

RESEARCH ARTICLE

APPLICATION OF SPATIAL TOOLS FOR ESTIMATING THE HYDROPOWER POTENTIALS OF UNGAUGED RIVER CATCHMENTS IN BENIN CITY, EDO STATE NIGERIA

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ABSTRACT

To improve the understanding of the response patterns of river basins to climatic variability, especially with regards to basin planning, the present study utilized Remote Sensing coupled with SCS-CN and NRCS estimation methods to generate rainfall and streamflow of ungauged Okhuwan and Okhaihe catchments in Benin City. The correlation coefficients ranging from 0.83 to 0.86 between Nigerian Meteorological Agency NIMET data and estimated rainfall were used as indicators of the model effectiveness. Estimated mean annual value ranged from a minimum value of 1443.9 mm in Obadan town to a maximum value of 1499.2mm in Okhuwan catchment, while in Okhaihe catchment, the lowest annual rainfall of 1176.6 mm was estimated for Ayen town and 1217.3 mm being the maximum annual amount in Edopa/Odjeva town. In Okhuwan catchment estimated mean annual streamflow values are 158.6 m³/s and 184.4 m³/s using SCS-CN and NRCS methods, while in Okhaihe catchment annual streamflow values were 166.3 m³/s and 163.5 m³/s using SCS-CN and NRCS methods respectively. Volumetric fluid flow rate (Q) was integrated with other variables such as density of water (ρ), gravity constant (g), height (h) and efficiency coefficient (η) to generate the potentials of various points across the catchments. In Okhuwan, mean power potentials were 13486.6 kW and 15194.3 kW using SCS-CN and NRCS computed streamflow values, while in Okhaihe catchment mean power potentials were 11401.2kW and 12653.4 kW using SCS-CN and NRCS methods computed stream flow values. On the whole the investigated catchments showed great potentials for run-off-river hydropower scheme.

KEYWORDS

Catchment, water resources, hydropower potentials, stream flow, basin characteristics

1. INTRODUCTION

Energy crisis and deficiency remain a huge challenge in Nigeria, with enormous implications for economic development, especially with regards to meeting the key Sustainable development goals that hinge on poverty reduction, good health/well-being, affordable and clean energy. Studies have shown that at present, 600 million people, or 43% of Africa's total population, lack access to electricity, most of them in sub-Saharan Africa (IEA, 2022). Additionally, Okwatch reported that power consumption per capita in sub-Saharan Africa is the lowest at 370 kilowatt-hours (kWh) annually compared with 6,500 kWh (Europe) & 11,000 kWh (United States) (Okwatch, 2022). According to World Bank Report 85 million Nigerians don't have access to grid electricity and this represents 43% percent of the country's population and makes Nigeria the country with the highest energy access-deficit in the world (The World Bank, 2021). The implication of this include economic backwardness, declining GDP, rising unemployment and difficulties to achieving the universal access to energy crucial for achieving key SDGs, including poverty eradication (SDG1) and affordable/clean energy (SDG7). It is also reported that the lack of reliable power is a significant constraint for citizens and businesses in Nigeria, resulting on annual economic losses estimated at \$26.2 billion (₦10.1 trillion) which is equivalent to about 2 percent of GDP (The World Bank, 2021).

Global warming and climate change exacerbate the challenges of energy availability in Africa. Energy crisis and energy inadequacy promotes such

land use activities like cutting down trees for fuel woods, use of fossil fuel and use of power generating sets, whereas modification of the land on the other hand to meet energy needs enhances feedback mechanisms that exacerbate global warming. The nexus between energy crisis and climate change pose serious environmental threats to Africa, especially Nigeria. Already the impacts of climate change and energy shortage-related challenges are evident in Nigeria, as seen in the increasing rates of farmers-herders crisis in the north, due to scarce resources occasioned by drought, high level of multi-dimensional poverty, youth/graduates unemployment, high mortality rates and shortening life expectancy, socio-economic losses due to flooding, erosion leading to loss of soil fertility etc.

The rural areas suffer the most electricity poverty, as more than 60% of those living in the rural communities lack access to electricity, which is partly responsible for rural-urban drift in search of better livelihood opportunities. The big question there is, if Nigeria, is struggling in the face of energy crisis and climate change to feed the current 200 million people, how will the country be able to feed the projected 377 million people by 2050? Small hydropower technologies especially run-off-river (ROR) hydropower scheme have been reported to have potential to address the challenges of energy availability and been also considered as more environmentally friendly, cost effective when compared to large hydropower schemes involving damming and impounding of rivers and which are known to cause profound alteration of the natural flow regime and impair the fluvial ecosystems to a considerable degree (Bilotta et al., 2017).

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Some studies have shown that Small RoR hydropower plants are among the most affordable renewable energy sources that can be developed in many low-income countries because of the low construction and maintenance costs and short construction time (Deyou et al., 2019). However, to effectively utilize and sustainably deploy run-off-river technology, it is prerequisite to undertake a detailed feasibility studies to generate data on the theoretical possibility or tendency for power to be generated from that river. Authors have shown that "The hydropower potential of a river is the inherent ability of a river to generate electricity if favoured with the required factors (WEC 2004; Okorafor, et al., 2013). It should also be noted that this theoretical capability is dependent on analysis of topography, land use, land cover, discharge volume etc. One of the major streams that drain Okhuaihe and Ugonoba communities, Benin City, Edo state are Okhuaihe and Okhuwan Rivers and the hydropower potentials of these streams have not been investigated in the past, hence the need for the present study. Thus, the study investigated the hydro power potential of rivers Okhuwan and Okhuaihe in Edo state to increase Nigeria's energy capacity.

2. MATERIALS AND METHODS

2.1 Study location

The study location is in Edo State, Nigeria which falls within the tropical rainforest zone of Nigeria. It has ample rainfall and temperature well

distributed over a year. It has a high mean annual rainfall that ranges from 1800 to 2780 mm and a mean temperature of 28° C (Oguntoyinbo, 1982). The rain comes in torrential storms and the area has double maxima rainfall distribution separated by a little dry season in July/August usually referred to as "August Break" (Atedhor et al., 2010). Rainfall in the area is determined by the position of the Inter Tropical Discontinuity in response to the interplay between the two dominant air masses in the area (the Tropical maritime mT and tropical continental cT). The ITD is at its southernmost position nearly hugging the coast around January but retreats inland, moving farther north up to southern Niger Republic at the peak of rainy season around July/August. At his period, every part of Nigeria is experiencing heavy shower as rainy season is at its peak often accompanied by thunderstorms.

The geology of the are is dominated by deeply weathered sedimentary rock of the Benin Formation (Ogunkule et al., 1980). It consists mainly of top lateralized reddish-brown clayey sand. It likewise consists of friable white sands, gravelly sands and clayey sands with basal ferruginised sandstone (Aziegbe, 2006). The area has dark reddish brown soils with fertile top cover within 0.0-50 cm (Odemerho, 1992). Urbanisation and agriculture have led to loss of most of the tropical rainforest vegetation, with an attendant effect of escalating land degradation due to increased storm water runoff and soil erosion (Odemerho, 1992). The main drainage of the area comprises Osiomo River and other minor streams.

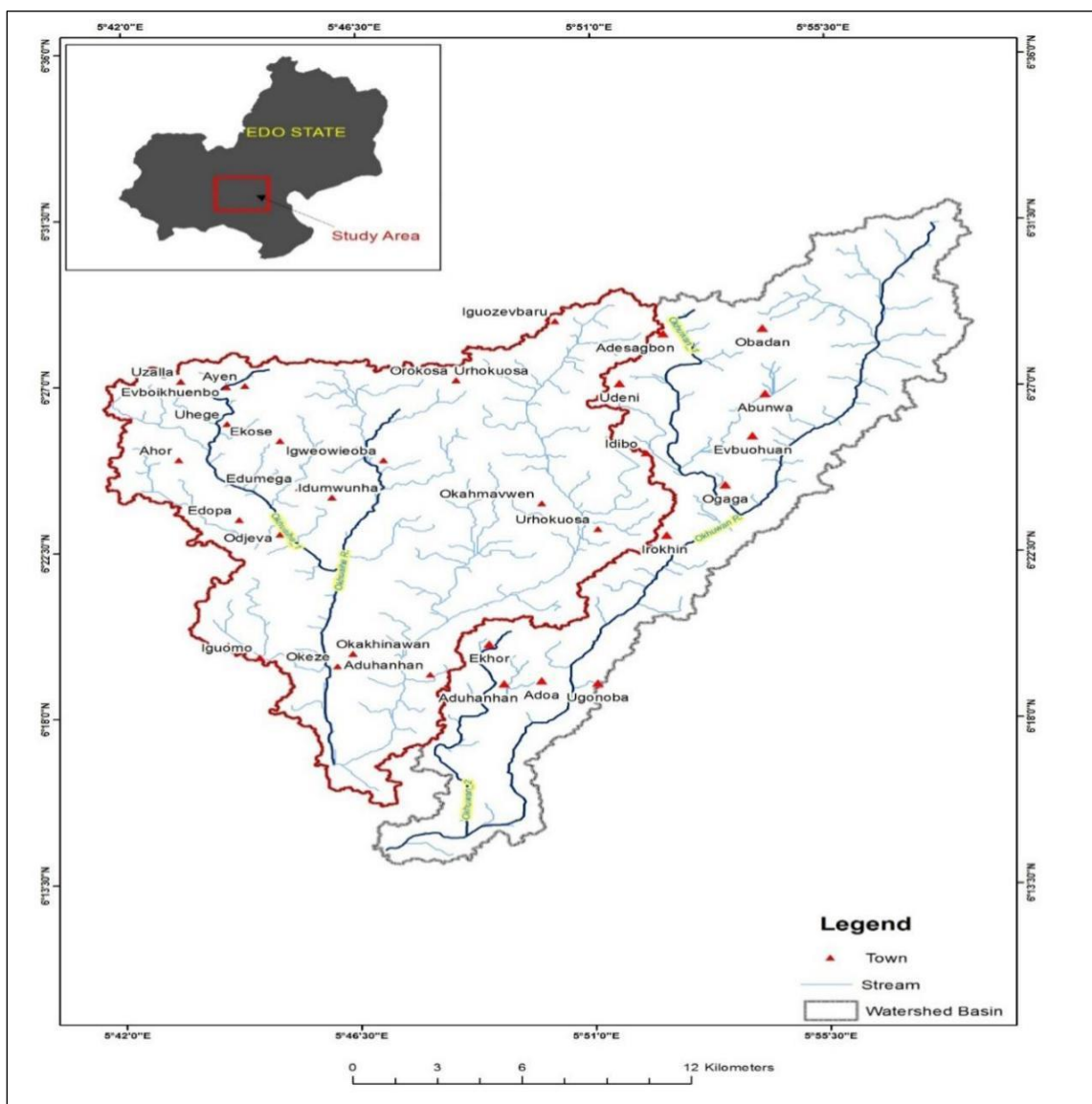


Figure 1: The Study Area

2.2 Data Collection

Gridded rainfall data were extracted from the Climate Prediction Centre website covering a period of 28 years (1990-2017). It is a raster data in "bil" file format, that covers most of the tropical world with the following extent: -20° to +55° longitudes by - 40° to +40° latitudes (Novella and

Thiaw, 2016). Pearson moment correlation coefficient test was used for a reliability test in relation to conventional data from NIMET. As such, those points with a positive correlation coefficient of 0.60 and above were selected for further analysis. Thus, seventeen points that comprised nine points in Okhuwan basin and eight points in Okhuaihe basin.

Table 1: Data type and sources of data

S/N	Data / Scale	Source	Purpose
1	Stream flow Data	Field Measurement done for 12 months.	Used to ascertain the quantity of water available from the basin.
2	30 years monthly Rainfall data (mm) Satellite estimated rainfall in mm for Africa	Nigerian Meteorological Agency (NIMET) Climate Prediction Center of the United States Agency for International Development (USAID).	To analyze rainfall- run off relationship. Used to determine the spatial dimension in rainfall distribution across the basins of interest.
3	Landsat 8 Satellite imagery (30m Resolution)	United states Geological Survey (USGS)	Used to generate the land use, land cover map of the study area, which are input variables for generating curve numbers.
5	SRTM Data (30m DEM Resolution)	United states geological survey (USGS)	Used to delineate the catchment
6	Harmonized World Soil Database (HWSD) v1.2	Food and Agriculture Organization of the United Nations (FAO) /United Nations Educational, Scientific and Cultural Organization (UNESCO	To determine soil texture attributes that are a prerequisite for runoff curve number for estimating stream flow.

2.3 Soil textural properties of the study area

There is no known soil database for Edo state, Nigeria. Hence, from the Harmonized World Soil Database (HWSD) obtained from <https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v20/en/>, the soil texture attribute that is required to get the Runoff Curve Number of SCS Curve was extracted. The dataset is available in ArcGIS shape file. To access this data for this study, the GIS technique was used. The following steps were undertaken to classifying the soil characteristics,

- The HWSD raster file was added to ArcMap using the add tool
- Using the clip tool the data was clipped to the study area
- Using the symbology tool, the soil texture field had its visualization improved.

Various soil moisture and textural characteristics (e.g. Organic composition and effective porosity, soil depth etc.), have been employed in basin studies to generate the desired representations of soil characteristics in drainage studies. In this study however, the soil characteristic employed is texture.

2.4 Catchment Delineation and Characteristics

The topographic features of the area that included basin area, elevation, slope, and drainage characteristics were extracted from the Shuttle Radar Topographic Mission SRTM Digital Elevation Model (DEM) of the basin using ArcGIS 9.3 software. The SRTM DEM is a 30-meter spatial resolution

data downloaded from the earth explorer website at <http://earthexplorer.usgs.gov/>. From the Spatial Analyst Module, the hydrological Tool was used to extract the basin's hydrologic features. The analysis comprise first filling every sink using the 'Fill sink' function/tool followed by flow accumulation and flow direction, basin delineation among others. The Harmonized World Soil Database (HWSD) from the FAO website was used get soil texture attribute which is required to generate Runoff Curve Number. The dataset is open-source data that can be freely downloaded once there is steady internet connection. The data is in ArcGIS "dbf" format.

2.5 Estimation of Stream Flow by computation methods

Points were generated along the river basins. They were assigned town names in proximity to the points to achieve spatial patterns in seasonal stream flow. The stream flow values at different points along the stream channel in each basin was obtain following the Soil Conservation Service (SCS)-curve number (CN) method. The SCS-CN method hinges on the water balance equation that relies on the cardinal assumption that the ratio of runoff to effective rainfall is equal to the ratio of actual retention to potential retention (Soulis et al., 2009).

2.5.1 Curve Number Determination

The coefficient of runoff based on four factors (Table 2) was computed first in accordance with the SCS-based method of estimating stream flow. The factors are normally assigned scores to define the extent to which the basin accommodates the runoff, also known as runoff curve number (Table 2).

Table 2: SCS Curve or Runoff Curve Number

Attributes	Utmost CN (100)	II High CN (75)	III Normal CN (50)	IV Low CN (25)
Relief (A)	Mountainous area Slope >30% (30-40)	Hilly with slope Slope 10-30% (25-32)	Rolling terrain Slope 5-10% (17-24)	Relatively flat slope 0-5% (5-16)
Soil Infiltration (B)	Rocky, thin soil mantle (17-20)	Clay, slow infiltration (12-16)	Prairie soil, loam, deep soil mantle (7-11)	Sand, deep soil, rapid infiltration (2-6)
Vegetative cover (C)	No effective cover, plant cover bare (17-20)	Less than 10% of area under good cover (12-16)	50% of area in good grassland, woodland (7-11)	90% of area in good grassland. Woodland (2-6)
Surface Storage (D)	No surface detention, no pond (17-20)	Small drainage way (12-16)	Lakes, ponds and marshes less than 2% (7-11)	Large number of lakes, ponds and marshes (2-6)
CN = A+B+C+D = 100				

Source: Schwab et al., 1971

The DEM and Landsat data were used to generate hydrologic, land use/land cover, and ground surface attributes in a GIS environment. The extracted information was used to generate the streams' runoff curve numbers at different points along the basins, that constituted input data for the SCS model. The land use, soil texture, elevation/slope and storage layers were overlain to determine the CN values at each point on the stream channels.

2.6 Methods for Stream flow Calculation

The first thing was to estimate the depth of excess rain (eq. 2) which is

cardinal for estimating stream flow using the SCS-CN method.

$$Q_d = \frac{(P_t - I_a)^2}{P_t - I_a + S} \quad (2)$$

Q is excess rainfall depth (cm), P is the total precipitation (mm), I_a is the initial absorbance (mm), S is the maximum potential of flow delay.

A constant value of $I_a = 0.2 S$ was used in accordance with (Hawkins, 1979). Hence, equation (2) can be re-written (eq. 3) as given below.

$$Q_d = \frac{(Pt - I_a)^2}{Pt - I_a + S} \quad (3)$$

where

S was determined from CN ((eq. 4).

$$S = \frac{1000}{CN} - 10 \quad (4)$$

2.6.1 SCS-CN Method

Peak discharge Q_p was calculated for yearly and each month using three different methods

$$Q_p = \frac{0.0208 \cdot A \cdot Q_d}{t_p} \quad (5)$$

Where t_p is the time to peak in hours (h), which is obtained from the relation;

$$t_p = 0.6t_c + t^{1/2} \quad (6)$$

A is the catchment area in consideration in Hectares (ha) and Q_d is the runoff in cm obtained from equation 3

2.6.2 Peak discharge (Q_p) estimation based on NRCS approach

The CN method was used to estimate peak runoff using results from several average-sized and uniform basins. The method is widely applied and has been adopted by diverse authors (Nadal-Romero et al., 2007; Singh et al., 2015). The USDA Soil Conservation Service SCS-CN equation was originally developed and used in USA. Several weaknesses including inability to effectively predict seasonal discharge led to its modification by including such parameters as length (Mishra et al., 2005; Singh et al., 2015). It is based on the assumption that drainage density is influenced by season and thus the graphical method of determining NRCS-CN was adopted. Peak runoff is established by the relationship shown below (eq. 7).

$$Q_p = q_u A Q_d \quad (7)$$

where (Q_p) represents peak flow (m^3/s), q_u is peak discharge (m^3/s) per unit runoff (cm) per unit area (km^2), A is the basin area (km^2) determined in a GIS environment using raster calculator and Q_d is the 24-hour rainfall excess (cm) for a specific return period computed using equation (2).

The parameter q_u was obtained by the empirical equation of the NRCS as shown in equation (8) (NRCS-National Resources Conservation Service, 2004).

$$\log q_u = C_0 + C_1 \log t_c + C_2 (\log t_c)^2 - 2.366 \quad (8)$$

where t_c is time of concentration (hours); C_0 , C_1 and C_2 are regression constants extracted from NRCS tables, where I_a is the initial abstraction, computed following equation (9):

$$I_a = 0.2S \quad (9)$$

when $I_a/P < 0.1$, values of C_0 , C_1 and C_2 corresponding to $I_a/P = 0.1$ should be used and if $I_a/P > 0.5$, values of C_0 , C_1 and C_2 corresponding to $I_a/P = 0.5$ should be used. For the study rainfall type, II applicable to tropical environment SCS (2004) (NRCS-National Resources Conservation Service, 2004) was used.

2.6.3 Computation of time of concentration

The kirpich equation (kirpich, 1940) (eq. 10) was used to compute the time of concentration t_c (in hours).

$$t_c = 0.0078 \frac{L^{0.0078}}{S^{0.385}} \quad (10)$$

where L is the basin length (ft or m) and S is slope in gradient which were extracted from the DEM of the study area.

2.7 Reliability Test of satellite-based Rainfall

The reliability of the satellite-based rainfall was assessed before used in computing runoff with the Pearson's Product Moment Correlation coefficient (PPMCC) test at 0.05 significance level (eq. 11).

$$r_{xy} = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}} \quad (11)$$

where, r_{xy} is the PPMCC, x and y are the two sets of observations where y is the dependent and x is the independent variable. The analyses were done in Excel Spreadsheet using the statistical functions at 0.05 level of significance.

2.7.1 Significance Test of the Correlation Coefficient

A test of significance was done for the correlation coefficient using the student's t test (eq. 12).

$$t = \frac{r_{xy}}{\frac{S}{\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}} \quad (12)$$

where \bar{x} and \bar{y} are the means of the independent and the dependent variables respectively, and n_1 and n_2 are the number of observations in the first and second datasets respectively, and S is the standard deviation.

2.8 Assessment of Head

Head is a vertical distance between two point (intake and turbine). It can also be defined as the pressure created by elevation difference between intake and turbine. For each sub-basin river, the potential head drop was computed. In this study our approach was to overlay the DEM of the basin, sub-basin and river network shape file and obtain the raster value of upstream and downstream end point of each sub-basin river. The difference in raster value between the upstream and downstream end points of the river in a given sub-basin is the potential head drop of the river.

2.9 Computation of Hydropower Potential

Having determined the potential head drop H from the DEM using GIS and stream flow Q using SCS method, the hydro potential was then calculated using the equation below (eq. 13).

$$P = \rho Q g h \eta \quad (13)$$

where P is power in watts,

ρ is the density of water (kg/m^3), Q is the volumetric flow rate of fluid (m^3/s), $g = \text{constant}$ (gravity = $9.81 m/s^2$), h is the drop height (m) (gross hydro head), and η is the coefficient of efficiency.

The density of water was assumed to be $1,000 kg/m^3$; the coefficient of efficiency was fixed at 0.8, while the hydro head was defined as the difference in height between the intake and the generating station. Based on these assumptions, only two parameters, Q and h , were required to determine the hydropower potential for a site in the area.

3. RESULTS AND DISCUSSION

The results of the correlation analysis between the CPC rainfall data and the NIMET rainfall data are shown in Tables 3 and 4. Tables 3 and 4 show that each basin has a strong positive correlation coefficient. This signifies that both variables move in the same direction and are thus closely related. The closer the value of r is to unity, the stronger and closer to perfect the linear relationship and vice-versa. Additionally, they are all significant at 0.05 significance level (Tables 3 and 4).

Table 3: Relationship between NIMET rainfall data and CPC rainfall data in Okhuwan Basin				
Name of town	r	r ²	Adjusted r ²	Standard Error
Ekhoh	0.82	0.67	0.65	42.9
Adoa	0.84	0.71	0.67	39.9
Aduhanhan	0.85	0.73	0.70	39.8
Ugonoba	0.85	0.72	0.700	39.9
Ogaga	0.88	0.77	0.75	34.6
Evbouhuan	0.91	0.82	0.81	29.4
Abunwa	0.85	0.73	0.70	70.1
Udeni	0.85	0.72	0.70	70.1
Obadan	0.83	0.67	0.64	42.9

* r is the correlation coefficient at 0.05 level of confidence, r^2 is the coefficient of determination. Source: (Isagba et al., 2022)

Table 4: Relationship between NIMET rainfall data and CPC rainfall data in Okhaihe Basin

Name of town	r	r ²	Adjusted r ²	Standard Error
Okeze	0.84	0.71	0.68	39.92
Idumwhuna	0.85	0.73	0.70	38.38
Igueowieoba	0.85	0.73	0.70	38.37
Edopa/Odjeva	0.84	0.71	0.68	38.20
Edumega	0.84	0.71	0.68	72.16
Ahor	0.84	0.71	0.68	72.16
Uhege	0.84	0.71	0.68	38.20
Ayen	0.86	0.75	0.72	35.54

*r is the correlation coefficient at 0.05 level of confidence, r² is the

coefficient of determination. Source: (Isagba et al., 2022).

The coefficient of determination (r²) is a measure of the percentage of variations in estimated values (CPC data) that can be explained by variations in the observed data (NIMET data). The r² ranged from 0.67 (67%) to 0.77 (77%) in Okhuwan and from 0.71 (71%) to 0.75 (75%) in Okhaihe, suggesting good correlation and good fit for the datasets. This shows that the CPC data might have been adequately verified for homogeneity by the National Oceanic and Atmospheric Administration (NOAA) and the World Meteorological Organization (WMO) for consistency (Novella and Thiaw, 2016). Thus, the CPC rainfall data are considered suitable for the study. In tables 5 and 6, the results of power potentials, coupled with other important catchment variables are presented. As can be seen, power potential values closely follows the basin factors such as curve number, slope factor, stream flow amount, river length etc. More so, annual power potential values both SCS.CN and NRCS using computed stream flow methods are closely related.

Table 5: Computed basin annual streamflow and power potential across Okhuwan, catchment, Benin City

Name of town	Curve Number	Average Slope %	Elevation (m)	Change in elevation (Head)	Annual rainfall mm	River length km	Area Km ²	Estimated Stream-flow SCS.CN (m ³ /s)	Estimated Stream-flow NRCS (m ³ /s)	Power Potential SCS.CN (KW)	Power Potential NRCS (KW)
Ekor	34.9	1.9	33.9	0.34	1463.1	45.3	195	70.7	78.2	692.3	768.6
Adoa	30.3	1.29	42.1	0.65	1458	45.3	195	37.5	41.9	711.9	801.8
Ugonoba	51.0	1.77	5.99	0.93	1498.2	45.3	195	21.6	221.8	1682.9	1703.9
Aduhanhan	27.9	1.02	79.4	1.49	1455.5	45.3	195	4.07	2.72	53.6	35
Ogaga	47.6	2.6	131.7	0.14	1499.2	14.1	195	351.9	320.4	13540.2	12300.4
Evbouhuan	51.9	0.69	78.5	1.76	1499.2	45.3	195	37.5	41.9	711.9	801.8
Abunwa	45.1	1.26	96.2	2.1	1481.1	45.3	195	126.5	118.7	2249.2	2102.5
Udeni	58.2	0.90	159.9	1.2	1476.6	14.1	195	662.3	728.5	13084.2	15229.3
Obadan	54.1	1.5	122.2	2.14	1443.9	45.3	195	114.9	105.2	2041.8	1889.7
Mean ±SD					1474.9± 21.0			158.6 ±216.1	184.4 ±226.7	3863.1 ±5406	3959.2 ±5644.9
Min					1443.9			4.07	2.72	53.6	35
Max					1499.2			662.3	728.5	13540.2	15229.3
Range					55.3			658.2	725.8	13486.6	15194.3

Table 6: Computed basin annual streamflow and power potential across Okhaihe, catchment, Benin City

Name of town	Curve Number	Average Slope %	Elevation (m)	Change in elevation (Head)	Annual rainfall mm	River length km	Area Km ²	Estimated Stream-flow SCS.CN (m ³ /s)	Estimated Stream-flow NRCS (m ³ /s)	Power Potential SCS.CN (KW)	Power Potential NRCS (KW)
Okeze	45.4	1.83	30.1	0.31	1214.3	19.87	272.2	359.6	390.3	831	625.4
Idumwhuna	53.6	2.69	50.4	4.48	1224.3	19.87	272.2	330.2	320.8	11524.3	12535.8
Igueowieoba	47.6	1.95	111.8	6.16	1224.0	19.3	272.2	207.9	160.3	10311	7901.2
Edopa/Odjeva	49.9	1.58	90.4	2.83	1217.3	14.96	272.2	410.6	422.2	67848.3	79740.2
Edumega	27.9	2.3	95.2	2.08	1183.7	14.96	272.2	4.9	3.1	94.5	57.5
Ahor	27.9	3.9	114.8	6.3	1183.7	14.96	272.2	4.8	3.0	272.6	162.1
Uhege	27.9	3.8	138.5	3.2	1183.7	14.96	272.2	5.4	3.3	142.9	84.5
Ayen	27.6	1.49	157.7	2.6	1176.3	14.96	272.2	7.30	4.8	184.6	120.8
Mean ±SD					1200.9± 20.8			166.3 ±405.8	163.4 ±187.3	11401.2 ±23309.9	12653.4 ±27510.11
Min					1176.3			4.8	3	94.5	57.5
Max					1224.3			410.6	422.2	67848.3	79740.2
Range					48.0			405.8	419.2	67753.8	79682.7

In order to understand the spatial distributions of stream flow using SCS-CN model the geographical Information system (GIS) was used to produce spatial discharge maps as presented in Figures 2 and 3.

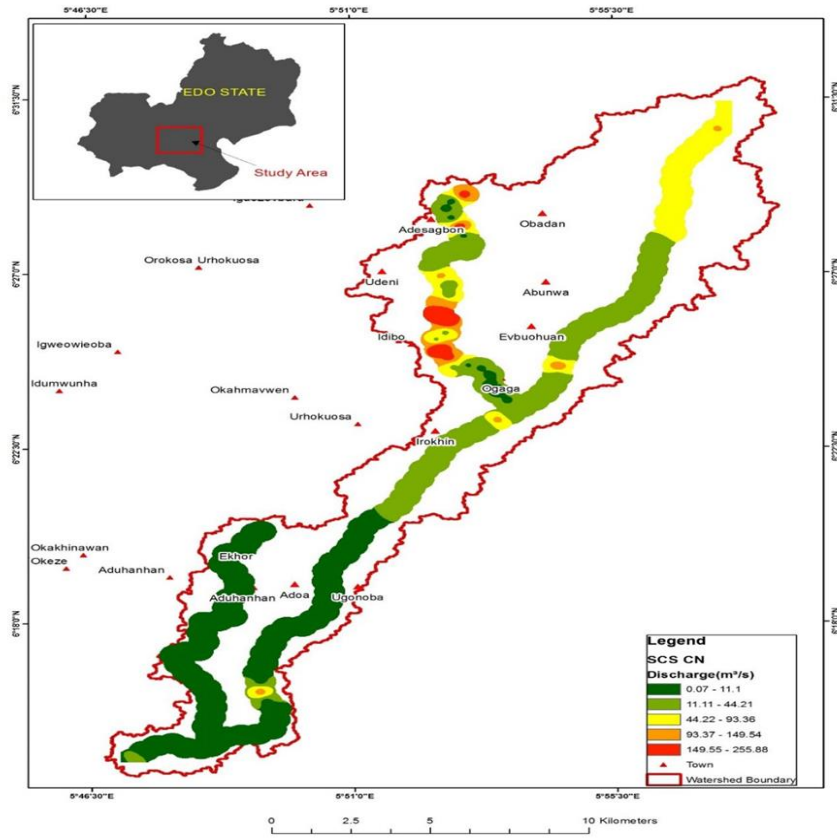


Figure 2: Spatial distribution of discharge in Okhuwan Catchment

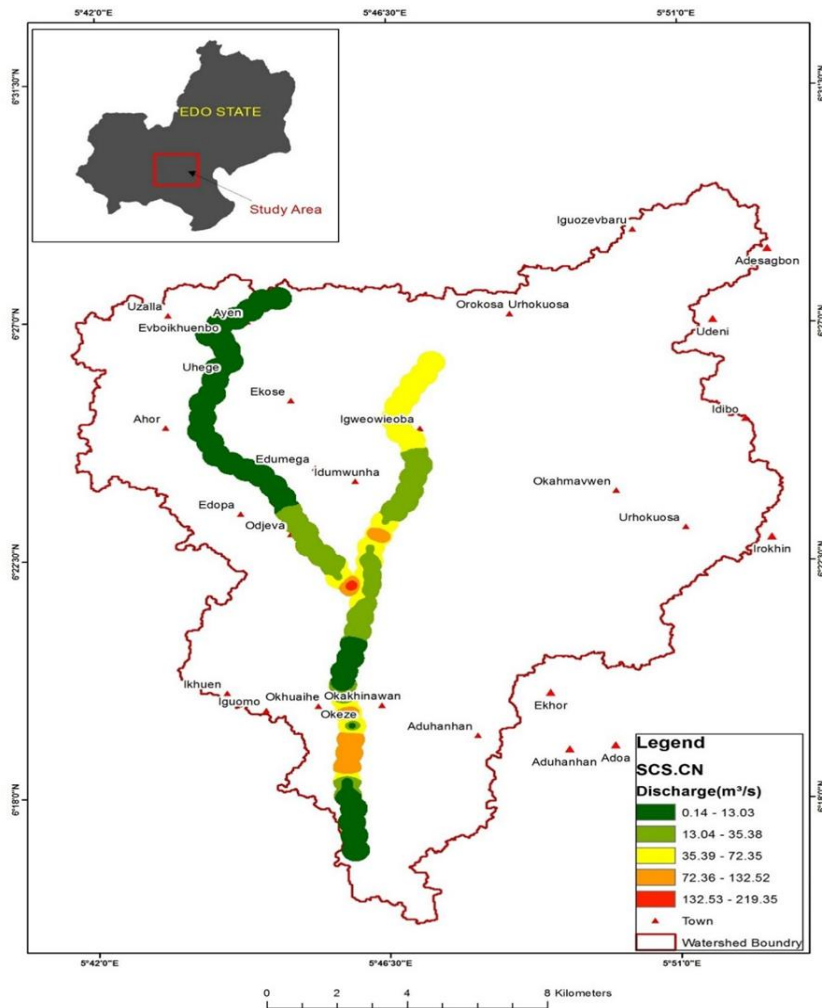


Figure 3: Spatial distribution of discharge in Okhuaihe Catchment

On the whole, stream flow magnitudes were seen to vary and relate closely to basin scale factors more especially land use type/cover, slope and rainfall patterns/variability. Heavily built up area within the two catchments with high curve numbers recorded higher discharge volumes (Figures 4 and 5). A result which was expected as seen in the catchment characteristics maps earlier presented. Areas with high curve numbers is characterized with high runoff. For example Udeni in the northern part of Okhwhuan catchment which have high CN values, recorded high discharge compared to areas in the southern part of the catchment such as

Ugonoba/Adoa which have low discharge. On the other hand, in Okhuaihe catchment, discharge is nearly evenly distributed. The fact that discharge in this area is uniformly high may suggest the effect of Benin urbanization on the Okhuaihe catchment. Information on spatial pattern of discharge is important in determining hydropower at different points especially as varying basin scale factors are expected to produce different discharge volumes and characteristics. The maps showing the spatial annual hydropower potential for Okhuwan and Okhuaihe catchments are presented in Figures 6 and 7.

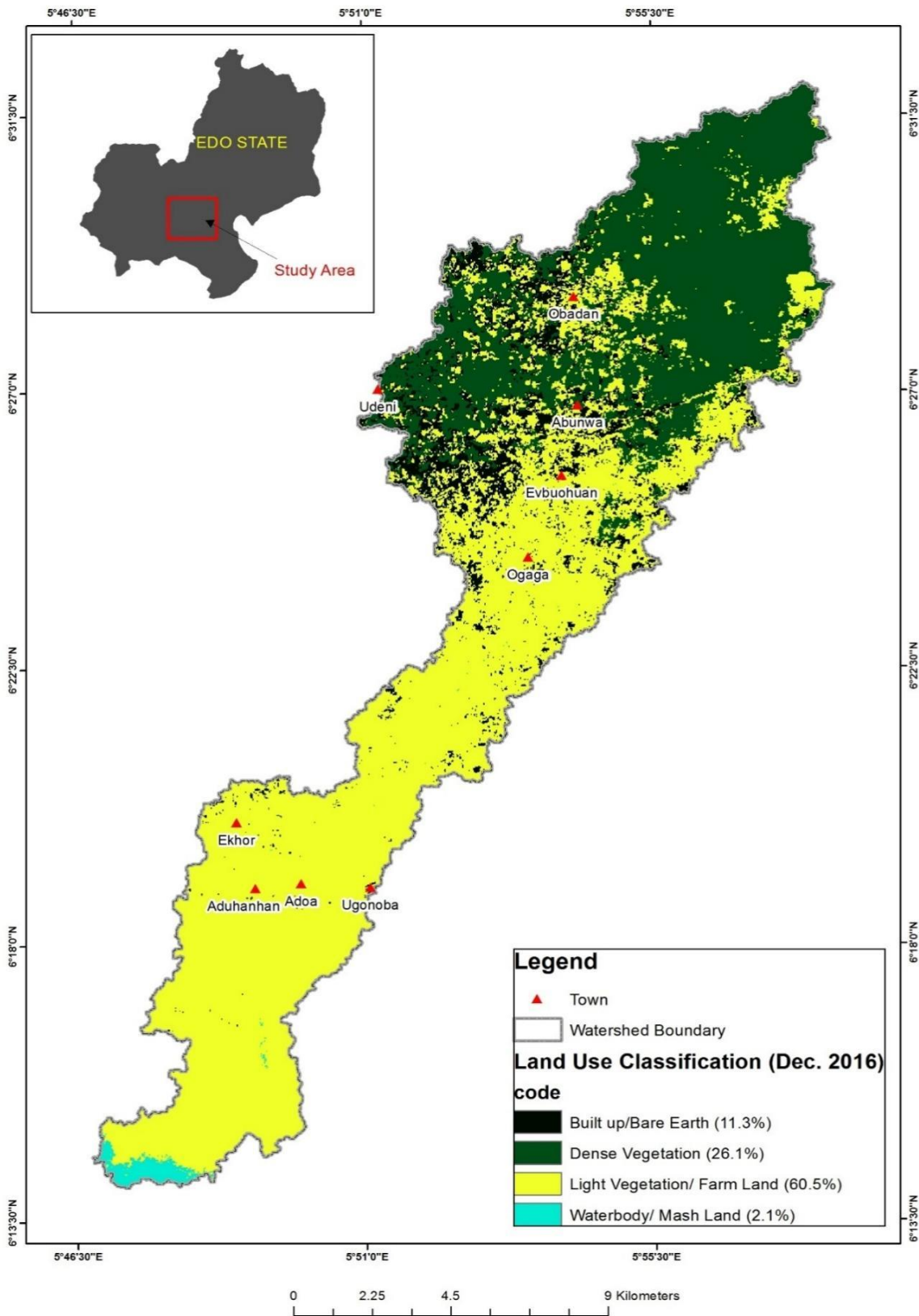


Figure 4: Map showing land use classification of Okhuwan River Catchment

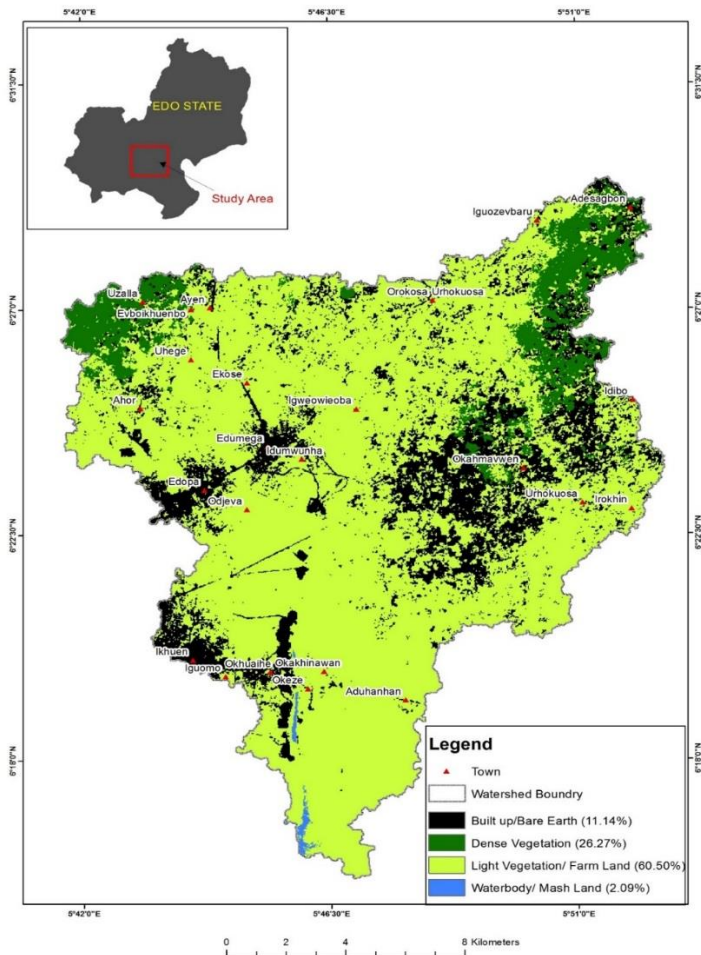


Figure 5: Map showing land use classification of Okhuaihe River Catchment

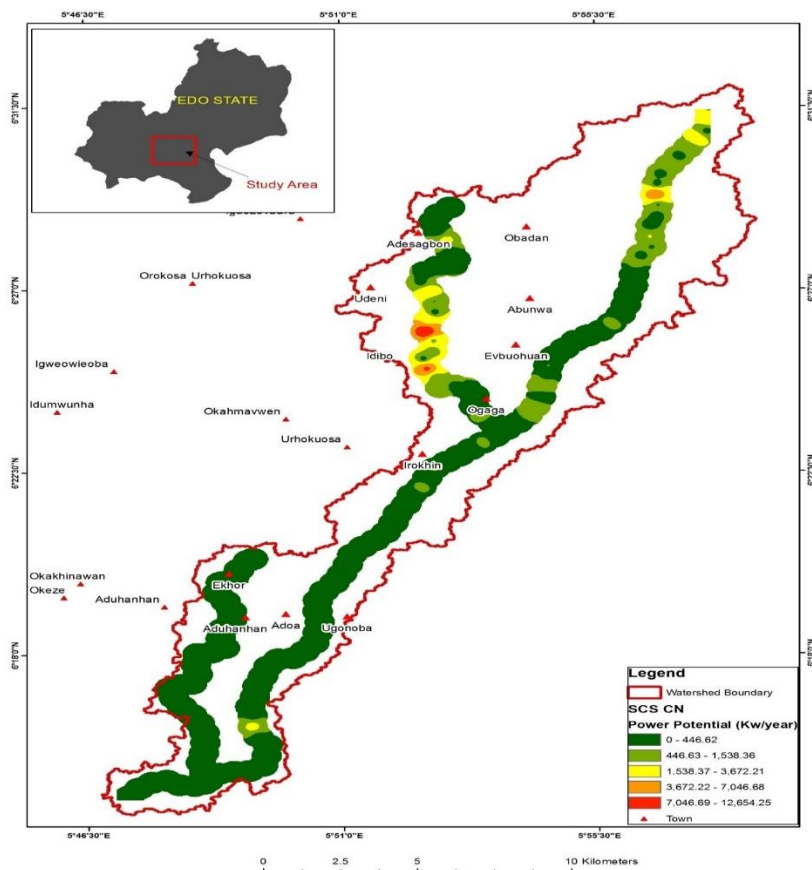


Figure 6: Spatial distribution of annual power potential in Okhuwan catchment

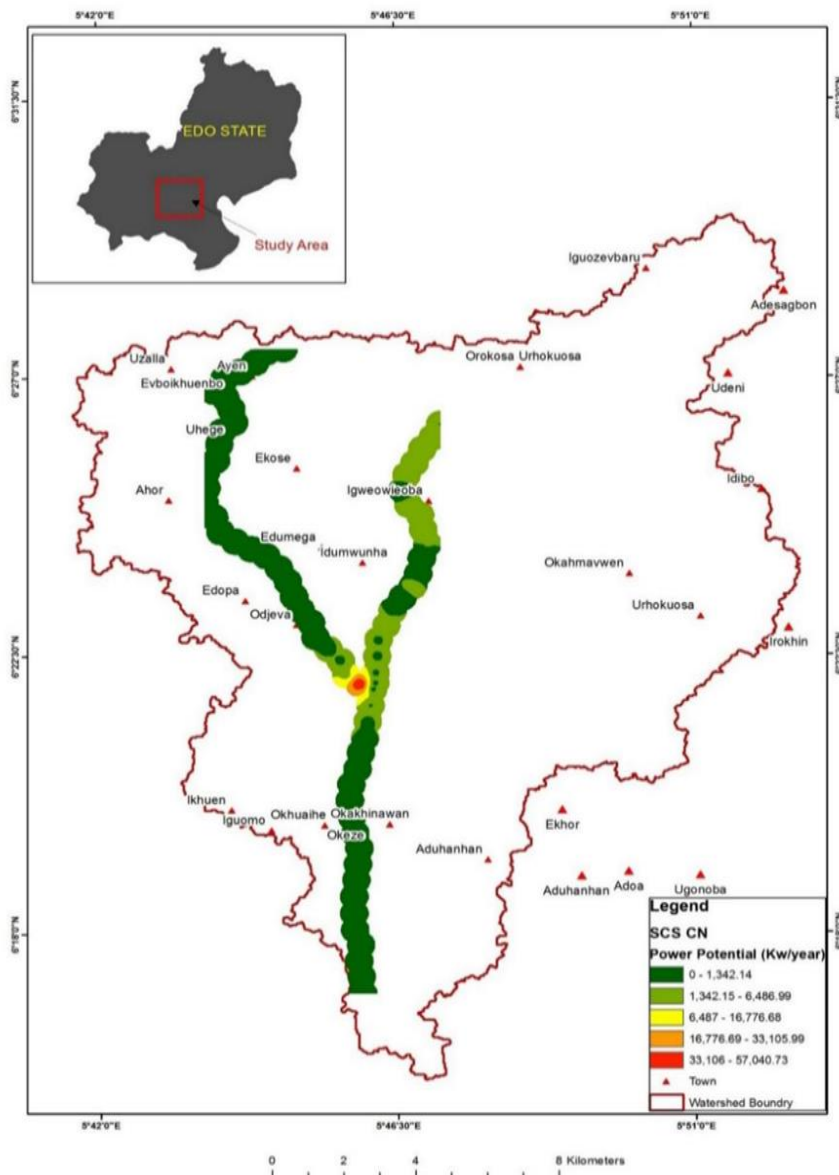


Figure 7: Spatial distribution of annual power potential in Okhuaihe catchment

The variation in power potential from place to place can be attributed to differences in discharge volume and height, which are equation inputs in the power factor. Places with high discharge and increased height has more potential when compared with areas with gentle slope and less discharge volumes. In order to understand the spatial distributions of power potential, the geographical Information system (GIS) was used to produce the spatial discharge maps. Overall, power potential spatial distribution was seen to be evenly distributed in both catchments and

highest power potential was mainly concentrated in the northern part and towards the middle of Okhwuhan catchment and concentrated in the middle in Okhuaihe. It was observed that the area with highest potential value is characterized with increased height and very steep slope. The classification of run-off-river hydropower potentials in the study area based on classification of Hydropower Plants Based on Capacity according is presented in tables 7 and 8 (Anderson et al., 1999; Tarife et al., 2017).

Table 7: Proposed Turbine types for Okhuwan Catchment: Power potentials computed from SCS-CN

Town	Mean Discharge (Cum/sec)	Head (m)	Power Potential (MW) /Year	Type of Hydropower	Turbine Type	Maximum Efficiency (%)
Ekuhor	70.7	0.34	0.69	Mini	Propeller & Kaplan	91
Adoa	37.5	0.65	0.71	Mini	Propeller & Kaplan	93
Ugonoba	21.6	0.93	1.68	Small	Propeller & Kaplan	93
Aduhanhan	4.07	1.49	0.054	Pico	Bulb	93
Ogaga	351.9	0.14	13.5	Medium	Propeller & Kaplan	93
Evbuohan	37.5	1.76	0.71	Mini	Propeller & Kaplan	91
Abunwa	126.5	2.1	2.25	Small	Propeller & Kaplan	91
Udeni	662.3	1.2	13.1	Medium	Propeller & Kaplan	93
Obadan	114.9	2.14	2.0	Small	Propeller & Kaplan	93

Note: > 100 MW=Large Hydropower; 10 - 100 MW= Medium Hydropower; 1 - 10 MW= Small hydro; 100 kW - 1MW =Mini hydro; 5 - 100 kW- Micro Hydro; < 5 kW=Pico hydro

Table 8: Proposed Turbine types for Okhaihe Catchment: Power potentials computed from SCS-CN

Town	Mean Discharge (Cum/sec)	Head (m)	Power Potential (MW) /Year	Type of Hydropower	Turbine Type	Maximum Efficiency (%)
Okeze	359.6	0.31	0.83	Mini	Propeller & Kaplan	93
Idumwhuna	330.2	4.48	11.5	Medium	Propeller & Kaplan	93
Igue owieba	207.9	6.16	10.3	Medium	Propeller & Kaplan	93
Edopa/Odjeva	410.6	2.83	67.8	Medium	Propeller & Kaplan	93
Edumega	4.9	2.08	0.09	Pico	Bulb	93
Ahor	4.8	6.3	0.27	Mini	Propeller & Kaplan	91
Uhege	5.4	3.2	0.14	Mini	Bulb	93
Ayen	7.30	2.6	0.18	Mini	Bulb	93

Note: > 100 MW=Large Hydropower; 10 - 100 MW= Medium Hydropower; 1 - 10 MW= Small hydro; 100 kW – 1MW =Mini hydro; 5 - 100 kW- Micro Hydro; < 5 kW=Pico hydro

4. DISCUSSION

Information such as annual, mean, maximum river discharge are vital indicators for water availability, and therefore is essential for flood risk management and sustainable development of water resources, including hydropower projects. Basin discharge of a river is defined as the surface runoff accrued from precipitation including base flow minus evaporation and anthropogenic withdrawals and discharges from the river, while the hydropower potential of a river is the theoretical possibility or tendency for power to be generated from that river (Higashino and Stefan, 2019; WEC, 2004). Overall, the potential hydropower assessments require the information of water resource availability, feasible head (basin topography/elevation), followed by careful analysis of these data. Hence, the hydrologic response of a basin to support any water resources projects, including run-of-river hydropower will be influenced by the interplay of surface and sub-surface processes, natural catchment characteristics such as soil type, which control infiltration capacity, soil depth, and porosity; geomorphology in terms of relief, slope, channel length, drainage area and density; and geology, particularly lithology and geological structures, Land use Land cover determined as percentage of forest, agricultural, and urban cover), will significantly affect hydrologic processes and rainfall pattern (Mohamoud, 2004; Tolentino 2017; Higashino and Stefan, 2019).

Land use and land cover changes impact the hydrological conditions such as river discharge, and hydrographic characteristics, and runoff and infiltration characteristics, and hydrological patterns of a basin including increase in average flows (Wudineh, 2023). Vegetal cover regulates hydrological processes by boosting infiltration, reducing runoff and the erosive forces of rainfall (Azuka and Igué, 2020). As can be seen in the study area, heavily urbanized areas of the Okhuwan catchment produced very high curve number and subsequently high discharge values. The impact of urbanization on flows has also been reported in studies carried out in Sub-Saharan Africa SSA and elsewhere (Leblanc et al., 2007; Dias et al., 2015; Feng et al., 2021). Similarly, flood peak discharges exhibit large increases in discharge due to urbanization (Al-Ghamdi et al. 2012; Zhao et al. 2016). Similarly, Chaplot and Le Bissonnais, found that sediments, runoff and runoff coefficient increase as the slope steepness increases (Chaplot and Le Bissonnais, 2003). However, effect of slope steepness on runoff and sediment yield is controlled by by nature of soil, antecedent soil moisture and the limiting factors like rainfall intensity and surface roughness (Defersha and Melesse, 2012; Shougrakpam et al., 2010). Likewise, a group researcher opined that antecedent soil moisture greatly impact the amount of surface runoff generated (Chiffard et al., 2018). Additionally, soil macroporosity strongly influences runoff generation processes which is greater in dense forests than croplands, pasture or bare soils (Shougrakpam et al., 2010; Beven and Germann, 2013). Rainfall is an important input to river basin, such that variation in basin discharge will depend on variation in rainfall input. Similar studies corroborate the fact that climatic and land use changes impact river regimes (Mzava et al., 2021; Tian et al., 2022; Nonki et al., 2019).

In recent times, emphasis has shifted to impact of climate change on basin discharge characteristics including water resources development projects. Hence, changes in the mean discharge, the amplitudes and phases of annual stream flow cycle, including changes in maximum annual flood discharges of rivers have ignited interest in the literature (Higashino and Stefan, 2019). Several studies have looked at how climate change might impact hydrological cycle including river flows globally (Amin et al., 2017; Reshmidevi et al., 2017). The General Circulation Models (GCMs) were coupled with hydrologic models with future precipitation, river discharge,

and other hydrologic parameters simulated under diverse climate change scenarios (Higashino and Stefan, 2019). The implications of the study finding is important for turbine selection because the stream discharge data and hydropower potential generated at different points will guide the Engineers or water resources managers on turbine type, specifications as well as environmental consideration required to minimize the environmental problems associated with the operation of Small Hydro Power. Different types of turbines have their own specific characteristics and are therefore suited for specific conditions of head, power and speed (Arora, 2014).

5. CONCLUSION

A number of countries including Nigeria have ambitious targets of increasing the use of renewable energy, thus the need to explore the hydropower potentials of lower order rivers for rural electrification is also growing in importance. It is estimated that 12% of the world's hydropower potential is found in Africa, with most of it located in the Sub-Saharan part. In spite of this, a huge gap exists between actual hydropower harnessed and the exploitable potential, with only a small percentage of the potential being currently tapped. With respect to small and micro hydro schemes, the gap is even wider. In Edo State, there is little that has been done to carry out detailed hydrological studies aimed at investigating the hydropower potentials of rivers in the State. The study found that the both rivers have great potentials for small – medium hydropower projects. Spatially the northern part of Okhuwan river and the middle part of Okhuaihe, have more areas with high potential as those areas have steeper slopes and good elevation (H). However, for both catchments, power potential was seen to be evenly distributed. The hydropower potential is highly dependent on stream flow as well as basin scale factors such as topography, slope characteristics, rainfall distribution, basin slope, drainage density, soil texture and land use, all of which influence the hydrological conditions in the respective catchment. The models SCS.CN and NRCS serve as alternative for estimating streamflow in the absence of measured data especially as no meaningful water resources development project can take place without stream discharge information and or without clear understanding of hydrological characteristics of basins of studies. There is an urgent need for government to establish more hydro-meteorological gauging stations across river basins in the country to increase data generation on a continuous basis, which will form a basis for potential investors to make informed and accurate decisions on construction of small-scale hydropower schemes on specific locations. Secondly, there is need to review the existing policy, legislation and regulatory framework in the energy sector that will facilitate systematic investigation of hydropower potentials of rivers in the country.

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