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BATHYMETRIC SURVEY OPTIONS AT AHMADU BELLO UNIVERSITY RESERVOIR; ECHO-SOUNDING VS MANUAL TECHNIQUES

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ABSTRACT
Kubanni Impounding Reservoir was 2,600,000 m3 after construction in 1971 and impoundment in 1974. The Reservoir lost its storage capacity to 1,031,275 m3 of silt and the remaining storage was 1,568,725 m3 in 2008. The reservoir was dredged in the year 2014 and the measurement of its depth was done using both Manual and Echo-Sounding Technique to determine the new volume after dredging. Manual technique was done by the researcher and the Echo- sounding was done as a team by staff from Adalen consulting limited with the researcher (for ABU Monitoring Committee) in year 2015 after dredging. The result of the Manual Technique was 2,038,759.90 m3, while that of Echo-Sounding was 2,021,703.00 m3 making the difference on the value to be 17,056.90 m3. It was concluded that Kubanni Reservoir, as a small reservoir is best surveyed manually considering some irregularities such as ; not being able to access the area close to the shore of the reservoir with echo – sounding because of the calibration, while large and deep reservoirs are best surveyed with echo – sounding to avoid sliding of the metric tape by the water wave and also save time using manual measurement.

KEYWORDS: *Bathymetric Survey, Reservoir, Echo-Sounding, Manual Technique, Dredging, Storage Capacity, Measurement, Comparison.*

INTRODUCTION

Background

Kubanni Impounding Reservoir was 2,600,000 m3 after construction in 1971 and impoundment in 1974 (Committee on Water Resources 2004, after the ABU Survey Report vol.1 1981). The Reservoir lost its storage capacity to 1,031,275m3 of silt and the remaining storage was 1,568,725 m3 (Implementation Committee on the Protection of the Kubanni Dam Drainage Basin, 2008). The reservoir was dredged in the year 2014 and the measurement of the reservoir depth was done using both Manual and Echo-Sounding Technique to determine the new volume of the Reservoir after dredging. The researcher ceased the opportunity to compare the two techniques to know the most suitable technique for the Kubanni Reservoir. This can also be applicable to other reservoirs in Nigeria since they were constructed almost at the same time (70's), they are up to 70% silted up and the remaining storage should be confirm before or after been dredged.

Assessment of Reservoir Siltation (Bathymetric Surveys)

The methodology to assess the volume of

sediments stored in a reservoir is currently quite well developed and described. The main steps to be taken in a bathymetric survey, as the methodology is called, are summarized below and based on the methodology used by the Spanish 'Centro de Estudios Hidrograficos' (CEH-CEDEX), which are consistent with guidelines described by the International Commission on Large Dams (ICOLD, 1989).

According to Ajibade et al., (2010), measurement and quantitative expression within drainage basins began with the work of James Hutton in 1775. Reservoir storage volume (capacity) can be estimated through direct and indirect techniques (Dada, 2009). The direct method involves obtaining field measurements directly using metric tape, a heavy weight and a slow moving boat, or even echo sounder using a speed boat. On the other hand, indirect methods involve analyses of satellite images using remote sensing softwares.

The first step in a bathymetric survey consists of the determination of the depths in the reservoir and this can be done by through direct and indirect techniques (Dada, 2009). Volume of sediment in the reservoir is done by comparison of the initial reservoir volume at the moment of dam construction (obtained from the construction plans) with the present volume (at the moment of the capacity assessment).

More recently, Liebe, Van de Giesen, and Andreini, (2005) developed a formula to estimate and monitor reservoir storage volumes of impounding reservoirs on the basis of their surface areas. They employed the direct field method and in combination with satellite imagery of large numbers of small reservoirs in Upper East Region of Ghana, situated in the Volta Basin. The use of satellite imagery allows measuring the reservoir surface areas. Using this method, the authors compared reservoir storage volume as a function of surface area using a theoretically derived relation. The derivation of this relation starts with a square based, top down pyramid that is diagonally cut in half, shown in Figure 1.

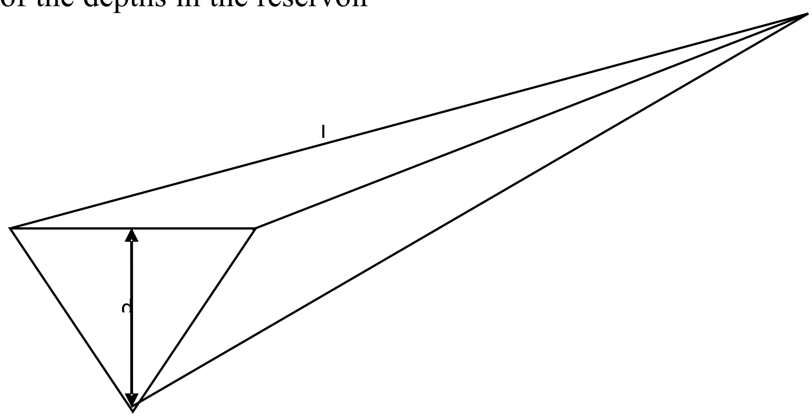

Figure 1: Reservoir model, after Liebe et al., (2005)

The volume of such a body is given by;

$$V_{half pyramid} = \frac{\square}{\square} A d \qquad (1)$$

Where,

V is volume,

A is the area defined by the square of its characteristic side length L.

Depth, d can be expressed as a fraction $\frac{1}{\square}$ of a side length L

Zola and Bengtsson (2007) compared three techniques in order to determine the area-depth relationship of Lake Poopo in Bolivia. Results from their measurement using the direct field technique from a slow moving boat was used to plot depth against elevation of the lake bottom along two cross-sections. Satellite images were used to determine the water surface area of the Lake at different water stages with Geographic Information System (GIS) software. Also they carried out water balance computations based on knowledge of water inflows to and outflow from the Lake; precipitation directly onto the lake surface; evaporation from the lake surface; and the lake surface area from satellite images, the change in storage can be determined. Results from the studies according to the authors revealed that information about the depth of Lake Poopo' is best obtained by performing measurements from a slowing boat using a rod, although cumbersome.

Dada (2009) studied the level of sedimentation in the Galma reservoir by carrying out depth measurement within an area about 640 m away from the embankment using land surveying technique (this is also a direct field technique) to fix survey points grid squares over the study area during dry season of 2007. Grid lines were drawn from the south bank to the north bank and from the embankment to the upstream. Eight grid lines labeled P1-P8 were drawn between the two banks at 80 m intervals. Nine grid lines labeled 1-9 were selected from the embankment towards the upstream at 20 m intervals. Similar grid lines were also taken from one bank of the reservoir to the other, each at an interval of 20 m. The intersection between these two sets of grid lines were designated sampling point and using the theodolite, a canoe was guided. Measurement of the lake depth was taken for 72 sampling points over the lake area using a rope, with a medium weight plumb tied to its end. It is worth noting that in Dada 2009, the study did not survey the entire reservoir. Only the portion of the reservoir extending up to about 160 m away from the dam crest was surveyed in order to determine the remaining depth of the reservoir. According to the writer, the depth obtained will not be a good representation of the entire reservoir. Also, the level of siltation in terms of volume was not quantified.

Iguisi (1997) used boat and metric tape to determine the depth of the Kubanni Impounding Reservoir, while Ahmadu Bello University Implementation Committee on Protection of Kubanni Dam Drainage Basin (2008) and Baba, et al (2009) used the same method to estimate the remaining storage capacity in the Kubanni and University Farm Lake respectively and also calculated the rate of siltation in the reservoirs. Vulegbo (2012), Ebenezer (2012) and Salawu (2014) also measured the remaining storage and calculated the rate of siltation of Mairuwa Reservoir, Tagwai Reservoir and Zaria Reservoir respectively. The volume of deposited sediments is defined by subtraction of the final volume of water from the initial volume of water.

The direct measurement was further classified by the author into Manual and Echo-Sounding Technique and it was an opportunity to compare the two techniques since the both were applied to determine the new volume of Ahmadu Bello University Kubanni Reservoir after dredging.

THE STUDY AREA

The study area is the drainage basin of Kubanni Impounding Reservoir. The drainage basin lies on part of sheet 102 Zaria SW of the first edition of 1:50,000 topographic maps of 1967, within Latitudes 11°05'N to 11°11'N and Longitudes 7°35'E to 7°40'E

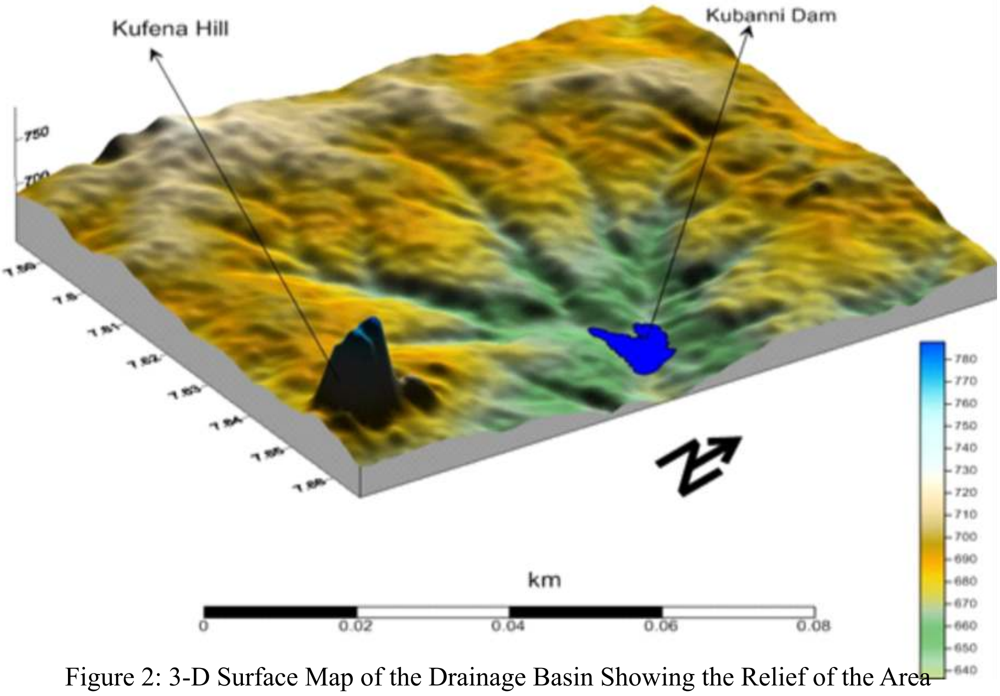

Figure 2: 3-D Surface Map of the Drainage Basin Showing the Relief of the Area

METHODOLOGY

Delineation of the Shoreline

The shoreline was located with satellite navigator on the 31st August and 1st of September, 2015 when water was still flowing through the spillway. That was not always easily accessible, often separated from dry land by a few meters swampy belt from where groundwater was seeping to the lake. In order to determine the area of the shoreline, points indicating boundaries of the shoreline were mapped by taking the coordinates of selected station points one after the other along station points (Plate Ia and Ib). This is repeated for several points round the impounding reservoir. These coordinates were plotted to indicate the boundaries of the reservoir on the bathymetric map (Figure 4.6). The outline of the shoreline obtained from the field was compared with the shoreline from European Space Agency (ESA) Google Earth Satellite Image downloaded from the internet.

Plate Ia: Delineation of Open Water table with satellite navigator

Plate Ib: Delineation of Open Water table with satellite navigator

Bathymetric Survey of Kubanni Reservoir (Echo-Sounding Technique)

Bathymetric surveys are accomplished using automated hydrographic surveying instrumentation such as echo sounder operating in the 200-kHz range, synchronized with the real-time global positioning systems (GPS) which are mounted on a moving boat. Echo-sounding is the technique of using sound pulses to find the depth of water. The interval from the emission of a pulse to reception of its echo is recorded, and the depth calculated from the known speed of propagation of sound through water. According to Kress, Sebree, Littin, Drain and Kling (2005) acoustic depth measurement systems measure the elapsed time that an acoustic pulse (sound wave) takes to travel from a generating transducer to the bottom material (signal reflector) and back. The relationship between the depths to each reflector (D) is a function of the two-way travel time (t) that is, the time it takes for the signal to travel from the transducer to the reflective layer and back to the transducer, and the velocity of sound in water (v), is presented in equation (2) and Figure 3.

$$D=\frac{1}{2}v\,t \qquad (2)$$

Plate II: Bathymetric Survey of Kubanni Reservoir by the Adele staff and the researcher (Echo-Sounding Method)

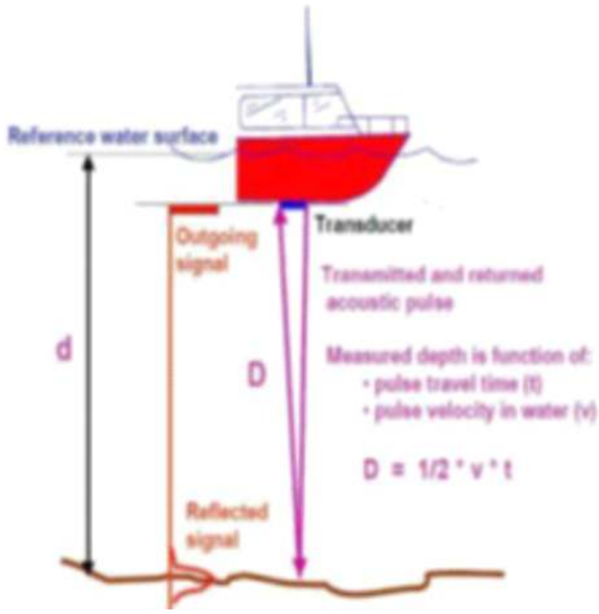

Figure 3: Principle of Acoustic Depth measurement (http://en.wikipedia.org/wiki/Echo_sounding)

Bathymetric Survey of Kubanni Reservoir (Manual Method)

The measurement was done on the 21st, 22nd and 23rd of August 2015, when water was still flowing through the spillway. Depth in metres to the reservoir was measured from a naumatic and fishing boat (Plate III) with metric tape having a weight tied to its end. Points of measurement were located with a Garmin Oregon 550T satellite navigator with horizontal accuracy of ± 3 m. The boat was immobilized with paddles at the time of depth reading. The measuring tape was released from the boat and lowered down until the heavy objects touched the bottom of the reservoir. The calibration on the tape at the point of interception between the tape and the reservoir's water surface is read and recorded after subtracting the length of the heavy weight. This is the remaining depth measured in metres at that particular station point. The same procedure was repeated for all the sampling points within the extent of the reservoir.

Plate III: Bathymetric Survey of Kubanni Reservoir (Manual Techniques)

RESULTS

The results of the measurements were shown in the figures below. Figure 4 shows the spot height of the shoreline in the reservoir with satellite navigator. Figure 5 shows the shoreline of the reservoir from figure 4. Figure 6 and 7 show the reservoir bed surface contour, captured by echo-sounding and manual techniques respectively. Figure 8 and 9 are the bathymetric map of the reservoir as captured by echo-sounding and manual measurement respectively from which the calculation of the reservoir remaining volume was made.

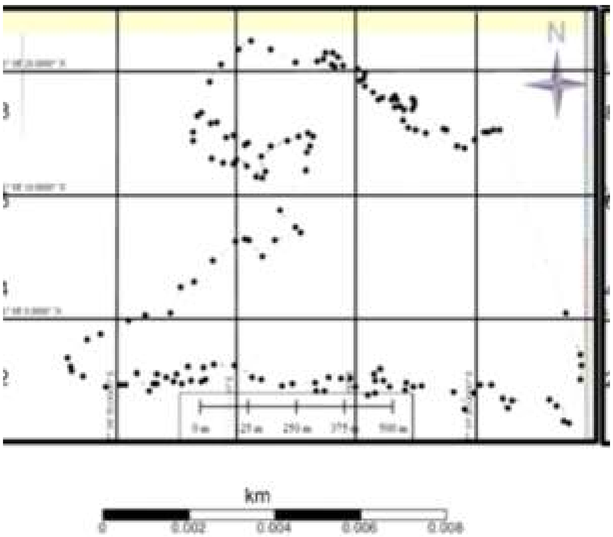

Figure 4: Spot height of open water table inKubanni Reservoir with satellite navigator

Figure 5: Boundary of open water table in Kubanni Reservoir from Figure 4.1.

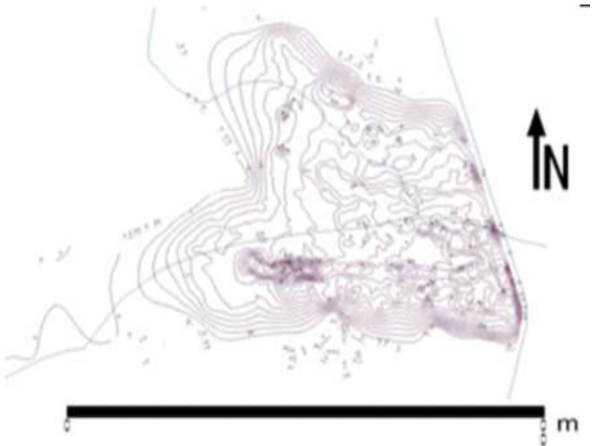

Figure 6: The Reservoir Bed Surface Contours Captured by Echo – Sounding (report of bathymetric survey of Kubanni Reservoir by Adalen consulting limited for ABU Monitoring Committee)

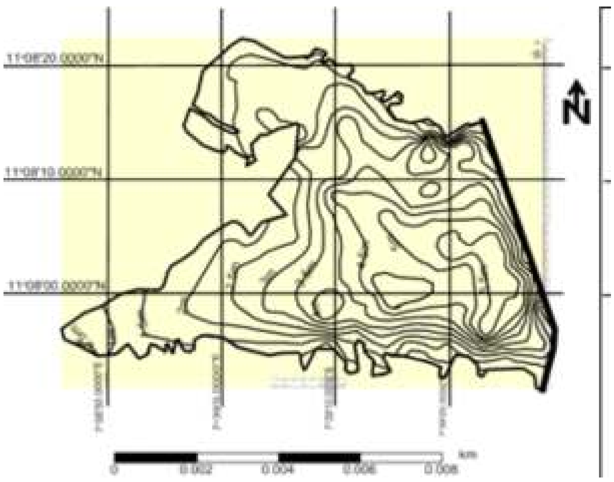

Figure 7: The Reservoir Bed Surface Contours Captured by the Researcher's Manual Measurement

This figure indicates area of open water table and bed surface contour of Kubanni Reservoir, captured by the Researcher on his manual bathymetric survey

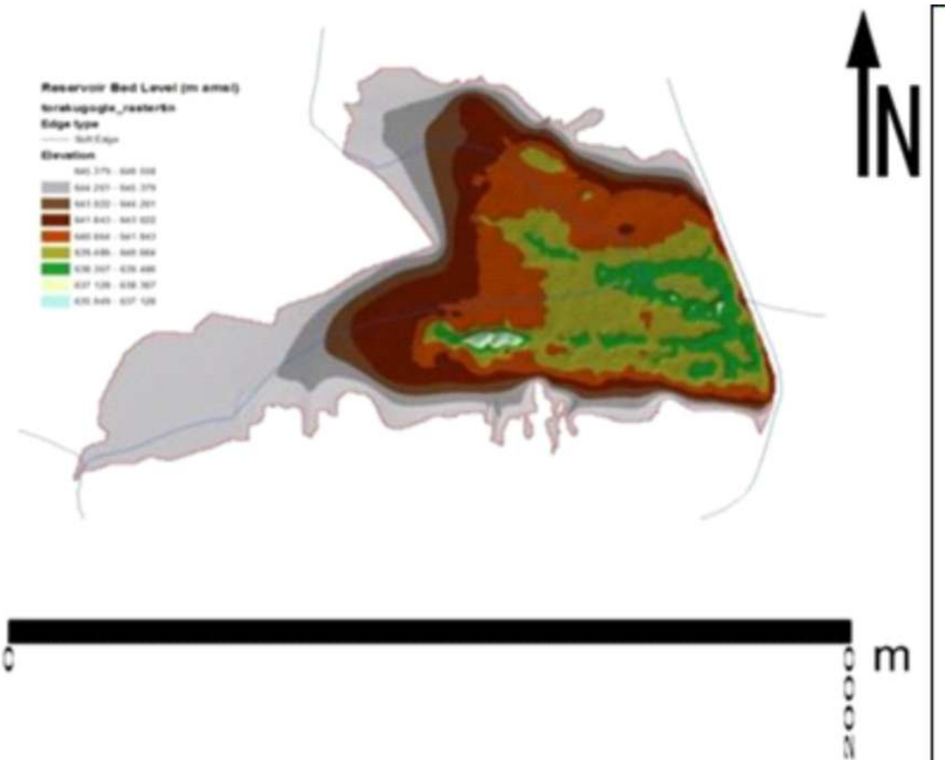

Figure 8, Bathymetric Map of Kubanni Reservoir by Echo – Sounding (report of bathymetric survey of Kubanni Reservoir by Adalen consulting limited for ABU Monitoring Committee)

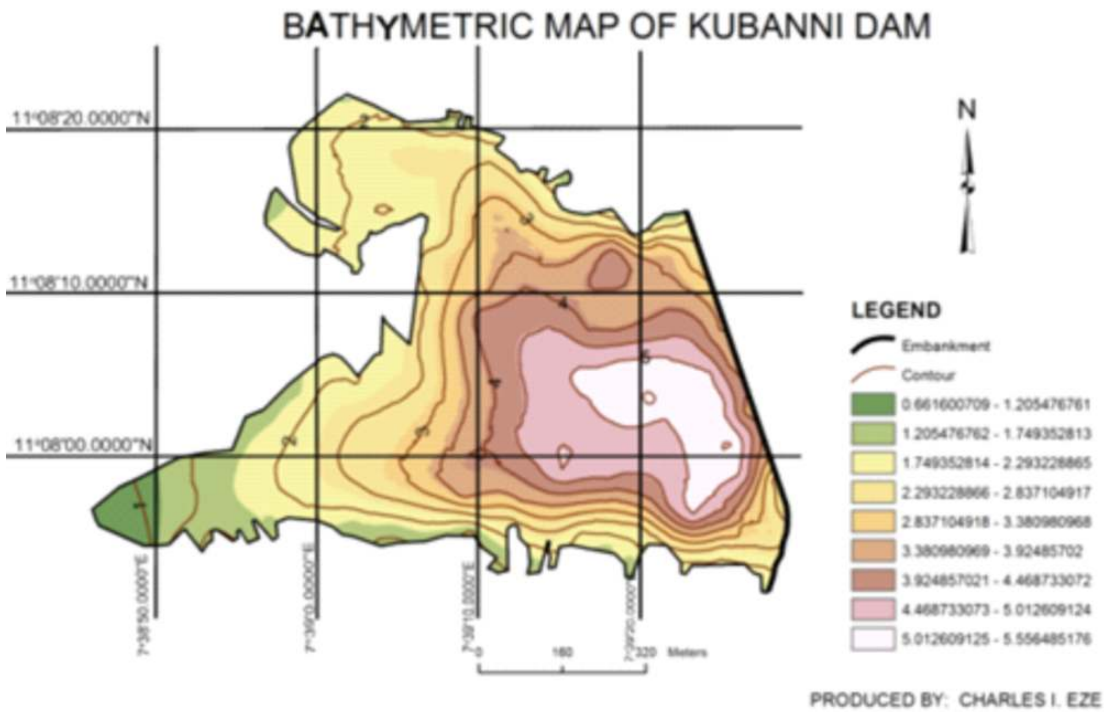

Figure 9: Bathymetric Map of Kubanni Reservoir by the Researcher's Manual Measurement

The echo-sounding result Fig. 8 was extracted and imported to GIS environment where the volume of the reservoir was calculated using 3D analysis while in Manual Technique, the volume was calculated using the average contour interval in Fig. 7 as reservoir depth and the corresponding surface area.

DISCUSSION

Comparison between Echo – Sounding and Manual Techniques.

The result of the Manual Measurement was 2,038,759.90 m3, while that of Echo –Sounding was 2,021,703.00 m3. The difference in the value was 17,056.9 m3. The difference was small but still noticeble. The bathymetric maps of various methods are shown in Figure (8) and (9).

During the Bathymetric Survey (Echo – Sounding), the measurement was faster (saves time) because of the use of speed boat, but could not access the areas around the shore of the reservoir. This is because the shore is shallow and the sounder can not move beyond the area of depth of 1m and below. Therefore, extrapolation was made to assume the contour interval in those areas. This is the weakness of the echo – sounding especially when there are areas of deeper than 1m, surrounded by depth of 1m contour and finally, is more expensive to carry out than manual methods.

Though, manual technique was time consuming, tideous, but the technique was able to access places close to the shore of the reservoir. Again, the technique is cheaper. The only challenge is that, at higher depths above 4m, the boat must be seriously immobilised to avoid sliding of the metric tape which would affect the value of the measurement. Two different types of boat were used in the manual measurement; Wooden and Naumatic boat. Naumatic boat was used only around the shore because it is light and could not be immobilized at the deeper part of the reservoir. The wooden boat was used at the deeper part of the reservoir.

CONCLUSION

From this study, it was discovered that Kubanni Reservoir is best surveyed manually to be able to access the area close to the shore while large and deep reservoirs are best surveyed with echo – sounding to avoid sliding of the metric tape by the water wave and also save time.

Then, for the purpose of this work, manual measurement data was used for the interpretation of the storage capacity since Kubanni is a small reservoir and the results from echo-sounding was not reliable; the calibration is best suited for large dams.

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