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Bathymetric survey and volumetric analysis of Bakolori dam reservoir North West Nigeria

Ahmed Mahi Shuaibu *

Department of Geological Sciences, Faculty of Science, Federal University Gusau, Zamfara State, Nigeria

Abstract

Many approaches have been devised for measuring water depth in bathymetric surveys, which are used to assess sediment deposited directly in lakes and reservoirs. This technique is mostly used to calculate the reservoir's capacity and the amount of sedimentation that occurs there. The results of the volumetric analysis and bathymetric survey of the Bakolori Dam reservoir, which is situated in Northwestern Nigeria, are presented in this work. During this investigation, the differential Global Positioning System receiver (GPS), automatic level measuring tool, echo-sounder, and engine boat were utilized. ArcGis 10.0 was used to analyze the acquired data. In order to evaluate the reservoir capacity loss during the Bakolori reservoir's operating period as of 1983, the designed computed reservoir capacity was compared with the current bathymetry survey. At a spillway crest elevation of 334 meters above mean sea level (amsl), the reservoir's initial capacity is reported as 430 million cubic meters (MCM). However, the capacity has since been revised to 291 meters at the same level, with a volume change of 139,269,495 m^3. As a result, the reservoir's volume changed by approximately 139 MCM during a thirty-five (35) year period of service, representing a loss of storage capacity, while the annual siltation rate was around 3,979,128 m^3/a. This indicated that 33 % of the reservoir's storage capacity had silted up. This is demonstrated by the aquatic weeds that have grown to a height of 334.21 meters on the lake's surface, rising from the lakebed. Therefore, to prevent total siltation, the dam reservoir needs to be adequately dredged.

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1. Introduction

The study of lake and ocean floor depths below the surface is known as bathymetry. Surface navigational information is provided by bathymetric survey charts, which are created to support the safety of surface or sub-surface

*Corresponding author: Tel. No.: +234-806-565-8349.
Email address: mahalkufr@gmail.com (Ahmed Mahi Shuaibu)

Table 1. Salient features of Bakolori reservoir.

Characteristics and estimate	430 MCM (million cubic metre)
Catchment area	4857 km^2
Active capacity	403 MCM
Dead capacity	47 MCM
Reservoir area	80 km^2
Mean annual inflow	757 MCM

navigations. These charts often depict seafloor relief or terrain as contour lines, or depth contours [1, 2]. The survey settings for the best description of the topographical aspects of the submarine, which may include more accurate slope corrections and sound velocity, while removing safety bias [3].

When a river section is dammed, a reservoir is created behind it that holds water and sediments. Because of the decreased flow velocity, suspended and bed load flows are transported in and deposited over time in the reservoir area [4]. After the dead storage region has completely silted over and sediment starts to accumulate in the active storage area, the reservoir starts to lose its capacity to hold water [5]. The benefits of small dams for the environment, society, and economy are adversely affected by the gradual loss of water-storage capacity brought on by sedimentation in dam reservoirs and rising water demand [6]. There is evidence of a consistent increase in reservoir siltation worldwide, posing a threat to reservoir projects and raising questions about the sustainability of both current and future reservoirs [7–9]. The impoundment of water for household use, flood control, and irrigation is an essential step toward socioeconomic growth. However, the goal for which the dam was built is hampered when sedimentation reduces a reservoir's storage capacity beyond a certain point. As a result, monitoring sedimentation becomes crucial for the administration and use of these reservoirs [10].

Sedimentation in reservoirs is a widespread issue over much of the world. Sedimentation is estimated to cause small and large reservoirs to lose between 0.5 % and 1 % of their volume capacity per year [11]. It is suggested that reservoir sedimentation is significantly higher in the majority of developing nations where sediment control practices are not implemented successfully. One of the several sedimentation issues affecting reservoirs is storage loss [12–14].

It is worthy to note that there is no previous research on the volumetric analysis of Bakolori dam reservoir since it was commissioned in 1983, this necessitates comprehensive research to unearth its current hydro-volume capacity against the backdrop of its initial capacity, in order to forestall any future adverse effect that may cripple the existence of Bakolori irrigation program. As such lack of attention to the deteriorating capacities of Nigerian reservoirs and its implications to acquire water for irrigation and water supply need [15, 16]. This study used a bathymetric survey technique to investigate how the Bakolori reservoir's sedimentation has changed over time.

2. The description of Bakolori dam reservoir

The Bakolori dam is situated initially in Sokoto State in the Northwestern part of Nigeria with a geographical coordinate point of 12°30′43″N and 6°11′0″E, respectively, before the emergence of Zamfara State in 1995. The construction was completed in 1978 and its reservoir filled by 1981 and commissioned in 1983. It is a major reservoir on the Sokoto River, a tributary of the Rima River, which in turn feeds the Niger River. Water from the dam supplies the Bakolori irrigation project (Figure 1). The dam has a capacity of 430 MCM, with a reservoir covering 8,000 hectares extending 19 km (12 mi) upstream as shown in Table 1. The dam incorporates a small 3MW hydroelectric power plant [17].

The Sahel savannah, where Bakolori dam is situated, has rainfall during the rainy season from April to June, ending in October when the dry season arrives. The range of the average yearly rainfall is 500-800 mm. Typically, there is irregular, unexpected rainfall that is linked to recurring droughts. Consequently, in order to replace the single, unstable rain-fed crop, an estimated 40,000 to 50,000 peasant farm families in the Sokoto valley, specifically in the districts of Talata Mafara and Bakura, can grow at least two crops annually over an area of 27,000 hectares. This is made possible by the construction of the Bakolori project, which includes the dam, reservoir, and canal systems.

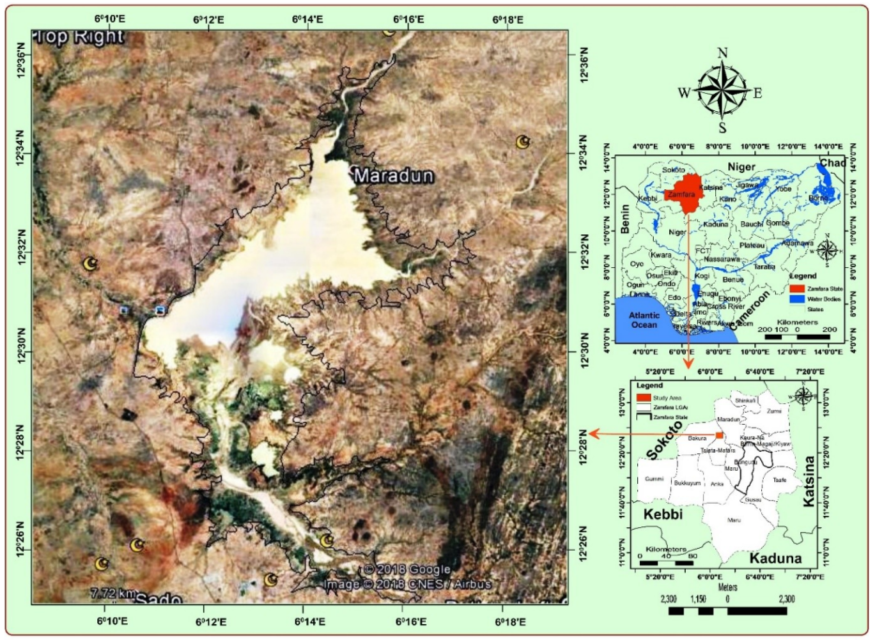

Figure 1. Location of Bakolori dam reservoir within the study area.

3. Materials and methods

The team and hydrographic survey equipment were transported on a 6-meter long, twelve-person fiber boat with a 60-horse Yamaha outboard engine powering the Garmin GPSMAP 546s unit, which was powered by a 12-volt battery. The bathymetric survey was carried out over the Bakolori reservoir along track lines. At the conclusion of each survey day, data were downloaded from the Global Positioning System (GPS) units. By default, the GPS receiver units were configured with the Minna datum and the WGS84 (National Geodetic System, 1984) projection system. The water level in the reservoir is measured on the dam axis water level gauge both before and after the daily depth sounding begins. The depths are continuously shown on while sounding.

The depth of the reservoir was determined by depth sounding with a Garmin-GPSMAP-546 echo sounder, which has dual-frequency (50/200 kHz) sonar capabilities for better shallow water performance. The survey boat moved along track lines spaced 10 meters apart, covering the reservoir, running perpendicular to the direction of inflow into the reservoir and parallel to the dam crest alignment from shoreline to opposite shoreline. The GPSMAP 546 receiver unit's specs, together with the horizontal coordinates of the depths measured, are likewise provided by the Garmin GPSMap 78 when it is linked to the GPSMAP-546 via the NME0183 connection. Water level depths were monitored using a set draft, or distance, of 0.2 meters below the water's surface and a five-second measurement period. While the echo sounder measures the water depth and both are in stream mode, the GPS receivers track the survey boat's horizontal position.

Using Microsoft Excel, the bathymetric data were downloaded and pre-processed into discrete x, y, and z data points. The 3D-Analyst Tool was then used in ArcGIS 10.0 to do additional analysis (Figure 2). The bathymetry data were transformed into raster format and utilized to generate a bathymetric contour map at different operating elevations of the Bakolori reservoir, a modeled surface of the reservoir bottom, or the Triangular Irregular Network (TIN) of the underwater topography of the reservoir. The GIS community has long employed triangle irregular networks (TINs) as a digital tool for representing surface morphology [18, 19]. TINs are created by triangulating a set of vertices, or points, and are a type of vector-based digital geographic data (Figures 3, 4 and 5, 6).

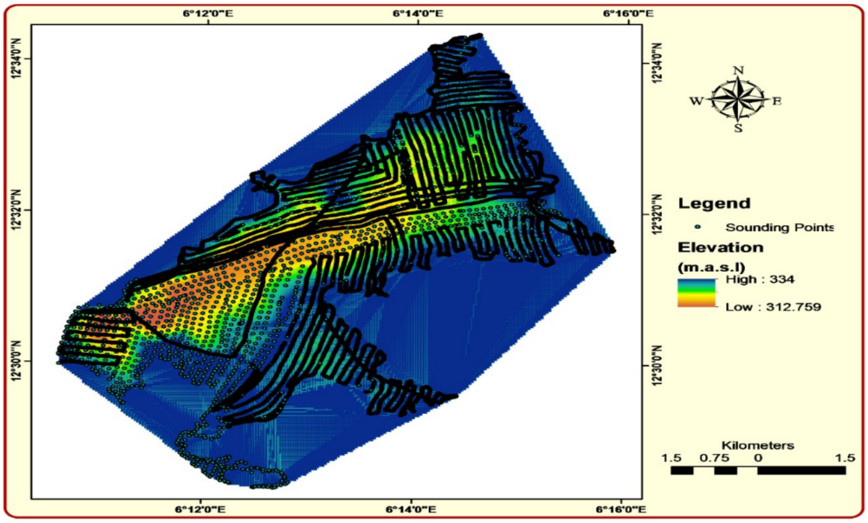

Figure 2. Bakolori reservoir survey spot height (survey data points) of boat (path) survey.

4. Results and discussion

Figure 2 depicts the coverage of the depth sounding activities over the Bakolori reservoir and shows that the maximum water level during the survey period was 338 m, while the spill crest is 334 m. The surveying date's lowest bed elevation was 312.759 m, and the surveying spot height was 334 m. The reservoir volume was calculated using two different approaches, and the results are nearly identical and are shown in Table 2. While the second technique is based on the reservoir depth below ground level (depth to bed rock) (Figures 5 and 5), the first way is based on the reservoir topography above mean sea level (amsl), as illustrated in Figures 3 and 4. Table 2 displays the undersea reservoir bed topography outcome as determined by this study.

Figure 3 displays the spot height coverage of the bathymetry survey collection in relation to the maximum water level of 338 meters above sea level. Figure 4 displays the spot height elevation above mean sea level at several locations within the dam reservoir. The plots are based on accumulative surface areas and storage volumes calculated from the TIN surface for water elevation ranges that bound around 312.76 m amsl as the lowest bed elevation, 325.09 m amsl at the topography's intermediate level, and 331.00 to 334 m amsl at the highest water elevation range (Figure 4). At the time of the survey, the observed change in depth based on the measured data was 21.24 m amsl.

Using the contour approach and the initial reservoir capacity at the spillway crest level of 334 meters (above mean sea level), or 430MCM, the bathymetric dataset was used to calculate the reservoir areas and volumes for the various operational levels of the Bakolori reservoir. The current revised reservoir capacity at the spill crest level of 334 meters was determined by analyzing the bathymetric survey, as shown in Table 2, to be 291MCM as opposed to the initial reservoir capacity of 430MCM.

As shown in Figures 5 and 6, the second technique for data analysis is based on reservoir depth below ground level (depth to bed rock). The lowest spot height elevation recorded was 0.0 meters below the ground level (b.g.l), and the greatest depth below that level was 22.36 meters. Still, the outcome shown in Table 2 is the same for both analytical methods. Thus, over thirty-five (35) years of service, the total storage capacity loss is estimated to be around 139 MCM, or the change in reservoir volume, whereas the yearly siltation rate is estimated to be around 3,979,128 m3/yr. This suggests that siltation has occurred in 33 % of the dam reservoir. This is demonstrated by the aquatic weeds that have grown to a height of 334.21 meters on the lake's surface, rising from the lakebed.

The development of deep-rooted aquatic vegetation, which has been seen throughout a sizable portion of the reservoir, is highly noteworthy since it clearly indicates elevated reservoir bed levels and sediment traps. The bedload samplings' particle size distribution study is consistent with the global sediment distribution pattern found in the majority of reservoirs. The topset deposits contain a variety of fine, medium, and coarse sand and fine and coarse gravels with diameters ranging from 0.425 mm to 0.6 mm. Particle sizes in the bottom sets range from 0.002 mm

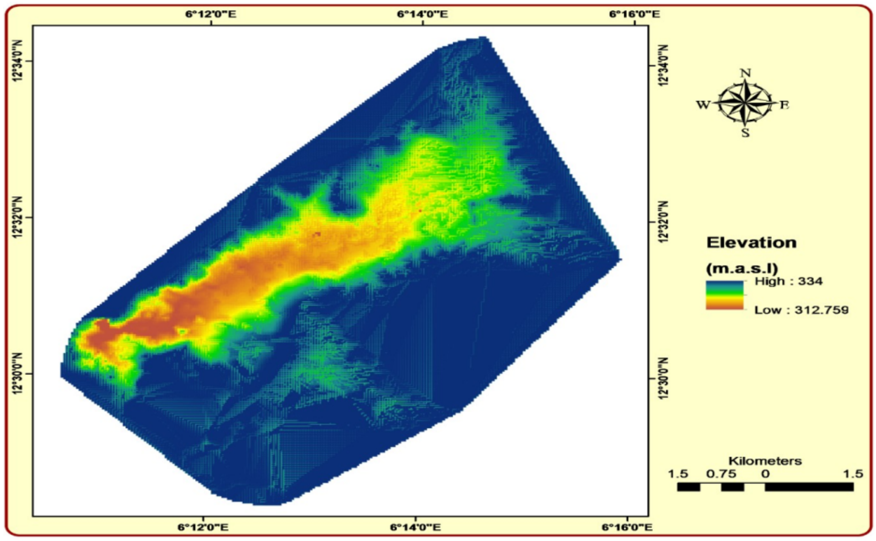

Figure 3. Bakolori reservoir bed surface topography above mean sea level (without points).

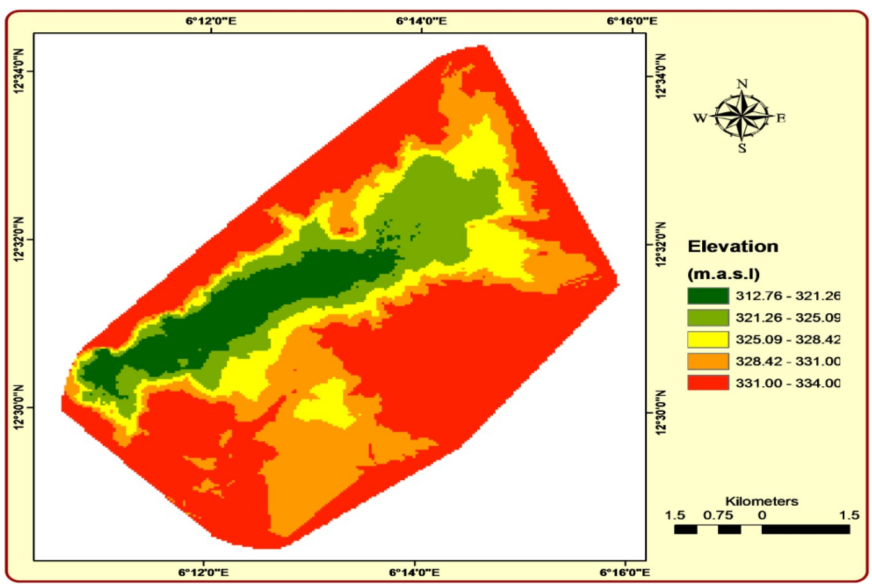

Figure 4. The classified bathymetric triangular irregular network map of Bakolori reservoir.

Table 2. Analysis of area elevation capacity of Bakolori reservoir.

Plane Height	Reference	Area (2D)	Area (3D)	Volume (CM)	Initial volume	Change in volume	No of Yrs	Siltation/ Yr (MCM)
334	Below	57012967	57019364	290730504.8	430000000	139269495	35	3979128
0	Below	57012968	57019365	290737000.6	430000000	139262999	35	3978942

to 0.14 mm, which are typically clay, silt, or fine sand. The samples are generally highly consolidated and include between 80 and 85 percent particles smaller than 0.08 mm, which is important when selecting the right equipment for dredging the reservoir.

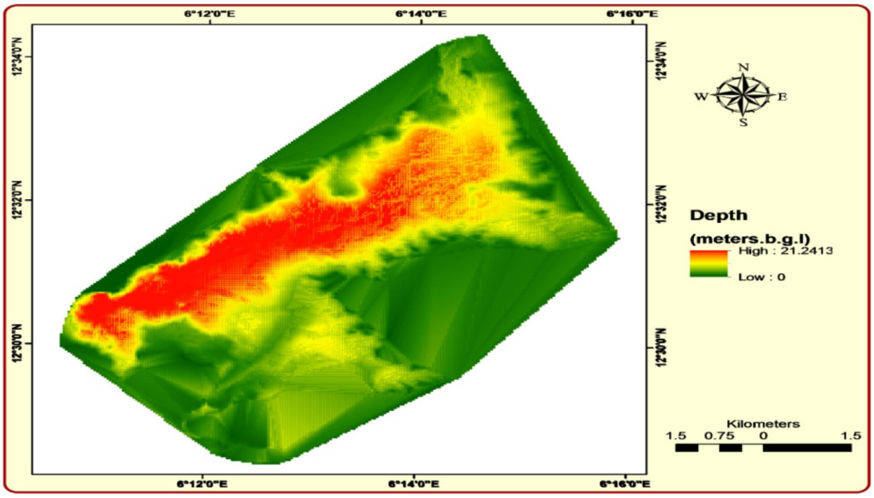

Figure 5. Bakolori reservoir bed surface topography below ground level (without points).

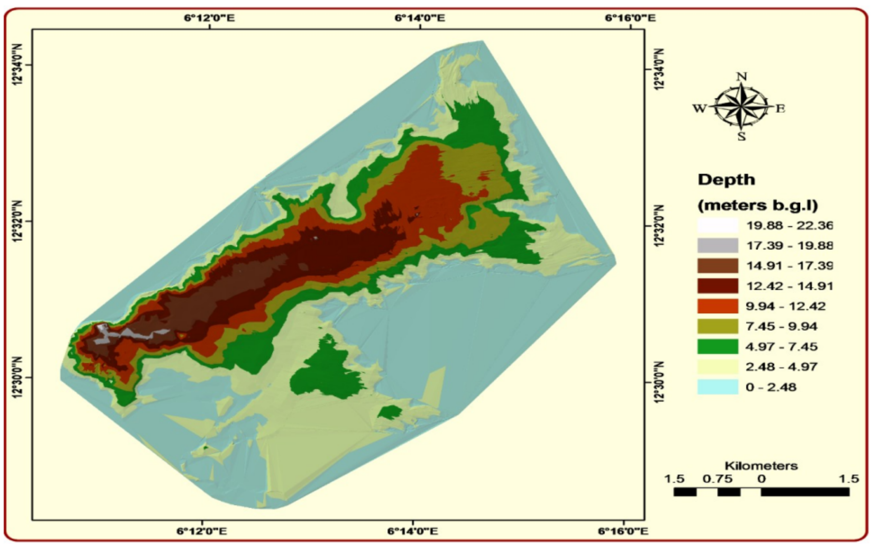

Figure 6. Bakolori underwater reservoir bed topography (TIN) (below ground level).

5. Conclusion

In order to evaluate the reservoir capacity loss during the Bakolori reservoir's operation as of 1983, the designed computed reservoir capacity was compared with the existing bathymetric survey. The current updated capacity at spillway crest level is 291 m with a change in volume of 139,269,495 m^3. The initial reservoir capacity, as reported, is 430 MCM at spillway crest level of 334 m amsl above mean sea level. The fact that the reservoir's present hydro-volume capacity is only one-third of its initial storage suggests that it is operating below its designated capacity. This will have a detrimental impact on the reservoir's agricultural output because there won't be enough water for irrigation to meet the dam's goals. Thus, suggests an urgent need for the removal of sediments from the dam reservoir to enable for prudent use.

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