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# Dual Echo Sounder Bathymetric Survey for Enhanced Management of Ruiru Reservoir, Kenya

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**Abstract** Lake and reservoirs have significant global function as a source of fresh water and they sustain various activities such as agriculture, fisheries, and recreation. They play a critical role in distributing spatially and temporally the meagre water resources in most watersheds. However, the design lifespans of reservoirs are being threatened by volume loss despite their critical role in development. Being able to regularly monitor this volume loss is an important aspect of reservoir sustainable management. In this paper, we present a method that combines dual echo sounding and Geographic Information System (GIS) in bathymetric survey to determine the current volume of Ruiru reservoir in central Kenya. In the reservoir, we showed that the current volume is 2,564,590 $m^3$ compared to the original volume of 2,980,000 $m^3$, which implies that the reservoir has lost about 14% of its recorded volume. Furthermore, the study established, the Depth- Surface Area - Volume relationships, important tools for reservoir management.

**Keywords** Bathymetric survey, Reservoirs, Ruiru, Dual echo sounder.

## 1. Introduction

### 1.1. Bathymetric Survey

Lake and reservoirs have significant global function as a source of fresh water and they also sustain various activities such as agriculture, fisheries and recreation [1]. These water bodies are important habitat for various aquatic flora and fauna and can be part of the diminishing wetland ecosystems. Despite these important roles, lakes and reservoirs lifespans are increasingly threatened. The main factor threatening the lifespan of the lakes and reservoirs are volume loss due to accelerated sedimentation rates. Sediment deposition gradually reduces reservoirs capacities over time, hence affect their functions.

To assess the sedimentation rate or to determine sustainable water withdrawals rates, the stage (Depth) – Surface Area - Volume or stage curve relationships provide invaluable information. These relationships quickly inform the reservoir management on the need to adjust their strategies and reduce any strain on the reservoirs or water supply. However, these relationships might not be available in all reservoirs because 40% of the world's largest lakes have not been studied and their volumes are therefore unknown or approximated [2]. The number of reservoirs which have not been surveyed in Sub-Saharan Africa is even higher than this global estimate. From FAO data [3] it is estimated that about 58% of the reported reservoirs have not been surveyed. Some of the factors that limit surveying of reservoirs include low prioritization [4], high survey costs, lack of equipment, poor accesses by survey boats [1] and lack of relevant capacities in reservoir surveys.

Where individual reservoir have been surveyed over time, these multiple surveys provides an estimate of volume loss [5]. The original volume of a reservoir can be estimated from pre-impoundment topographic maps and aerial survey photographs. For example, Wooldridge [6] used pre-impoundment aerial photographs of 1965 to determine the volume of Masinga dam in Kenya. He reported that the survey data compared accurately with the design data. However, use of aerial photography is only possible before impoundment of the dam or when there is complete loss of water volume.

Advances in remote sensing have opened opportunities to use Light Detection and Ranging (LIDAR) data in reservoir survey. Airborne bathymetric LIDAR may offer comparable accuracy to bathymetric surveys but a reduction in the cost of acquisition for shallow water bathymetric data as compared to hydrographic surveys. However, the surveys are prohibitively expensive, equipment intensive, and time consuming [4]. This makes it unattractive to use LIDAR in regular survey.

A rapid and low cost methodology for bathymetric survey and digital map generation could contribute to understanding of reservoirs hydrology globally [5]. This is possible by providing the means required to create baseline bathymetry for over 60% reservoirs, which have not been surveyed in developed and developing countries.

### 1.2. Objective of Bathymetric Survey in Ruiru Reservoir

Ruiru reservoir is one of the critical sources of water to the City of Nairobi. It supplies the city with about 21,700 $m^3$/day [7, 8]. Construction of the reservoir began in 1936 and it was commissioned in 1949 as the first source of water to the city [3, 9]. Currently, Ruiru reservoir is among the four main sources of water to the city. The management of this reservoir has transitioned from the colonial government during its construction stage to the subsequent councils in charge of the city to the current County Government. This transition has significantly affected the management of the reservoirs in terms of information transfer, where some information and institution memory may have not been transitioned appropriately.

It is essential to develop a reservoir information system that characterizes the status of reservoirs and document their volume change over time [10]. This would require a systematic and recurring survey of the reservoirs. Hence, the objective of this study was to use a dual echo sounder bathymetric survey coupled with Geographic Information System (GIS) to determine the current bathymetric characteristics of Ruiru reservoir in central Kenya. The bathymetric survey results give information on depths and topography, and corresponding water storage volume. The information was used to derive the stage (Depth) - Surface Area and stage (Depth) - Volume characteristics of the reservoir, which was missing but essential for the reservoir management.

## 2. Methodology

### 2.1. Location of Ruiru Reservoir

Ruiru reservoir is located near Githunguri town in Central Kenya. It is about 60 km north of the City of Nairobi (Fig. 1). The reservoir covers about 100 acres and is about 18 meters deep at the dam wall [9]. Ruiru and Kimaiti rivers are the main sources of water to the reservoir (Fig. 1). Other rivers that flow into the reservoir are Kamiditi, Kanyiriri, Kibathiti I, Kibathiti II, Ngeteti, and Waingere. These rivers flow mainly from cultivated or grazing land within the reservoir's watershed [9]. Given the age of the reservoir and the significant role it plays in water supply to the city it was important to determine its current volume and Depth - Surface Area - Volume characteristics for improved management.

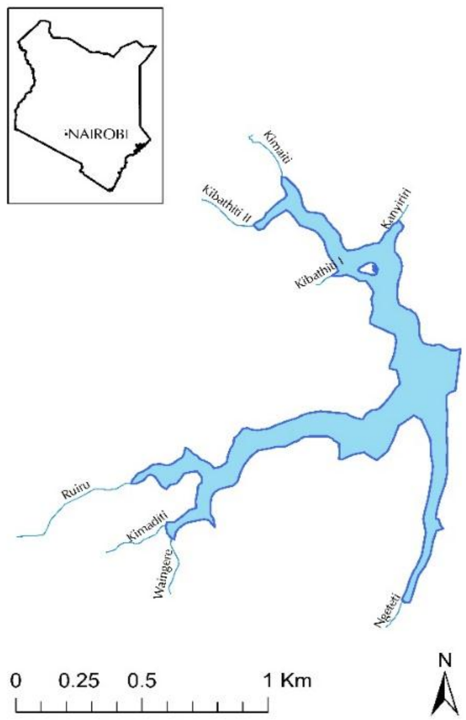


**Fig. 1.** Location of Ruiru reservoir in central Kenya about 60 km north of the capital city Nairobi

### 2.2. Equipment Used in this Study

In determining reservoir storage capacities, the survey team utilized dual echo sounder fitted with an in-built Global Positioning System (GPS) to collect reservoir data. The dual echo sounder is a Fish finder (Raymarine Dragonfly 87*), whose sounder head is equipped with a dual frequency of 200 and 350 kHz transducer. According to [11] the 200 kHz acoustic signal is suitable for mapping water depth to determine the reservoir storage capacity. This echo sounder was mounted on motor driven Dual-Jon-boats (Fig. 2). The boats were specifically modified for bathymetric survey and sediment vibro-coring system by Specialty Devices Inc. (SDI) in Plano, Texas. A GIS software was used to analyse the collected data.


**Fig. 2.** Bathymetric surveying in Ruiru reservoir using a Dual Echo sounder and specialized Dual-Jon boats fitted with vibro coring system

### 2.3. Determining the Boundary of the Reservoir

The boundary of the reservoir was determined from remote sensing images. Digital Globe images of 2015, which were accessed via Google Earth, were used to digitize the boundary of the reservoir. This boundary was then loaded to the Fish finder for the survey exercise.

### 2.4. Bathymetric Survey

Bathymetric survey is determined by driving the survey boats in predetermined profiles (Fig. 3), where there is sufficient water depth for the survey boats. This is a similar approach to the methods used by [11] and [12] in flood control reservoirs in central Texas, [13] in three Arkansas reservoirs and US Army Corp of Engineers for large water supply reservoirs [14]. It has been reported that the accuracy of the volumes produced by surveys conducted with modern instrumentation is estimated to range from 1% to 12%, with parallel profiles spaced at 1% to 12% of the axial length of the reservoir [15]. The profile spacing used in the Ruiru reservoir survey was 10 m apart (about 2% of the axial length of the Ruiru river arm of the reservoir), with the profiles spaced both parallel and perpendicular to the three arms main axis. In past application of a similar profile spacing [11] reported that the reservoir bottom appeared smooth and the resulting volume calculation was expected to be accurate within 5%. Further in this survey, to ensure data quality and enhance safety of the boat the maximum speed of survey boat was limited to 6 km/h. All the survey data were recorded in to a microSD card for post-survey processing.

* This is not a brand endorsement.

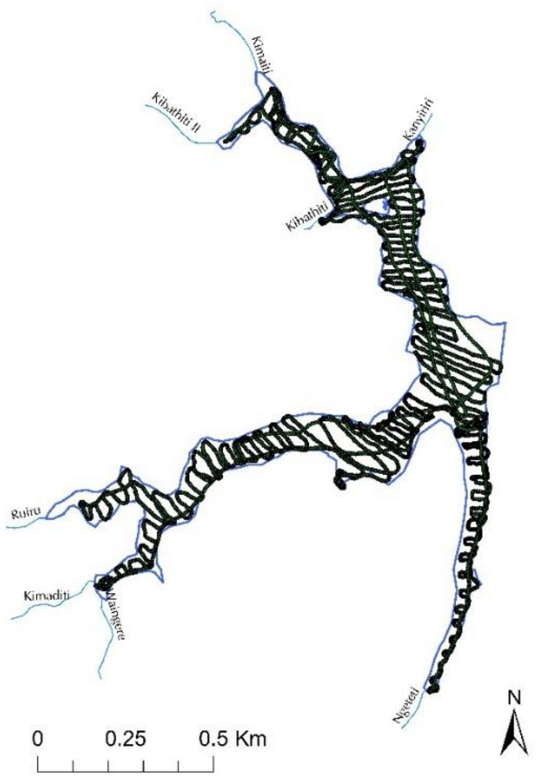


**Fig. 3.** Profile lines recorded during bathymetric survey in Ruiru reservoir

### 2.5. Post-survey Data Processing

In laboratory, the data were downloaded to a computer for processing from microSD and analysed using Microsoft Excel and ArcGIS. In MS Excel, the data were checked for any data points with completely out of range GPS coordinates or unreliable depth values. After excluding these outliers, the remaining sounding points were checked for sudden and unexpected change in depths. These sudden and unexpected change in depths have been attributed to interference caused by fish, local changes in thermocline, or excessive turbulence/wave action [5]. These outliers were also excluded from the subsequent analysis.

These data were analysed in ArcMap and 3D analyst to generate volume at different contour heights. The data had to be first interpolated to generate a surface. Before interpolation the shoreline dataset from digitized boundary was merged with the survey dataset. Different point interpolation can be applied but as reported by [1] Sibson interpolation after [16] offers a marginally higher accuracy. After interpolation, the surface was masked using the boundary layer and the layer extracted by using the mask operation in spatial analyst. From the interpolated Depth - Surface Area - volume relationships were then derived using the area and volume statistics operation of the 3D analyst in ArcGIS.

## 3. Results and Discussions

### 3.1. Reservoir Volume and Surface Area.

From the survey results, a modelled surface of the reservoir's bottom and the corresponding depths were used to determine reservoir capacity. It was established that the capacity of Ruiru reservoir is 2,564,590 $m^3$ and covers an area of 36 ha (89.2 acres). This is based on the analysis of bathymetric survey data collected in July 2015.

This finding was compared to the available records. Lind [9] reported the surface area of Ruiru is about 100 acres. FAO data reports the volume of the reservoir as 2,980,000 $m^3$ [3]. This result shows that part of the reservoir volume has been lost. Assuming that the FAO is the known pre-impoundment volume, then it can be estimated that the reservoir has lost about 14% of its volume. It will require systematic and frequent survey to establish the rate of volume loss in the reservoir. Alternatively, recovery and dating of sediment cores could establish the rate of sedimentation.

### 3.2. Stage/Surface Area and Stage/Volume Curves

Depth-Surface area and Depth - Volume curve are a technical illustration of reservoir area and volumes, respectively, at corresponding reservoirs depths. The curves obtained in this study are shown in Fig. 5 and Fig. 6. Fig. 5 shows the Depth - Surface Area of Ruiru reservoir when water surface was modelled at various depths from the deepest point of 17 m to when it is full (0 m depth). Similarly, Fig. 6 show the volume characteristic across the same range of depth.

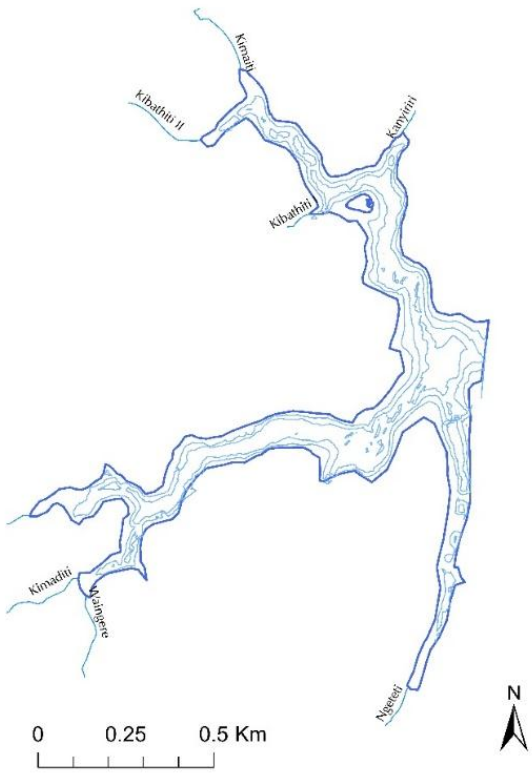


**Fig. 4.** Contour map of Ruiru reservoir obtained from processing bathymetric survey data

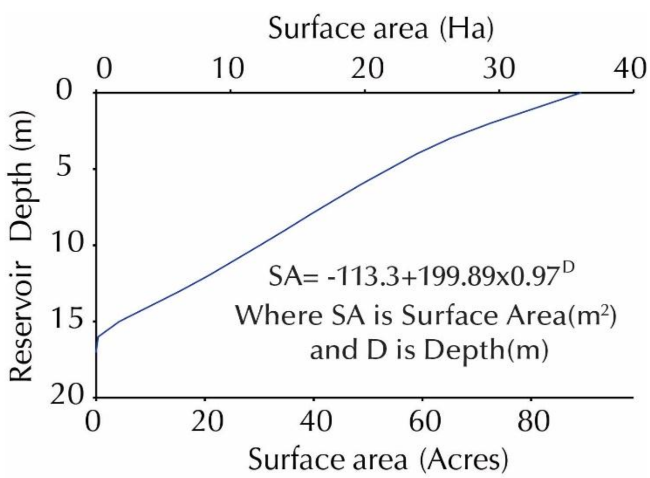


**Fig. 5.** Depth-Surface Area relationship of Ruiru reservoir based on bathymetric survey data

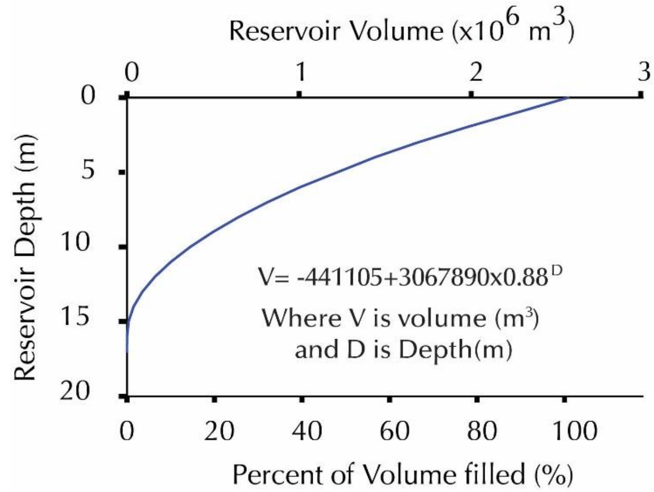


**Fig. 6:** Depth - Volume relationship of Ruiru reservoir based on bathymetric survey data

These curves, which were not available before this study, are important tools for management of reservoir. The stage curves can be used to assess the water volume and area at specific water level or the inverse to calculate the water level using the lake area established from remote sensing [1]. They could be used as a standalone system or part of an extensive real time and/or forecasting information system. As a standalone these curves could be used to estimate the volume and area covered by the reservoir in their day to day management activities. However, in a real time and/or forecasting information system it could be coupled with other system to enable dam managers to make informed decision about the status of water volume in the reservoir and project potential future scenarios.

The use of echo sounding offered a cheap and quick alternative method of assessing a reservoir which is already filled with water. Other methods can only be applied during pre-impoundment e.g. aerial photographs and LIDAR, but as aforementioned their associated costs are still prohibitive.

## 4. Conclusions

Dual Echo Sounder bathymetric surveying provides an alternative and cheaper method for establishing current reservoir volume. An example application of this bathymetric survey method in Ruiru reservoir was able to determine the current volume of the reservoir and surface area to be 2,564,590 $m^3$ and 36 ha, respectively. Further using the collected data Depth - Surface Area - Volume relationships of the reservoir was successfully reconstructed. These curves, which were missing before this survey, are important tools for the reservoir management.


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