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)](image-url)
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 loam as the predominant soil which spans a total area of 1216.50km².

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.
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.

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

\[ Q = C(h - a)^{\alpha} \] (1)

Where \( Q \) = discharge, \( h \) = stage height and \( C, a, \alpha \) = calibration constants. Effective flow depth (h-a) = 1 when C = discharge; \( a \) = zero flow gauge height; \( \alpha \) = 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).

\[ S = \frac{25400}{CN} - 254 \] (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).

\[ Q_d = \frac{(P - 0.25)^2}{P + 0.85} \] (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).

\[ Q_p = \frac{2.083 \times A \times Q_d}{t_p} \] (4)

\( Q_p \) = peak runoff rate unit hydrograph (m³/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);

\[ NRCS \ t_p = 0.6 \ t_c \] (5)

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

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

\[ P = \frac{M}{n+1} \times 100 \% \] (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 \( (Q_o) \) 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 ($Q_{92}$) at each town which was adopted as $Q_{92}$, the Run of River (ROR) hydropower potential was computed using equation 8 (Taulo 2007)

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

(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.
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 (M²) | 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 |
|     | Sandy Loam | ✓             |                   |                |
|     | Loam       |              |                   |                |
| 5.  | LULC       | Mixed Veg    | 59596041          | 49.53          |
|     |            | Dense Veg    | 553206204         | 45.98          |
|     |            | BU/Bare Earth | 53993104        | 4.99           |
| 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  | R²  | Adjusted R² | 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 |
| Igbezi | 0.839988    | 0.705579 | 0.676137 | 0.00063 | Highly significant    | Accepted |
| Ugborutu | 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 |
| Iruhe | 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 | R² | Adjusted R² | P-value | Statistical relevance | Remark |
|---------|----------|------------|----|-------------|---------|-----------------------|--------|
| Urole   | 0.818394 | 0.669769   | 0.636746 | 0.00114 | Highly significant | Accepted |
| Ebymien | 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 |
| Ehior   | 0.824666 | 0.680074   | 0.648081 | 0.00096 | Highly significant | Accepted |
| Sabongida | 0.826373 | 0.682892   | 0.651181 | 0.00092 | Highly significant | Accepted |
| Opiuje  | 0.832809 | 0.693571   | 0.662928 | 0.00077 | Highly significant | Accepted |
| Igubezi | 0.834841 | 0.69696    | 0.666656 | 0.00073 | Highly significant | Accepted |
| Ugeteturu | 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   | 0.63588  | 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 |
| Ebymien            | 2662.744 | 2716.224 | 7377871.779 | 8049.800 | 2.023 | 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 | 45669.410 |
| Umokpe             | 15272.753  | 15488.504 | 23993751.378 | 47225.071 | 6.991 | 47232.062 | 183273.034 |
| Ehior              | 10855.008 | 10655.394 | 11353741.579 | 31313.446 | 13.359 | 31326.805 | 130260.095 |
| Sabongida          | 2951.661   | 2967.188  | 8804205.742 | 8807.393 | 1.706 | 8809.098 | 35419.931 |
| Opiuje             | 7354.844   | 7128.337  | 50813185.359 | 21089.914 | 10.011 | 21099.916 | 88258.131 |
| Igubezi            | 4278.149   | 4284.424  | 18356291.127 | 12813.864 | 3.379 | 12817.242 | 51337.786 |
| Ugeteturu          | 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 | 126549636.643 | 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 | 14473.92 | 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 (µ ± σ) for Owan catchment because the values across all the examined towns are within one SD which is 68% where µ and 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 m³/s with minimum and maximum estimated values of 15.561 m³/s and 47,232.062 m³/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
Figure 18: Opuje Rainfall hyetograph-runoff hydrograph

Figure 19: Igabezi 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
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 (m³/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} (m³/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 | 2.06055 | 13.000 | 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 | 747292.140 | 7.62469 | 54.000 | 28.424 | 10744.106 |
| 9.  | Ehor    | 44     | 832412.618 | 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 | 4.91691 | 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 |
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.
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.

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.

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.

Satellite-based RS application has advantages like large area coverage, synoptic view, and capability to provide information over all accessible and inaccessible regions.

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.

The power available at 92% exceedance of the viable 20 hydrological points identified as SHP potential ranges between 423.015 kW to 5,456.646 kW.

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