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MORPHOLOGICAL AND MORPHOMETRIC ASSESSMENT OF BOSSO, CHANCHAGA AND TAGWAI DAMS IN NIGER STATE OF NIGERIA FOR HYDROPOWER ELECTRIC APPLICATIONS

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ABSTRACT

The morphological and morphometric assessment of Bosso, Chanchaga and Tagwai dams was carried out between 16th of November 2023 and 31st December 2023, to determine their suitability for hydropower electric generation. The morphological and morphometric primary data were collected from the dam sites through direct observations of the morphological characteristics of the dams and morphometric measurements of the width of the dams using tape rule in order to calculate their volumes and storage capacities, since they are relatively small dams with pre-existing structures that facilitated the measurements. The result shows that Bosso dam is a storage, lake, upstream and valley dam with height of 17 m, length of 132 m, width of 110 m, volume of 246,800.0 m^3 and storage capacity of 41,466.7 m^3 with the dam capable of supplying water to drive extremely minimum flow turbine of 0. 27 m^3/s for 157,577.77 seconds, 2.559.63 minutes, 42.66 hours and 1.78 days assuming there is no further inflow of water into the dam and no water is lost from the dam. Tagwai dam is storage, plain and lake dam with height of 25 m, length of 1,770 m, width of 98.5 m, volume of 4,458,625.0 m^3 and capacity of 726,437.5 m^3. Chanchaga dam is a storage, downstream, lake and valley dam with height of 33.0 m, length of 2,400 m, width of 65 m, volume of 5,148,000.0 m^3 and capacity of 858,000.0 m^3. The assessment of the dam proves that they are suitable for hydroelectric power applications.

Keywords: Bosso dam, Chanchaga dam, hydropower electric generation, storage capacity, Tagwai dam

INTRODUCTION

Standard of living in Nigeria is significantly low with almost 90% of factories moribund due to epileptic power supply with effects ranging from domestic comfort to national embarrassment (Ajibola *et al.,* 2018). Energy sector of a nation must be developed as one of the conditions for the nation to grow, one of the cleanest sources of renewable energy is hydropower (Anaza and Yakubu 2017). The oldest and most common method of harvesting energy of the nature is hydropower (Stefan, 2018). Hydropower is the most widely used source of power in the world today because of some of its remarkable advantages of being low cost and high reliability, relative to other sources of energy (Collins *et al.,* 2022). According to Anaza and Yakubu (2017) one of the cleanest sources of renewable energy is hydropower, tidal flows and large dams can provide water power to generate large quantity of electricity. One of the most considered and desirable source of energy is hydropower because of it environmentally friendly nature and extensive potential worldwide (Alie, 2016).

Generation of electricity from renewable energy sources like hydropower is a way to address the devastating impact of environmental degradation and climate change. Presently, exploration of world's hydropower potential is 25% (Collins *et al.,* 2022). There are several studies on sources of renewable energy for power generation. Akpootu *et al.* (2022); Akpootu and Fagbemi (2022); Ohaji *et al.* (2022) have carried out studies on wind energy electric power generation. However, large and small hydropower by far remains the most important renewable energy source for electrical power production. According to The World Hydropower Atlas 2000, published by the International Journal of hydropower and Dams, the world hydropower potential that is technically feasible is estimated at 14,370 TWh/yr and this is equal to 100% of the current global energy demand. The proportion of hydropower that is economically feasible at present is considered to be 8080 TWh/yr, which 2650 TWh/yr was exploited in 1999. Hydropower is the most cost-effective energy technologies for rural electrification, especially the small-scale hydropower. Small hydropower technology is extremely robust which can last for fifty (50) years or more with little maintenance (Alie, 2016).

It is well established from United Nations Industrial Development Organization's (UNIDO's) report that Nigeria is endowed with small hydropower potential with large percentage not yet exploited country's entire hydropower potential. The prospect of small hydropower in Nigeria as at 2005 was targeted at 734 MW with only about 30 MW being developed presently (Collins *et al.,* 2022). The existing small hydropower schemes in Nigeria according to Samaila *et al.* (2010) are shown on the table

Table 1: The Existing Small Hydropower Schemes in Nigeria

S/N	River	State	Installed Capacity (MW)
1	Kwall	Plateau	2
2	Kurra	Plateau	8
3	Lere I	Plateau	4
	Lere II	Plateau	4
4	Bakalori	Sokoto	3
5	Tiga	Kano	6
6	Oyan	Ogun	9
		TOTAL	36

From the table 1 above, only few small hydropower schemes are in existence in Nigeria, while there are 278 small hydropower potential sites surveyed across 12 states in Nigeria with Niger state alone having 30 potential sites Rufai *et al.,* (2012). Hydropower is the most widely used source of power in the world today because of some of it remarkable advantages of being low cost and high reliability, relative to other sources of energy (Collins *et al.,* 2022). Hydropower is the primary source of water dependent energy that is primarily used to drive turbines as well as to generate electrical energy based on the difference between greater and lesser altitudes. When water is released from reservoir, the energy output occurs due to distance between the height of the dam and tailrace of the water known as the head (Schrader *et al.,* 2019). A flowing stream or river can generate considerable amount of electrical energy with conversion efficiency of almost 90% (Ang *et al.,* 2022). Hydropower is the most cost-effective technologies for rural electrification, especially the small-scale hydropower which is extremely robust and can last for fifty or more years with little maintenance (Alie, 2016). In a study conducted by Rufai *et al.* (2012), Chanchaga dam is one of the proposed small hydropower dams while Bosso and Tagwai dams are among the proposed large dams in Niger State.

To professionally operate reservoirs for hydropower electric production, the management of water quantity within the reservoir is required (Salami *et al.,* 2012). Beside volume of water in the reservoir the water surface elevation within the reservoir can be an indication of available storage. These relationships between elevation and storage volume, similar to area-volume and elevation area relationships enable the engineers to find fairly accurate value of one parameter from the other (Magome *et al.,* 2003). From surface water resources the adequacy and reliability of the water supplies for deferent propose are dependent upon the ability of reservoirs to make available sufficient water storage during the critical dry (Khan *et al.,* 2017)

Morphology of reservoirs such as dams is the study of the form or features of the reservoirs (CAWATERinfo, 2024). Morphologically, hydropower electric reservoirs such as dams take one or more of the forms of; valley, in-channel, flood plain, basin, lake, upstream and downstream. Some of the dams are located in one or more of; mountains, sub-mountains, plain land, coastal plain, with some being upstream or downstream reservoirs (CAWATERinfo, 2024). Morphometric assessment of reservoirs such as dams is the mathematical measurements and analysis of the configuration of the dams with respect to their; sizes, shapes, elevation, length, breath, height, capacity and surface run-off etc (Yunusa and Abdulkadir, 2019). In their study, Yunusa and Abdulkadir (2019) used maps, Landsat images for the year 2016, Digital Elevation Model (DEM) map shown in figure 1 and 3D spatial analysis to acquire the length, depth and the width of river Chanchaga. According to World Bank, large dams have height greater than 15 m (Senzenje and Chimbari, 2002).

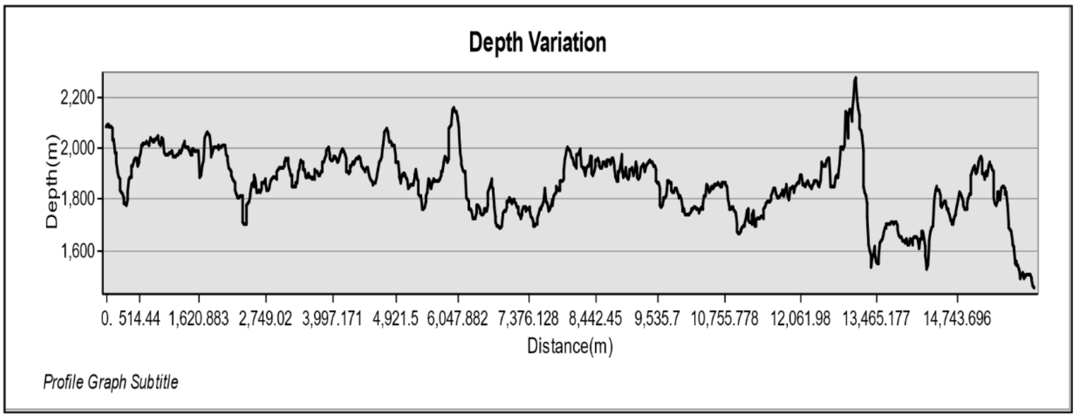

Figure 1: Graph of 3D spatial analysis of variation of depth with width of River Chanchaga (Yunusa and Abdulkadir, 2019)

The result of the study showed that river Chanchaga has the lowest depth of 1,501 m at width of 14,743 m while the highest depth was found to be 2280 m at the width of 12,762 m, as shown in figure 1

This study aimed to investigate the morphological and morphometric assessment of the proposed Bosso, Chanchaga and Tagwai hydropower electric dams in Niger State with the view to determine their suitability for hydropower applications has become inevitable. Hence the need to explore how the vast water resources in Niger state could be utilized to generate additional electrical energy for domestic and commercial purposes.

MATERIALS AND METHODS

Bosso, Chanchaga and Tagwai dams are all in Bosso Local Government Area of Niger State. Bosso dam is located on longitude 6^{o}30’58” N and latitude 9^{o}39’12”E, Chanchaga is located on longitude 6^{o}32’25” – 6^{o}35’00” N and latitude 9^{o}36’50” – 93^{o}9’72” E (Yunusa and Abdulkadir, 2019) and Tagwai dam is located on longitude 6^{o} 39’ – 6^{o} 44’N and latitude 9^{o} 34’ – 9^{o} – 37’ E (Gavid and Auwal, 2020). The three dams are located in Bosso Local Government Area of Niger State, Nigeria as the study areas are shown on the map in figure 2

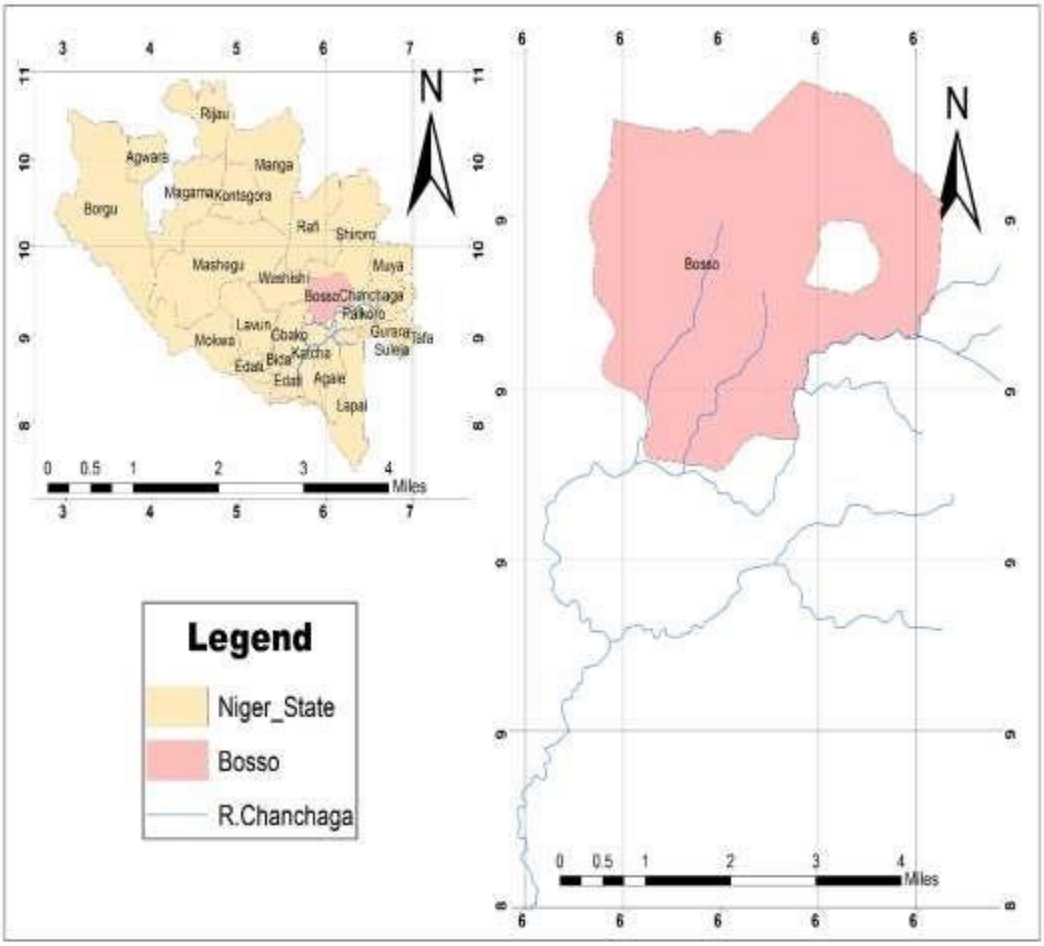

Figure 2: Map of Bosso Local Government Area of Niger State (Yunusa and Abdulkadir, 2019)

The morphological assessment of the three proposed hydropower electric dams was done by observing their locations and configurations, while morphometric assessment of the dams was done using the data collected from the relevant journals/other resource materials. Direct measurement of width of Bosso dam was done using meter rule. The parameters considered were the length, height, width and volume and storage capacity of the dams. The data on the length and height of the three reservoirs were collected from a journal. The total storage capacity of all the dams was calculated using equation (1). The volume of all the dams was calculated using equation (2). The data on the width of Bosso and Chanchaga dams were collected by direct measurement using tape rule.

Tandai (2005) shows a reservoir with important parameters required for calculation of its storage capacity as shown in figure 3.

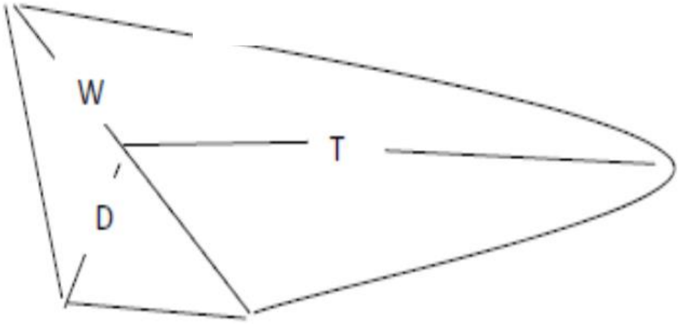

Figure 3: Reservoir showing width (W) in meters, the throwback (T) in meters and the depth (D) in meters (Tandai, 2005)

According to Senzenje and Chimbiri (2002), the capacity of the reservoir can be calculated using equation (1) Senzenje and Chimbiri (2002) as

$$C = \frac{D \times W \times T}{6} \quad (1)$$

C is the reservoir storage capacity in cubic meters, D is the reservoir height or depth in meters and T is the reservoir throwback or length in meters

Volumes of Bosso and Chanchaga dam reservoirs were calculated from the literature value of their height and length in addition to their measured width all in meters using equation (2) according to PBS (2024) as

$$V = L \times W \times H \quad (2)$$

V is the volume in cubic meters, L is the length in meters, W is the width in meters and H is the height in meters

The picture of Bosso dam taken from the site on 31/12/2023 is shown in figure 4.

Figure 4: Picture of Bosso Dam. Source: Field work

The picture of Tagwai taken on 16/11/2023 dam is shown in figure 5.

Figure 5: Picture of Tagwai dam. Source: Field work

The Picture of Chanchaga dam taken on 14/12/2023 is shown in figure 6

Figure 6: Picture of Chanchaga Dam. Source: Field Work

Mathematical equations models were also used to describe the dam reservoirs water balance dynamics, water volume changes and capacities of the dams. According to Hadekazu (2020), Reservoir water balance dynamics driven by inflow and outflow processes, considering the intake of water for the hydropower generation is given by equation (3) Hadekazu (2020) as

$$\frac{dv_t}{dt} = Q_i - (q_t + d\dot{t})i \qquad (3)$$

For $t \geq 0$, with initial condition $V_o = V \geq 0$
where
V_t is the level in the reservoir at time (t)
q_t is the downstream flow discharge at time (t)
d_t is the water intake for hydropower generation at time (t)
Q_t is the inflow discharge at time (t)

The downstream outflow (q) and water intake for hydropower generation (d) should carefully be taken for serious mathematical modelling. Assuming $0 < V_t < 1$, the admissible flow discharge range (q) Hadekazu (2020) is

$$A = [\, 0, \underline{q}] \qquad (4)$$

$\underline{q} > 0$ being imposed upper bound, assuming some restrictions. If $\underline{q} > Ij$, where $Ij$is the inflow discharge for I regime, assuming that the system has high sufficient ability to handle the inflow process, the admissible range for intake (d) is set as being binary shown in equation (5) Hadekazu (2020) as

$$B = (0, \underline{d}) \qquad (5)$$

where $\underline{d} > 0 \; and \; d = 0$ implies hydropower production while d = $\underline{d}$ implies water intake from the reservoir.

If we assume that the intake of water for hydropower production is done before the outflow is determined, the following admissible ranges shown in equation (6) are imposed at the boundaries (Hadekazu, 2020)

$$B = \{\{0\} \qquad d \geq Q_d \; v_t = 0 \left\{0, \underline{d}\right\} \qquad v_t = 1 \text{ and}$$

$$A = \{[Q, Q_t - dt](v = 0) \left[m_{ax\cdot\{Q_i - d_i,\ 0\}}\, q \quad \right] v_t = 1 \qquad (6)$$

According to Danjan *et al.*, (2014) mass balance equation (7) is used to calculate the water volume changes in reservoirs (Danjan *et al.*, 2014) as

$$V_t = (t + \Delta t) = Vi(t) + \Delta t \,(\sum Q_{ln}(\Sigma Q_0 u_t) \qquad (7)$$

where V_t is current water volume in the reservoir or dam in cubic meters at the time (t), Q_{in} is the total water inflow for specific reservoir subsystem in cubic meters per seconds, Δt is the simulation time step and Q_{out} is the total water outflow in cubic meters per second for specific reservoir subsystem.

The seepage through the dam's body which is capable of affecting the reservoir mass balance is calculated using equation (8) (Danjan *et al.*, 2014) as

$$Q_{seepage} = K\text{-}Z^{x}_{res} \qquad (8)$$

K is seepage coeeficient, Z_{res} is the reservoir water level in meters and x is seepage exponent. Inductive failure water level can be calculated using equation (9) (Danjan *et al.*, 2014) as

$$Z_{sensor,i} = Zi + \Delta Z_{noise} + \Delta_{Zdrift} \qquad (9)$$

$Z_{sensor,I}$ is the sensor reading the reservoir$_i$ water level for the purpose of operation decision, ΔZ_{noise} is sensor noise which statistically uncertain and Δ_{Zdrift} is zero drift error which systematic uncertainty while Z_i is the system variable. The magnitude of zero drift error and magnitude of sensor noise varies depending time step used in the simulation (Danjan *et al.*, 2014).

According to Atil (2023), hydropower reservoirs have uncontrolled water inflow and controlled water outflow. The capacity of the reservoirs is the total volume of quantity of water that they can store. The capacity of the reservoir can be calculated using topographic map of the region by measuring the area inside different elevation contours in order to enable the construction of the curve of the area against elevation as shown in figure 7

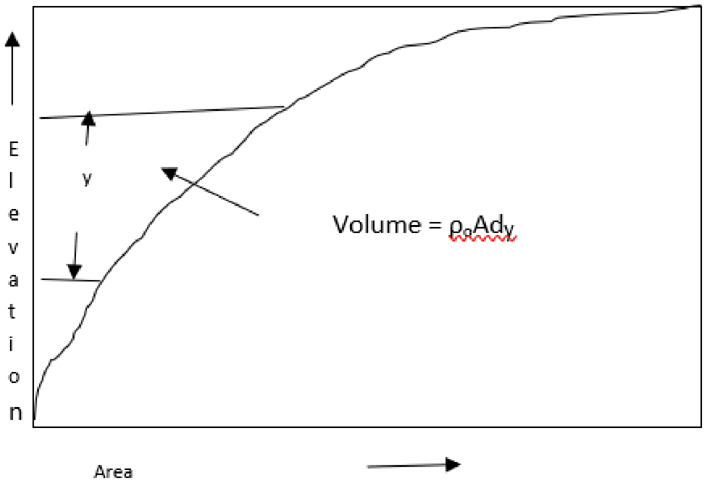

Figure 7: The area against elevation of reservoirs

RESULTS AND DISCUSSION

The results of the morphological assessment of the three dams are shown on table 2

Table 2. Morphological characteristics of Bosso, Chanchaga and Tagwai proposed Hydropower Electric Dams

S/N	Dam	Morphological Characteristics
1	Bosso	Upstream, Lake, Valley, Earth and Storage dam
2	Tagwai	Plain, Lake, concrete and Storage dam
3	Chanchaga	Downstream, Lake, Valley, concrete and Storage dam

The morphology of Bosso dam is similar to that of Shiroro hydroelectric Power Dam because the two dams are characterized as storage, lake, valley and upstream reservoirs which also suggest that Bosso dam is suitable for hydropower electric application similar to Shiroro dam. Tagwai dam is similar to Kainji Hydroelectric Power Dam because they are all concrete, plain, lake, and storage which also means that it can support hydropower electric applications. Chanchaga is a concrete, storage, lake, valley and downstream dam, most of its morphology are similar to those of the existing hydroelectric power dams in Nigeria also implies that it can support hydropower electric application.

According to Sawsan *et al.* (2019), rock fill dams are more stable because the frictional force acting between pieces of rock gravels ensures it safety against sliding failure during earth quark, they are less expensive and safe time to construct being embankment dams and can also safer in severe climatic condition conditions especially relating to temperature and cannot be constructed very high relative to concrete dams. Concrete dams on the other hand are easier to construct and facilitate complex designs such as spillways within the dams and can be constructed very high, but are easily affected by climatic conditions such as temperature that cause cracks in the dams, expensive and consuming more time to construct and more vulnerable to seismic hazard such as earth quark relative to rock fill dams.

The results of the morphometric assessment of the three dams are shown in figures, 8, 9, 10, 11 and 12 respectively for the height, length, width, and capacity of the various dams.

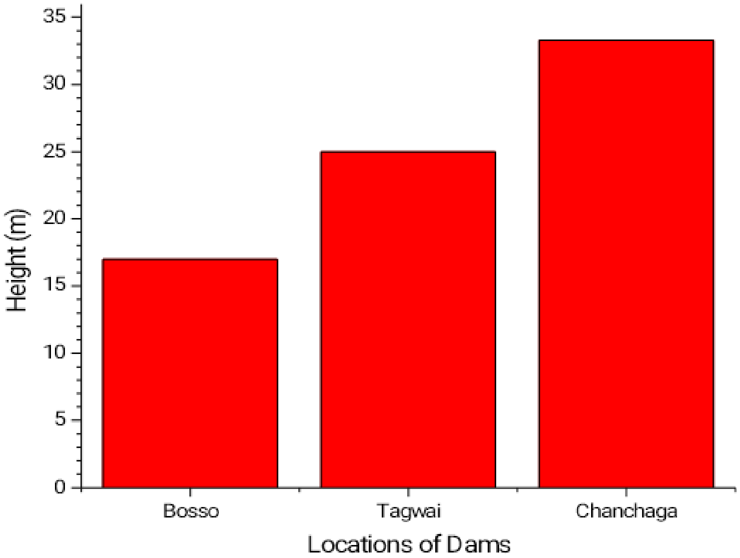

Figure 8: Heights of the dams with respect to their locations

According to World Bank, large dam reservoirs have heights greater than or equal to 15 m (Senzenje, 2002). By implication, the three dams under consideration as hydropower electric dams are large dams.Considering the heights of the dams as shown in figure 8, Chanchaga has the highest height of 33.3 meters which gives it the advantage of having the highest head suitable for hydropower electric applications, followed by Tagwai dam with the height of 25.0 meters and Bosso dam with the least height of 17.0 meters. The result of the study with respect of the result of Yunusa and Abdulkadir (2019) on the depth of chanchaga river shows that the highest depth (height) of the river was found to be 33.3 m compared to the result of Yunusa and Abdulkadir (2019) which was found to be 2,280 m, the variation in the depth (height) from the two studies could be due to weather factors or methodologies used in the studies or both.

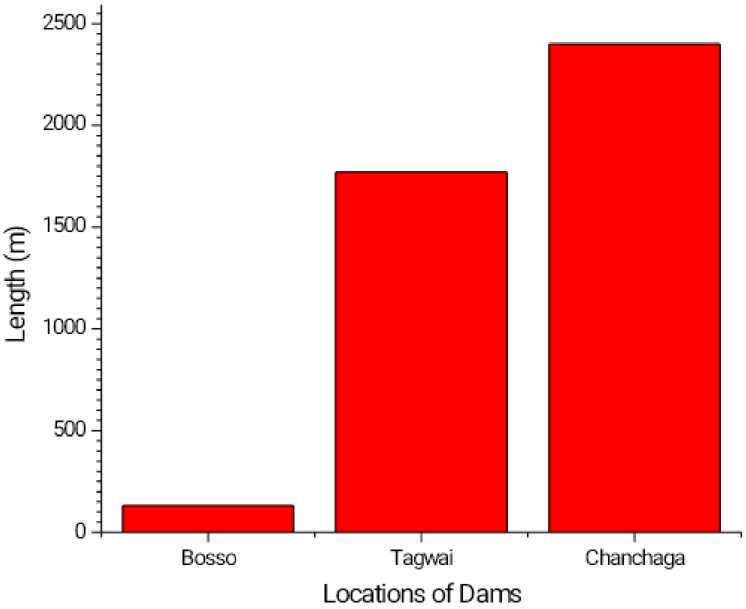

Figure 9: Lengths of the dams with respect to their locations

Considering the lengths of the dams as shown in figure 9, Chanchaga has the highest length of 2,400 meters which implies that Chanchaga dam can accommodate a greater number of cascaded hydropower electric plants relative to Tagwai dam with the length of 1,770 meters and Bosso dam with the least length of 132 meters

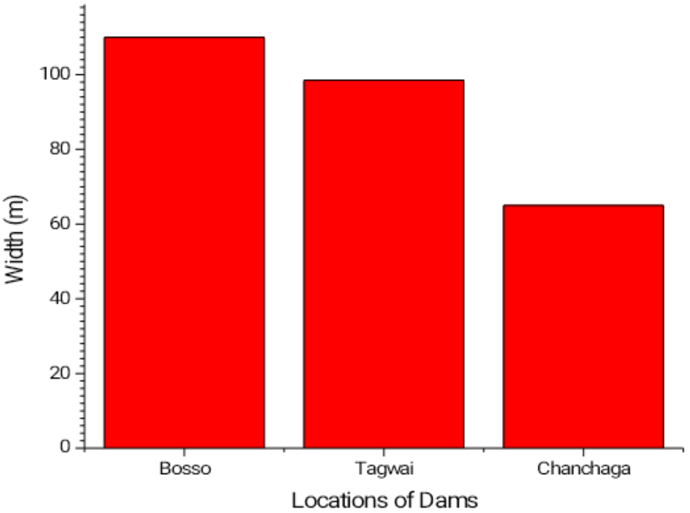

Figure 10: Widths of the dams with respect to their locations

In terms of width as shown in figure 10, Bosso dam has the highest width of 110 meters which implies the dam can accommodate more number of inflow water supply channels, more turbines and spillways relative to Tagwai dam that has the width of 98.5 meters and the least being Chanchaga dam with the width of 65.0 meters capable of accommodating only few inflow water supply channels and turbine. This study found the width of chanchaga dam to be 65 m compared to the lowest and highest widths of river Chanchaga found to be 14,734.7 m and 12,762. 6 m respectively, as shown in figure

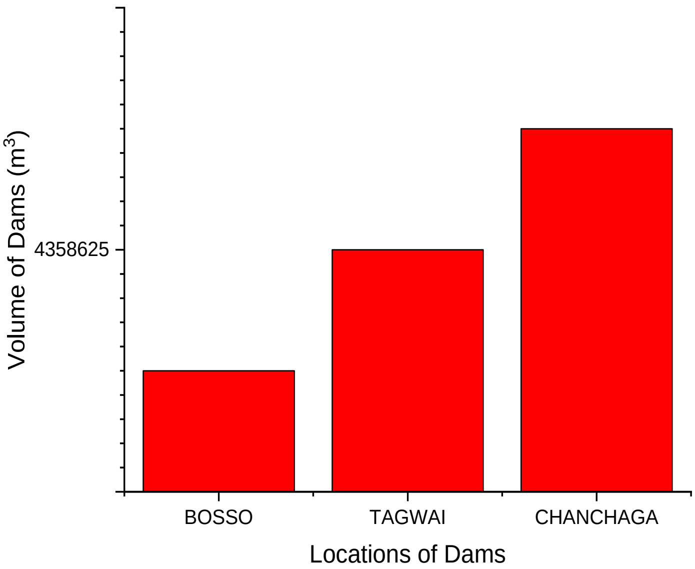

Figure 11: The histogram of the volumes of the dams with respect to their locations

From figure 11, it is well established that Chanchaga dam has the highest volume of 5, 148,000 cubic meters followed by Tagwai dam with volume of 4, 358,625 cubic meter and Bosso with the least volume of 246,800 cubic meters. This implies that Chanchage dam has the greatest hydropower electric application potential by virtue of its volume.

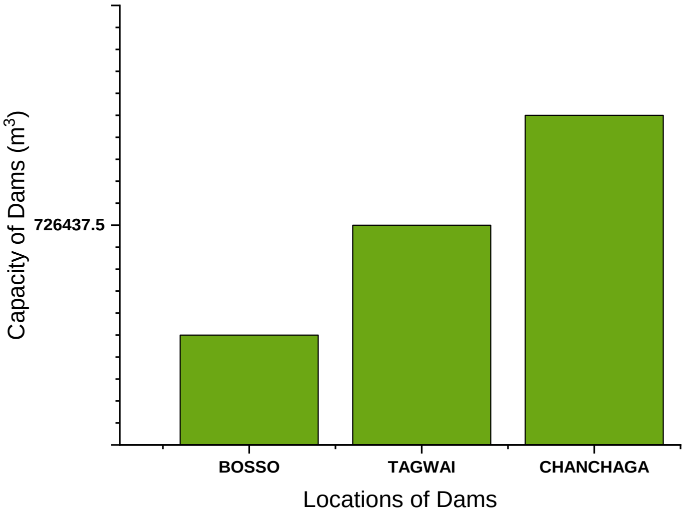

Figure 12: The Histogram of Capacities of the Dams with Respect to their Locations

Figure 12 shows the water storage capacities of the three dams, Chanchaga has the highest water storage capacity of 858,000.0 cubic meters implying that it has the greatest hydropower electric application potential, capable of driving turbines for a longer period of time while Tagwai dan follows with water storage capacity of 726, 437.5 cubic meters and then Bosso dam being the least with water storage capacity of 41,466.7 cubic meters. The storage capacity of Bosso, Chanchaga, and Tagwai dams of 41,466.7 m^3, 858,000.0 m^3, and 726,437.0 m^3 respectively, which implies that the three dams under consideration have the storage capacity to support hydropower electric application because for example Bosso dam can drive a turbine with minimum flow of 0.27m^3/s such as Bulb turbine (Sonel *et al*., 2019; Emiliano, 2020) for 153,577.76 seconds, 2,559.63 minutes, 42.66 hours and 1.77 days while Chanchaga dam can drive similar turbine for 3,177,777.78 seconds, 52,962.30 minutes, 882. 72 hours and 36.78 days and Tagwai dam driving similar turbine for 2,690,508.26 seconds, 44,841.82 minutes, 747.36 hours and 31.14 days, assuming no single water flows into the dam and evaporation of water from the dam is zero. It is a requirement that a dam reservoir should contain enough water drive hydropower turbines for some moments if water inflow into the dam stops, in order to remedy the problem of water inflow

CONCLUSION

The morphological and morphometric assessment of Bosso, Chanchaga and Tagwai dams were investigated. The results indicated that height of all the three dams are greater than 15 meters, since the least height was 17.0 meters and the highest was 33.3 meters, which shows that the dams are large dams capable of supporting hydropower electric application. The three dams have a water storage of capacity for driving a turbine with minimum flow of 0.27m^3/s for a minimum of at least one and half day with net inflow and outflow of water in the dams equal to zero, this clearly indicates that the hydropower electric plants that would be established on these dams can run for a minimum of at least one and half day assuming no water flows into the dams or escape from the dam which is enough time to enable the fault responsible for lack of water inflow into that dams to be corrected. The morphological and morphometric assessment of the three dam indicates that the three dams are capable of supporting hydropower electric applications with little modifications being made to their existing structures with Chanchaga dam having the highest potential for hydropower electric application by virtue of its capacity, as shown in figure 12.

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