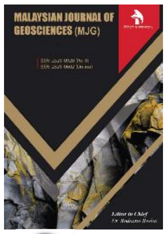
ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-0920 (Print)
ISSN: 2521-0602 (Online)
CODEN: MJGAAN

Malaysian Journal of Geosciences (MJG)

DOI: http://doi.org/10.26480/mjg.01.2024.76.81



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RESEARCH ARTICLE

BATHYMETRY AND SILTATION ANALYSIS OF ABULOMA INLAND WATER, RIVERS STATE

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ARTICLE DETAILS

Article History:

Received 20 February 2024
Revised 24 March 2024
Accepted 23 April 2024
Available online 27 April 2024

ABSTRACT

Siltation, the accumulation of sediment particles in aquatic environments, poses significant challenges to water resource management, ecological health, and infrastructure maintenance. To effectively monitor and manage siltation, accurate data acquisition methods are crucial. Bathymetric data offer high-resolution spatial data, allowing for precise identification of sediment accumulation zones and the tracking of sediment transport pathways. This study focuses on siltation monitoring within an inland water channel: Abuloma River, using the bathymetric surveying data, which involves measuring the depth and morphology of water bodies. The bathymetric data was acquired using MK III single beam dual frequency echo sounders, processed and analyzed using Qinsy software. ArcGIS software was used to quantify sediment deposition rates, distribution, and changes in underwater topography. The result of the study shows a siltation rate of 762.249m3/year. This study underscores the importance of bathymetric surveying as a powerful tool in siltation monitoring efforts. It emphasizes the need for interdisciplinary collaboration between hydrologists, engineers, ecologists, and GIS specialists to effectively analyze and interpret the collected data. Ultimately, siltation monitoring using bathymetric surveying data contributes to a holistic approach in managing sediment-related challenges and promoting sustainable water resource management practices.

KEYWORDS

Siltation, Sedimentation, Bathymetric survey, geomorphology.

1. INTRODUCTION

Siltation monitoring is the process of measuring and assessing the accumulation of sediment, silt, or other fine particles in water bodies such as rivers, lake, reservoirs and coastal areas (Robert, 2009). Sediment accumulation, also known as siltation are the resultant effect of several interacting factors of both human activities and natural phenomenon. Human activities such as deforestation, construction activities, poor agricultural practices that disturb the landscape and reduced the natural protective cover of vegetation are significant contributors to accelerate siltation (Owens and Collins, 2006). Natural phenomenon such as climatic events ranging from heavy rainfall associated with storms or hurricanes, volcanic eruption and landslides can introduce massive quantity of sediment into water bodies (Julien, 2012; Charles and Robert, 2010). Whatever the cause, siltation can have negative effect on the marine ecosystem. It reduces water clarity and turbidity, which inhabits light penetration and can harm submerged aquatics microbes and vegetation. Dams, reservoirs, irrigation canals, and navigation channels can be clogged with sediment, reducing their capacity and efficiency Mama and Okafor, 2011).

Despite the critical role of siltation monitoring in maintaining water quality, preserving aquatic habitats, and ensuring sustainable water resource management, challenges persist in accurately assessing and managing sediment accumulation in various water bodies (Köthe, 2003). The complex interactions between hydrological processes, sediment transport, and environmental factors demand comprehensive research efforts to enhance our understanding of siltation patterns and develop innovative monitoring approaches that account for diverse geographical, climatic, and anthropogenic conditions. While various siltation monitoring techniques and methods have been developed such as sediment sampling, core sampling, sediment traps, turbidity measurement, measurement of water quality parameters, remoting sensing and Geographic information system and using environmental sensors, there remains a need to enhance our understanding of the spatial and temporal dynamics of sediment deposition (Li and Yang, 2015; Thonon et al., 2006 Eelke, 2003; Ibrahim and Sternberg, 2021;Förstner and Owens, 2007; Bartlett and Smith, 2005; Schroeder, 1992).

To ensure safety of marine navigation, it is important to determine the rate of siltation so as to determine the navigability potential. The need to determine the rate of siltation for the Abuloma water channel is critical to quantify the effect of sediment materials on the navigability potential of the river and also to monitor the rate of erosion within the riverine communities associated with the River. The Abuloma River is a major channel connecting the mainland to the atlantics ocean. More also, it the major route connecting the Nigerian Liquified Natural Gas (NLNG) head office to her GAS plant in Bonny.

Concerted effort has been made to model, monitor and manage siltation for effective water resource management. (Lopes and de Araujo, 2019) [14] developed a simplified method for the assessment of siltation in semiarid reservoir in the northeastern Brazil using satellite imagery. The results were compared with bathymetric surveying data. The simplified method estimated the updated storage capacity of the reservoir with an

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error of 11%. Siltation assessed through the developed method was over estimated nearly twice 94% as high as that observed through conventional surveys. Similarly, in northern china (Dawei et al., 2022) studied the characteristic of the siltation of the middle route project studied infrastructure developed for alleviating water scarcity. Internet of things based automatic siltation monitoring system using cloud was installed at the outlet of the inverted siphon project on Xiao River. The siltation samples at five sites were gathered for particle size examination, along with three years' worth of online monitoring data going back to 2018. The monitoring data shows that siltation mainly occurs during March to October, and almost no siltation occurs in winter. The maximum siltation speed can reach 390 mm per day. The bathymetric data monitor the rate of siltation using Remote sensing techniques in Malaysia (Masayu et al., 2012). The main changes observed for the time period of 2005 until 2010 using Land-SAT imageries was an increase in area due to siltation of approximately 5599.73 hectares, which mean the increasing within five years is about 80%. In Nigeria, (Ezugwu, 2013) examined the issues of sediment deposition, factors affecting siltation and the impacts of reservoir on the environment. This analysis also investigated the level of siltation and flood menace in Oyan dam, Ogun state using an integrated approach (Adejare, 2022). Topographic, bathymetric and satellite data between 2018 and 2020 were integrated using ArcGIS 10.6. Volumetric analysis of sediment budget computed for the dam was 251.7 × $10^6 m^3$ compared with the reservoir design capacity of 270 × $10^6 m^3$. The study shows a loss of about 6.7% of the reservoir capacity due to siltation.

To effectively monitor and manage siltation, accurate data acquisition methods are crucial. Bathymetric data offer high-resolution spatial data, allowing for precise identification of sediment accumulation zones and the tracking of sediment transport pathways. This study demonstrates the applicability of bathymetric data (echo sounding) acquired within the period of 5 years from 2019 to 2023 in siltation monitoring of a section of the Abuloma water channel, Rivers State, Nigeria.

1.2 Aim and Objective of The Study

The aim of the study is to determine the rate of siltation of a section of the Abuloma water channel between the year 2019 -2023.

It is based on the following objectives

1. To carry out a baseline survey and subsequent hydrographic survey of the study area
2. To determine the changes in volume between the period under investigation
3. To determine the rate of siltation within the study area.

1.3 Study Area

The Abuloma water channel is a very important tidal inland water connecting major economic hubs within Rivers State including the Nigerian Liquified Natural Gas (NLNG) head office to the Port Harcourt Sea Port, Onne Sea Port extending to the territorial sea and the Atlantic Ocean. The nature and characteristic of the inland water requires regular monitoring to determine the rate of siltation and sedimentation particularly for navigation purpose. Since it serves as the only inland water connecting the hinterland to the bonny gas station. The study area is a section of the Abuloma River, defined by the geographic coordinate *4˚ 47' 43.7" N, 7˚01'20.14" E to 4˚ 47' 43.7" N, 7˚01'47.20"* E as shown in Figure 1.

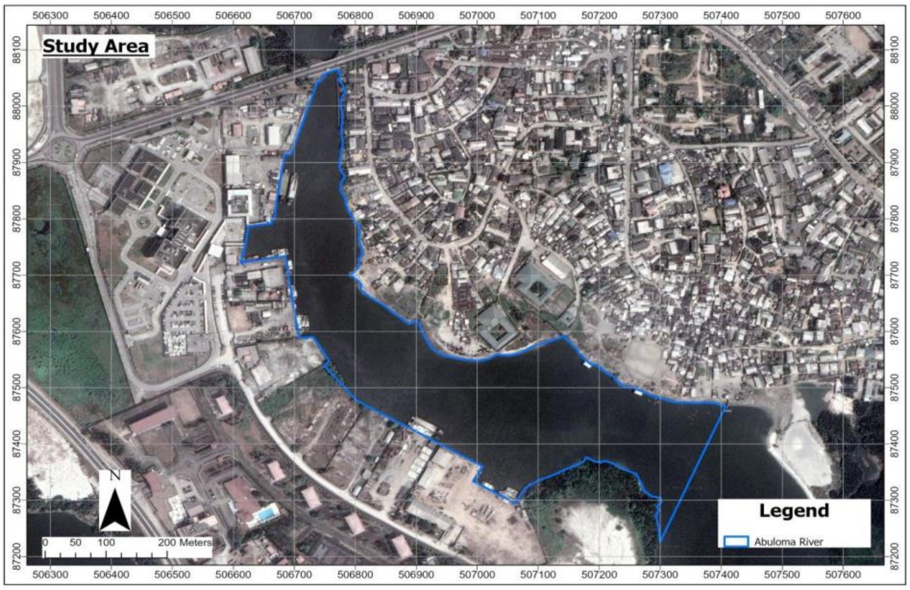

Figure 1: The Study Area.

3. Materials and Methods

Measuring siltation rate using bathymetric data involves analyzing changes in the depth of a water body over time to estimate the accumulation of sediment. It involves data collection, establishment of baseline data, regular data collection, data processing and volumetric analysis, delineate sediment accumulated area, and calculating siltation rate. The following material as given in Table 1 was used for the Study.

Table 1: List of Equipment

S/N	Equipment	Remark
1	Single beam Echo Sounder and Transducer	Odom MKII
2	PC Computer	DELL
3	GNSS Receiver and Accessories	Septentrio
3	Survey boat	Camille
4	Sound Velocity Probe	Valeport
6	Tide Gauge	Tari
7	Bar Plate	
8	ArcGIS & Qinsy Processing Software	Version 9.4
9	E-Chart for Logging	Version 4.2
11	Batteries	12V

4. Data Collection

The data used for this study was acquired using single beam echosounder, to map the underwater topography or depth configuration of the water body. This involves the use of acoustic signal to measure the depth configuration of the Abuloma river. The MK III single beam echosounder emit a short burst of high frequency sound (usually in the ultrasonic range, around 20-200kHz) as an acoustic pulse. The sound wave propagates through the water column is been reflected by the sea bed and picked by the transducer. The two-way time travel of the acoustic pulse is measured and used to derived the water depth. it uses the formula as expressed in equation 1 (Ojinnaka, 2007).

$$d = \frac{vt}{2} \tag{1}$$

Where: $\boldsymbol{v}$ is the speed of sound in water: The speed at which sound travels through water (varies with water temperature, salinity, and pressure)n (Basil et al., 2022). t is the round-trip time. That is, time taken for the sound pulse to travel to the end of the water depth and return to the transducer. Equation (1) is the simplest mathematical expression, however, it is rather more complex due to the refraction of sound wave through the water column (Pierce, 2019).

Precise Point Positioning (PPP) strategy was deployed to determine the 2D position of the survey vessel. PPP is a positioning technique that used precise state vectors (precise satellite orbits and clock offset) from either commercial provider (Fugro, CNav) or public infrastructures such as the International Global Navigational Service Station (IGNSS) network stations to provide precise positioning and navigational solution to standalone receivers. The advantage of this positioning strategy is it ability to provide accurate 3D information using a single receiver, more also, it is not dependent on differential distance as in the case of Real Time Kinematics (Choy and Higgins, 2018). Precise space state corrections to account for GNSS errors arising from error in satellite orbital and clock, ionospheric and tropospheric delays and receivers clock error was obtained from Fugro geostationary satellite IOSAT and EMSAT (Goode, 2015).

5. Data Processing

Bathymetric data processing involves the transformation of raw depth measurements obtained from bathymetric surveys into meaningful, usable, and visually interpretable information about the underwater topography. This process includes tidal and sound velocity correction, data filtering, interpolation, visualization, and analysis. The data processing was done using Qinsy and Auto Clean (Beam WorX) software as shown in Figure 2 and 3. The Digital bottom model of the study area for the period under investigation was imported to ArcGIS for data Analysis.

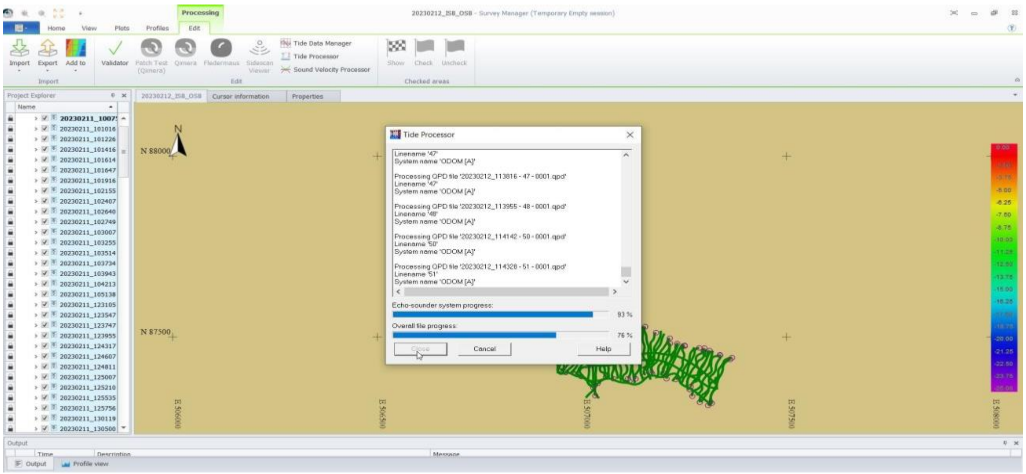

Figure 2: Tide Application using the Qinsy Survey Manager

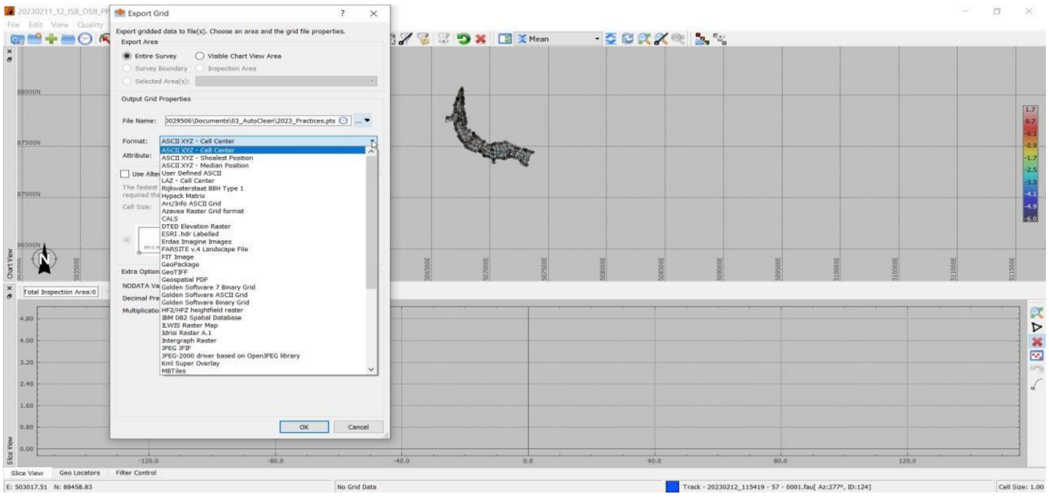

Figure 3: Exporting the processed data to DTM in Beam WorX Auto Clean Environment.

6. Data Analysis

Geographic information system (GIS) tools (ArcGIS Pro) was used for the data analysis. The data analysis involves comparing the bathymetric data from the baseline survey with data from subsequent surveys. The differences in water depth and volume at each survey epoch was used to identify areas where sediment accumulation or erosion has occurred as shown in Table 2. Figure 4 and 5 shows the bathymetric model of the study area for the year 2019 and 2022 respectively in ArcGIS environment.

6.1 Siltation Rate Calculation

The rate of siltation was for the study area was computed using the difference in volume between the year 2019 and 2022. The volume computation was done using the Simpson's 3/8 rule as given in equation (2).

$$\text{Volume } (m3) = 3h/\ \{f(X_0) + f(X_1) + 3f(X_2) + f(X_3) + 3f(X_4) + 3f(X_5)\} \tag{2}$$
$$8 + f(X_6) + \cdots + f(X_{n-3}) + 3f(X_{n-2}) + 3f(X_{n-1}) + f(X_n)$$

Figure 4: Bathymetric Model of the Study area, 2019 (Source: Author, 2023)

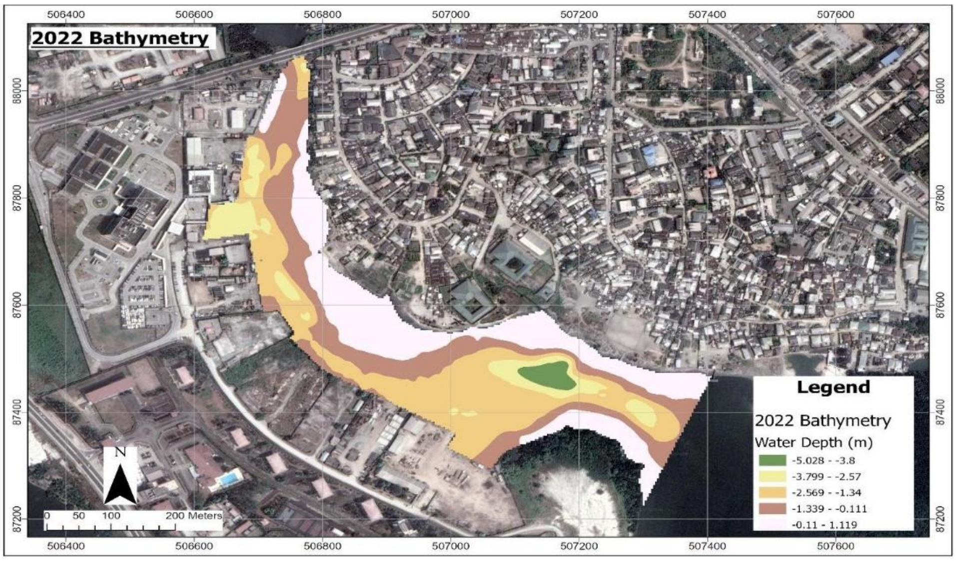

Figure 5: Bathymetric model of the study area, 2022 (Source: Author, 2023)

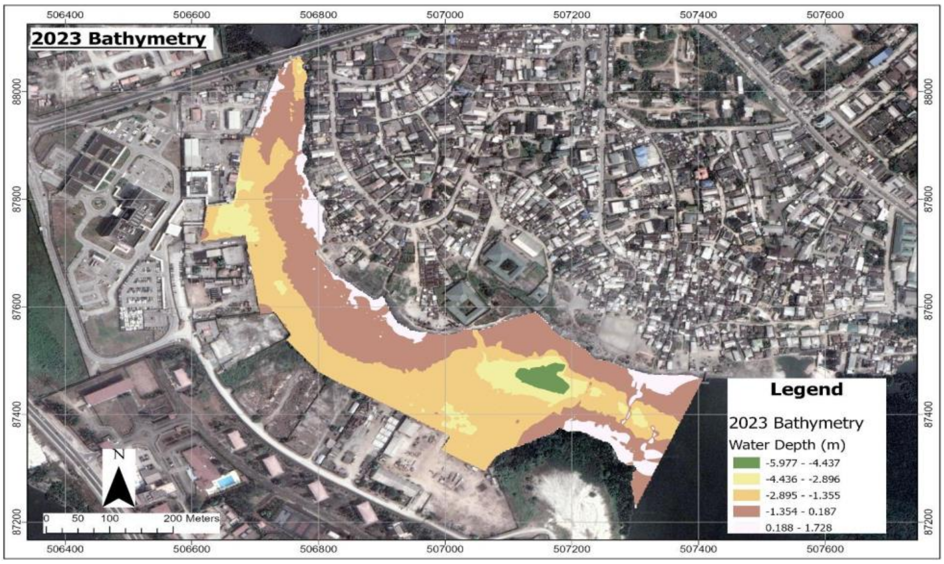

Figure 6: Bathymetric model of the study area, 2023 (Source: Author, 2023)

The method of volume computation utilizes cubic interpolation. Integrating equation (2), given equation (3) as:

$$\text{Volume } (m^3) = 3h/8\ \{f(X0) + 3\sum_{t=1}^{n-1} f(X1) + 3\sum_{t=2,5,8}^{n-1} f(X1) + 3\sum_{t=3,6,9}^{n-3} f(Xn)\} \quad (3)$$

Where; n is the number of segment, h is the vertical distance which in this case the reduce depth, and X is the area.

The result of the volume computation is given in table 2 and table 3.

Table 2: Showing the Difference in volume between the year 2019 – 2022					
Year	Plane Height	Z_Factor	Area_2D	Area_3D	Volume
2019	0	1	119537.054	119782.451	188388.032
2022	0	1	119540.149	115857.131	186101.286
	Difference			**3925.320**	**2286.746**

Table 3: Showing the Difference in volume between the year 2022 – 2023					
Year	Plane Height	Z_Factor	Area_2D	Area_3D	Volume
2022	0	1	119540.149	115857.131	186101.286
2023	0	1	140834.920	141474.532	246469.392
	Difference			25617.400	**60368.106**

To determine the rate of siltation (sediment deposition) the sediment volume is divided by the time interval between surveys (2019 – 2022). The formula for siltation rate is:

$$\text{Siltation Rate (m3/year)} = \frac{\text{(Depth Change in cm)}}{\text{(Time Interval in years)}} \quad (4)$$

Siltation Rate = 762.249m3/year

6.2 Spatial Analysis

The spatial analysis of was carried out to identify areas with high rate of siltation within the study area. Figure 6 shows the horizontal and vertical profile the seabed profile of a section of the study area. The green, red and blue profile represent the vertical seabed profile for the year 2019, 2022 and 2023 respectively.

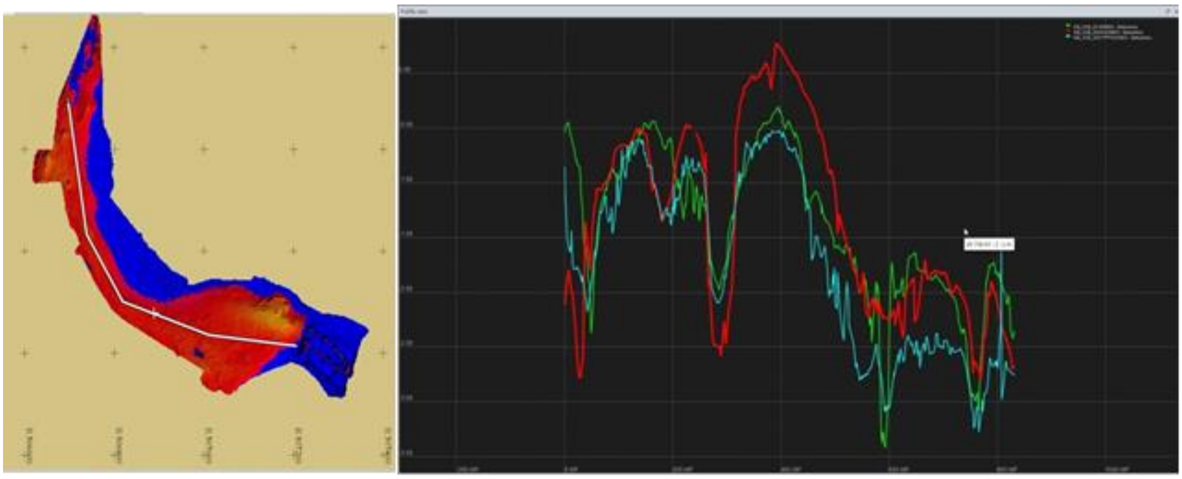

Figure 7: Horizontal and Vertical Profile of a section of the Study area.

7. Result and Discussion

This study analyses the rate of siltation using bathymetric data spanning the period of five years collected at three different epoch, 2019, 2022 and 2023 respectively. The raw bathymetric data were processed using Qinsy and reduced to the same datum. The difference in volume of about 2286.746m3 was observed between 2019 and 2022 as shown in Table 2. Which result to an overall siltation rate of 762.249m3/year. However, the rate of siltation varies with position, as such, sectional analysis was carried out to determine the rate of siltation on various section within the study area. The result of the sectional analysis is as presented in Figure 6.

Further to this, change in volume between 2022, and 2023 was observed of about 60368.106m3. This indicate that dredging exercise was carried out within the study area. Since only bathymetric data was used for this study, the cause of the siltation couldn't be readily identified. However, it is suspected that the siltation might have been due to erosion associated with heavy rainfall within the Abuloma community. Considering the high rate of siltation within the study area, further dredging of the study area without adequate embarkment will further exacerbate the rate of siltation which will undoubtedly affect the neighboring community. For effective land management and erosion control, this study recommends that shoreline protection be carried out within the Abuloma water channel to mitigate the rate of siltation.

8. Conclusion

Measuring siltation rates using bathymetric data is a valuable tool for understanding the dynamics of sediment deposition and erosion in water bodies, which can inform environmental management and conservation efforts. This study underscores the importance of bathymetric surveying as a powerful tool in siltation monitoring efforts. It emphasizes the need for interdisciplinary collaboration between hydrologists, engineers, ecologists, and GIS specialists to effectively analyze and interpret the collected data. Ultimately, siltation monitoring using bathymetric surveying data contributes to a holistic approach in managing sediment-related challenges and promoting sustainable water resource management practices.

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