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DETERMINATION OF VOLUME AND DIRECTION OF FLOW OF KAINJI RESERVOIR USING HYDRO-GEOMATICS TECHNIQUES

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ABSTRACT

Determination of volume and direction of flow of river plays a key role in determining the direction of transported materials to the downstream. Bathymetry survey which incorporate sounding to determine the depths with respect to a known bench mark together with coordinates of points referenced to a minimum of two horizontal controls are enough to fix position of points aboard a boat traversing a river during field work. In this paper, MIDAS Echo Sounder and Trimble Dual Frequency GPS was used for data acquisition. Data analysis was done with the aid of Surfer golden software. The results obtained showed a computed volume of 13200456.595Mm³, 13226766.629Mm³ and 13209519.223Mm³ for the reservoir using trapezoidal, Simpson's and Simpson's 3/8 rules respectively. A contour map, 3D wireframe map overlaid with grid vector maps of the river bed were produced to create a 3D effect of Kainji reservoir flow direction. A depth of 23.50m was obtained during the sounding field operation.

Key Words: *Kainji Dam, Reservoir, Bathymetry, Volume, Direction of flow*

1. INTRODUCTION

The construction of dam across River Niger at Kainji has impacted on its rate of flow. Prior to dam construction, most natural rivers have a flow rate that varies widely throughout the year in response to varying conditions. Of course once constructed, the flow rate of the river below a dam is restricted. The dam itself and the need to control water releases for the various purposes of the particular dam result in a flow rate that has a smaller range of values and peaks that occur at times related to need rather than the dictates of nature.[1]

The impoundment of water behind a dam causes the velocity of the water to drop. Sediment carried by the river is dropped in the still water at the head of the lake. Below the dam, the river water flows from the clear water directly behind the dam. Because the river no longer carries any sediment, the erosive potential of the river is increased. Erosion of the channel and banks of the river below the dam will ensue. Even further downstream, sediment deprivation affects shoreline processes and biological productivity of coastal regions [1]

1.1 Acoustic Depth Sounding Principle

Sounding refers to the act of measuring depth. It is often referred to simply as sounding. Data taken from soundings are used in bathymetry to make maps of the floor of a body of water, and were traditionally shown on nautical charts in fathoms and feet [2].

Basic principle: Acoustic depth measurement systems measure the elapsed time that an acoustic pulse takes to travel from a generating transducer to the waterway bottom and back [3]. This is illustrated in Figure 1 where the measured depth (D) is between the transducer and some point on the acoustically reflective bottom. The travel time of the acoustic pulse depends on the velocity of propagation (v) in the water column. If the velocity of sound propagation in the water column is known, along with the distance between the transducer and the reference water surface, the corrected depth (d) can be computed by the measured travel time of the pulse. This is expressed by equations 1 and 2 as follows [2].

$$D = {}^{1}/_{2} \times V \times t \qquad (1)$$

In (1), D is the depth, V is the average velocity of sound in the water column t is the measured elapsed time from transducer to bottom and back to transducer.

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$$d = {}^{1}\!/_{2} \times (V \times t) + k + dr \qquad (2)$$

In (2), d is the corrected depth from reference water surface v is the average velocity of sound in the water column t is the measured elapsed time from transducer to bottom and back to transducer k is the system index constant dr is the distance from reference water surface to transducer (draft) [2].

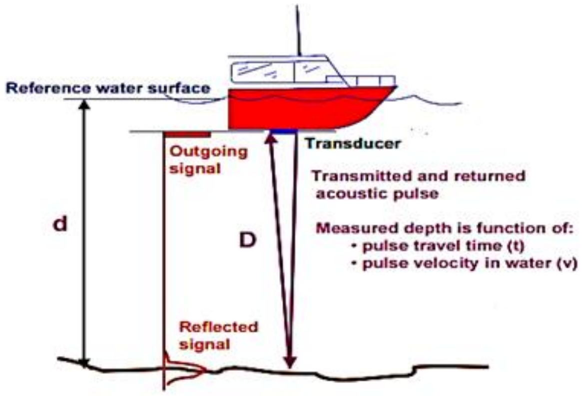

Figure 1: Principle of acoustic depth measurement.

2. STUDY AREA

The study area is as depicted in figure 2, the coordinates of Kainji dam is given as: (10°11'45.71"N, 4°34'32.82"E and 09°51′45″N, 04°36′48″E). It is a dam used to impound water across the Niger River. Kainji hydroelectric dam is located in New Bussa which was formerly part of Kwara state but later transferred to Niger state on the 27th of August 1991, thereafter became the headquarter of Borgu Local Government Area of Niger State, Nigeria. The Kainji dam has a main dam and a saddle dam. The main dam is constructed of concrete and rock fills while the saddle dam is rock filled which protects the main dam during flooding. There are four spillways with hydraulic operated gates of 50ft x 50ft (about 15m x 15m), which could be opened to control flood and to release water for use at the Jebba hydropower dam downstream if there is need to do so. The lake has a total capacity of 15 billion cubic meters covering an area of 1,270 sq. kilometres. It has a power plant with initial six generating units and six turbines at the site [3]. Table 1 shows the designed characteristics of the dam at construction.

Table 1. Kainji dam designed parameters

First Year of Operation	1968
Installed Capacity (MW)	760
Design power plant factor	0.86
No of units in operation	8
No of units not installed	4
Reservoir flood storage capacity (Mm^3)	15,000
Reservoir flood level (m)	143.50
Water Surface Area (Km^2) at elevation141.7 m	303
Maximum operating reservoir elevation (m.a.s.l)	141.83
Minimum operating reservoir elevation (m.a.s.l)	132.00
Maximum storage (Mm^3) (Active storage capacity)	12,000
Minimum storage (Mm^3) (Dead storage capacity)	3,000
Hydraulic head (m)	24.0 to 42.2
Spilling capacity (m^3/s).	7,900
Maximum head elevation is (m)	141.7
Minimum tail Elevation (m)	103
Surface Area (Hectares)	130,000

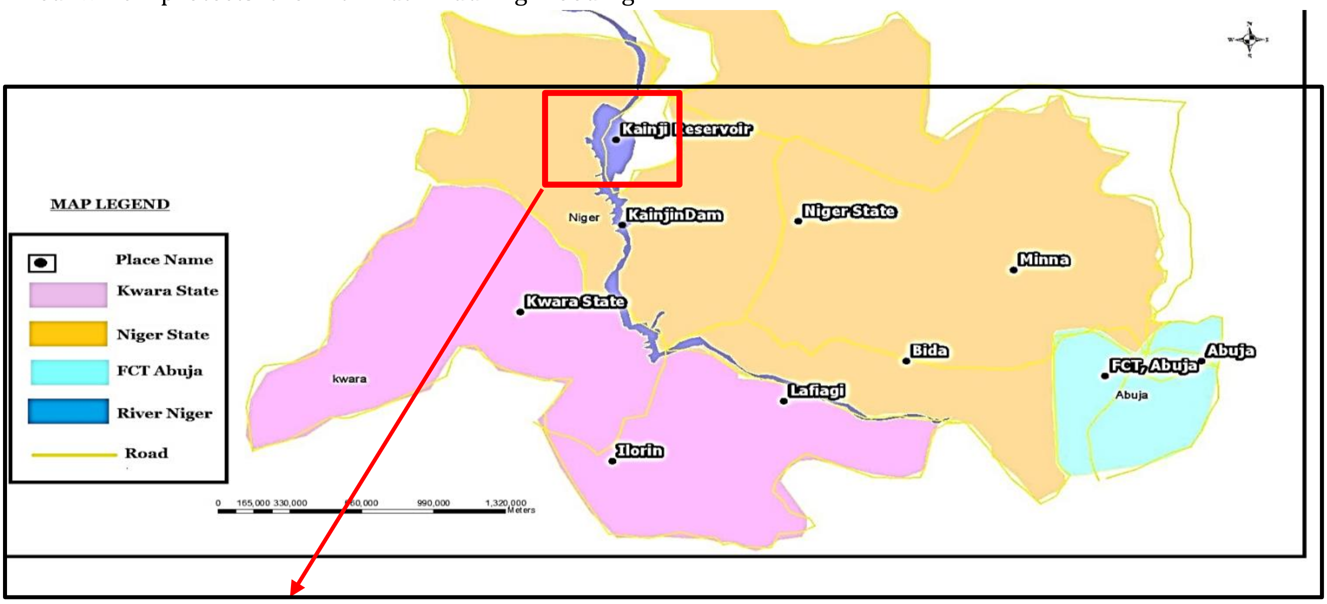

Figure 2: Location map of Kanji reservoir and its drainage basin.

3. BATHYMETRIC SURVEY PROCEDURE

The bathy Survey boat used was an open fibre boat of 2 metre width, 5 metre length and 0.5 metre draft, mounted with 2 x 85 HP engines. The echo-sounder 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 [5].

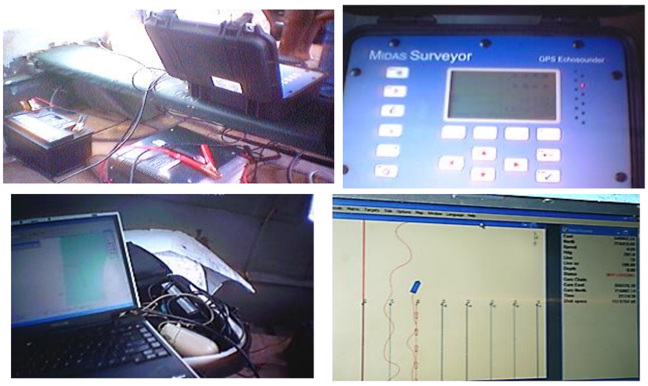

Figure 3: Survey Boat, MIDAS Surveyor Echo Sounder, Toshiba Laptop and Hypack Navigation System software window.

Figure 3, shows the part of the bathy boat, the Toshiba laptop and accessories and the Midas echo sounder used in the process of data acquisition.

3.1. Area Computation

The area of expanse of land covered by the dam through traverse was computed using cross coordinate method using equation [3]. However, there are other methods for computing area commonly used in surveying such as, midpoint ordinate rule, graphical rule, average ordinate rule, Simpson's rule and trapezoidal rule but the method used depends on user's choice.

$$Area\ (m^2) = \frac{1}{2}\,(N_1E_2 - E_1N_2 + E_2N_3 - E_2N_3 \ldots\ldots\ldots.. + N_nE_1 - E_nN_1) \qquad (3)$$

IN (3), represents the Northing and E, represent the Easting of points within the network under investigation. The planer area covered gave:

Positive Planar Area [Cut]: 122,342.807 ha
Negative Planar Area [Fill]: 7,778.483 ha
Blanked Planar Area: 0
Total Planar Area: 130,121.28 ha

3.2 Volume Computation

In the computation of volume, several rules can be applied among which are; prismoidal, end area, trapezoidal, Simpson's etc. In this paper volume computation was done using three different methods (rules) stated as follows.

3.2.1 Volume Computation Using Trapezoidal Rule

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 in form of Volume (cutting or filling),

$$Volume\ (m^3) = D\left\{\frac{A_{1+}A_n}{2} + A_2 + A_3 \ldots + A_{n-1}\right\} \quad (4)$$

Where, V is the volume, A_1 is the area of first section, A_n is the area of last section, D is the the common distance.

3.2.2 Volume Computation Using Simpson's Rule

The volume was computed using Simpson's rule. Equation [5] expresses the formula which produced the result presented in section 4.1 for volume alloted to Simpson's rule .

$$Volume\ (m^3) = \frac{D}{3}\,\{A_0 + 4A_1 + 2A_2 + 4A_3 + \cdots + 2A_{n-2} + 4A_{n-1} + A_n\} \qquad (5)$$

Where, V = volume, A_0 = area of starting section, A_n = area of last section, D = the common distance

3.2.3 Volume Computation Using Simpson 3/8 Rule

Volume computation using Simpson's 3/8 rule was done using equation 6a or 6b. The outcome was also presented in section 4.1 for volume allotted to Simpson's 3/8 rule.

$$V = \frac{3h}{8}\{f(X_0) + 3\,f(X_1) + 3f(X_2) + f(X_3) + f(X_3) + 3f(X_4) + 3f(X_5) + f(X_6) + \cdots + f(X_{n-3}) + 3f(X_{n-2}) + 3f(X_{n-1}) + f(X_n)\} \qquad (6)$$

$$V = \frac{3h}{8}\left\{f(X_0) + 3\sum_{i=1,4,7}^{n-2} f(X_i) + 3\sum_{i=2,5,8}^{n-1} f(X_i) + 2\sum_{i=3,6,9}^{n-3} f(X_i) + f(X_n)\right\} \qquad (7)$$

In (7), V is the volume, n is the no of segement and h is the vertical distance/elevation

4. RESULTS AND ANALYSIS

In comparison, the area from table 1 (130,000 ha) shows a significant compliance with the computed area in section 3.1 which gave (130,121.28 ha). The little difference could be as a result of the river eroding the former border line.

In another development, a remarkable difference was noticed in the designed volume of (15,000Mm^3) excluding dead and active storage to that which was computed which gave (13.226Mm^3). The volume of water falling below half of the designed capacity. This could be attributed to why we have erratic power supply all across the country.

4.1 Determination of Volume of Kainji Reservoir

The volume of water computed from the data obtained from the reservoir gave the following values with application of different rules are:

Trapezoidal Rule:	13200456.59Mm^3
Simpson's Rule:	13226766.63 Mm^3
Simpson's 3/8 Rule:	13209519.22 Mm^3
Positive Volume [Cut]:	13731859.24 Mm^3
Negative Volume [Fill]:	531519.09 Mm^3
Net Volume [Cut-Fill]:	13200340.15 Mm^3

4.2 Generation of Contour for Kainji Reservoir

Figure 4 shows the contour map of the reservoir, and elevations (depths) of points in colour scale. The closely packed contour indicates high depths and vice versa. Toward the left hand side of the figure a high depth can be visualized but toward the right hand side a low depth was recorded. Major contours were shown with tick brown line.

4.3 Map Overlay

Figure 5, shows the direction of flow of Kainji reservoir. The arrows point in the direction of the water flows that is from high elevation to low elevation. The magnitude is indicated by arrow length. As can be observed, the steeper slopes have longer arrows. The vector map information which revealed the direction and magnitude, can be derived from the same grid file generated in surfer. The arrow symbol points in the "downhill" direction and the length of the arrow depends on the magnitude, or steepness, of the slope. The contour map, grid vector map and the 3D surface map were overlaid to create the impression shown in Figure 5. On the scale bar absolute values was used to depict the depth by simply multiplying the Z- values by (-1) in the excel or surfer spreadsheet. Places shown with red circles were few areas selected to show where high depths were recorded.

4.4 Results and Discussion

From the foregoing, the designed capacity (volume) of the dam based on table 1 and what was computed from field observation showed a short fall. Two things were observed:

(i) the entire area was not traversed due to inaccessibility problems due to poor maintenance culture which has made some areas to be covered with grown up weeds.

(ii) (ii) Sedimentation at the bottom of the reservoir has resulted in volume lost.

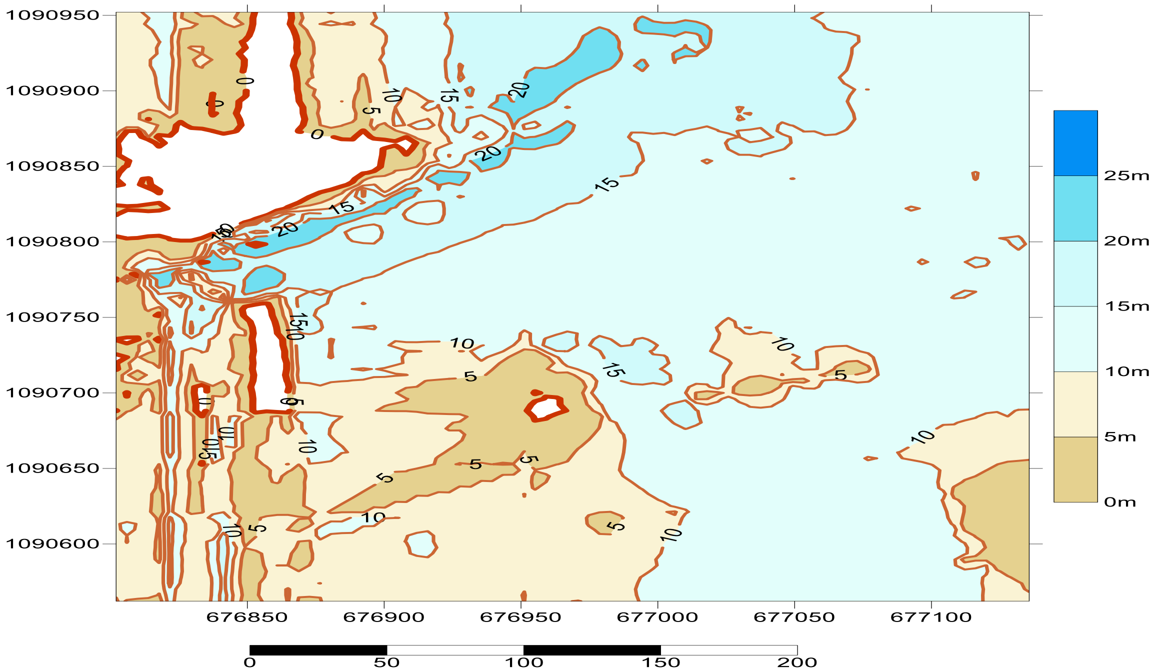

Fig 4: Contour map kainji reservoir

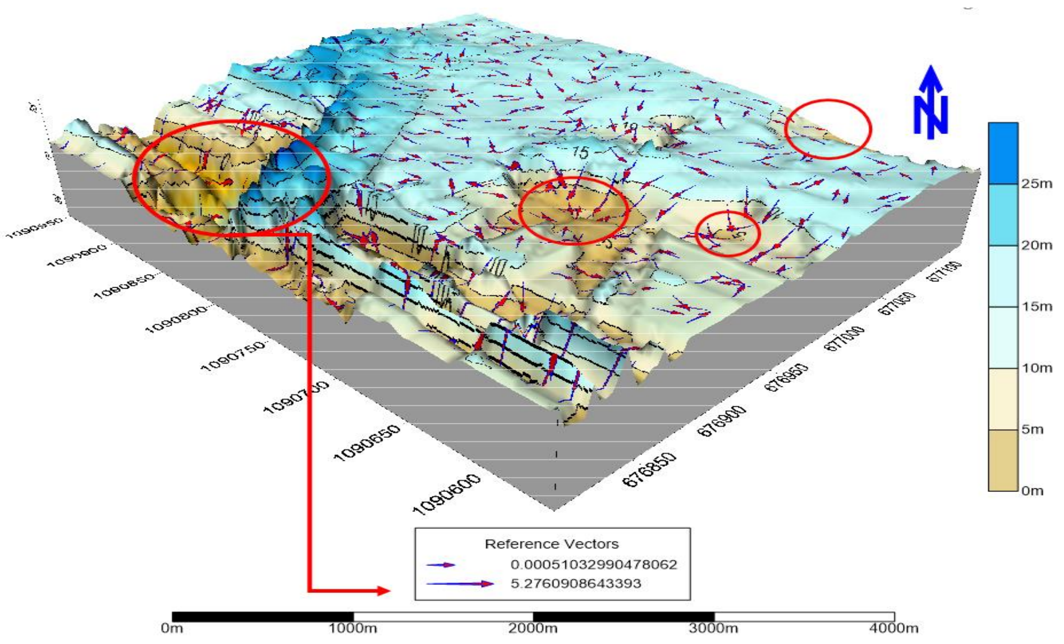

Figure 5: The magnitude and direction of flow of Kainji reservoir

To maintain a balance of volume within the reservoir the ideal thing is to get the net volume which has been shown in section 4.1 of this paper by subtracting the Negative Volume [Fill]:*531519.09 Mm³* from the Positive Volume [Cut]: *13731859.24 Mm³* which gave the Net Volume [Cut-Fill] as: *13200340.15 Mm³*. The maximum depth recorded during the field operation gave 23.50m. The 3D map can provide invaluable information for fishing and recreation purposes it can also be used for long term temporal morphological changes.

5. CONCLUSION

The volume and direction of flow of Kainji reservoir has been determined. The contour map and grid vector map of the reservoir was also produced and presented. It was observed from the forgoing that the reduction noticed in the reservoir volume could be attributed to sedimentation and the slight increase in the area was resulted from erosion of the bank by the river Niger.

6. RECOMMENDATIONS

The following recommendations were made with respect to the findings from the project.

- That the bathymetry of the dam should be done every year to determine the volume of water in the dam's reservoir.
- That the deformation monitoring of the dam should be carried out on regular basis.
- That the information on the direction of flow of the reservoir can be of immense help to the downstream inhabitants.
- Good maintenance culture can remove the problem of sedimentation.

7. ACKNOWLEDGEMENT

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