Bathymetric and Volumetric Analysis of Jebba (Hydropower) Dam Harnessing its Capability for Multipurpose Use

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ABSTRACT

The need to carry out routine bathymetric survey on dam in order to analyse the quantity of water in the dam's reservoir cannot be underrated. "multipurpose water uses of hydropower reservoirs" has been the world water council advocacy. Multipurpose water use include categories, such as domestic purposes, cooling of power plants, irrigation, mining, recreation, navigation, fisheries, etc., This research uses topographic and bathymetric data obtained from field operations to compute the volume of water present in the dam. Midas Surveyor dual frequency GPS echo sounder, Trimble 5700 Dual Frequency GPS 'Base Station' receiver and Trimble 5800 Dual Frequency GPS 'Rover' receiver, were employed for data collections. Data processing and presentation were done with Surfer 10 software. The volume computed from data analysis gives 3880×10^6 MCM. The volume of water needed to run the six turbines per day added up to 1,735,200 litres and that of per capita use was 0.006 litre per day for minimum and 0.025 litres per day for maximum. The volume left after removing other withdrawer was 62% of the actual volume computed for the dam.

Keywords: Hydropower, Dam, Bathymetry, Volume, Per Capita Use, Multipurpose use

1.0. Introduction

Jebba dam though built for specific purpose of generating hydroelectric power can be harnessed and use as multipurpose dam. Construction of multi-purpose dams has been favoured in recent years due to their ability to use single facility to fulfill a number of purposes. This multi-purpose dams, if well planned and managed, provide an important option to meeting some of today's major development and economic challenges. By providing clean and reliable energy, storage volume to improve drinking water supply or agricultural food production, and enhanced flood control, they contribute to energy, water and food security and to human security in general. In vulnerable regions, multi-purpose dams can also be an appropriate response to the impacts of climate change.

According to World Commission on Dams (WCD, 2000), International Commission on Large Dams (ICOLD, 2015) and (WWC, 2015), more than one third of the World's large dams are multipurpose dams. Among those, 26% have hydroelectric generation capacities as one of their purposes (single or multipurpose reservoirs).

In addition to electricity, the development of hydropower with reservoirs often contributes to other services the most important ones being: water supply, flood and drought management, irrigation, navigation, fisheries, environmental services and recreational activities). These objectives (power services, water quantity management, ecosystem services economic growth and local livelihoods) can conflict at times, but are also often complementary (Adie *et al.*, 2008).

1.1. The Different Purposes of Hydropower Reservoirs

Hydropower reservoir projects are also used for freshwater management and they provide a variety of value-added uses. The reservoir provides the opportunity to release water when it is most advantageous and provides a constant flow of water via penstocks through turbines to generate electricity. Storage

hydropower can therefore be used for both base and peak power load. The multipurpose uses of hydropower reservoir usually imply “multi-users”. Hydropower reservoirs can also regulate water flows for freshwater supply, flood control, drought mitigation, irrigation, navigation services and recreation. Such regulation of water flow may be important to climate change adaptation (AET, 2017).

1.2. Bathymetry

NOAA, (2015) defined bathymetry as the study of the "beds" or "floors" of water bodies, including the ocean, rivers, streams, and lakes. The term "bathymetry" originally referred to the ocean's depth relative to sea level, although it has come to mean “submarine topography,” or the depths and shapes of underwater terrain. Bathymetry is the foundation of the science of hydrography, which measures the physical features of a water body. Hydrography includes not only bathymetry, but also the shape and features of the shoreline; the characteristics of tides, currents, and waves; and the physical and chemical properties of the water itself.

1.3. Sounding

The process of sounding involves the use of an Echo-sounder equipment for the determination of the depth of river bed. The basic principle of operation is that the Echo-sounding transducers emit ultrasonic waves that are reflected and refracted off the river bottom. Part of this signal is returned to a receiver aboard the transmitting vessel and recorded to derive two-way travel time. This process allows depth calculations based on the known velocity of sound in water.

1.4. Water Uses

Based on the assumption that hydroelectric power generation is a dam's primary use, a variety of economic benefits can be yield by adding other uses. The more compatible these different uses are, the easier becomes the management of a reservoir thus it become imperative to understand a project's purposes and their relative compatibility (Government of India, 2015).

2.0. Description of the Study Area

The study area is Jebba Dam. Figure 1, depict the map and the google earth imageries of the study area. The dam is located along River Niger in Jebba town which shares boundary partly in Kwara State and Niger State. It has a hydropower station which has an installed capacity of 540MW.

Figure 1: Map and google earth imageries of the study area (Source: Google Earth)

2.1. Geographical Location of the Study Area

Geographically Jebba dam is located between coordinates 9° 04' 40.52"N, 4° 33' 36.12"E and 9° 35' 30.76"N, 4° 46' 15.51"E at an elevation of 71.917m above sea level. Its basin falls within Latitude 90° 06', 9° 55' North and Longitudes 4°02', 4°05' East. The dam is about 3 km upstream of the main town of Jebba.

2.2. Construction Data of Jebba Dam

The length, width and crest elevation of the main dam are 108.669 m, 670.020 m and 10.001 m respectively. The spillway capacity of this dam is 13, 600 m³s⁻¹. The surface area of the reservoir is 3000 km and its length is 100 km. The capacity of water volume is put at 3,600 million (m³), while the Surface Area is 35,000 Hectares. It essentially consists of a suite of six earth/rockfill embankment and gravity dams, the main one being of the former class. (PHCN, 2010). The construction of a series of dams was necessary because the valley where the main dam is situated is very wide. The reservoir created by this dam forms backwater up to Kainji, with an area of 270km² and over a distance of about 100km. Additional data of the dam from PHCN are provided in the table 1.

Table 1: Jebba dam's characteristics; source (PHCN, 2010).

First Year of Operation	1984
Installed Capacity (MW)	540
Design power plant factor	0.7
No. of generators	6
Reservoir flood storage capacity (Mm ³)	4,000
Reservoir flood level (m)	103.55
Water Surface Area (Km ²) at elevation 103.0m	303
Maximum operating reservoir elevation (m.a.s.l)	103
Minimum operating reservoir elevation (m.a.s.l)	99
Maximum storage (Mm ³) (Active storage capacity)	3,880
Minimum storage (Mm ³) (Dead storage capacity)	2,880

2.3. Population

Jebba settlement has an estimated population of 22,411 in 2006 population census figure (NPC, 2006).

2.4. Rainfall Pattern

The rainfall in the study area indicates that no part receives less than 180 - 200mm of rainfall in July while August to September constitute the peak rainy season within Jebba and its environs with highest rainfall record of over 400mm which occur in September during normal rainfall year (Adefolalu and Oguntinyinbo, 1985).

3.0. Materials/Method

3.1. Instrumentation

- i. 1 x Midas Surveyor – dual frequency GPS echosounder & accessories
- ii. 1 x Trimble 5700 Dual Frequency GPS (Global Positioning system) 'Base Station' receiver
- iii. 1 x Trimble 5800 Dual Frequency GPS (Global Positioning system) 'Rover' receiver
- iv. 1 x Navigation computer

- v. 1 x Data Processing computer
- vi. 1 x Hypack hydrographic software
- vii. 1 x Generator etc. were used during the operations (GSES, 2011).

There are various methodologies in use nowadays to carry out a hydrographic survey, depending on the end use of the survey and the size of the area to be surveyed (Hydrographic Survey, 2010). It was also observed from the article that vertical depth measurements may be carried out using:

- a) Hand-held calibrated lead sounding line;
- b) Simple engineering echosounder recording on paper; and advanced engineering echosounder recording on a data logger and linked to position fixer via integrated software (fully automated).
- c) Single and multi-beam acoustic system

Horizontal position fixing measurements may be carried out using:

- a) Hand-held optical square in conjunction with a float line;
- b) Single theodolite in conjunction with a float line or twin theodolites;
- c) Constant range tracking electronic positioning system (EPS); and
- d) Differential Global Positioning System (GPS).

3.2. Bathymetric Survey Procedure

The bathy Survey boat used was an open fiber boat of 2 metre width, 5 metre length and 0.5 metre draft, mounted with 2 x 85 HP engines. The bathymetric survey equipment was mounted on an aluminum vessel with the transducer and GPS unit located over the side, the hydrographic system included a GPS receiver with a built-in radio, a depth sounder, a helmsman display for navigation, a computer, and hydrographic system software for collecting the underwater data. On-board batteries powered all the equipment. The shore equipment included a second GPS receiver with an external radio. The shore GPS receiver and antenna were mounted on survey tripods over a known datum point and powered by a 12-volt battery (GSES, 2011).

Figure 2: Survey Boat, MIDAS Surveyor Echo Sounder, Toshiba Laptop and Hypack Navigation System software displayed in laptop screen (Source: GSES, 2011)

The Navigation System comprised of a Toshiba Laptop Computer. The Computer receives corrected GPS derived Latitude and Longitude (X-Y) coordinates from the MIDAS GPS receiver or Trimble 5700 which also receives SBAS DGPS corrections. The antenna position is converted into the local datum coordinates. The Hypack Navigation System software provided display presentations suitable for sailing pre-determined lines and included a visual aid for the Helmsman. The DGPS antenna and the echo Sounder transducer were arranged in such a way as to have zero offset from each other (GSES, 2011).

Digitized water depth (raw soundings), together with position and time, were recorded at 25m intervals and logged to the Hypack Software hard disk (later copied to back-up Compact disks) for post-processing onshore. The MIDAS digital Echosounder (E/S) was used throughout the survey (GSES, 2011).

The MIDAS is a modern and sophisticated Echosounder that has the advantage of measuring depth on two (2) frequencies – High frequency (HF) and Low Frequency (LF), 210 MHz and 33 MHz respectively. In addition, the transducer cable is arranged in such a way that other manufacturers Transducers can easily be connected to it and used on the MIDAS.

The MIDAS is also fitted with an onboard GPS and antenna capable of receiving Differential corrections. It also has an internal Hard disk and can store acquired sounding depth and positions. The outboard transducer was marked, from the base of the transducer shoe, at 1m intervals (these marks were used to confirm transducer draft once the arrangement was deployed) (GSES, 2011).

Figure 3, shows the principle of DGPS real-time measurement of position of survey vessel. Real-time measurement allow positions of points below the river bed to be fixed as well as the corresponding coordinates of such points. This enable post-processing of sounding data to be achieved.

Figure 3: Differential GPS real-time measurement of position of survey vessel. Source (www.fao.org)

3.2.1. Echo Sounder Calibration (Bar Check)

The Bar Checks Sling was checked to confirm the marks are at regular 1 m and 0.1 m intervals and that the marks were readily identifiable. Bar checks during the survey operations were regularly carried out prior to the start of the day's survey and also at the end of the day's survey. The transducer of the E/S was installed rigidly to its bracket and side mounted on the Survey Vessel, the transducer shoe was sufficiently deep not to experience turbulence and aeration when the vessel steams at survey speed. The depth of the transducer below waterline was ascertained by reference to the marks on the transducer pole. The echo sounder was interfaced to the navigation and data logging computer to confirm that the digitization of depths was operational.

3.3. Topographic Survey Procedure

3.3.1. Reconnaissance

A reconnaissance was done to identify suitable benchmarks with known elevation which could also serve as a GPS base station. The considerations were accessibility, satellite visibility, multipath, etc.

BM_AMOS was chosen as the Reference Station. The elevation value was obtained from the Hydrological office, but no Horizontal coordinates could be obtained from the DAM's authorities. The Measured WGS84 coordinates of the Benchmark was therefore adopted viz. (Ehigiator *et al*, 2014).

Table 2: coordinate and elevation of the reference point

Pt ID	Easting (m)	Northing (m)	Elevation (m)
BM_AMOS	4°47'13.55888"	9°08'47.03917"	108.669

Figure 4: BM_AMOS mark on the rock: source (GSES, 2011)

3.3.2. Post Processing Correction

Differentially correcting GPS data by post processing uses a base GPS receiver that logs positions at a known location and a rover GPS receiver that collects positions in the field. The files from the base and rover are transferred to the office processing software, which computes corrected positions for the rover's file. This resulting corrected file can be viewed in or exported to a GIS environment.

3.3.3. Hydrographic Data Processing

As a prelude to processing, the data was properly archived in the Hypack system. Corrections of the measured depth for water above the chart datum are applied, making use of the gauge readings. The Corrected data was saved as *.dat* files in surfer or as *.xls* file in MicroSoft Exel database tables for onward transfer to Surfer Golden Software for processing.

Figure 5: Tide gauge reading point: source (GSES, 2011)

3.3.4. Back computation

Back computation was carried out to calculate bearings and distances between each traverse leg. These bearings and distances are determined from final corrected coordinates.

Length of the traverse lines was computed using, $L = \sqrt{\Delta E^2 + \Delta N^2}$

(1)

Bearing of the line was computed from, $(\theta) = \tan^{-1} \frac{\Delta E}{\Delta N}$

(2)

3.3.5. Area and Volume Computation

The area of expanse of land covered by the dam through traverse was computed using cross coordinate method in the determinant form as follows.

The product of the coordinates along full lines is taken positive and along dashed line is taken negative, therefore the area is given as;

$$Area (m^2) = \frac{1}{2} (N_1 E_2 - E_1 N_2 + E_2 N_3 - E_2 N_3 \dots \dots \dots + N_n E_1 - E_n N_1) \quad (3)$$

The computation of volume of water in the dam's reservoir was done using the trapezoidal rule which can also be verified with the help of surfer 10 software. Volume (cutting or filling), is given as;

$$Volume (m^3) = \frac{D}{2} \{A_1 + A_2 + A_3 \dots \dots \dots + A_{n-1}\} \quad (4)$$

Where, **V** = volume, **A₁** = area of first section, **A_n** = area of last section, **D** = the common distance.

The volume of water from the obervation data of the reservoir gives the following values with different rules.

Trapezoidal Rule:	3888778.941Mm ³
Simpson's Rule:	3888804.750Mm ³
Simpson's 3/8 Rule:	3888843.833Mm ³

Figure 6, depict the 3D depth topography of Jebba dam elevation points in colour scale. The variation in colour was due to changes in depth as recorded by the echo sounder after reduction.

Figure 6: Jebba dam 3D depth topography

Figure 7, shows the contour representation of the Jebba river bed and the corresponding scale showing variation in depth elevations.

Figure 7: Contour representation of the Jebba dam's basin

Figure 8, shows the direction of flow of Jebba river with colour scale depicting high and low current or speed

Figure 8: Direction of flow of Jebba river

4.0 Analysis of Water Consumption

4.1. Volume of Water needed to Run the Turbines

The amount of head available in hydro energy system determines the amount of power available from the water as Power is proportional to Head x Flow. The flow of water through the turbine is normally expressed in litres per second, (litre/s) or cubic metres per second (m^3/s) and refers to the quantity or volume of water used by the turbine to turn the shaft (Adebola *et al*, 2014). They also, noted that $3\text{m}^3/\text{s}$ of flow is needed to produce 1MW of power and when multiplied by the total power output given in megawatts gives the amount of water required to produce power per second. But Jebba HPP comprises of 6 identical generating units having an output capacity of 96.4 MW each, at a rated net head of 27.6 m and a discharge of $385\text{ m}^3/\text{s}$. The six installed units have a total capacity of 578.4 MW, (Bathymetric Survey, 2013).

Volume of water needed for 1 turbine per day = $3000 \times 96.4 = 289200$ litres

Volume of water needed for 6 turbine per day = $6 \times 289200 = 1735200$ litres

4.2. Per Capita Water Use

According to (David, 2009), per capita water use is calculated by dividing the total amount of water withdrawn from all water suppliers by the population. The per capita water use by the Jebba inhabitants with population of 22,411 is displayed in the following figures.

Figures 9 was derived from Table 3. It shows the percentage of water consumed by Jebba inhabitant per day. The volume of water use per person per day gives (0.006 litres) at minimum rate. Total water consumed by the entire population per day added up to 134.446 litres at minimum rate as shown in the chart.

Table 3: Analysis of per capita water consumption in litres and meters

Per Capita Usage	Min. (Liters)	Max. (Liters)	Min. (m^3)	Max. (m^3)
Brushing teeth	0.01	1	1.00E-05	0.01
Cooking a meal	1	5	0.01	0.005
Flushing toilet	5	10	0.005	0.01
Washing hands	1	3	1.00E-05	0.003
Dish washer	30	50	0.03	0.05
Washing machine	30	100	0.03	0.1
Shower	1	40	1.00E-05	0.04
Cleaning car	5	200	0.005	0.2
Drinking	1	2	1.00E-05	0.002
Bath	50	150	0.05	0.15
Total	124.01	561	0.13004	0.57

Figure 9: Percentage of water consumption per inhabitant per day (minimum) litres

Figure 10 was derived from Table 3. It shows the percentage of water consumed by Jebba inhabitants per day. The volume of water use per person per day gave (0.025 litre) for maximum. Total volume of water consumed by the entire population per day added up to 560.275 litres at maximum rate.

Figure 10: Percentage of water consumption per inhabitant per day (maximum) litres

Table 4: Computed total volume (consumed) by both turbines and per capita use per day (litres)

Computed (volume consumed) by turbines per day (L)	1735.20
Computed (Minimum) per capita volume consumed by inhabitant per day (L)	124.01
Computed (Maximum) per capita volume consumed by inhabitant per day (L)	561.00

Figure 11 was derived from Table 4, it shows the total consumption capacities, which is the sum of the total consumption by the turbines and per capita use per day. It can be seen that 72% was allotted to the turbines while 28% catered for per capita use at maximum and minimum rates respectively.

Figure 11: Computed volume (consumed) by both turbines and per capita use per day (litres)

Table 5: Analysis of computed volume and consumption volumes in (litres)

Volume computed (ML)	3888.778941
Computed volume consumed by turbines per day (L)	1735.20
Computed (Minimum) per capita volume consumed by inhabitant per day (L)	124.01
Computed (Maximum) per capita volume consumed by inhabitant per day (L)	561.00

Figure 12 was derived from Table 5, it shows the quantities in percentages of computed volume, volume consumed by turbines and the per capita use per day for the study area. It can be seen the 38% of the total volume of water was in use per day while 62% water in the dam remain unused.

Figure 12: Total consumption per day of turbines and per capita use deducted from the main reservoir per day (litres)

5.0 Conclusion and Recommendations

From the foregoing it can be observed that Jebba dam can be used as a multi-purpose dam if properly harnessed. The total water used by the six turbines added up to 1,735.2 litres per day. If this is subtracted from the computed volume the remaining water in the dam can serve the inhabitant of Jebba town for their domestic purposes. Total water consumed by the entire population per day at minimum and maximum rates are 134.446 litres and 560.275 litres respectively. This will not in any way affect the dam's optimal performance. From the chart in figure 12, volume of water after all withdrawer gave 62%.g

It is recommended that Jebba hydropower dam can be used for other purposes due to the following findings:

- i. That the volume of water in the dam is sufficient to serve a dual purpose of running the turbines and solving the domestic water uses of the inhabitant of the study area
- ii. That the dam has not been used to the maximum by making it a single purpose dam
- iii. That the bathymetry of the dam should be done every year to determine the volume of water in the dam's reservoir
- iv. That the government and other decision makers should look into how well the dam can be manage to enhance economic growth and sustainability.
- v. That deformation monitoring of the dam should be carried out on regular basis.

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