

Identification of Owan Catchment Run-of-River Hydropower Potential Sites in Benin Owena River Basin Nigeria Using GIS And RS Procedures

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Abstract
Hydropower is recognized internationally as a source of clean, affordable, and reliable energy that has contributed in a significant way to the global energy supply mix but unfortunately, this is not the case in Nigeria considering hydropower potential of 15 GW where only approximately 2 GW (13%) has been harnessed. Nigeria Small Hydropower (SHP) level is low, as less than 0.1 GW out of 3.5 GW SHP potential is available in a country of over 200 million people with potentials of 333BCM of surface water annually which can be used to increase energy access especially in the rural area where the percentage in 2018 is 34. In this study, Natural Resources Conservation Service - Curve Number (NRCS-CN) method which calculates surface runoff volume for a particular rainfall event in a watershed was applied in conjunction with Remote Sensing (RS) and Geographic Information System (GIS). Land Use Land Cover (LULC) classes of Owan Sub-basin were delineated from Landsat 8 satellite Image using Image Classification procedure and integrated with the hydrologic soil group (HSG) of the sub-basin in a GIS environment to obtain runoff Curve Numbers (CNs) for this study. The estimated CNs and rainfall data of Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks - Climate Data Record (PERSIANN – CDR) of the study area for the year 2018 were used to calculate the peak discharges over 125 mapped out points at 2km interval in Owan river. The gauging station data correlates NRCS-CN with a coefficient of 68 % while the Nigerian Meteorological Services Agency (NIMET) data compared with PERSIANN-CDR yielded a 70 % correlation. Using the basin hydrometric indicators of 2% minimum slope and 10m available head which must exist between two points before a site can be considered for ROR hydropower, 20 points were identified in Owan with power range from 423.015kW to 5,456.646kW at 92% available flow exceedance annually. This study revealed that NRCS-CN method combined with RS and GIS can simulate discharge successfully using watershed hydrometry in the absence of weak hydrological data. Also, owing to a significant degree of agreement between the observed and calculated runoff, the method, and models employed for this study are recommended for field applications in Benin-Owena River Basin, Nigeria at large, and other regions with data scarcity challenges hydrologically.
Keywords: run-of-river, hydropower potential, Remote Sensing, Geographic Information System, NRCS-CN model.
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1. Introduction

Increasing request for energy, particularly from inexhaustible and green sources, encourages small hydropower (SHP) plants development and energizes interest in new investigation studies. Prefeasibility studies to survey hydropower potential generally convey enormous hesitations about the financial, technical, and eco-friendly practicability of the undeveloped potential (Larentis et al. 2010). Unlike the evaluation of single hydropower projects, where the site is characterized and other limit conditions are well defined, investigation of river basin presents a problem type where project location is not known and the energy potential in every site depends on the existing catchment harnessing plan in the same basin. Furthermore, the incorporated technical and environmental evaluation includes the appraisal of numerous conditions and spatially-dispersed data (Kusre et al 2010; Rojanamon, et al. 2009; Yi, et al. 2010; Dudhani et al. 2006). According to (Dudhani et al. 2006) a survey phase carefully carried out in a site gives administrators appropriate and correct details to arrive at the concluding set of choices with minimal impact of the hydropower exploitation over other activities, active infrastructure amenities, and the environment.

Within this scenario, Streams in developing countries including Nigeria are poorly gauged and lacking in critical hydrological information and data even though world's hydropower potential of about 12 % is in Africa just 5 % of this potential has been tapped (ESHA 2006); (FAO 2008). Also, where detailed baselines studies exist like in the Benin Owena River Basin through the publication of (BORBDA 1992; 1993; 1997; 2005; 2007), there is discontinuity in data gathering about existing sites. Moreover, the hydrological potential for SHP development of many streams and rivers in the rural areas are not studied and yet SHP can be a veritable source of efficient, reliable, and clean energy for rural communities when harnessed. There are many streams and rivers in Nigeria, but like many developing countries SHP deployment is minimal considering that out of the evaluated 3.5GW SHP utilizable potential existing in the country, less than 0.1GW has been tapped which represents approximately 2% (ECN 2014; Bala 2019; Ochigbo 2019).

The need to use renewable energies as a crucial tool becomes more urgent in the effort towards sustainable growth in developing territories of the world. In Nigeria, approximately 4,500MW of electricity is available in 2018 owing to technical, grid, and gas constraints out of 13.7 GW electricity generation installed capacity in contrast with 51 GW South-Africa generation capacity (NESP 2019). Nigeria is positioned ninth in Africa in terms of hydropower potential with 32,450 GWh/yr. technically realistic hydropower energy (IJHD 2015; Oyedepo et al. 2018).

Improvements in GIS, RS, and hydrological modeling offer genuine, modern, and suitable data in the evaluation of hydropower resource potential. GIS environment makes it easier to collect and scrutinize information on land-use practice, geology, topography, and river morphology compare to regular field survey because GIS can deal with catchment characteristics with respect to a specific location and make available analysis about the impact zone of the hydropower project (Pandey et al. 2015).

Several scholars have applied GIS and RS techniques in hydropower study: (Feizizadeh et al. 2012) utilized GIS topographical and meteorological datasets in the Tabriz basin of Iran to calculate the supposed surface hydropower potential. The study reveals the highest potentials are in Mehran Roud river branches. (Chandra et al. 2013) applying geo-spatial techniques in Andhra Pradesh state spotted suitable location for micro-hydropower station locations. (Pandey et al. 2015) in their study of Mat River Basin, southern Mizoram, India employs spatial technologies and hydrological models to evaluate water accessibility, and obtained results show hydropower potential of the basin was successfully investigated utilizing GIS tools, satellite data, and SWAT (Soil and Water Assessment Tool) model. Also, RS data and GIS-based technologies have gained more influence across various countries with their application in spotting and selecting hydroelectric prospects of distinct classes, for instance, pumped storage hydropower systems in Ireland (Connolly et al. 2010), small run-of-river (ROR) schemes in Thailand (Rojanamon et al. 2009), US (Hall et al. 2004) and Brazil (Avila et al. 2007), and water retention facility (dams) in India (Kusre et al. 2010), Brazil (Larentis et al. 2010), South Korea (Yi et al. 2010) and South Africa (Ballance et al. 2000).

Meanwhile, in any significant SHP (Figure 1) project, data on topographical, hydrological, and geological characteristics of the basin of concern, techno-economic, and social characteristics of project beneficiaries are fundamental and prerequisite. Owan sub-basin is gifted with enormous surface water resources which can be exploited for hydropower projects in the Sub-basin. Unfortunately, not much is known regarding the hydropower viability of the sub-basin in terms of potentials for SHP projects using GIS and RS techniques and this necessitates the study.

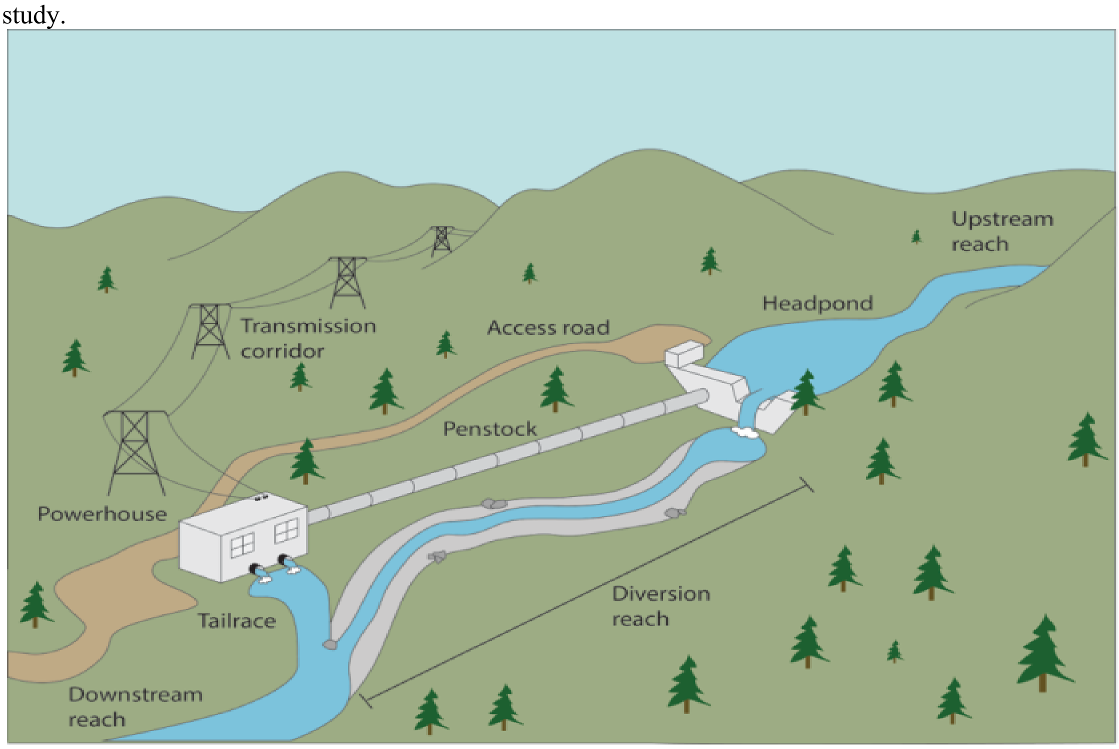

Figure 1: ROR SHP Scheme showing the components (Panlenlab 2017)

2. Methodology

This paper taking into account technical, economic, and environmental vulnerabilities of Owan sub-basin describes the application of GIS & RS tools together with NRCS-CN rainfall-runoff model in the selection of sustainable hydropower potential sites and categorizing them based on available power annually amidst insufficient comprehensive hydrological data.

2.1 The Study Area

Owan sub-basin is one of the sub-catchments of the Benin-Owena River Basin Development Authority (BORBDA) Catchment Area. Owan sub-basins (Figure 2) is on 6°4'52.039" to 5°43'51.465" East longitude and 7°8'58.834" to 6°39'53.906"North latitude with elevation coverage 50 - 400m above Mean Sea Level (MSL), yearly precipitation 1630 – 2133mm, slope class 0 to 42.7%, Land Use Land Cover (LULC) that varies from dense and mixed vegetation to Build up areas with loamy and sandy loamy as the predominant soil which spans a total area of 1216.50km^2.

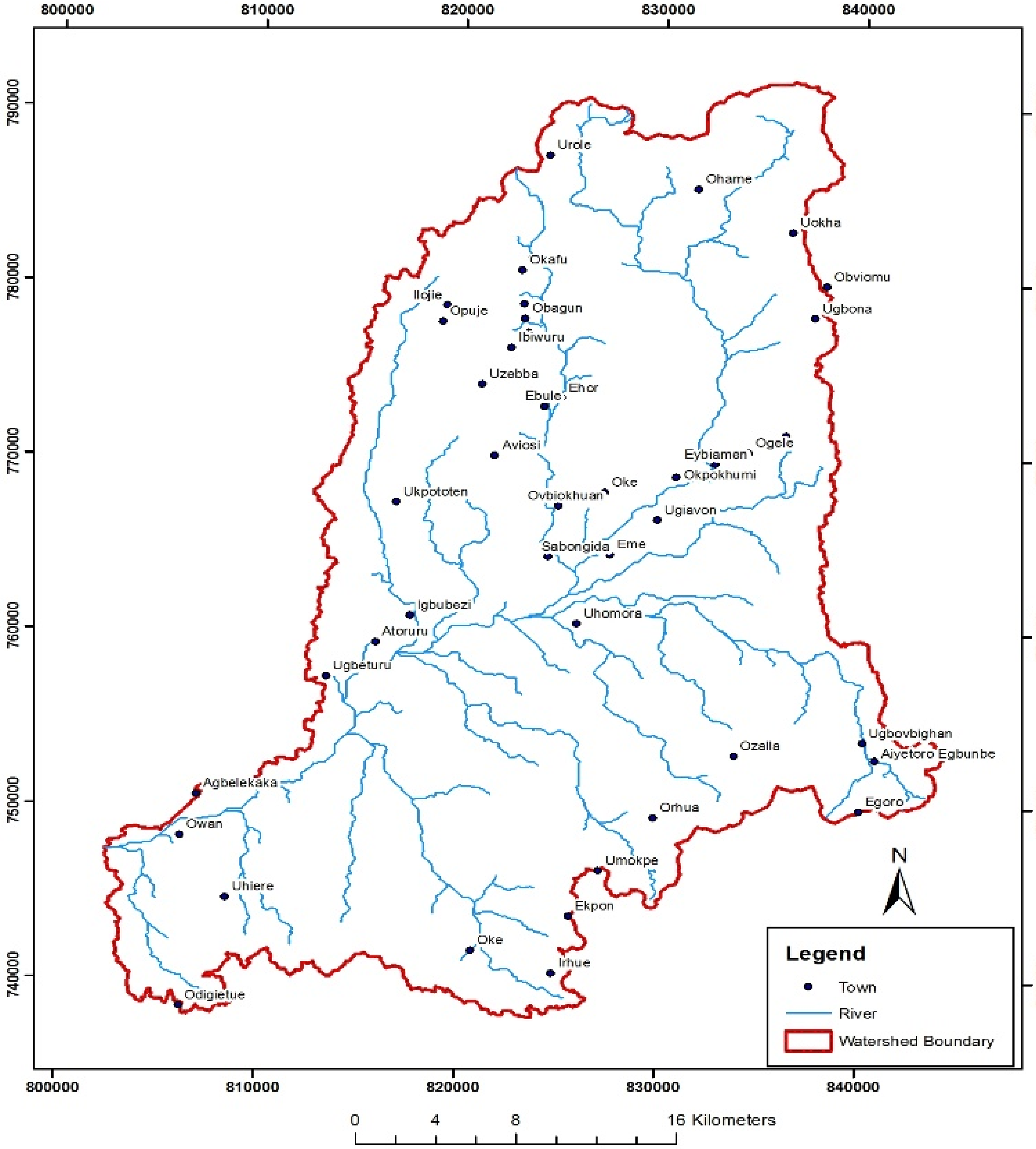

Figure 2: Owan Sub-basin Watershed map

The step by step procedure to determine the SHP potential of Owan sub-basin is presented as a flow chart in figure 3.

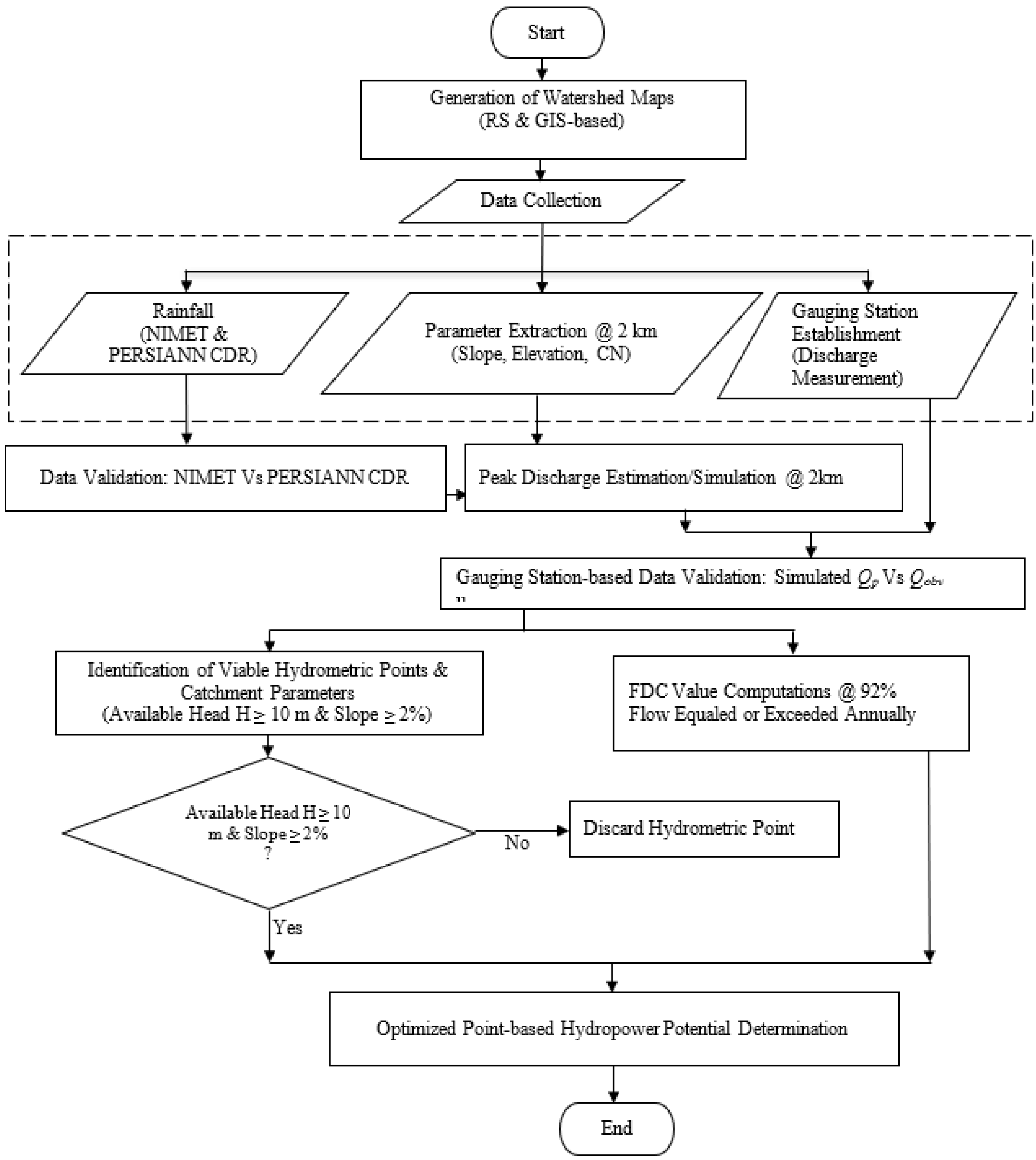

Figure 3: Methodology flow chart diagram (Fasipe and Izinyon 2020)

2.2 Data collection

2.2.1 Rainfall Data

The rainfall data which consists of monthly series (secondary data) were obtained from Nigerian Meteorological Services Agency (NIMET) and the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks - Climate Data Record (PERSIANN-CDR). The 0.25°×0.25° grid cell satellite-based rainfall data of the year 2018 were obtained using RS & GIS techniques from PERSIANN-CDR and compared utilizing Pearson's Product Moment Correlation statistics at 0.05 significance level with NIMET data from Benin Synoptic station which is close to the study site in order to use the former to achieve spatial results across Owan Sub-catchment.

2.2.2 Slope / Elevation from Digital Elevation Model (DEM)

The elevation raster for the study area was generated from the DEM using the create elevation tool. Also, slope classes were generated using the Slope tool out of the Spatial Analyst toolbox. The DEM data of the Shuttle Radar Topography Mission (SRTM) were used to compute slope and elevation for the study area.

2.2.3 Soil & LULC Classifications and Curve Number (CN) Estimation

The Curve Number (CN) is a physical constant lacking unit (Verma et al. 2017). The runoff CN of hydrologic soil cover is expressed in terms of land cover, soil type, and changes based on antecedent soil moisture conditions (AMC) namely: AMC-I, AMC-II, and AMC-III. In determining the CN, basin characteristics such as information on LULC, hydrological soil type, and ground surface condition were first generated using RS and GIS method. These LULC and Soil data were integrated into a GIS environment for intersection which produces a quick and accurate estimation of the runoff curve number for the streams, which is a function of the data acquired via RS.

2.2.4 Establishment of Gauging Station for Field Measurement of streamflow

As the last available archival data in Owan sub-basins was recorded in the year 1999, there was need to validate simulated data obtained from using the NRCS-CN model of the United States Department of Agriculture (USDA) with the field measurements from gauging station established along Owan river course in Sabongida where stage height data were collected for a period of 12 months (January to December 2018) and converted to discharge utilizing equation 1 (ISO 1998). In creating the gauging station certain factors such as site accessibility, the security of gauging equipment, flow consistency, etc. were considered. The gauging station monthly average discharge measurements obtained were compared with simulated data obtained using the NRCS-CN method by Pearson's product-moment correlation statistical approach at 0.05 level of confidence to determine the statistical significance of the obtained results.

$$Q = C(h - a)^{\propto} \tag{1}$$

Where Q = discharge, h = stage height and C, a, α = calibration constants. Effective flow depth (h-a) = 1 when C = discharge; a = zero flow gauge height; α = rating curve slope; (h-a) water effective depth.

2.3 Estimation of Streamflow for Ungauged Parts of Owan Sub-Basins using NRSC-CN

Since the CN map has been successfully generated and necessary CN values obtained from the 125 mapped out points at 2km, the next goal is the computation of maximum potential retention (S) expressed by the relation in (2) (Salimi et al. 2016).

$$s = \frac{25400}{CN} - 254 \tag{2}$$

where S = potential maximum retention (mm); CN = Curve Number.

The depth of runoff (Q_d) was calculated for each rainfall event by using equation (3) (Salimi et al 2016).

$$Q_d = \frac{[P-0.2S]^2}{P+0.8S} \tag{3}$$

Q_d = runoff depth (mm); P = rainfall (mm) and S = potential maximum retention (mm)

Peak discharge Q_p for the stream on yearly and monthly bases was calculated using equation (4): Salimi et al, (2016).

$$Qp = \frac{2.083 * A * Qd}{tp} \tag{4}$$

Q_p = peak runoff rate unit hydrograph (m^3/s), and t_p = time to peak runoff unit hydrograph (h). The only unknown variable in equation 3 is time to peak t_p, and this was evaluated using the relationship between time of concentration t_c and t_p. The relationship between t_p and t_c is given in equation 5 (Roussel et al, 2005);

$$NRCS\ t_p = 0.6\ t_c \tag{5}$$

The value of t_c was obtained by equation 6 (NRCS 1997; Li, et al 2008):

$$t_c = 0.0526[(1000/CN) - 9]\ L^{0.8}\ S^{-0.5} \tag{6}$$

where t_c = time of concentration (hr); CN = curve number; L = flow length (ft); S = average watershed slope, (%).

2.4 Generation of Flow Duration Curve

A flow duration curve (FDC) is a statistical illustration of the quantity of hydrologically obtainable water and the allocation or characteristics of daily, monthly, or yearly flows. FDC of Owan sub-basin was generated on monthly basis to determine the amount of water available per time in the basin as applied by (Smakhtin 2001; Yu et al, 2002) in their research. The probability of exceedance (P) was calculated utilizing relation 7:

$$P = \frac{M}{n+1} X\ 100\% \tag{7}$$

P = the probability that a given flow will be equaled or exceeded (% of time); M = the ranked position on the listing (dimensionless) n = the number of events for a period of record (dimensionless). The essence of developing the FDC is to assist the selection of a design discharge (*Qo)* favorable to identified towns and settlements in the sub-basin that will be adopted for calculation of SHP potential of sustainable hydrological points in this study.

2.5 Hydropower Potential (P) Optimization

In this study, a total of One hundred and twenty-five (125) points were represented along the main river course and tributaries of Owan sub-basin at 2 km intervals as presented in Figure 4 using RS and GIS tool. To determine suitable points for hydropower exploitation, optimization benchmarks were set for this study using the sub-basin physiographic indicators (Slope and Available head). The optimization criteria state that for a hydrometric point to be considered viable for SHP project it must have a minimum slope and available of 2% and 10m respectively between two ends equal 2km. The Slope (≥ 2%) conforms to the standard discussed in (Kusre et al. 2010; Pandey et al. 2015) while the available head was reduced to 10m in contrast to 20m proposed to accommodate the peculiarity of Owan sub-basin.

On determination of flow exceedance or design discharge (Q_0) at each town which was adopted as Q_{92}, the Run of River (ROR) hydropower potential was computed using equation 8 (Taulo 2007)

$$P\ (kW) = 7 \times Q_{92}\ (m^3/s) \times H\ (m) \quad (8)$$

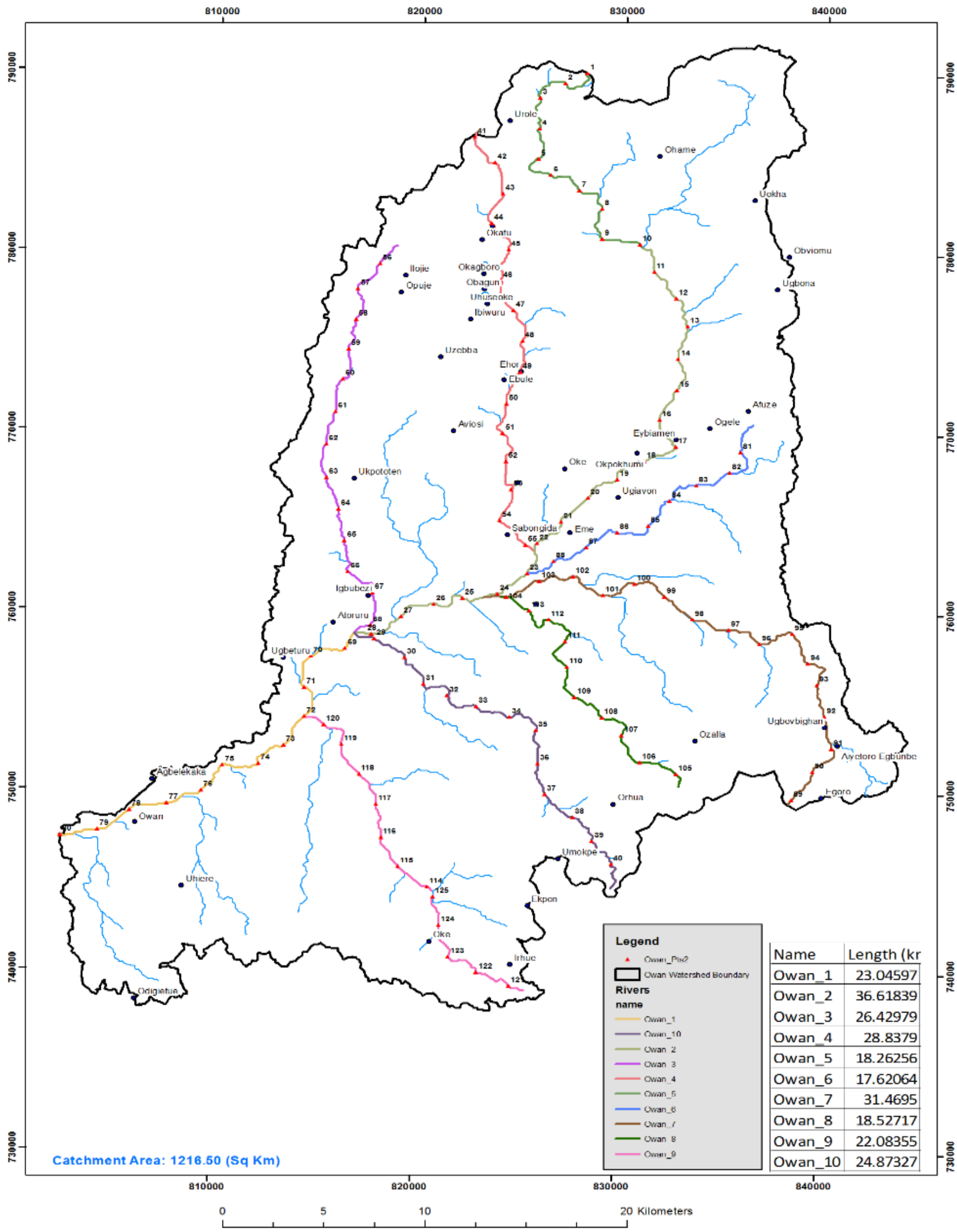

Figure 4: Selected hydropower potential sites in Owan watershed at 2km points.

3.0 Results & Discussions

3.1 Owan Catchment Characteristics

The basic objective of verifying Owan catchment physiographic is to have an in-depth understanding of the watershed for the purpose of maximizing its hydrological and power potential. This was carried out by generating the necessary study maps such as DEM (Figure 5), Rainfall (Figure 6), Slope (Figure 7), Soil (Figure 8), LULC (Figure 9), CN (Figure 10) with the aid of RS and GIS procedures.

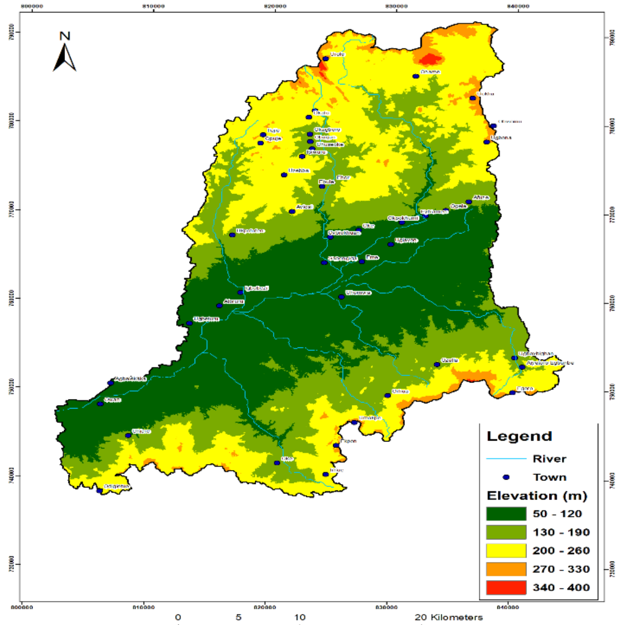

Figure 5: Owan DEM Map

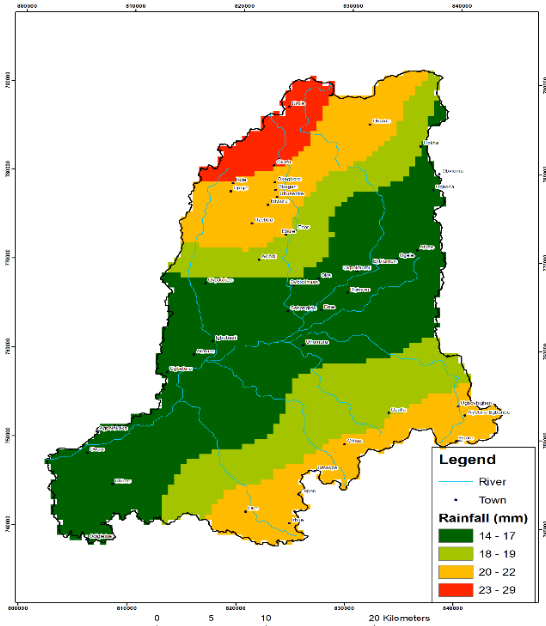

Figure 6: Owan Rainfall Map

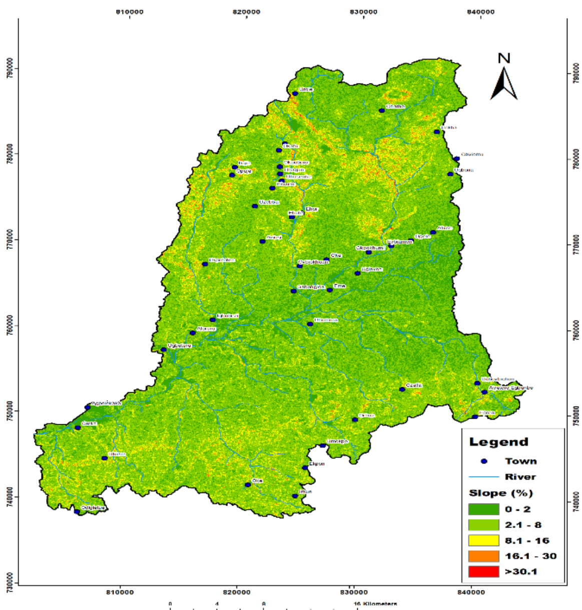

Figure 7: Owan Slope Map

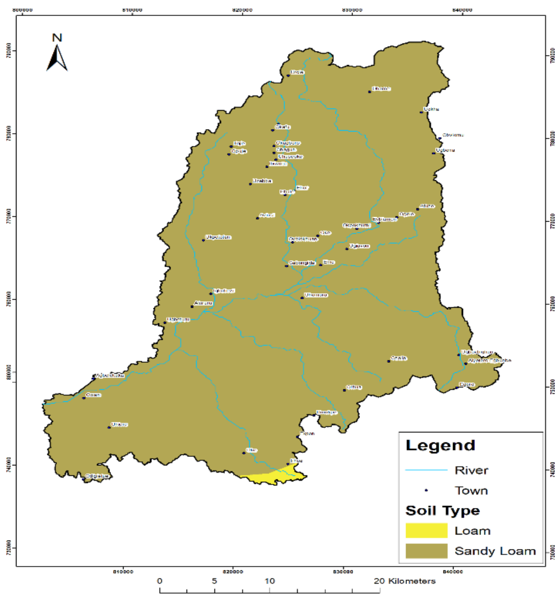

Figure 8: Owan Soil Map

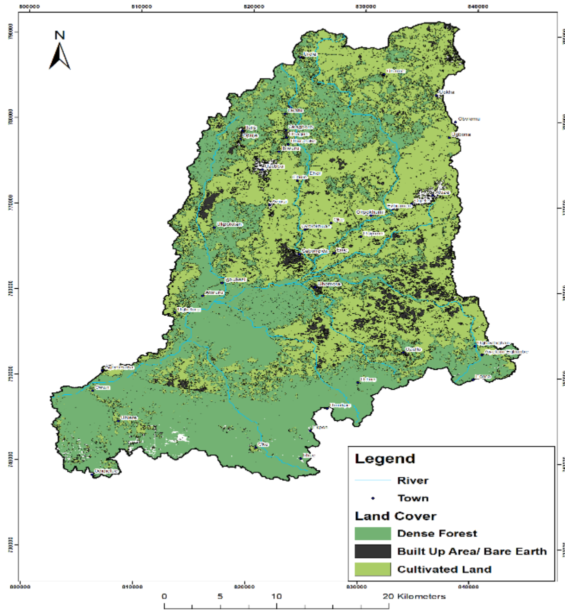

Figure 9: Owan LULC Map

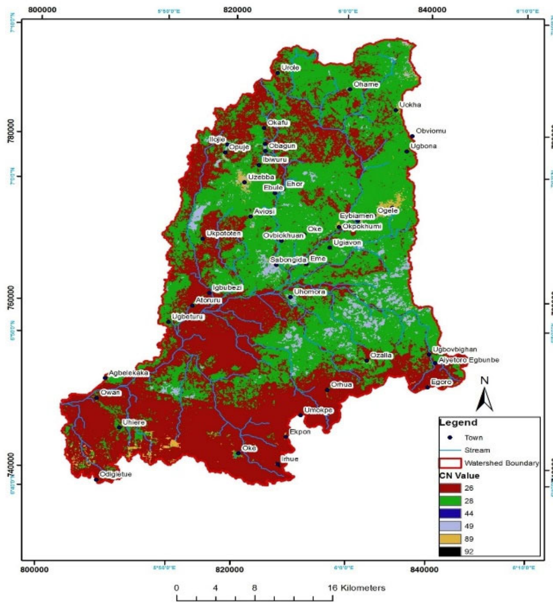

Figure 10: Owan CN Map

In SHP potential investigation, one of the regular variables to consider is the available head/falling height of the river which was obtained from Figure 5 by calculating the change in elevation between two points of interest. The DEM of Owan sub-basin ranges between 50 – 400 m and this implies adequate hydraulic head exist for SHP scheme development.

The rainfall map (Figure 6) was developed to obtain temporal and spatial precipitation allocation over the catchment which is critical in hydrological interpretation and substantiation (Douglas et al. 2008). The obtained rainfall distribution in the watershed is 14.40 mm to 28.90 mm categorized as moderate rain and moderately heavy rain (Mannan et al. 2008).

The slope indicates the resultant SHP potential of any scheme. The identified slope discovered in Owan watershed varies between 0 – 42.7%. From Figure 7, the slope was grouped based on existence into five (5) relief sizes namely Plane (0-2 %), Undulating (2.1-8 %), Gently sloping (8.1-16 %), Strongly sloping (16.1-30 %) and Highly Steep (>30.1%) terrains **(**Vemu et al. 2010). This was further utilized in computing time of concentration.

Owan soil map (Figure 8) was developed to identify the soil texture present in the catchment with a view of categorizing it into Hydrological Soil Groups (HSGs) based on the USDA classification. The identified soil texture (IST) in Owan sub-basin are sandy-loam and loam which belong to the Hydrological soil group (HSG) family of A and B respectively (Viji et al. 2015). The RS obtained IST is in good agreement with field investigation.

Supervised image classification was performed on Landsat 8 satellite imagery within the ArcGIS environment using the Image Analysis tool, to generate the LULC map of Owan watershed. The watershed map produces three (3) LULC categories i.e., dense forest, built-up/bare earth, and cultivated land (Figure 9).

The CN is a derivative of land use and HSG. Therefore, the intersection of LULC and HSG maps was carried out in ArcGIS environment for the purpose of obtaining the CN map (Figure 10) where accurate CN values were extracted for use in calculating potential maximum retention in the sub-basin and time of concentration. CN values fluctuate between 0 and 100. Small CN values result in high infiltration and low runoff capabilities while large CN values suggest low infiltration and high runoff. The runoff potentiality of Owan is still poor considering CN values between 26-28 constitute 95.51 % of the basin.

Table 1 shows the breakdown of identified Owan catchment parameters, class sizes, the area covered, and percentages obtained by the application of RS and GIS techniques.

Table 1: Owan Catchment characteristic Parameters

S/N	PARAMETERS	CLASS SIZES	AREA COVERED (M^2)		PERCENTAGE (%)
1.	DEM	50 - 120	258658200		22.59953
		130 - 190	269534700		23.54983
		200 -260	217606500		19.01275
		270 -330	246900600		21.57224
		340 -400	151829100		13.26564
2.	RAINFALL	14.00 – 17.00	545297400		47.408
		18.00 – 19.00	284127300		24.702
		20.00 – 22.00	263886300		22.942
		23.00 – 29.00	56903400		4.947
3.	Slope	0-2 %	192918600		16.86
		2.1 - 8 %	611336700		53.41
		8.1 -16 %	261778500		22.87
		16.1 -30 %	70011000		6.12
		>30.1 %	8483400		0.74
4.	Identified Soil Texture	Hydrologic Soil Group			
		A	B	C	D
	Sandy Loam	✓			
	Loam		✓		
5.	LULC	Mixed Veg	595960041		49.53
		Dense Veg	553206204		45.98
		BU/Bare Earth	53993104		4.49
6.	CN	26	559489500		45.98
		28	603845100		49.63
		49	39888000		3.28
		89	13436100		1.10
		92	102600		0.01

3.2 Rainfall Correlation

The validation was carried out for monthly precipitation and the analysis was based on a statistical approach using Pearson's Product Moment Correlation statistics between NIMET and PERSIANN datasets for towns in Owan sub-basin. On the Average, Owan Sub-basin indicates spatial correlation coefficients of 0.70 (Table 2) to show that the PERSIANN-CDR data are reliable with highly significant dependability status (Travers et al. 2017).

Table 2: Result of Correlation between NIMET and PERSIANN Rainfall data set for Owan Sub-basin

Town	**Multiple R**	**R^2**	**Adjusted R^2**	**P-value**	**Statistical relevance**	**Remark**
Urole	0.83519	0.697543	0.667297	0.00072	Highly significant	Accepted
Eybiamen	0.827032	0.683981	0.652379	0.00090	Highly significant	Accepted
Eme	0.829629	0.688285	0.657113	0.00084	Highly significant	Accepted
Uhomora	0.834138	0.695787	0.665366	0.00074	Highly significant	Accepted
Umokpe	0.831864	0.691997	0.661197	0.00079	Highly significant	Accepted
Ehor	0.838442	0.702984	0.673283	0.00066	Highly significant	Accepted
Sabongida	0.836126	0.699107	0.669018	0.00070	Highly significant	Accepted
Opuje	0.844274	0.712798	0.684078	0.00055	Highly significant	Accepted
Igubezi	0.839988	0.705579	0.676137	0.00063	Highly significant	Accepted
Ugbeturu	0.839197	0.704251	0.674676	0.00064	Highly significant	Accepted
Owan	0.846558	0.71666	0.688326	0.00051	Highly significant	Accepted
Afuze	0.827254	0.68435	0.652785	0.00090	Highly significant	Accepted
Egoro	0.818605	0.670114	0.637125	0.00113	Highly significant	Accepted
Ozalla	0.825081	0.680759	0.648834	0.00095	Highly significant	Accepted
Oke	0.836467	0.699676	0.669644	0.0007	Highly significant	Accepted
Irhue	0.837508	0.70142	0.671563	0.00067	Highly significant	Accepted

3.3 Discharge Correlation between Observed and Estimated

A 68 % correlation was registered at Owan sub-basins which proves the NRCS-CN model can successfully simulate runoff for poorly gauged or ungauged basins. The results as presented in Table 3 show that the GIS and

RS basin parameters determined from satellite images such as LULC help examine the runoff response of ungauged basins. The study reveals that there is a complementarity between measured and estimated runoff. The correlation results of estimated discharge across Owan sub-basins are reasonably acceptable; considering statistical tests and p-values as outlined by (Travels et al. 2017) that P-values ≥ 0.05 (not significant), < 0.05 (significant), < 0.02 (highly significant).

Table 3: Result of Correlation between Measured and Estimated Discharge data set for Owan Sub-basin

Town	**Equation**	**Multiple R**	**R^2**	**Adjusted R^2**	**P-value**	**Statistical relevance**	**Remark**
Urole	NRCS-CN	0.818394	0.669769	0.636746	0.00114	Highly significant	Accepted
Eybiamen		0.812576	0.660279	0.626307	0.00132	Highly significant	Accepted
Eme		0.815745	0.66544	0.631984	0.00122	Highly significant	Accepted
Uhomora		0.825961	0.682211	0.650432	0.00093	Highly significant	Accepted
Umokpe		0.824883	0.680433	0.648476	0.00096	Highly significant	Accepted
Ehor		0.824666	0.680074	0.648081	0.00096	Highly significant	Accepted
Sabongida		0.826373	0.682892	0.651181	0.00092	Highly significant	Accepted
Opuje		0.832809	0.693571	0.662928	0.00077	Highly significant	Accepted
Igubezi		0.834841	0.69696	0.666656	0.00073	Highly significant	Accepted
Ugbeturu		0.836622	0.699936	0.66993	0.00069	Highly significant	Accepted
Owan		0.846472	0.716515	0.688167	0.00052	Highly significant	Accepted
Afuze		0.818437	0.669839	0.636823	0.00114	Highly significant	Accepted
Egoro		0.810855	0.657485	0.623234	0.00137	Highly significant	Accepted
Ozalla		0.81764	0.668535	0.635388	0.00116	Highly significant	Accepted
Oke		0.831781	0.691859	0.661045	0.00079	Highly significant	Accepted
Irhue		0.828524	0.686451	0.655096	0.00087	Highly significant	Accepted

3.4 Discharge Descriptive Statistics Across Owan Catchment

The discharge descriptive statistics across towns in Owan is presented in Table 4.

Table 4: Descriptive Statistics for Discharge in Owan Catchment

TOWN	**Mean**	**SD**	**Variance**	**Range**	**Minimum**	**Maximum**	**Sum**
Measured	3298.422	3650.352	13325070.412	11488.454	15.561	11504.015	39581.063
Urole	2703.224	2705.991	7322388.341	7908.061	1.558	7909.619	32438.69
Eybiamen	2662.744	2716.224	7377871.779	8049.800	2.203	8052.003	31952.923
Eme	406.590	419.167	175701.320	1261.660	0.170	1261.831	4879.078
Uhomora	3807.451	3886.494	15104832.065	11734.741	2.175	11736.916	45689.410
Umokpe	15272.753	15488.504	239893751.378	47225.071	6.991	47232.062	183273.034
Ehor	10855.008	10655.394	113537431.579	31313.446	13.359	31326.805	130260.095
Sabongida	2951.661	2967.188	8804205.742	8807.393	1.706	8809.098	35419.931
Opuje	7354.844	7128.337	50813185.359	21089.914	10.001	21099.916	88258.131
Igubezi	4278.149	4284.424	18356291.127	12813.864	3.379	12817.242	51337.786
Ugbeturu	702.493	707.785	500959.497	2139.296	0.576	2139.872	8429.917
Owan	1288.029	1274.924	1625430.669	3857.134	1.001	3858.135	15456.345
Afuze	10957.095	11251.428	126594636.643	33866.259	4.574	33870.834	131485.143
Egoro	8346.926	8616.693	74247403.364	26168.084	5.957	26174.041	100163.106
Ozalla	4634.274	4746.998	22533985.776	14470.773	2.720	14473.492	55611.285
Oke	9508.391	9558.595	91366733.508	29242.811	6.320	29249.131	114100.687
Irhue	8055.525	7989.029	63824589.596	24508.784	0.925	24509.709	96666.295

To ascertain the quantity of water available for energy generation activities and flow seasonality of Owan catchment, the available discharge potential was evaluated. From Table 4, the standard deviation (SD) which shows the degree of convergence of the data around the mean indicates a normal distribution ($\mu + \sigma$) for Owan catchment because the values across all the examined towns are within one SD which is 68% where μ & σ denote mean & standard deviation correspondingly (Czitrom et al. 1997; Pukelsheim 1994). The maximum and minimum monthly average discharge values are 15,272.753 and 406.590 obtained in Umokpe and Eme respectively. Umokpe registered the greatest annual discharge of 183273.034 m^3/s with minimum and maximum estimated values of 15.561 m^3/s and 47,232.062 m^3/s respectively. Comparing the estimated discharge values with the last set of archival values obtained in 1999 for Owan, (BORBDA 2007), there is a rise in runoff owing to LULC.

3.5 Rainfall Hyetograph – Runoff Hydrograph for Owan Catchment

Figure 11 to 26 describes the monthly analysis of rainfall and discharge behaviors across townships of Owan catchment in year 2018. The hyetograph and hydrograph illustrate more time is need for them to peak as indicated by the growing limb compare to diminishing limb from the January to December successiveness consider for analysis. Rainfall configuration significantly influences runoff hydrograph (Sraj et al. 2010) as observed in the Figures below. This clearly presents the importance of precipitation data in the NRCS-CN method.

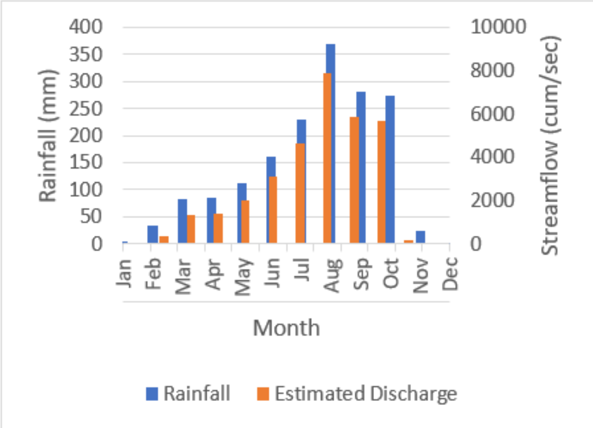

Figure 11: Urole Rainfall hyetograph-runoff hydrograph

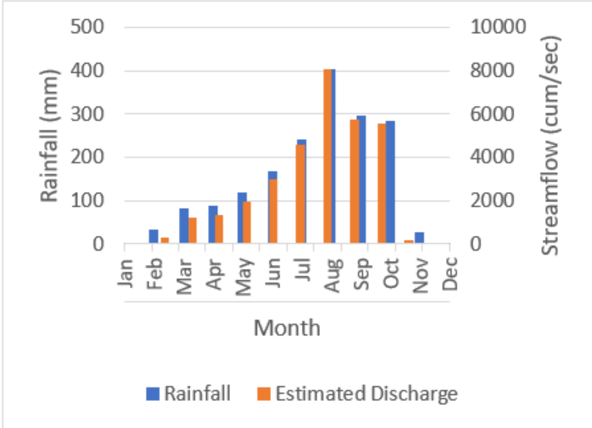

Figure 12: Eybiamen Rainfall hyetograph-runoff hydrograph

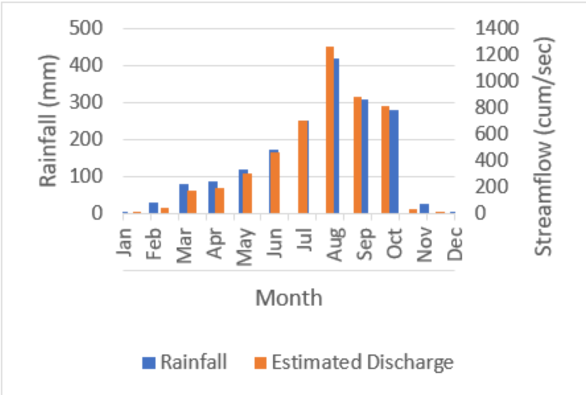

Figure 13: Eme Rainfall hyetograph-runoff hydrograph

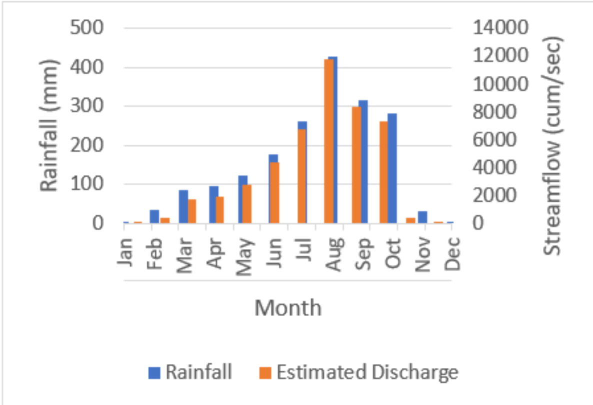

Figure 14: Uhomora Rainfall hyetograph-runoff hydrograph

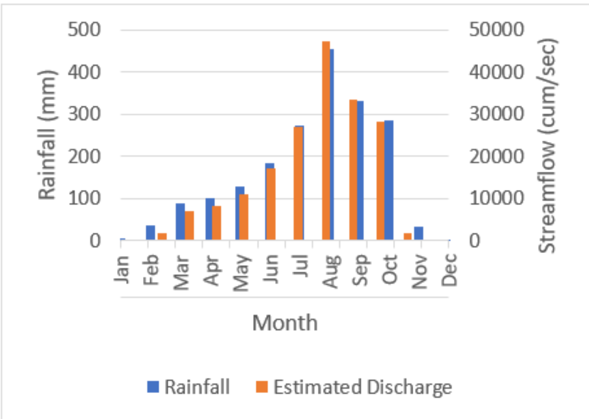

Figure 15: Umokpe Rainfall hyetograph-runoff hydrograph

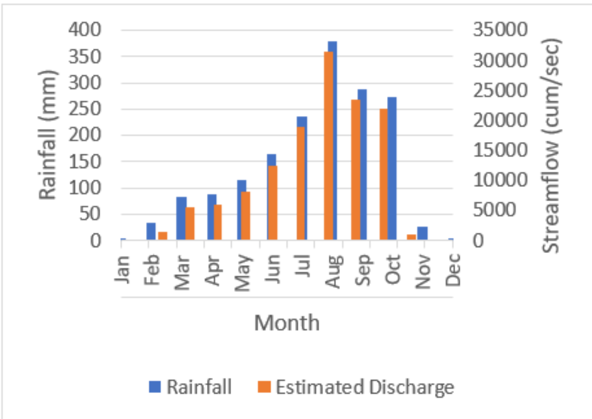

Figure 16: Ehor Rainfall hyetograph-runoff hydrograph

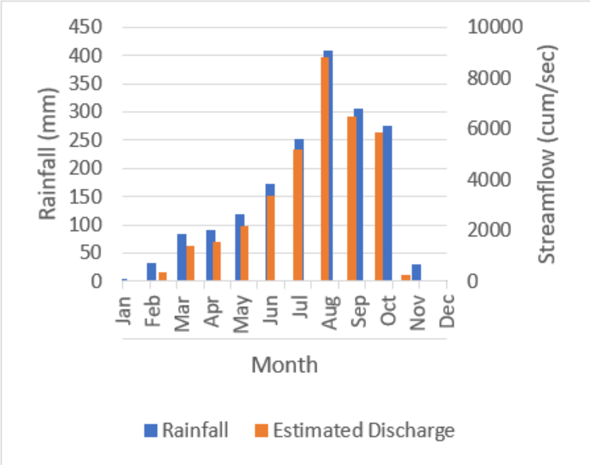

Figure 17: Sabongida Rainfall hyetograph-runoff hydrograph

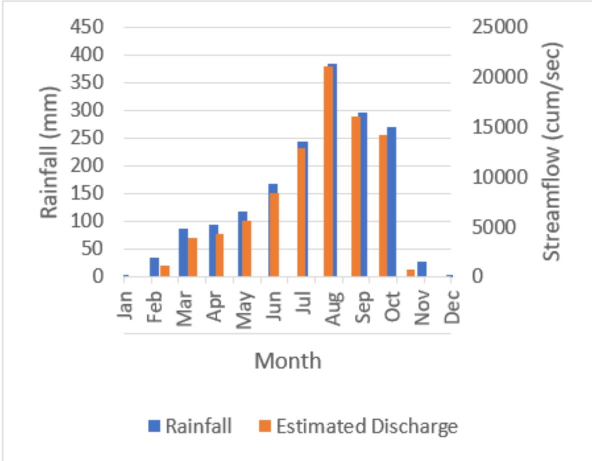

Figure18: Opuje Rainfall hyetograph-runoff hydrograph

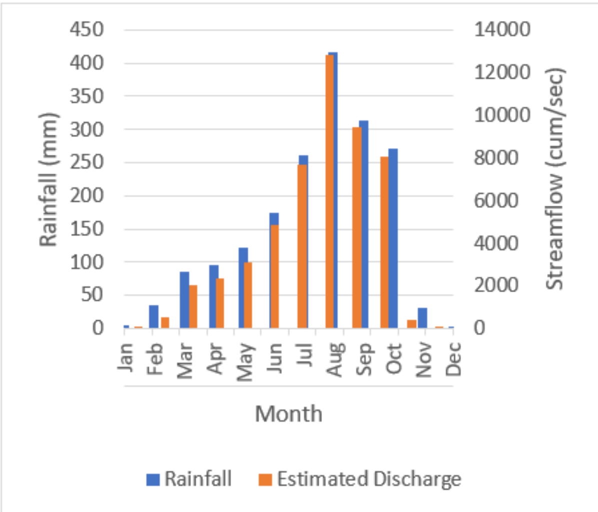

Figure 19: Igubezi Rainfall hyetograph-runoff hydrograph

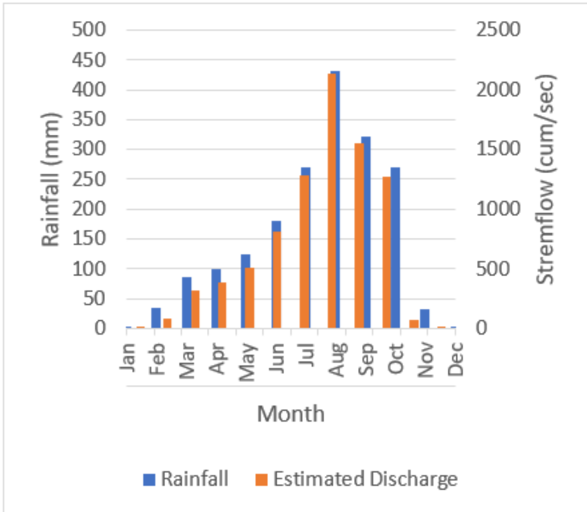

Figure 20: Ugbeturu Rainfall hyetograph-runoff hydrograph

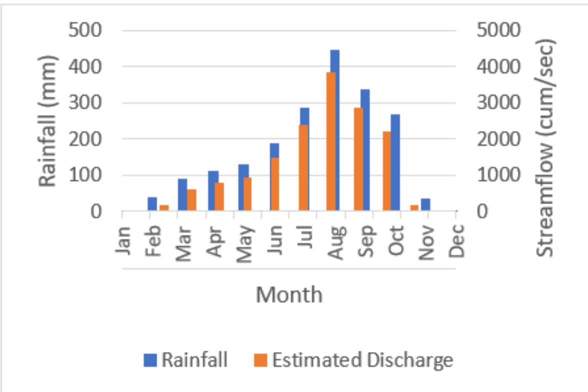

Figure 21: Owan Rainfall hyetograph-runoff hydrograph

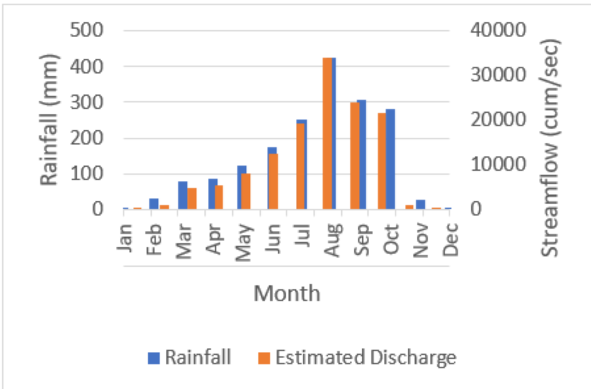

Figure 22 Afuze Rainfall hyetograph-runoff hydrograph

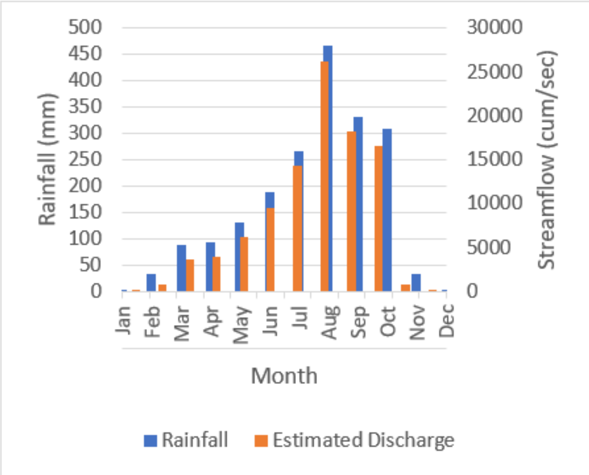

Figure 23: Egoro Rainfall hyetograph-runoff hydrograph

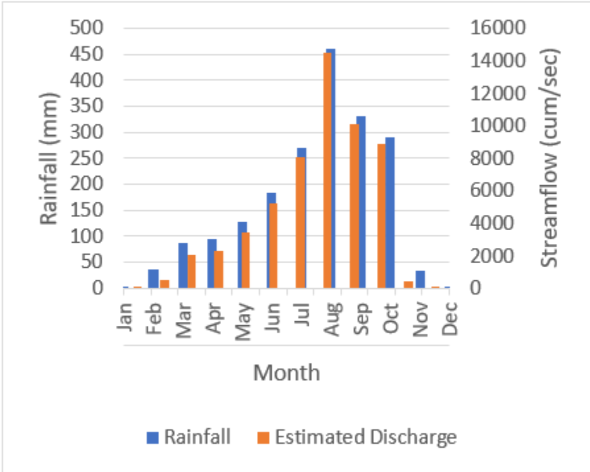

Figure 24: Ozalla Rainfall hyetograph-runoff hydrograph

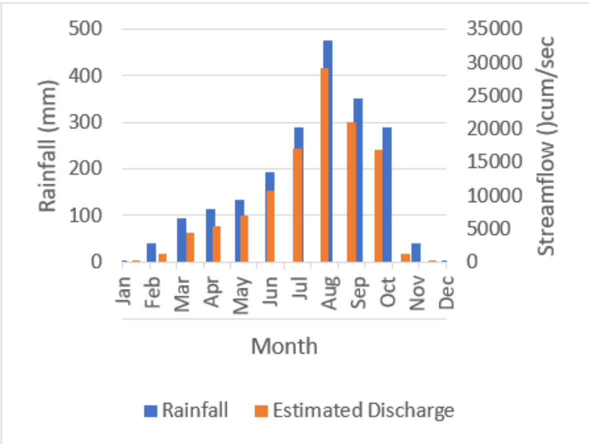

Figure 25: Oke Rainfall hyetograph-runoff hydrograph

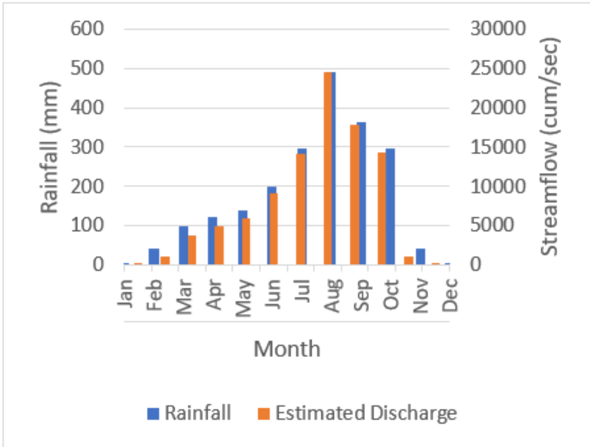

Figure 26: Irhue Rainfall hyetograph-runoff hydrograph

3.6 FDC Analysis for Towns in Owan Sub-basin.

From the developed FDC of Owan catchment for a period of twelve months, flows which are equaled or exceeded at 8%, 17%, 25%, 33%, 42%, 50%, 58%, 67%, 75%, 83%, 92% and 100% were obtained. (Sahu 2015; MNRE 2008) utilized 75% and 90% exceedance values respectively in their studies while this research adopts 92 % exceedance probability. Table 5 shows the obtainable discharge equaled or exceeded at 92% of the time utilized for hydropower potential estimations across viable points in Owan watershed.

Table 5: FDC Q_{92} for Towns in Owan Sub-basin

Town	Q_{92} Flow equaled or Exceeded (m^3/s)
Urole	5.035888
Eybiamen	5.941597
Eme	1.402623
Uhomora	10.48928
Umokpe	28.42356
Ehor	16.16917
Sabongida	5.328053
Opuje	10.98024
Igubezi	9.116655
Ugbeturu	1.513738
Owan	1.809837
Afuze	33.10717
Egoro	32.48003
Ozalla	10.1014
Oke	17.17374
Irhue	5.732755

3.7 Owan SHP Potential

Having established a strong relationship between the rainfall and discharges in the Owan catchment, this study recommended the use of the Q_{92} flow statistic obtained from the FDC of relevant towns close to the potential point as listed in Table 5. Reflecting the catchment optimization criteria as defined for this study to identify viable points which are 2 % minimum slope (slope ≥ 2 %) (Kusre et al. 2010; Pandey et al. 2015) and minimum 10 m available head (H ≥ 10 m), 20 potential sites as represented in Figure 27 were discovered in Owan sub-basin and the locations/point number along the river network are shown in Table 6. This gives rise to the determination of SHP potential using equation 8.

Table 6 Hydropower Potential and Turbine Choice for Owan Sub-Basin

S/N	**Town**	**Points**	**X-Cord**	**Y-Cord**	**Slope (%)**	**Available Head (m)**	**Discharge Q_{92} (m^3/s)**	**Power Potential (kW) /Year**
1.	Urole	8	828875.742	782483.273	3.07759	12.000	5.036	423.015
2.	Eybiamen	11	831506.564	778991.701	3.65935	13.000	5.942	540.685
3.	Eybiamen	12	832607.667	777528.317	10.91840	12.000	5.942	499.094
4.	Umokpe	32	821533.300	755302.058	4.91619	16.000	28.424	3183.439
5.	Umokpe	33	823001.333	754724.140	2.06055	13.000	28.424	2586.544
6.	Umokpe	37	826442.758	749877.418	5.39147	12.000	28.424	2387.579
7.	Umokpe	38	827827.611	748623.690	3.83370	27.000	28.424	5372.053
8.	Umokpe	39	828802.631	747293.556	7.62469	54.000	28.424	10744.106
9.	Ehor	44	823412.618	781614.983	5.65751	33.000	16.169	3735.077
10.	Ehor	45	824297.750	780152.374	5.74345	14.000	16.169	1584.578
11.	Opuje	57	816872.689	777901.439	2.55580	10.000	10.980	768.617
12.	Opuje	60	816189.808	772885.547	2.35633	14.000	10.980	1076.063
13.	Egoro	91	840591.448	752545.288	11.38700	24.000	32.480	5456.646
14.	Egoro	92	840213.220	754344.072	3.33236	20.000	32.480	4547.205
15.	Egoro	94	839375.294	757281.645	2.35633	11.000	32.480	2500.963
16.	Oke	116	818369.515	747414.069	4.91619	12.000	17.174	1442.594
17.	Irhue	122	823162.378	739967.165	4.35238	52.000	5.733	2086.723
18.	Irhue	123	821761.758	740792.431	9.73221	23.000	5.733	922.974
19.	Irhue	124	821274.709	742550.178	3.23286	16.000	5.733	642.069
20.	Oke	125	820976.768	744147.165	2.35633	16.000	17.174	1923.459

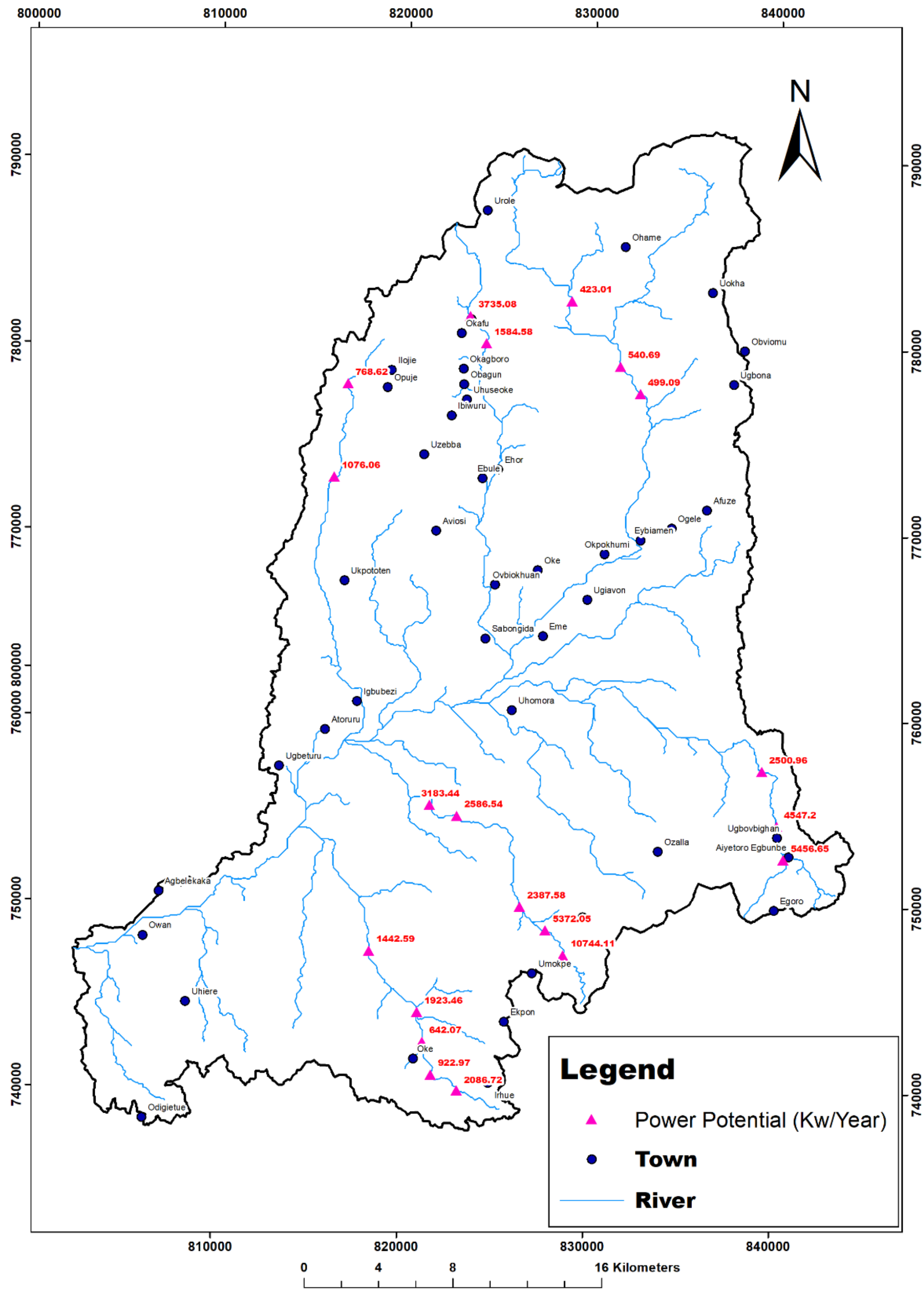

Figure 27: Owan Catchment SHP potential Location

4.0 Conclusion

The method utilized in this paper creates a process that is free from error by requiring specific data that are obtained from RS and GIS that best copy and reproduces the Owan catchment sufficiently for example rainfall, CN, DEM where slope and elevation were derived. Other physiographic characteristics assessed in the sub-basin includes catchment area, stream network length, discharge capabilities. From this study the following conclusions are made:

[1] This approach is better and faster compared to traditional practice where different types of equipment are utilized independently to acquire various topographic data.

[2] The combination of NRSC-CN model, RS, and GIS shows high dependability status when paired for evaluation of run-of-river (ROR) discharge vis-a-vis SHP potential.
[3] The estimated power potential calculated in kW for each viable location considering the catchment features (Slope and elevation) indicates the sites are qualified to yield such energy.
[4] The success achieved in this research can be attributed to the utilization of accurate terrain data resources and high-resolution images. This enhances the investigation by producing good correlation results for both discharge and rainfall.
[5] Satellite-based RS application has advantages like large area coverage, synoptic view, and capability to provide information over all accessible and inaccessible regions.
[6] Adequate topographic conditions exist in which the water resources of Owan river can be utilized to generate power either as an off-grid or on-grid system
[7] The power available at 92% exceedance of the viable 20 hydrological points identified as SHP potential locations ranges between 423.015 kW to 5,456.646 kW

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References
Avila, C.J.C.P., Júnior, O.A.C., Guimarães, R.F., Bentancurt, J.J.V. (2007). Preliminary survey of undeveloped hydropower potential using GIS-based tools [Use of GIS tools for preliminary inventory of remaining potentials]. Technical paper: National Reference Center for Small Hydroelectric Plants. Department of Geography, University of Brasilia. Available at, http://www.cerpch.unifei.edu.br/at01.php?grp
Bala, E.J. (2019). The Role of SHP in Nigeria's Energy Policy. Paper Presented at the Capacity Building Workshop on Small Hydro Power Development for Policy Makers and Renewable Energy Project Developers In Nigeria Under The Framework Of The GEF-5 Project "Scaling Up Small Hydro Power In Nigeria" Organized By United Nations Industrial Development Organization (UNIDO), Nigeria, 28th October 2019 at Barcelona Hotel, Abuja.
Ballance, A., Stephenson, D., Chapman, R. A., & Muller, J. (2000). A geographic information systems analysis of hydro power potential in South Africa. *Journal of Hydroinformatics*, *2*(4), 247–254.
https://doi.org/10.2166/hydro.2000.0022
Bennui, A., Rattanamanee, P., Limjirakhajorn, K., Yongsatitsak, T., Yongchalermchai, P., Yisuwan, C. (2012). Application of Geo-informatics on assessment of mini-hydropower potential in Khao Luang mountain range, Nakhon Si Thammarat Province. 33rd Asian Conference on Remote Sensing 2012, ACRS 2012. 1. 719-731.
BORBDA (1992), Benin Owena River basin Hydrological year Book, 1989-1990
BORBDA (1993), Benin Owena River basin Hydrological year Book, 1991-1992
BORBDA (1997), Benin Owena River basin Hydrological year Book, 1993-1994
BORBDA (2005), Benin Owena River basin Hydrological year Book, 1995-1998
BORBDA (2007), Benin Owena River basin Hydrological year Book, 1999-2000
Chandra, B. A., Giridhar, M. V. S. S., Venkateswar, R. C., & Viswanadh, G. K. (2013) Identification of Suitable Locations for Micro Hydro Power Stations Using Geospatial Technology. In World Environmental and Water Resources Congress: Showcasing the Future (pp. 1377-1381). ASCE.
Connolly, D., MacLaughlin, S., & Leahy, M. (2010). Development of a computer program to locate potential sites for pumped hydroelectric energy storage. *Energy*, *35*(1), 375–381. https://doi.org/10.1016/j.energy.2009.10.004
Czitrom, V. and Spagon, P., (1997). *Statistical Case Studies for Industrial Process Improvement*. Philadelphia, Pa.: Society for Industrial and Applied Mathematics (SIAM, 3600 Market Street, Floor 6, Philadelphia, PA 19104) p. 342.
Dudhani, Surekha & Sinha, A.K. & Inamdar, S.S., (2006). "Assessment of small hydropower potential using remote sensing data for sustainable development in India," Energy Policy, Elsevier, vol. 34(17), pages 3195-3205, November.
ECN. (2014). Draft National Renewable Energy & Energy Efficiency Policy (NREEEP) 2014 Ed. Energy Commission of Nigeria Available: http://www.energy.gov.ng/.
ESHA/IT-Power, (2006). "Small Hydropower for Developing Countries". European Small Hydropower Association. Belgium 2006. www.esha.be
FAO (2008). Water for Agriculture and Energy in Africa: The Challenges of Climate Change. Report of the ministerial conference 15-17 December 2008, Sirte, Libyan Arab Jamahiriya. Available at: www.fao.org/docrep/014/i2345c01.pdf (last accessed 28 May 2016).

Fasipe, O., & Izinyon, O. (2020). GIS and RS Techniques for Identification of Hydropower Potential Sites in Benin-Owena River Basin in Nigeria. *INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH O. Fasipe and O. Izinyon*, *10*(1), 486–498.

Feizizadeh, B., & Haslauer, E. M. (2012). GIS-based procedures of hydropower potential for Tabriz basin, Iran. International Journal, 495-502.

Hall, D.G., Cherry, S.J., Reeves, K.S., Lee, R.D., Carroll, G.R., Sommers, G.L., et al (2004). Water energy resources of the United States with emphasis on low head/low power resources. US Department of Energy. Available at: http://hydropower.id.doe.gov/resourceassessment/pdfs/03-11111.pdf

International Journal on Hydropower and Dams (IJHD), (2015). *World Atlas & Industry Guide*, IJHD Wallington, ISO 1100-2, 1998, *Measurement of liquid flow in open channels - Part 2: Determination of the stage-discharge relation* Surrey.

Kusre, B. C., Baruah, D. C., Bordoloi, P. K., & Patra, S. C. (2010). Assessment of hydropower potential using GIS and hydrological modeling technique in Kopili River basin in Assam (India). *Applied Energy*, *87*(1), 298–309. https://doi.org/10.1016/j.apenergy.2009.07.019

Larentis, D. G., Collischonn, W., Olivera, F., & Tucci, C. E. M. (2010). Gis-based procedures for hydropower potential spotting. *Energy*, *35*(10), 4237–4243. https://doi.org/10.1016/j.energy.2010.07.014

Li, M.H., & Chibber, P. (2008). Overland Flow Time of Concentration on Very Flat Terrains. *Transportation Research Record: Journal of the Transportation Research Board*, *2060*(1), 133–140. https://doi.org/10.3141/2060-15

MNRE, (2008). Government of India standards/manuals/Guidelines for small hydro development: manual on project Hydrology and installed capacity. Ministry of New and Renewable Energy Available from: http://www.iitr.ac.in/PageUploads/files/2_3_GUIDELINESFOR_STRUCTURAL_DESIGN_OF_SHP_PROJECTS.pdf.

OCHIGBO, A.J. (2019). Resource Potential, Challenges and Suggestions for Efficient Exploitation of Small Hydropower in Nigeria. A Paper Presented at Capacity Building Workshop on Small Hydropower Development for Policy Makers and Renewable Energy Developers In Nigeria Held on 28thOctober, 2019 at Barcelona Hotel, WuseII, Abuja.

Oyedepo, S. O., Babalola, O. P., Nwanya, S. C., Kilanko, O., Leramo, R. O., Aworinde, A. K., Adekeye, T., Oyebanji. J. A., Abidakun, A. O. and Agberegha, O. L. (2018). Towards a Sustainable Electricity Supply in Nigeria: The Role of Decentralized Renewable Energy System. European Journal of Sustainable Development Research, 2(4), 40. https://doi.org/10.20897/ejosdr/3908

Panlenlab, (2017). *New Paper In Canadian Journal Of Fisheries And Aquatic Sciences: Run-Of-River Hydropower And Salmonids – Potential Effects And Perspective On Future Research*. [online] Palen Lab. Available at: <https://palenlab.wordpress.com/2017/10/11/run-of-river-hydropower-and-salmonids-potential-effects-and-perspective-on-future-research/> [Accessed 23 September 2020].

Pandey, Ashish, Daniel Lalrempuia & S.K. Jain (2015) Assessment of hydropower potential using spatial technology and SWAT modeling in the Mat River, southern Mizoram, India, Hydrological Sciences Journal, 60:10, 1651-1665, DOI:10.1080/02626667.2014.943669)

Pukelsheim, F. (1994). The Three Sigma Rule. *The American Statistician*, *48*(2), 88. https://doi.org/10.2307/2684253

Rojanamon, P., Chaisomphob, T., & Bureekul, T. (2009). Application of geographical information system to site selection of small run-of-river hydropower project by considering engineering/economic/environmental criteria and social impact. *Renewable and Sustainable Energy Reviews*, *13*(9), 2336–2348. https://doi.org/10.1016/j.rser.2009.07.003

Roussel, M.C., Thompson, D.B., Fang, Xing, Cleveland, T.G., and Garcia, C.A. (2005). Time-parameter estimation for applicable Texas watersheds: Texas Department of Transportation Research Report.0–4696–2: Beaumont, Texas, Lamar University.

Sahu, S. (2015). *Small Hydropower: Feasible Location, Potential and Installation in Odisha*. M.Tech. Thesis National Institute of Technology, Rourkela, India.

Salimi, E., Nohegar, A., Malekian, A., Hoseini, M., and Holisaz, A. (2016). Estimating time of concentration in large watersheds. *Paddy and Water Environment*, *15*(1), 123-132. https://doi.org/10.1007/s10333-016-0534-2.

Smakhtin, V. (2001). Low Flow Hydrology: A Review. *Journal of Hydrology*, *240*(3-4), 147-186. https://doi.org/10.1016/s0022-1694(00)00340-1

Šraj, M., Dirnbek, L., & Brilly, M. (2010). The influence of effective rainfall on modeled runoff hydrograph. *Journal of Hydrology and Hydromechanics*, *58*(1). https://doi.org/10.2478/v10098-010-0001-5

Taulo, J.L. (2007). *A Study on the Utilization of Small-Scale Hydropower for Rural Electrification in Malawi*. M.Sc. Thesis, University of Cape Town, South Africa.

The Nigerian Energy Support Programme II (NESP, 2019). Fostering Investments for Renewable Energy and

Energy Efficiency and Improving Access to Electricity for Disadvantaged, Rural Communities.
Travers, J., Cook, B., & Cook, L. (2017). Null Hypothesis Significance Testing and p Values. *Learning Disabilities Research & Practice*. https://doi.org/10.1111/ldrp.12147
US Natural Resources Conservation Service (NRCS) (1997) Ponds planning, design construction. In: Agriculture handbook. United States Department of Agriculture (USDA)
Vemu, S., and Bhaskar, P. (2010). Estimation of Catchment Characteristics using Remote Sensing and GIS Techniques. *International Journal of Engineering Science and Technology*, *2*(12), 7763–7770.
Verma, S., Verma, R. K., Mishra, S. K., Singh, A., & Jayaraj, G. K. (2017). A revisit of NRCS-CN inspired models coupled with RS and GIS for runoff estimation. *Hydrological Sciences Journal*, *62*(12), 1891–1930. https://doi.org/10.1080/02626667.2017.1334166
Viji, R., Prasanna, P.R., & Ilangovan, R. (2015). GIS Based SCS - CN Method for Estimating Runoff in Kundahpalam Watershed, Nilgries District, Tamilnadu. *Earth Sciences Research Journal*, *19*(1), 59–64. https://doi.org/10.15446/esrj.v19n1.44714
Yi, C.-S., Lee, J.-H., & Shim, M.-P. (2010). Site location analysis for small hydropower using geo-spatial information system. *Renewable Energy*, *35*(4), 852–861. https://doi.org/10.1016/j.renene.2009.08.003
Yu, P, Yang, T and Wang, Y. (2002). "Uncertainty Analysis of Regional Flow Duration Curves."Journal of Water Resources Planning and Management128: pp 424-430.

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