



ASSESSMENT OF THE HYDROELECTRICITY GENERATION POTENTIAL OF GWAIGWAYE RESERVOIR IN FUNTUA, KATSINA STATE, NIGERIA

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ABSTRACT

Access to quality and adequate supply of electricity is one of the major challenges hampering development in Sub-Saharan Africa. Funtua as the industrial, commercial, and agricultural hub of Katsina State, Nigeria, needs to overcome the problem of epileptic power supply from the national grid. This study explored the hydro generation potential of Gwaigwaye Reservoir, the largest water resource in the area, by evolving a hydrological profile using water surface area in absence of flow gauging data. It also outlined from analysis, the technical requirements for hydroelectricity generation from the reservoir. Consequently, it was discovered from analysis that the average discharge obtainable is 18.54 m³/s. This would flow through four bulb turbines of 750 rpm speed to generate 17.8 MW of power or 14.033 GWh of energy in a year. It is therefore recommended that the Government of Katsina State should seek to implement this project for its potential to improve the living conditions and economy of the people of Funtua, the surrounding communities and the State.

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1.0 Introduction

Access to quality and adequate supply of electricity is one of the major challenges hampering socioeconomic development in Sub-Saharan Africa. This barrier to progress in a nation with large population, like Nigeria, is a problem that requires intensive study and analysis to come up with viable and lasting solutions for its impact on a variety of development indicators, ranging from health care, economic opportunities, improved education, job creation, food security, livelihood, to poverty reduction (World Bank, 2021; ECOSOC, 2023). Many studies and efforts aimed at discovering alternative solutions to the energy dilemma confronting most developing nations, include works on renewable energy generation, distributed generation, energy efficiency programs and so on (Mohammed *et al.*, 2013; Nwozor *et al.*, 2021; Streimikiene *et al.*, 2021; Pehlivanoglu *et al.*, 2021). In tackling this problem, rural electrification required for household lighting, production purposes which include water pumping for irrigation, water supplies, processing and preservation of farm produce and other agro-industry processes and small commercial and manufacture activities, is of a major concern in developing economies (Barnes *et al.*, 1997; Akbas *et al.*, 2022; Dibaba *et al.*, 2022). In order to meet the energy needs of the vast population of the Nigerian people, it has become necessary to explore and harness the hydroelectric potentials in various parts of the country (Manohar and Adeyanju, 2009; Mohammed *et al.*, 2013; Fakenhinde *et al.*, 2019).

This study explored the possibility of hydroelectricity generation for Funtua, a semi-urban town located on longitude 11.5185° N and latitude 7.3129° E at an elevation of 709 m in the southern part of Katsina State, Nigeria, and its environs. Funtua has average rainfall that last for 6 to 7 months in a year, usually from April to October, and peaks to about 21 cm in August (Weather Spark, 2021). There are two dams in the community, Mairuwa Dam and Gwaigwaye Reservoir, which supply water for domestic and irrigation purposes to the people of Funtua and its environs. The Gwaigwaye Reservoir was chosen as the study site for hydroelectricity generation, being the more strategically positioned and larger in size and volume than the other. The project has a prospect of benefitting the local small-scale industries in boosting their productivity, hence for the profitability, employment, and poverty reduction for the people of the area. This will avail them with a more reliable, qualitative, and affordable electricity supply. This project is being proposed and geared toward

developments in distributed off-grid solutions and envisaged for sustainable development (Zebra et al., 2021; Roy et al., 2023; Moran et al., 2022, Strielkowski et al., 2021).

With the deregulation of Nigeria's power sector (Olugbenga et al., 2013; Okedu et al., 2018; Necoechea-Porras et al., 2021), investment opportunities in energy that have emerged include generation of renewable electricity by means of small, mini, and micro hydroelectric systems, solar photovoltaic (PV) farm, wind turbines, and Biogas (Elum and Momodu, 2017; Babatunde et al., 2023), as obtainable in some other countries (Hatata et al., 2019; Qamar et al., 2022). Nigeria is indeed endowed with many distributed power generation potentials which can be harnessed into micro-grid design and consequently help to increase the availability, reliability and stability of the power supply, thereby alleviate energy poverty (Opara et al., 2018), as in other developing countries around the world (Palakshappa et al., 2019; Uddin et al., 2019; Wu et al., 2023; Arthur et al., 2020). This research is focused on exploring and highlighting the hydroelectricity generation potential of Gwaigway Reservoir in Funtua, Katsina State, Nigeria.

2. Materials and method

2.1 Theoretical analysis

The electrical power generated by a hydroelectric plant depends on factors as

- i. rate of flow of water through the turbine, Q (in m^3/s),
- ii. the height from which water flows to the ground level where the turbine is located, termed as head, H (in m), and
- iii. the acceleration due to gravity, g (in m/s^2). (Ajibola et al., 2018):

These terms are modeled mathematically with the generated power, P , given by Iglinski (2019):

$$P = \rho Q g H \lambda \quad 1$$

where, ρ (kg/m^3) is the density of water as a constant value of 1000 kg/m^3 , λ is the overall efficiency of the turbine, the gear and the generator.

This implies that water flow of certain volume must be available at a certain elevation for a hydroelectric project to be feasible. The volume of water stored in a reservoir could be related to the water surface area by a power relation given by Ekeu-wei and Blackburn (2020):

$$V = 0.0231 \times Area^{1.3272} \quad 2$$

The water flow rate is formulated as:

$$Q = \frac{Volume}{Time} (m^3/s) \quad 3$$

As shown in Figure 1, this study was organized to go from the initial site identification stage through the physical activities carried out to examine the available hydrological, structural, and electromechanical parameters with a view to optimally generating electricity.

2.2 Site identification

The proposed site is the Gwaigway Water Reservoir (Plate 1), situated on River Gwaigway at Unguwar Biri village, 3 km off Funtua – Sokoto Road in Funtua, Katsina State, Nigeria. It is a local segment of the Sokoto River which originated from Machika hills in the neighboring Dandume local government area (Lawal et al., 2020). It is located on the longitude $7^{\circ}12'23''$ E, and latitude $11^{\circ}34'47''$ N, with a catchment area of 120 km^2 , an earth dam length of 350 m and a height of 13 m (Weather Spark, 2021). At Full Supply Level (FSL) of 109 m, it has a depth of 12 m, capacity of $42.99 \times 10^6 \text{ m}^3$, surface area of $1,701,966.333 \text{ m}^2$ and shoreline of 8.2 km.



Figure 1: Block diagram of the technical feasibility.



Plate 1: Satellite image of Gwaigway Reservoir

2.3 Demand Analysis

The load to be supplied was profiled from the point of view of the total connected load on the 11 kV feeders at Funtua transmission substation presented in Table 1 and given as 19 MW. In addition, there are two 33 kV feeders feeding the remote areas of Malumfashi (13 MW) and Dandume (4 MW) from the same transmission substation.

Existing supply from Kano Electricity Distribution Company (KEDCO) has a maximum value of 15.1 MW for 1000 hours (KEDCO, 2023). This is shared between the 33 kV feeders supplying remote locations and 11 kV feeders feeding the town. The proposed power project when implemented will definitely not supply this entire load independently, but will be complemented by the grid supply to Funtua town. The load is first de-rated by its diversity factor, determined for the distribution network by:

$$\text{Diversity Factor (DF)} = \frac{\text{Sum of individual max. demand of 11 kV feeders}}{\text{Max. Demand on the bus feeding 11 kV feeders}} \quad 4$$

The demand here can be reduced to the ratings of the protecting feeder breakers. So that,

$$DF = \frac{\sum I_i}{I_n} \quad 5$$

where, I_i is the rating of the 11 kV breakers and I_n is the rating of the breaker of the 11 kV bus.

Since the Katsina Road feeder 33 kV and Textile feeder 33 kV main bus breaker ratings are on the 33 kV sides of the transformers, the quantities are therefore referred to 11 kV sides of the transformers to tally with the ratings of the individual breakers and given by:

$$I'_n = I_n * \frac{E_p}{E_s} \quad 6$$

The de-rated value of the demand is therefore obtained from:

$$\text{Load Demand} = \text{Total connected load} \times DF \quad 7$$

Hence, the prospective capacity of the hydro station is obtained from:

$$\text{Demand} = \text{Required Capacity} = \frac{\text{Annual Demand (kWh)}}{365 \text{ days} \times 24 \text{ hrs}} \times \frac{100}{\text{Annual Load Factor \%}} \quad 8$$

Table 1: Total connected load and breakers rating on Funtua 11 kV feeders (KEDCO, 2022)

30 MVA Transformer 132/33/11 kV			60 MVA Transformer 132/33/11 kV		
Feeder location	Breaker Rating (A)	Connected Load (MW)	Feeder location	Breaker Rating (A)	Connected Load (MW)
Katsina Road (33 kV)	400	9.5	Textile (33 kV)	400	9.5
Jabiri (11 kV)	300	4.0	Nakowa feeder (11 kV)	350	4.5
DutsenReme (11 kV)	200	1.5	Mairuwa (11 kV)	250	1.3
Town (11 kV)	250	2.2	Water works (11 kV)	150	1.2
Industrial (11 kV)	100	1.8	Textile (11 kV)	100	2.5
Total Connected Load		19.0	Total Connected Load		19.0

The generating capacity of the project is also de-rated in terms of the losses in transmission and distribution and the own use of the power station. The following formula is used to calculate the proposed generation capacity:

$$\text{Proposed Generation Capacity} = \frac{\text{Electricity Demand}}{1 - (\text{TD losses \%} + \text{own use \%})/100} \quad 9$$

2.4 Site Survey and Analysis

Necessary surveys are carried out at the identified site to identify physical, hydrological, and geological features that may influence the feasibility of the project. The survey is in two stages: the topographical survey and the hydrological survey.

2.4.1 Topographical Survey

Generally, topographical maps of 1:50,000 are generated in hydroelectricity feasibility studies to optimize the project planning (The World Bank, 2018a & b; Pöyry Energy Ltd, 2019), and cover areas of major civil structures. For this study, the topographical map by (Lawal et al., 2020) is adapted and shown in Figure 2. Existing structures like the reservoir, access road, intake tower, and spillway, would be optimized to suit the requirements of the proposed project.

2.4.2 Hydrological Survey

River Gwaigwaye is not gauged, making it difficult to extract runoff data directly from the river. The availability of water in the reservoir can be accurately represented by the water level records as correlated by several studies (Yuanshou et al., 2008, Wang et al., 2023). It is therefore appropriate for this study to utilize the operational records of the monthly water level captured at the intake tower of the reservoir by the Funtua Water Works as given in Table 2 (Lawal et al., 2020). Figure 3 shows the graphical plot of the water level by months of the year.

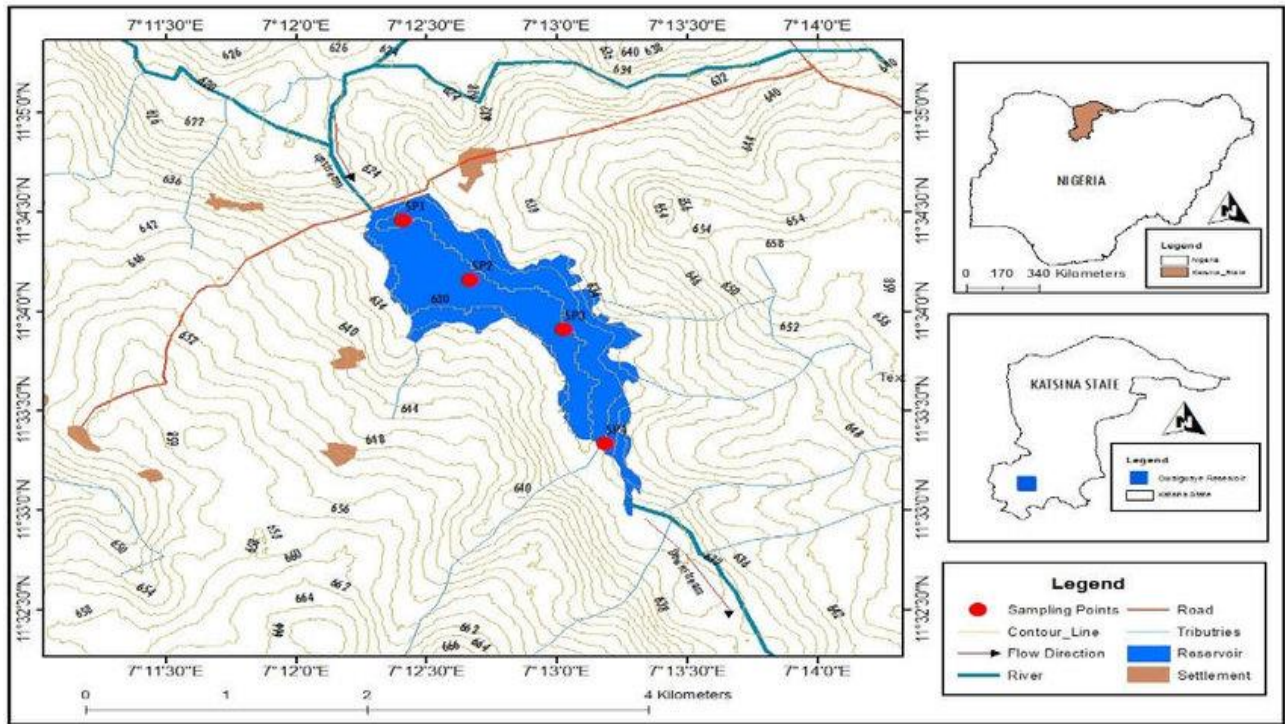


Figure 2: Topographic map of Gwaigway Reservoir.

Table 2: Extracted data for Gwaigway Reservoir

Month	Monthly Average of		
	Water level (m)	Water Temperature (°C)	pH Value
January	10.9	25.69	7.37
February	10.6	27.19	7.35
March	10.1	20.63	7.5
April	9.7	24.95	7.6
May	10.2	21.33	7.46
June	10.5	26.14	7.16
July	11.7	25.17	7.1
August	12.0	25.71	7.53
September	11.8	26.48	8.13
October	11.6	25.87	7.97
November	11.4	25.53	7.91
December	11.2	25.53	7.35

The volume of water in a reservoir using water surface area captured from satellite images is used to obtain the monthly flow rate (Q_M), which is used to adjust Table 2 to obtain Table 3.

$$Q_M = \frac{V_i}{86400 * D_i} \tag{10}$$

where, V_i is the water volume stored in month i , D_i is the days of month i and 86400 is the number of seconds in a day. Using values of the flow rate (Q), a flow duration curve was plotted as shown in Figure 4, from which the average flow rate was determined to be 18.54083 m³/s.

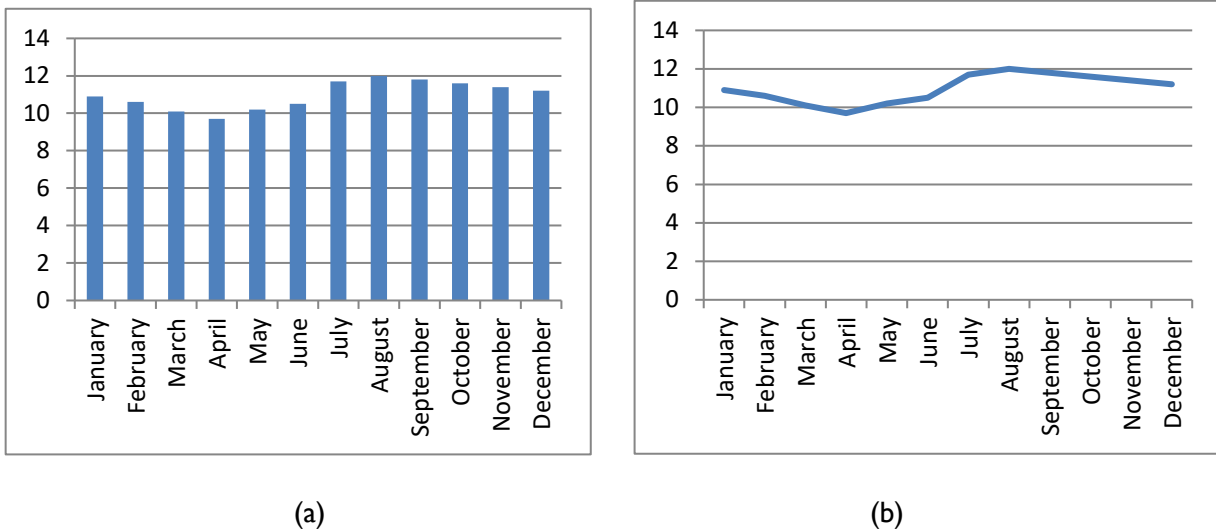


Figure 3: (a) The bar chart and (b) plot of the monthly hydrograph of Gwaigway Reservoir.

Table 3: Maximum depth, water surface area and volume of stored water

Month	Depth (m)	Area (m ²)	Volume (m ³)	Qm (m ³ /s)
January	10.9	1824171	47130079	17.6
February	10.6	1742299	44343504	17.7
March	10.1	1525733	37181310	13.9
April	9.7	1496299	36232339	13.98
May	10.2	1577247	38856571	14.51
June	10.5	1799353	46280967	17.86
July	11.7	1957112	51742130	19.31
August	12	2020052	53962138	20.15
September	11.8	2097885	64027550	24.70
October	11.6	2051728	55088044	20.57
November	11.4	2071009	55776172	21.51
December	11.2	2060708	55408273	20.69

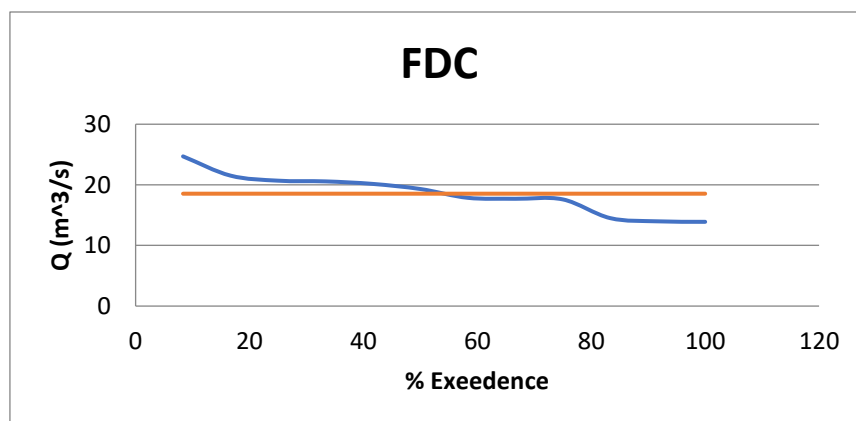


Figure 4: Flow duration curve.

2.5 Civil and structural design

During site visits, locations for civil and structural works necessary for the realization of this project were identified. The items for the civil and structural works are discussed in this section.

2.5.1 Intake Structure

The intake point was identified as a point on latitude 11.5759 and longitude 7.2071 at 2070 m above sea level, on the earth-dam close to the intake tower bridge of the reservoir (see Plate 2). Physical measurements on site revealed that: the thickness of earth dam is 56.01 m, the height of earth dam is 13 m, the water elevation FSL is 631.5 m, the ground elevation of the powerhouse is 620.6 m and the gross head is 10.9 m. Based on these measurements, the civil and structural works that included the intake canal, the fore-bay and lay-out of the penstock with its supporting concrete bases were designed. The powerhouse is therefore designed accordingly as shown in Plate 3.



Plate 2: Intake Point



Plate 3: Location of the Powerhouse

2.5.2 Design Parameters

Having established locations for the civil and structural design and having measured values both on site and on Google Earth, the following calculations were done to determine the required parameters for the design. Generally, hydroelectric stations have an overall efficiency of 80% as the global best practice (Signe *et al.*,

2017). On this basis, and taking the average discharge as indicated in the flow duration curve, the power generation capacity of the station is determined using the equation (1).

Likewise, the diameter, D (m), of the penstock pipe, which is preferably of galvanized steel, is given by:

$$D = \frac{2.69(n_p^2 * Q^2 * L_p)}{H_g} \quad 11$$

and, the thickness of the penstock pipe, t (m), is obtained from:

$$t = \frac{D + 508}{400} + 1.2 \quad 12$$

where, n_p is the Manning's coefficient, L_p (m) is the Length of the penstock pipe and H_g (m) is the Gross head.

2.6 Design of electromechanical elements

The electromechanical elements include the hydraulic turbine that converts hydraulic energy to rotational mechanical energy. The generator then converts mechanical rotation into electricity and the step-up transformer that raises the voltage level to the required transmission voltage.

2.6.1 Hydraulic Turbine

Tkac (2018) noted that large number of hydro systems exist with uses depending on physical conditions of the development site, given by the water discharge as against the net head with respect to the desired demands. Hydro turbine systems are therefore majorly categorized as: the Reaction and the Impulse turbines. Reaction turbines produce power from combination of forces of pressure and moving water, and are generally: Propeller, Francis and Kinetic turbines. The impulse turbines use the velocity of running water to move the runner by hitting the buckets and emptying and are generally: Pelton and Cross-flow turbines (Uddin *et al.*, 2019; Energy.gov, 2023).

Factors that affect selection of hydraulic turbines for hydroelectric power plants are seven in number, namely: Head, Specific speed, Rotational speed, Efficiency of the turbine, Cavitation, Disposition of turbine shaft and Part load operation (Adepoju, 2021). Tables 4 and 5 consist of summaries for the head, specific speed and the required types of turbines. It can be noted that specific speed is high for turbines which work under high heads and low flow rate, and vice versa. The turbine application chart, an industry standard guide, shown in Figure 5 assists in selecting the appropriate turbine for this work, based on the operational discharge rate and measured head (Iglinski, 2019, Chen *et al.*, 2013).

In addition to the head versus discharge relationship, other factors that influence the selection include the turbine rotational speed, the specific speed, and the turbine efficiency. The rotational speed, which for this study should match the requirements to generate voltage at a frequency of 50 Hz, is given as follows for a 4-pole generator chosen for convenience:

$$N = \frac{60f}{p} \quad 13$$

Conversely, the specific speed (which is defined as the speed of a geometrically similar turbine that produces 1 kW of power discharged under 1 m of net head) is determined by:

$$N_s = \frac{N\sqrt{P}}{H^{\frac{5}{4}}} \quad 14$$

This project is therefore characterized by high specific speed, low head and low discharge.

Table 4: Head and types of turbines.

Head	Head Range in meters	Suitable turbine	Notes
Very low head	3 - 10	Bulb turbine	Kaplan turbines are also suitable but uneconomical for very low heads
Low head	10 - 60	Kaplan Turbine	Propeller turbines are also suitable up to 15m head but without load variations.
Medium head	60 - 150	Francis turbine	-
High head	150 - 350	Pelton or Francis turbine	One of them is decided based on the specific speed.
Very high head	>350	Pelton turbine	-

Table 5: Specific speed and types of turbines.

Specific speed range	Type of Turbine
10 - 70	Pelton turbine
80 - 400	Francis turbine
300 - 1000	Kaplan turbine
1000 - 1200	Bulb turbine

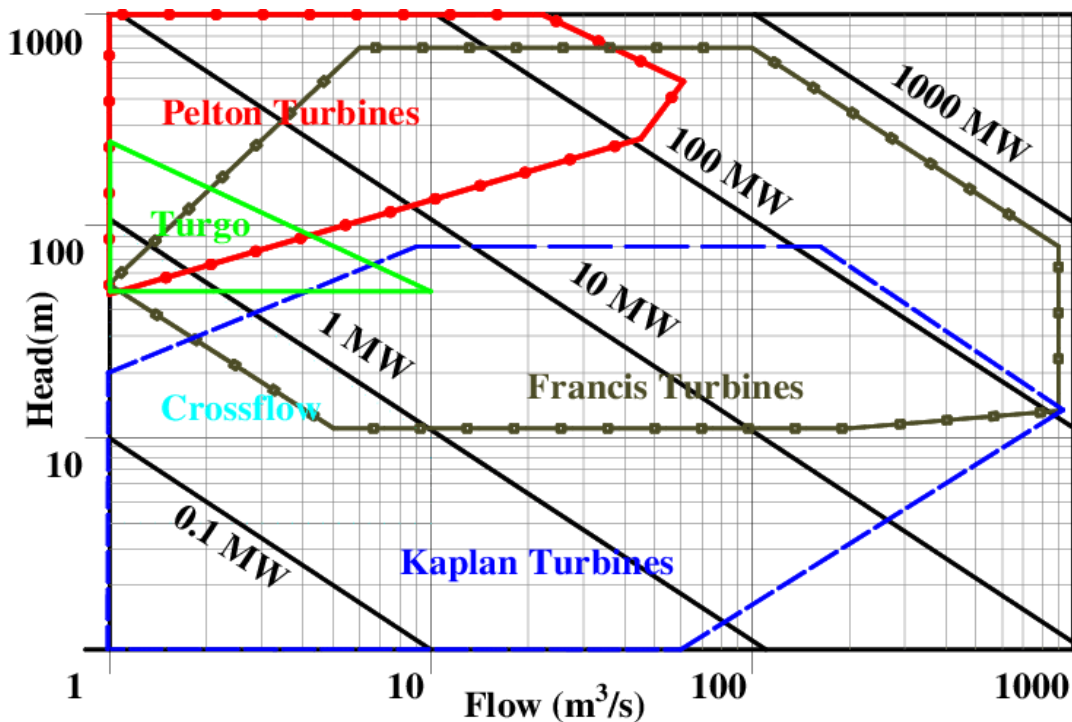


Figure 5: Turbine Application Chart.

2.6.2 Generator

The generator would be coupled to the turbine to convert the mechanical energy produced by the turbine into electricity. Therefore, the specifications of the generator, namely: generator power capacity, the rotor speed, and the voltage frequency, should match those of the turbine.

3. Results and Discussion

The results of the study carried out to determine the hydroelectricity potential of the Gwaigway Reservoir is presented and discussed in this section. Recorded in Table 6 are the site location data and description for all site structures and installations identified for the project, namely: hydro-technical, structural, civil, mechanical, and electrical structures and installations.

3.1 Demand Analysis Results

The connected load on the 11 kV feeder bus at Funtua Transmission Substation was used for the demand analysis and the result is presented in Table 7.

Table 6: Key structure's locations

#	Structure	Location	Description
1.	Intake point	Lat. 11.575917	A point on the dam close to the existing intake tower access track
2.	Canal	Lon. 7.207110 Lat. 11.576435	Beginning at the intake point and terminating at the fore bay
3.	Fore-bay	Lon. 7.206834 Lat. 11.576435	Beginning at the end of the canal
4.	Penstock	Lon. 7.206834	From the fore bay and ending at the powerhouse
5.	Powerhouse	Lat. 11.577115	A room to shelter the hydraulic and electromechanical components located at the edge of the existing reservoir spill way tail race
6.	Draft tube	Lon. 7.206979	Directly discharges into existing reservoir spill way tail race
7.	Tailrace		Same as the existing reservoir spill way tail race

Table 7: Demand Analysis Results

#	Quantity	Value
1.	Total connected load	19 MW
2.	Demand Factor	70%
3.	Actual demand	13.3 MW
4.	Proposed generation capacity	14 MW

3.2 Site survey and analysis results

As discussed, sub-section 3.3, the two major surveys considered are the topographical and hydrological surveys. The topographical survey map of the site used in this study was adapted from (Lawal *et al.*, 2020). For the hydrological survey, the hydrological setting of the proposed site studied and analyzed through capturing and recording the monthly water surface area with the aid of Google Earth pro has the results tabulated in Table 8. This result is used for the calculation of stored reservoir water volume for the months of the year using the water volume (V) power equation. The results were then used to calculate the amount of water discharge to the turbine with the results presented in Table 9.

3.2.1 Flow Duration Curve

The flow duration curve is generated from the exceedance with the results given in Table 9.

3.3 Civil and Structural Design

The results of the calculations of the design parameters for the civil and structural works, which consist mainly of the parameters of the intake structure and fore-bay, are presented in Table 10.

Table 8: Monthly water level, surface area, stored volume and discharge.

Month	Depth (m)	Area (m ²)	Volume (m ³)	Q _m (m ³ /s)
January	10.9	1824171	47130079	17.6
February	10.6	1742299	44343504	17.7
March	10.1	1525733	37181310	13.9
April	9.7	1496299	36232339	13.98
May	10.2	1577247	38856571	14.51
June	10.5	1799353	46280967	17.86
July	11.7	1957112	51742130	19.31
August	12	2020052	53962138	20.15
September	11.8	2097885	64027550	24.7
October	11.6	2051728	55088044	20.57
November	11.4	2071009	55776172	21.51
December	11.2	2060708	55408273	20.69

3.3.1 Intake Structure

The intake canal would be excavated and constructed of reinforced concrete across the dam fill with the dimension of the dam determined from the following measurements and calculations. Given that the average discharge into the turbine is 18.54083 m³/s, it is desirable that this volume of water travels at least five seconds in the intake canal before settling in the fore-bay. This implies the canal should be able to accommodate five times single discharge volume at any given time. With the thickness of the dam measured as 56 m, and a 4 m length outside the dam wall added to isolate the fore-bay from the dam structure, we have a total canal length of 60 m.

Therefore, the capacity of the canal would be:

$$5 * Q_{av} = 5 * 18.5408 = 92.7 \text{ m}^3 \quad 15$$

With the length of the canal designed to be 60 m, the canal cross-sectional area is given by:

$$\frac{\text{Capacity of the canal}}{\text{length of the canal}} = \frac{92.7}{60} = 1.545 \text{ m}^2 \quad 16$$

With the canal designed to be of square cross-section, the length and breadth is determined by:

$$l = b = \sqrt{1.545} = 1.243 \text{ m} \times 1.243 \text{ m}$$

The canal dimension is therefore given as: Longitudinal length = 60 m, Cross-sectional length = 1.243 m and Cross-sectional breadth = 1.243 m.

3.3.2 Fore-bay

The fore-bay should be of sufficient volumetric capacity to accommodate the discharge of five-minutes before being exhausted without replenishment. This will enable the penstock become always completely submerged to avoid turbulence and air bubbles that may destabilize the required smooth flow into the turbine chambers. So, the capacity of the fore-bay is obtained as:

$$V_{fb} = Q_{av} * t = 18.54 * 5 \text{ min} * 60 \text{ sec} = 5562 \text{ m}^3 \quad 17$$

The design of the fore-bay considered the need for its effective volume to be at least 2 m deep below the floor of its intake canal. Therefore, the floor area of the fore-bay is obtained as:

$$A = \frac{\text{desired capacity}}{\text{minimum depth}} = \frac{5562 \text{ m}^3}{2 \text{ m}} = 2781 \text{ m}^2 \quad 18$$

The floor was designed to be a square surface with the length and breadth determined by:

$$l * b = \sqrt{2781} * \sqrt{2781} = 52.7 \text{ m} * 52.7 \text{ m} \quad 19$$

Table 9: Discharge results

Rank	Discharge (m ³ /s)	% Exceedance	Average Discharge
1	24.7	8.33	18.54083
2	21.52	16.67	18.54083
3	20.69	25	18.54083
4	20.57	33.33333	18.54083
5	20.15	41.66667	18.54083
6	19.31	50	18.54083
7	17.86	58.33333	18.54083
8	17.7	66.66667	18.54083
9	17.6	75	18.54083
10	14.51	83.33333	18.54083
11	13.98	91.66667	18.54083
12	13.9	100	18.54083

Table 10: Civil and structural design parameters

#	Quantity	Value/Unit	Remark
1.	Canal dimension	1.243 m * 1.243 m * 60 m	Calculated
2.	Fore-bay dimension	52.7 m * 52.7 m * 2 m	Calculated
3.	Dam thickness	56 m	Measured
4.	Dam height	13 m	Measured
5.	Gross Head	10.9 m	Calculated

3.3.3 The Powerhouse

The powerhouse is located at the edge of the tailrace of the reservoir spillway so that the existing tailrace of the reservoir is also used to serve the powerhouse. However, the location is important in determining the length of the penstock to be installed. The ground distance from the fore-bay to the powerhouse was measured from Google Earth Pro to be 65 m. The penstock intake on the fore-bay is at a height of (10.9-2) m or 8.9 m. Applying Pythagoras theorem, the penstock length is determined as:

$$\text{Penstock length} = \sqrt{65^2 + 8.9^2} = 66 \text{ m}$$

3.3.4 The Penstock

The penstock in this application is desired to be of galvanized steel (pressure pipe). Taking Manning's coefficients for smooth steel as 0.012, the diameter of the pipe is determined by:

$$D = \frac{2.69(0.012^2 * 18.54^2 * 66)}{10.9} = 0.8 \text{ m}$$

Also, the thickness of the penstock pipe is determined by:

$$t = \frac{D + 508}{400} + 1.2 = \frac{0.8 + 508}{400} + 1.2 = 2.5 \text{ cm}$$

3.3.5 Generation Potential

The main goal of this research work is to determine how much electricity can be generated from the Gwaigwaye Reservoir. This aspect is achieved using the power equation given in Equation (1) and hereby obtained as:

$$P = 1000 * 18.54 * 10.9 * 90\% = 1782399 \text{ W} = 1.78 \text{ MW}$$

3.4 Electromechanical design and analysis

At this stage, the components that convert hydraulic energy to mechanical energy and then to electrical energy are selected from results of analysis carried out so far in this study.

3.4.1 Hydraulic Turbine

As the penstock was separated into four pieces, also the estimated turbine generation power was divided into four 445 kW capacities. The chart in Figure 8 is used to select the most suitable turbine type for this application, as a conventional practice based on discharge or flow rate (in m³/s), head (in meters) and generated output power (in Watts). The point of convergence of discharge of 18.54 m³/s, head of 10.9 m and output power of 445 kW on the chart falls within the envelope of Kaplan turbine. This is because the configuration for the chosen site can be categorized as low head, low discharge, and low output power. However, a more appropriate turbine type for this setting could be a bulb turbine. It operates like the Kaplan turbine with added advantage of better yield under very low head, but has been proven to be uneconomical for very low heads.

3.4.2 Specific Speed

To ascertain the selection of bulb turbine for this application, specific speed of the system was calculated and compared with the range of specific speeds within which bulb turbine is best suited for this generation. However, the specific speed equations (13) and (14) are used to calculate the rotational speed of the system and obtained as:

$$N = \frac{60 * 50}{4} = 750 \text{ rpm}$$

For a four-pole generator, the specific speed is therefore determined as.

$$N_s = \frac{750 * \sqrt{450}}{10.9^{5/4}} = 895 \text{ rpm}$$

This falls within bulb turbine specific speed range, 750 to 1200 rpm, making it most appropriate.

3.4.3 Generator

The generator was selected to match the requirements of the load as well as the statutory regulations. The Nigerian Electricity Regulation Commission (NERC) requires that voltages for utility in Nigeria must be 230 V or 220 V, 400/230 V or 380/220 V and 15,000 V, 11,000 V, 400/230 V or 380/220 V respectively (Electrical Installation Guide, 2022), with a frequency of 50 Hz ± 1%. The generator was therefore selected as a 4-pole synchronous generator. The output power was determined considering a Transmission and Distribution loss of 5% and an own use power by the station of 1%.

Therefore, the output power of the generator is obtained as:

$$G = \frac{P}{1 - \frac{TD + Own Use}{100}} = \frac{1.78}{1 - \frac{5 + 1}{100}} \quad 20$$

$$= 1.8936 \text{ MW or rounded to } 2.0 \text{ MW} = 500 \text{ kW each}$$

4. Conclusion

From the results and findings of this study and reflecting on the objectives of the research, the following conclusions were drawn.

1. The locations identified for the major site structures took advantage of the existing reservoir infrastructure, such as dam wall, tailrace, access road and intake tower.
2. The surface area was used to calculate the volume of the water and the flow rate due to the absence of an alternative to flow gauging at River Gwaigwaye.
3. The selected hydraulic, mechanical, and electrical equipment for the powerhouse were considered the optimal selection for the prevailing site configuration in question.
4. The calculated power generation of the project, 1.78 MW, will not suffice to power the total load demand of 13.3 MW. It is only intended to complement the supply from the national grid.
5. Generally, the research is found to satisfy its purpose with the Hydro-generating potential of Gwaigwaye Dam determined and the components necessary to achieve this potential identified.

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