m^3/s and minimum and maximum estimations of 163.138 m^3/s and 21931.643 m^3/s respectively for Okhunwan. This research pointed out that there were decreasing trends for mean monthly flow from September to January while increase occurs from February to August in streamflow and the outcomes of these studies share similarities with documented literature about trend analysis on river streamflow [27]. A contributing piece of this study is the assessment of the seasonal and annual characteristics of discharge potentials for the development of flow duration curves (FDC) to ascertain the volume of flow available per time or could be exceeded.

In conclusion, trends in streamflow of Okhunwan sub-basins were analyzed on an annual and monthly basis. Therefore, this study reveals significant facts about the past and present and predicts future trends that streamflow of the Sub-basins will continue to rise with respect to LULC. Also, trends of the streamflow should be continuously monitored to forecast the future of water resources.

3.5 FDC Analysis for Towns in Okhunwan Sub-basin.

There are no particular rules for time series used in generating flow duration curves (FDC). FDC can be created daily, monthly and yearly for particular streamflow [28]. Table 10 presents the discharge available at 92% of the time in Okhunwan Sub-basin used for the calculation of hydropower potential across viable towns in each sub-basin. A flat FDC was obtained from the plot of FDC across all the towns in Okhunwan sub-basin which suggests a consistent flow with small variations and little noticeable difference between low and high flows over Okhunwan sub-basin. A sharp FDC indicates large flow differences between dry and flood seasons and high variability which is not applicable in this case. [29] adopted 75% dependability over a period of 6 years while this study investigated FDCs at 9 points and embraced 92% dependability over the 12 months of 2018 examined.

Table 9. Descriptive statistics of streamflow for Okhunwan sub-basin

Town	Mean	SD	Variance	Range	Minimum	Maximum	Sum
BORBDA	2708.888	2881.071	8300567.471	8601.841	11.200	8613.041	32506.653
Obandan	4000.839	3721.289	13847989.983	11462.520	3.774	11466.294	48010.074
Adesagbon	8093.374	7039.042	49548109.030	21768.505	163.138	21931.643	97120.493
Abunwa	2586.693	2332.720	5441583.883	7173.269	8.080	7181.348	31040.320
Ogaga	1001.241	901.187	812138.451	2764.458	3.101	2767.558	12014.893
Evbuohuan	842.672	763.626	583123.917	2349.109	2.551	2351.660	10112.060
Aduhanhan	1552.452	1422.409	2023248.516	4287.844	0.233	4288.077	18629.425
Irokhin	1233.000	1108.677	1229164.089	3395.097	3.164	3398.261	14796.003
Ugonoba	713.399	654.988	429009.533	1982.651	0.110	1982.761	8560.785
Forest Reserve	265.375	242.620	58864.628	729.936	0.039	729.975	3184.501

Table 10. FDC Q_{92} for towns in Okhunwan sub-basin

Town	Q_{92} Flow equaled or exceeded (m^3/s)
Obadan	14.08582
Adesagbon	201.6105
Abunwa	13.87242
Ogaga	5.327199
Evbuohuan	4.413133
Aduhanhan	1.068451
Irokhin	7.677807
Ugonoba	0.498395
Forest Reserve	0.180555

3.6 Okhunwan Sub-Basin Hydropower Potential

In this study, a total of 37 hydrometric points was mapped out along the main river course and tributaries of Okhunwan sub-basin at 2km set points as presented in Fig.10. using stream index by town name as generated by the GIS tool.

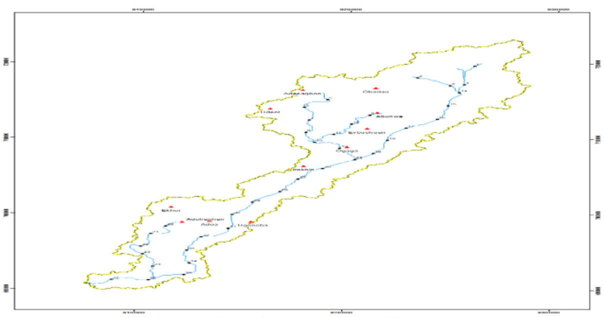

Fig.10. Selected hydropower potential sites in Okhunwan watershed at 2km points.

The choice of 2km set points for this research work is to avoid clustering of the map and notice any significant changes that occur in basing hydrometric indicators if any between two points. Considering the possibility of the basin having similar properties within less than 2km on evaluation, therefore; there is need to enhance the possibility of tying potential points to towns near them and avoid result repetition by selecting points of 2km with higher chance of variable hydrometric properties. After a careful examination of Okhunwan sub-basins hydrometry, an optimization study to determine technical and economically feasible points in Okhunwan sub-basin was carried out by varying the norm proposed by [4, 30]; for the head 20 m to 10 m in the present case and 500m for 2km spacing arrangements to further develop the most favorable basin plan. Also considering and adopting [29], a stream reach is regarded as sufficient for hydropower exploitation when slope is greater than two percent (>2%). Therefore, a stream reach must have a minimum slope of 2% and available head between two ends equivalent to 10m. The practicable point for SHP establishment is the downstream end of the stream. According to [30], in India, year with flow of 90% exceedance is adopted and utilized in the design and planning of hydropower projects. This guarantees adequate flow exists 90% of the time in a year for hydropower generation.

However, having established a strong relationship between the rainfall and discharges in Okhunwan sub-basins, this study recommended the use of the Q_{92} flow statistic obtained from the FDC of relevant towns close to the potential point (flow which is exceeded 92%) as listed in Table 10 and this is adopted for this study in contrast to [29, 30] which adopt 75% and 90% respectively. The choice of 92% flow exceedance is to guide against failed schemes, additionally; it is a common practice among water researchers to establish power potential based on rainfall-runoff model. Considering the yardstick above, 5 potential sites in all were identified in Okhunwan sub-basin and there locations and point numbers along the stream network are shown in Table 11 to enable the determination of hydropower potential using equation 6. The selected turbine from referenced chart [31] are as presented in Table 11.

Table 11. Hydropower potential for Okhunwan sub-basin

S/N	Town	POINTS	X-CORD	Y-CORD	Discharge Q_{92} (m^3/s)	Available head (m)	Power potential (kW) /year	Recommended Turbine
1.	Obandan	3	824891.167	717050.653	14.086	10.000	986.007	Bulb turbine/ propeller
2.	Adesagbon	8	818005.491	710818.817	201.610	12.000	16935.279	Francis
3.	Obandan	14	825335.048	716133.026	14.086	26.000	2563.619	Vertical Kaplan turbine
4.	Aduhanhan	24	810826.563	693029.424	1.068	20.000	149.583	cross flow turbine
5.	Ogaga	25	820402.997	707232.531	5.327	14.000	522.065	Bulb turbine/ propeller

4. Conclusion

Improper modeling and paucity of data are the main reasons for the poor hydrologic analysis in data scares region of Benin-Owena River Basin and Nigeria at large. In such a situation, the reliable solution is the NRCS-CN method which is not too simple to ignore the major processes and yet not requiring very much detail of data that is not available in real-life applications. In this study, various GIS-based spatial tools were utilized in spotting and categorizing potential hydropower sites in Okhunwan Sub-basin. The high-resolution DEM was used appropriately to modeled the watersheds and stream networks. The Run-of-River hydropower potential was estimated using 92% flow available in the sub-basin. Using the analysis of results obtained in this research, the following conclusions are drawn:

- RS and GIS-based applications to delineate slope, flow accumulation, DEM, drainage, contour, watershed maps, flow direction, etc. were very useful in determining SHP installation sites.
- Maps (such as Slope, Elevation, Curve Number, Soil, Stream, and Land Use Land Cover) generated from the application of GIS not only saves time but makes the computations 90% accurate as well as when shifting with respect to reality.
- Despite the very weak hydrological baseline data, the application of a database system for collecting information in combination with an extensive GIS for cross-checking and visualization of the study area was done successfully.
- Applying a transparent and simple ranking methodology allowed an unbiased selection of possible SHP sites. The established ranking method using the group criteria allows further the possibility of conducting a strength, weakness, opportunities and threat (SWOT) analysis of the basin for proper process of Site development and optimal catchment harnessing.
- When comparing the rainfall-runoff results, the month with the highest rainfall and runoff is august.
- It has been observed from the results that places where there is development owning to land use results in high CN which leads to an increase in runoff.
- Composite CN II value is determined for each sub-basin by integrating LULC and HSG Map.
- HSG Maps for the selected watersheds are developed for the study region by interpreting soil maps with the help of Soil Taxonomy.
- Validation of results carried out between Simulated and observed discharge shows a correlation coefficient of 0.75 at Okhunwan sub-basins.
- From the result of hydropower potential optimization carried out on thirty-seven (37) hydrometric points at two (2) kilometer (km) interval in Okhunwan Sub-basin only five (5) points can feasibly generate hydropower between the range of 149.583 kW to 16,935.279 kW at 92% available flow annually.
- Providing electricity to lots of rural populace with no access to energy will lead to improved standard of living and increased human development index of Edo state and Benin-Owena river basin.

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