Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v35i1.2026.464
Volume 35(1), March 2026

Measurement of Head and Flow of Bosso, Chanchaga and Tagwai Dams Proposed Storage and Off-Shore Hydroelectric Power Plants

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ABSTRACT

Standard of living in Nigeria is significantly low with almost 90% of factories at moribund due to epileptic power supply with the effects ranging from domestic discomfort to national embarrassment. 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. The quantity of electrical power that can be obtained from hydropower is the product of head and flow. The study measured the gross head using hose level and direct meter rule methods and the gross head was also calculated using the relevant formula. The flow was measured using bucket/container method. The results showed that the gross heads for Bosso, Chanchaga and Tagwai proposed storage hydroelectric plant were 3.0 m, 7.0 m and 4.0 m respectively, while the alternative gross head for Bosso, Chanchaga and Tagwai dams were calculated to be;24.74 m, 31.38 m and 38.89m respectively. While the mean gross head of the proposed off shore plants for the three dams were 4.98 m, 1.08 m and 6.12 m respectively. The mean reservoir flows were found to be 111.91m^{3}s^{-1}, 759.45 m^{3}s^{-1} and 1,571.03 m^{3}s^{-1}for proposed Bosso, Chanchaga and Tagwai storage and off-shore hydroelectric power plants respectively. The results showed that the heads and flows of the three dams satisfied the requirements for establishment of hydroelectric power plants that requires a minimum head of 0.2 m and minimum flow of 0.02 m^{3}s^{-1}.

Keywords:
Measurement,
Flow,
Dam.

INTRODUCTION

Energy utilization globally is on the rise with the availability of fossil fuel dwindling, combustion of fossil fuel has hastened environmental deterioration with the situation leading to increase in demand for renewable energy sources (Akpootu *et al.*, 2024). Water is important in energy sector especially hydropower (Akpootu *et al.,* 2023). According to Yusuf *et al.* (2024), hydropower in one of the cleanest source of renewable energy. Hydro energy is a form of energy generated by utilizing the kinetic energy of flowing water to drive water turbines for the purpose of production of electricity or for driving other machines such as milling machines for agricultural purposes. Hydropower occurs from converting the energy in flowing water into useful mechanical energy by means of water wheel or turbine which in turn is being converted into electricity by generator attached to the water wheel or turbine (Elie *et al.,* 2017). According to Elie *et al.* (2017), one of the promising energy technologies is hydropower. The potential energy of water at a height is converted to mechanical energy that turns a turbine at lower level for generating electricity (Alie, 2016). 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 *et al.* (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 environmental 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). Large and small hydropower by far remains the most important renewable energy source for electrical power production.

Bosso, Chanchaga and Tagwai dams are all in Bosso Local Government Area of Niger State. Bosso dam is located on longitude 6°30'58" N and latitude 9°39'12"E, Chanchaga is located on longitude 6°32'25" – 6°35'00" N and latitude 9°36'50" – 93°9'72" E (Yunusa and Abdulkadir, 2019) and Tagwai dam is located on longitude 6° 39' – 6° 44'N and latitude 9° 34' – 9°37' E (Gavid and Auwal, 2020). These dams are potential hydroelectric power generating site and therefore the aim of the study was to measure the head and flow of these dams for the proposed hydroelectric power application to the potential beneficiary communities.

MATERIALS AND METHODS

The materials used for data collection were; 100 m long and 0.02 m diameter hose. Other materials include; 100 m long tape rule, 10 m long stick, 2 inches diameter 40 cm long plastic pipe, Canoe, Stop watch and 3 litre transparent plastic bucket

The research on the proposed Bosso, Chanchaga and Tagwai hydroelectric power plants was done between November 2023 and July 2024. The measurement of heads of Bosso and Chanchaga dams were done using direct meter rule method, while hose level method was used for measuring head of proposed Tagwai hydroelectric power plant. Figure 1 shows the heads and some other parameters such as the height of the tailrace above the floor of the dam and penstock lengths the distance of the turbine from the foot of the dams for Bosso and Chanchaga dams.

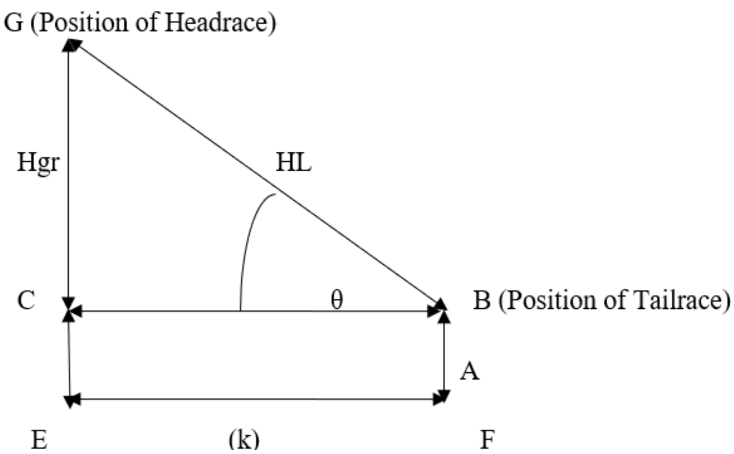

Figure 1: Geometry of Proposed Bosso, Chanchaga and Tagwai Hydroelectric power Plant

Figure 1 shows the gross head (Hgr) of Bosso and Chanchaga proposed storage hydroelectric power plant measured using direct meter rule method which 100 m tape rule was used, while the same figure shows the gross head (Hgr) of Tagwai proposed storage hydroelectric power plant using hose level method which one end of 100 m long 0.02 m diameter hose filled with water together with 100 m tape rule were tied to the tip 10 m high stick and rose up by the researcher at point (B) till water began spill at the other end of the hose held at 0 .00 m in position (A). The height (GC) as the gross head (Hgr), and the height (FB) as the height (A) of the Tailrace above the floor (EF) of the dam were measured and recorded. Each process was repeated three times and the average was calculated as the result.

The direct meter rule method was used to measure the total depth (GCE) from which the gross head (Hgr) and the height (A) of the tailrace above the floor of the dams as shown in Figure 1, were determined for Bosso, Chanchaga and Tagwai off shore hydroelectric power plant, from November 2023 to July 2024. The process was repeated three times in three different locations in the dam and the averages were calculated on monthly basis as shown in Figures 2, 4 and 5.

The mean gross head of Bosso, Chanchaga and Tagwai proposed off shore hydroelectric power plants were calculated and presented on Table 1.

HL is penstock length, H_{gr} is the gross head and θ is the angle of inclination of penstock to the horizontal. From equation (1) according to (Atil, 2024), the gross head can be determined as

$$H_{gr} = H_L \sin\theta \quad (1)$$

The result of the alternative heads calculated for Bosso, Chanchaga and Tagwai dams proposed storage hydroelectric power plants are shown in Table 1.

Bucket/container method of flow measurement was used to measure the flow of Bosso, Chanchaga and Tagwai dams proposed storage and off-shore hydropower electric plants. A calibrated transparent 3 litres plastic bucket, a stop watch and 2 inches diameter 40 cm long plastic pipe were used as the research apparatus for measurement of flow. The plastic pipe was inserted into the dam's weir water outlet vent to direct water into the plastic bucket with the time (t) taken for the volume (v)of the water collected in the plastic bucket recorded. Three measurements were taken and the averages were calculated for the volume and time. The flow (Q) in (m^3s^{-1}) was calculates by dividing the average volume of water collected with the average time for collection of the volume. The results for the flow against the months are presented in figures 6, 7 and 8 for the proposed Bosso, Chanchaga and Tagwai hydroelectric power plant respectively.

RESULTS AND DISCUSSION

Head of Proposed Bosso Hydroelectric power Plant

As shown in Figure 1 which is the geometry of Bosso dam proposed storage hydropower electric plant,

The Gross head (Hgr) for the proposed storage plant measured using direct meter rule method was 3.0 m

The hypotenuse penstock length (HL) = 10.27 m

The adjacent (k) = 9.80 m

The height (A) of the tailrace above the floor of the dam = 1.00 m

The depths (GCE) and the gross head (Hgr) of proposed Bosso dam off-shore hydropower electric plant measured from November 2023 to July 2024 also using direct meter rule method are shown on Figure 2.

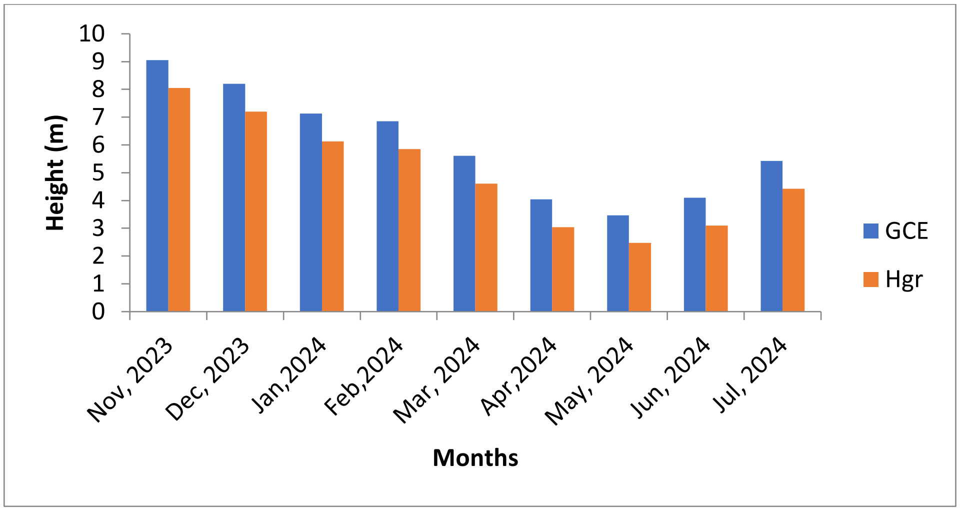

Figure 2: Depth (GCE), Gross Head (Hgr) and Heigth (A) of Tailrace above the Floor of Proposed Bosso Dam Off-Shore Hydropower Electric Plant

From Figure 2, it can be seen that the maximum reservoir depth and head of 9.05 m and 8.05 m respectively were measured and recorded in November 2023. It can also be seen that the least depth and head of 3.47 m and 2.47 m respectively were recorded in May 2024. The reservoir depth and head began to rise again in June 2024 with the value of 4.10 m and 3.10 m respectively. This was because the water in the dam has been evaporating and some water seeping through the dam walls reducing the volume of water without enough water from rainfall or other sources to replace the lost water till June 2024 before the depth and head of the dam began to rise, as a result of rainfall with enough water in the soil to drain into the reservoir, reduction in evaporation due to lower temperature and relative humidity and reduction in water seepage through the dam wall due to enough moisture in the dam wall. The interest was on the minimum depth and head measured and recorded before they began to rise again to ensure that the minimum depth and head of the reservoir satisfied the requirement for hydroelectric power plant operation which according to literature should be at least 0.2 m, as shown by hydroelectric power turbine selection chart by Arash and William, (2020), that guarantees that there is enough water in the reservoir to operate the proposed hydroelectric power plant all year round

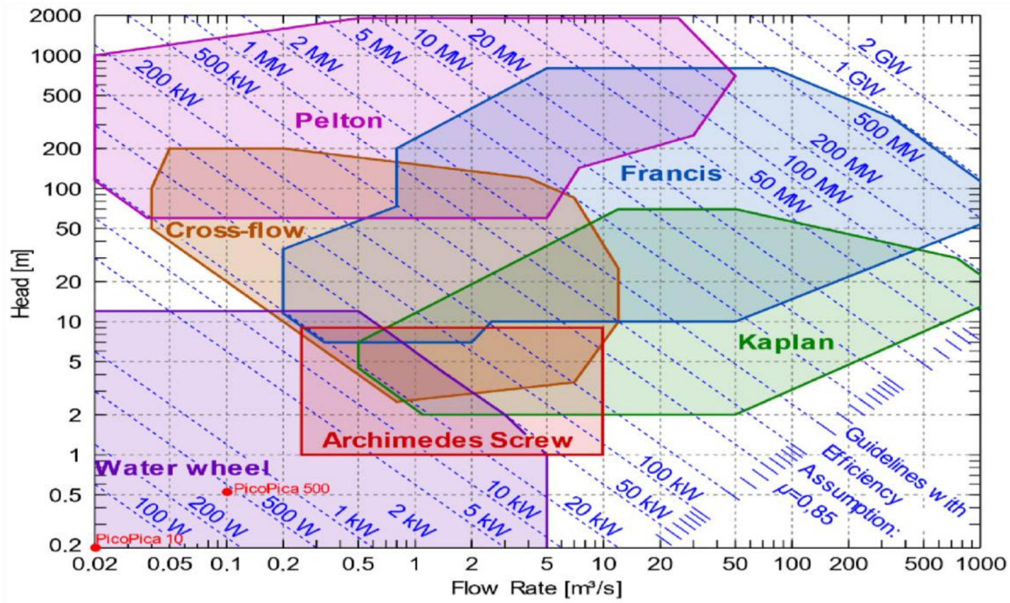

Figure 3: Hydroelectric Power Turbine Selection Chart (Arash and William, 2020)

From Figure 3, the least head required to operate a hydroelectric power turbine is 0.2 m for operating water wheel while the maximum head required is 2000 m for operating Pelton turbine, the rest turbines can be operated with various heads between the extremes as shown in the figure.

Head of Chanchaga Hydroelectric Power Plant

From Figure 1 which is the geometry of the proposed Chanchaga dam storage hydropower electric power plant measured using direct meter rule method. The Gross Head (Hgr) was 7.00 m, the Penstock length (HL) was 27.43 m, the adjacent (k) was 7.92 m and the height (A) of the tailrace to the floor of the proposed dam was 1.88 m

The depth (GCE) of proposed Chanchaga dam off-shore hydropower electric plant measured from November 2023 to July 2024 using direct meter rule method is shown on Figure 4.

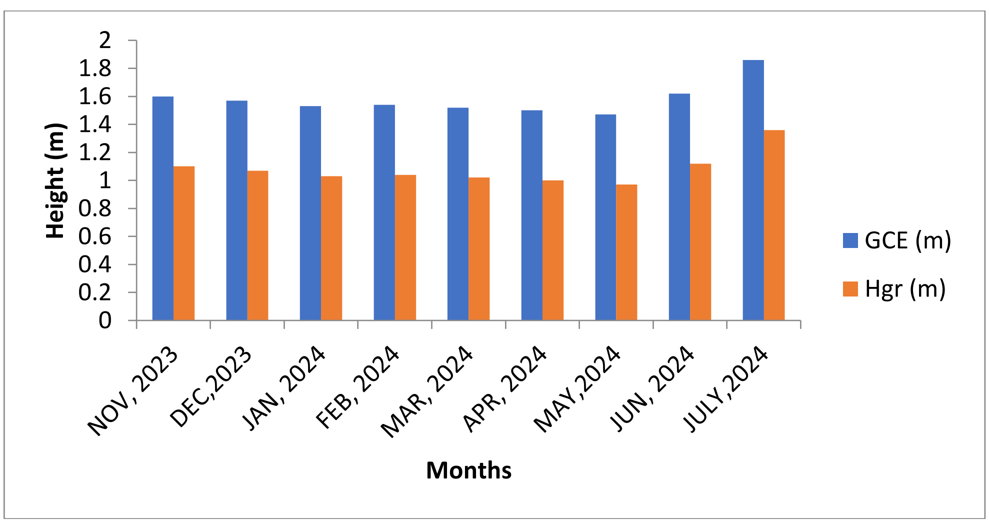

Figure 4: Depth (GCE), Gross Head (Hgr) and height (A) of tailrace above floor of dam for Proposed Chanchaga Hydroelectric Power

Also as shown in Figure 4, the maximum depth and head of proposed Chanchaga hydroelectric power plant were measured to be 1.60 m and 1.10 m respectively in November 2023, the least were measured to be 1.47 m and 0.97 m in May 2024 while the depth and head began to rise again in June 2024 the value of 1.62 m and 1.12 m respectively. The reasons for the decrease in the depth and head and subsequent rise in the depth and head of the proposed Chanchaga hydroelectric power plant were similar to those of Proposed Bosso Hydroelectric power plant and the minimum depth and head also satisfied the requirement for operation of hydroelectric power plant turbine as shown in Figure 3 and explained under proposed Bosso hydroelectric power plant.

Head of Proposed Tagwai Hydroelectric Power Plant

The gross head of proposed Tagwai dam storage hydropower electric plant (Hgr) as shown in Figure 1 was measured using hose level method to be 4.00 m.

The depth (GCE) and gross head (Hgr) of Tagwai dam measured using direct meter rule method from November 2023 to May 2024 are shown in Figure 5

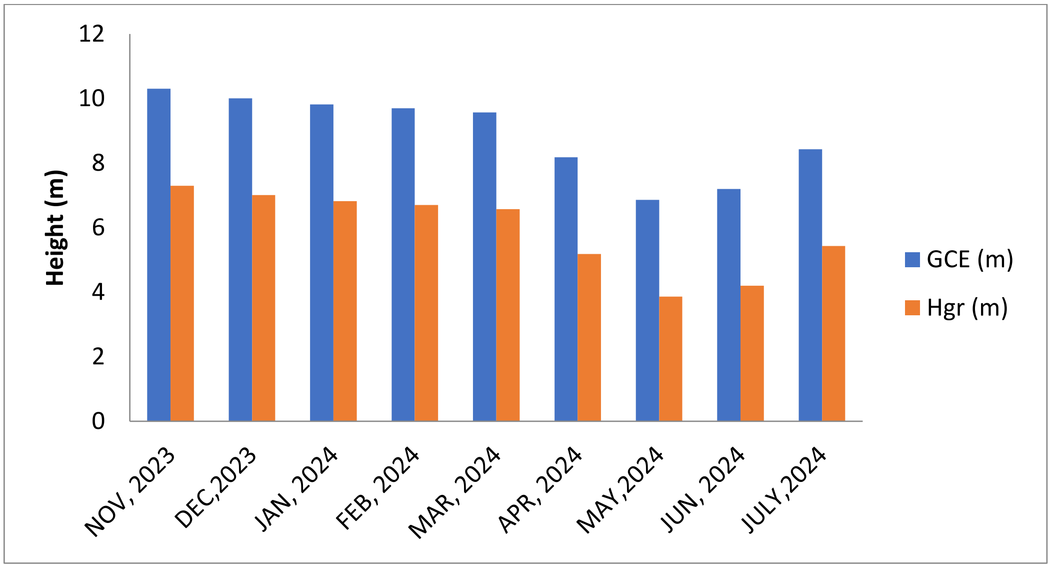

Figure 5: Depth (GCE), gross head (Hgr) and height (A) of tailrace above floor of dam for Proposed Tagwai Hydroelectric Power

From Figure 5, it can be seen that the highest reservoir depth and head of 10.30 m and 7.30 m respectively were recorded in November 2023. It can also be seen that the least depth and head of 6.86 m and 3.86 m respectively were recorded in May 2024. The reservoir depth and head began to rise again in June 2024 with the value of 7.20 m and 4.20 m respectively. This was because the water in the dam has been evaporating and some water seeping through the dam walls reducing the volume of water without enough water from the rainfall or other sources to replace the lost water till June 2024 before the depth and head of the dam began to rise, as a result of rainfall with enough water in the soil to drain into the reservoir, reduction in evaporation due to lower temperature and relative humidity and reduction in water seepage through the dam wall due to enough moisture in the dam wall. The interest was on the minimum depth and head recorded before they began to rise to ensure that the minimum depth and head of the reservoir satisfied the requirement for hydroelectric power plant operation which according to literature should be at least 0.2 m, as shown by hydroelectric power turbine selection chart by Arash and William, (2020) in Figure 3

Measurement of Flow of Bosso Proposed Hydroelectric Power Plant

Result for measurement of flow for Bosso dam proposed storage and off-shore hydropower electric plant is shown in Figure 6

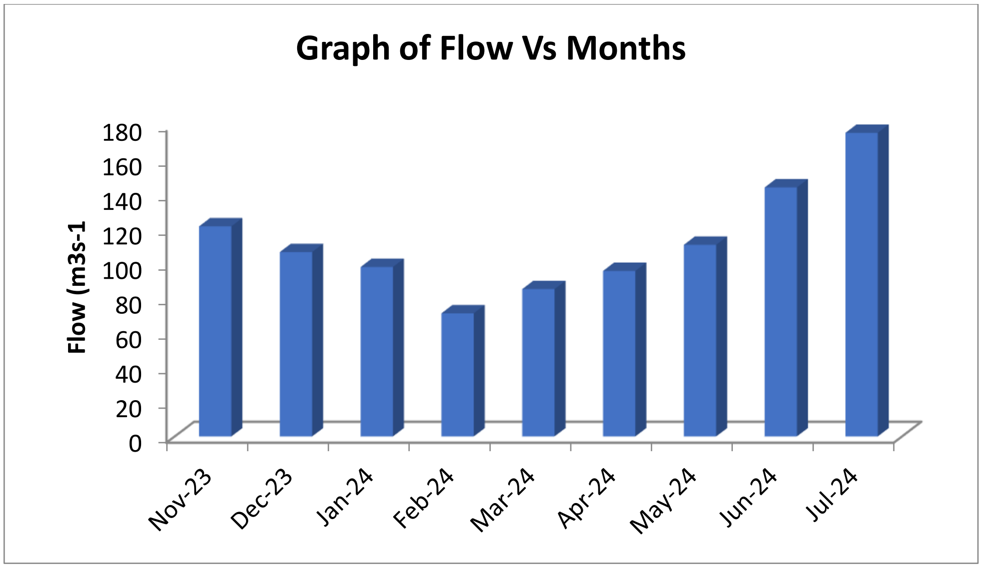

Figure 6: Flow for Bosso Dam

As shown in Figure 6, the flow kept declining from 121.31 m^3s^{-1} in November 2023 and reached the minimum of 71.09 m^3s^{-1}in February 2024 before it began to rise again with a value of 85.09 m^3s^{-1} in March 2024 till it reached the maximum of 175.32 m^3s^{-1} in July 2024. The result shows that proposed Bosso dam can retain reservoir water flow to operate the proposed hydroelectric power throughout the year round because the minimum flow of the reservoir measured was greater than the least standard value of 0.02 m^3s^{-1}required for all the turbines to operates as shown by hydropower turbine selection chart in figure 3

Measurement of Flow of Proposed Chanchaga Hydroelectric Power Plant

Result for Measurement of Flow of Chanchaga Dam Proposed Storage and Off-Shore Hydropower Electric Plant is shown in Figure 7.

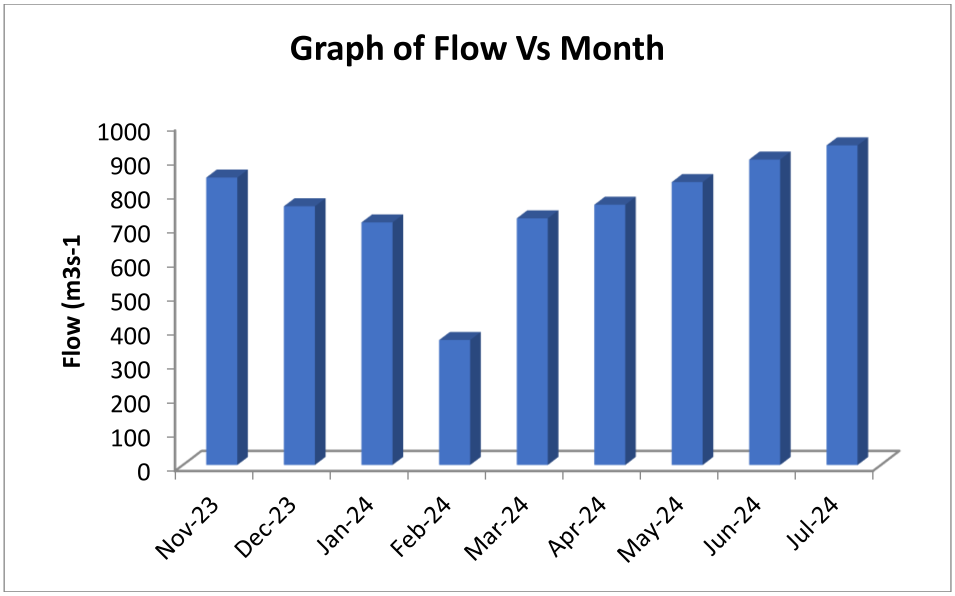

Figure 7: Flow of Chanchaga Dam

As shown in Figure 7, the flow kept declining from 843. 67 m^3s^{-1} in November 2023 and reached the minimum of 366.78 m^3s^{-1}in February 2024 before it began to rise again with a value of 724.00 m^3s^{-1} in March 2024 till it reached the maximum of 938.24 m^3s^{-1} in July 2024. The result shows that proposed Chanchaga dam can retain reservoir water flow to operate the proposed hydroelectric power throughout the year round because the minimum flow of the reservoir measured was greater than the least standard value of 0.02 m^3s^{-1}required for all the turbines to operates as shown by hydropower turbine selection chart in Figure 3. The minimum flow of Chanchaga dam is higher than that of Bosso dam.

Flow of Tagwai Proposed Hydroelectric Power Plant

Result for the Measurement of Flow of Tagwai Dam Proposed Storage and Off-Shore Hydropower Electric Plants

The data analysis and result of the measurement of flow of Tagwai dam proposed storage and off-shore hydropower electric plant is presented in Figure 8.

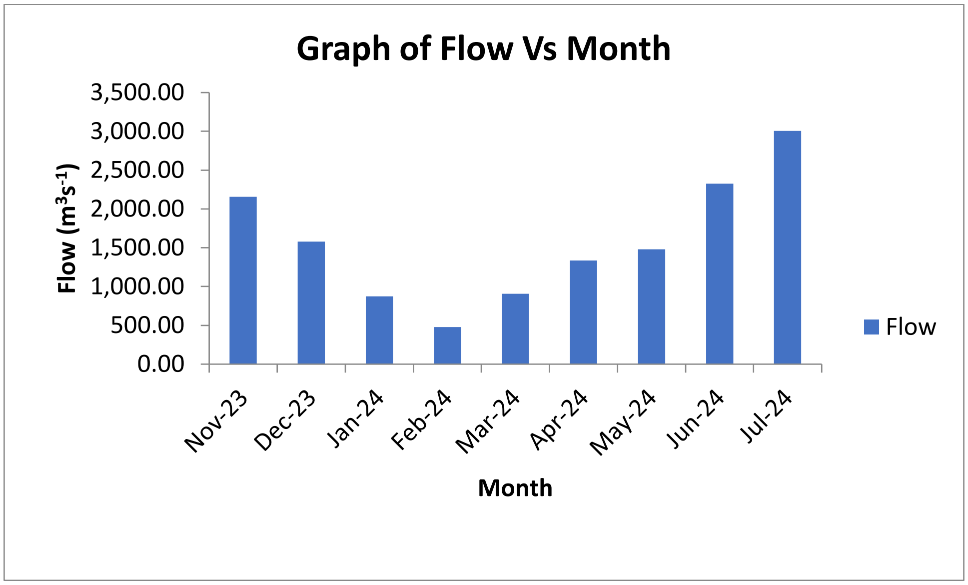

Figure 8: Flow of Tagwai Dam

As shown in Figure 8, the flow kept declining from 2,156.69 m^3s^{-1} in November 2023 and reached the minimum of 476.14 m^3s^{-1}in February 2024 before it began to rise again with a value of 905.51 m^3s^{-1} in March 2024 till it reached the maximum of 3,005.65 m^3s^{-1} in July 2024. The result shows that proposed Tagwai dam can retain reservoir water flow to operate the proposed hydroelectric power throughout the year round because the minimum flow of the reservoir measured was greater than the least standard value of 0.02 m^3s^{-1}required for all the turbines to operates as shown by hydropower turbine selection chart in Figure 3. The minimum flow of Tagwai dam is the highest relative to those of Bosso and Chanchaga dams.

Table 1: Summary of Heads and flows of the Proposed Bosso, Chanchaga and Tagwai Dams Hydroelectric Power Plants

S/N	Parameter	Source of Parameter	Bosso Dam	Chanchaga Dam	Tagwai Dam
1	Mean Reservoir Flow (m^3s-^{1}) for Storage and Off-shore Plants	Measured	111.91	759.45	1,571.03
2	Gross Head (H_{gr}) (m) for Storage Plants	Calculated	3.0	7.0	4.0
3	Head loss (H_L) (m) for Storage Plants	Calculated	0.15	0.35	0.2
4	Net Head (H_{Net}) (m) for Storage Plant	Calculated	2.85	6.65	3.80
5	Distance of Turbine from Foot of the Dam (m) for Storage Plants	Calculated	9.80	7.92	34.0
6	Mean Depth of Dam Reservoir (m) for Storage and Off-shore Plants	Calculated	5.98	1.58	9.12
7	Height (m) of Tailrace above the floor of the Dam for Off-shore Pants	Calculated	1.00	0.5	3.00
8	Penstock Length (HL) in (m) for Off-shore plants	Measured	7.04	1.53	8.73
9	Gross Head ($_{Hgr}$) (m) for Off-shore Plants	Calculated	4.98	1.08	6.12
10	Head Loss (H_L) (m) for Off-shore Plants	Calculated	0.250	0.054	0.300

11	Net Head (H_{Net}) (m) for Off-shore Plants	Calculated	4.74	1.03	5.60
12	Alternative penstock length (HL) in (m) for storage hydroelectric plant	Calculated	35	45	55
13	Alternative Gross Head (Hgr) in (m) for storage hydroelectric power plant	Calculated	24.74	31.83	38.89

From Table 1, Tagwai dam has the highest mean reservoir flow because of higher pressure which supports better turbine operation relative to Bosso dam with the least. Chanchaga dam has the highest gross head, head loss and net head due to the much height and support turbine operation better, relative to Bosso dam with the least. Bosso dam has the longest turbine distance from the foot of the dam and this implies power house being further from the dam which is good for safety, with Tagwai dam having the least. Tagwai dam has the highest mean depth, indicating it is deeper and more supportive for offshore hydroelectric power plant, compared to Bosso and Chanchaga dams. Tagwai dam has the highest penstock length which is more costly to procure relative to Bosso and Chanchaga dams. Tagwai dam has higher alternative gross head, alternative gross head loss and alternative net head which can support hydroelectric power application better, relative to Chanchaga and Bosso dams.

CONCLUSION

The gross heads of proposed Bosso, Chanchaga and Tagwai storage hydroelectric power plants with the values of 3.00 m, 7.00 m and 4.00 m with alternative gross head of; 24.74 m, 31.38 m and 38.89 m for Bosso, Chanchaga and Tagwai dams respectively, as shown in Table 1 satisfied the standard minimum head of 0.2 m required to operate any hydroelectric power turbine as shown by hydroelectric power turbine selection chart in Figure 5. Likewise, the mean gross heads of proposed Bosso, Chanchaga and Tagwai off shore hydroelectric power plants with the values 4.98 m, 1.08 m and 6.12 m respectively, satisfied the standard minimum head value of 0.2 m required to operate any kind of turbine as shown by the turbine selection chart in Figure 3. The mean reservoir flow of Bosso, Chanchaga and Tagwai dams proposed storage and off shore hydroelectric power plants with the values of 111.91 m^3s^{-1}, 759.45 m^3s^{-1} and 1,571.03 m^3s^{-1} respectively as shown in Table 1 satisfied the standard minimum value of 0.02 m^3s^{-1} to operate any kind of hydroelectric power turbine as shown by hydroelectric power turbine selection chart in Figure 3.

It is concluded that the measured head and mean flow for the proposed storage and offshore hydroelectric power plants of Bosso, Chanchaga and Tagwai dams are greater than the minimum values of .02 m and 0.02 m^3s^{-1} respectively required for hydroelectric power application and satisfied the requirements for the purpose.

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