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Research article

Estimation of reservoir sedimentation using bathymetry survey at Shumburit earth dam, East Gojjam zone Amhara region, Ethiopia

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ABSTRACT

Sediment accumulation is a major factor in reducing the useful life of irrigation reservoirs. As a result, information on any changes in storage capacity is required to reduce the reservoir's risk. Therefore, the goal of this research was to identify the amount of sediment accumulated in the reservoir using a bathymetric survey. The bathymetric survey method involves subtracting the two-period capacities (before dam construction and after dam construction). The bathymetric survey of the reservoir was carried out by analyzing volume and surface area using ArcGIS 10.8, and developing the Triangulated Irregular Network (TIN) surface from topo-sheet data. The bathymetric survey showed that 297,000 m^3 (362,340 tons) of sediment had accumulated in the reservoir over six years of operation. This means the reservoir's total capacity has been reduced by 7.52% over the last six years. The average rate of sedimentation was assessed to be 49,500 m^3/y (60,390 tons/year) and the annual capacity reduction of the reservoir was 1.25 percent. The proportion of dead storage capacity to sediment deposition level was used to calculate the reservoir's useful life. Hence; the sedimentation rates of the dead storage and live storage regions were 31,666.67 m^3/year and 48,333.33 m^3/year, respectively. Finally, this indicates that the reservoir will not be functional for more than 15 years if the sediment deposition rate remains the same as the previous six years throughout the operation periods.

1. Introduction

Reservoirs are used for many purposes, such as water supply, irrigation, residential use, flood control, and hydropower. However; they are unable to serve their intended functions due to a sedimentation issue. The process of reservoirs being filled with sediments delivered from watersheds into the reservoir is known as reservoir sedimentation. It's a global phenomenon that's been considered one of our generation's most serious environmental problems (Kothyari et al., 2009). Sediment accumulation in reservoirs is a severe offsite result of soil loss that undermines the long-term viability of dams constructed for many drives in Ethiopia and elsewhere (Haregeweyn et al., 2006).

The building of a barrier, which creates a reservoir, affects the natural circumstances of a stream or river, resulting in lower flow velocity, which promotes slow sediment deposition in the inflowing waters. As a result of the increased sedimentation, reservoir water storage capacity is often lower than before (Dutta et al., 2016). Furthermore, reservoir silting is one of Ethiopia's most difficult water-related challenges, diminishing water depth and aiding aquatic plant growth, as well as blocking bottom exits, entrances, and regulators. Such issues are found in many of Ethiopia's areas. Even while they are being built to collection water for agricultural and/or drinking dedications are being occupied with silt.

The topography, soil, surface cover, drainage networks, and rainfall-interrelated ecological aspects all influence watershed erosion and accumulation processes, which result in sediment deposition in reservoirs (Zeleke et al., 2013). Reservoir function can be influenced by sediment influx and deposition. This is also happening at the Shuburit reservoir. As a result, determining the rate of sedimentation and the period before sediment accumulation obstructs the reservoir's ability to function effectively is crucial. While planning a reservoir, enough sediment storage capacity should be considered so that sediment accumulation does not affect the reservoir's function during its useful operational life. This would be effective when sediment yield information from the watershed is available. However, statistics on watershed sediment output and reservoir sedimentation rates for Ethiopia are scarce.

The scarcity of appropriate local databases on sediment produce and adoptable sediment yield models has been a concern for reservoir inventors. A bathymetric survey is a direct extent method for determining

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the capacity and distribution of deposits in reservoirs, making it more precise than indirect methods (Furnans et al., 2008).

According to (Omer et al., 2015 and Zarris et al. (2002) studies, reservoir surveys are frequently required for a variety of reasons such as to estimate the amount of silt deposited in the reservoir and the silt distribution within the reservoir. Few studies were carried out in Ethiopia to estimate the number of accumulated sediments in the reservoirs using a bathymetric survey. However, there has been no reservoir sedimentation investigation using the bathymetry survey method in the Shumburit reservoir. As a result, this study was used to guess the amount of sediments accumulated inside the reservoir, to evaluate the spatial distribution of sediment deposition in the reservoir, as well as to obtain important information about the reservoir's useful life.

2. Materials and methods

2.1. Description of the study area

2.1.1. Location

This study is conducted at the East Gojjam zone of Amhara regional state in Ethiopia, which is located in Debre Eliayas woreda, in particular at Yegdad and Yekomit kebele. The Shumburit dam is 56km far from Debre Markose, the town of and 14km from Debre Eliyas town of the East Gojjam zone (Figure 1 and Table 1). The geographical location of the site is 324999.95m East and 1147300.0m North. The Shumburit dam project was constructed in 2015 and started harvesting water in 2016. The project was implemented to irrigate over 270 ha of land.

2.1.2. Topography

Because the slope is the most significant terrain feature and plays a critical role in soil erosion, understanding its spatial distribution in the study area is critical. Thus, the slope map of the study area was created by downloading the DEM in Earth Explorer Home at 30 m × 30 m resolution from NASA's website and running the process through ArcGIS10.8. The watershed has a slope ranging from 0 to 35.13 percent, and the reclassification slope in percent and the coverage area of each reclassified slope area in hectares are described in Figure 2 and Table 2 below, where the slope classification is based on FAO (1989).

Table 1. The Salient features of the Shumburit reservoir.

Item	Features	Unit
Dam height	16	m
Dam crest length	338	m
Gross Freeboard	2.5	m
Spillway crest length	10	m
Live storage at Full supply level, FSL	*216.75*	(ha.m)
Gross storage at FSL	*261.52*	(ha.m)
Gross storage at max. full supply level	*394.7*	(ha.m)
Irrigable lands size	270	ha
Watershed size	13.5	Km^2

(Source Amhara regional state Bureau of water resource development (BoWRD) in 2014).

2.1.3. Land use/land cover of Shumburit watershed

The watershed's land use/land cover are characterized by seven major land use/land cover types, as presented in Figure 3 and Table 3: built-up land, cultivated land, forest land, bare land, pasturage land, shrubland, and water body. Cultivated land is the watershed's most common land use/land cover type, accounting for 53.63 percent of the total area in 2021.

2.1.4. Soils

The Shumburit watershed soil is characterized using data obtained from the FAO world soil classification website, and the soil was classified as shown below in Figure 4 and Table 4. The dominant soil groups are chromic vertisols and pellic vertisols.

2.2. Materials

The following materials were used in this study: a local boat (canoe) for bathymetry surveying, a total station for land surveying, a soil sampler/core sampler used to collect soil samples, a hand-held Global Positioning System (GPS) used to record X and Y coordinates, an echo sounder or VEIXILAR LCO portable sounder (LPS-1) depth measuring device used to measure water depth, a meter, a reservoir area

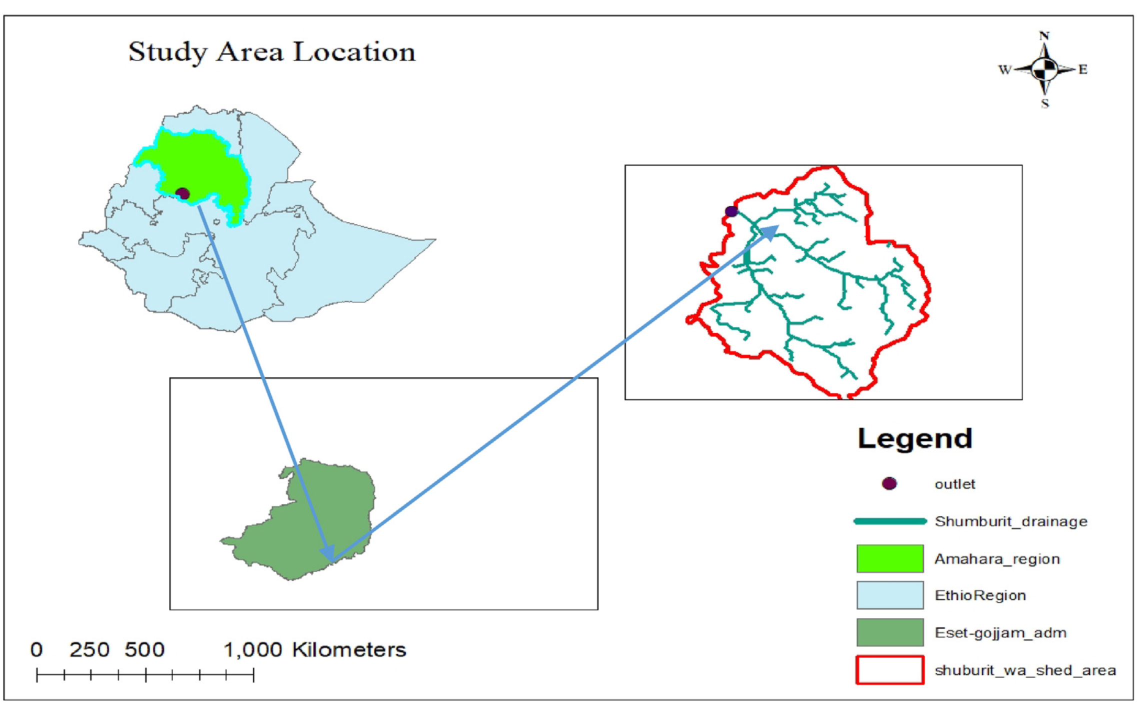

Figure 1. Location map of the study area.

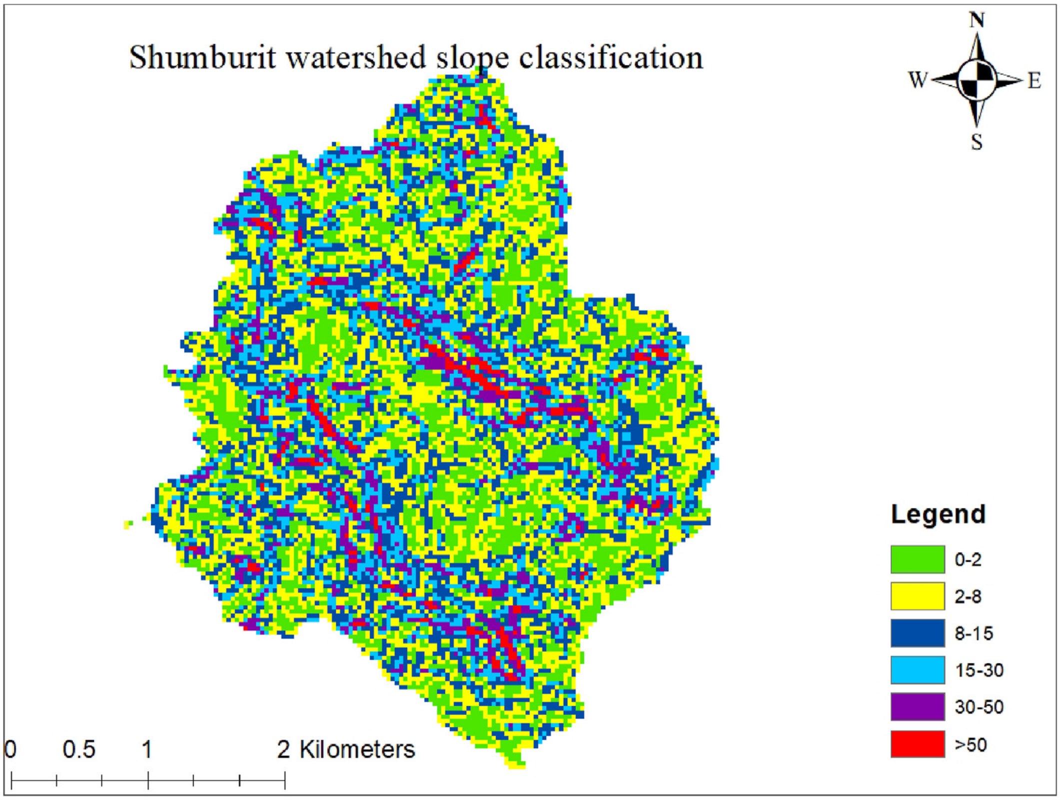

Figure 2. Slope map of Shumburit watershed classification based on FAO (1989).

topographic map, and a marked metal or stick as shown in Figure 5. The VEIXILAR LCO portable sounder (LPS-1) handheld digital depth sounder can't measure depths below 0.55 m or above 60.96 m.

2.3. Data collection and processing

Data for this study was gathered through interviews with community members or experts, field testing, field testing, laboratory testing, and collection from various organizations.

2.3.1. Primary data

2.3.1.1. Bathymetry and land survey data. A bathymetry survey was used to determine the depth of the wetted reservoir bed below the water's surface. This survey was supplemented by a land examination to collect land surface elevation figures up to the spillway crest or higher if the reservoir level was below full supply. When data from a bathymetry survey was collected, the reservoir level was not at full supply. In this study, the amount of sediment deposition in a reservoir was measured using bathymetric and land survey techniques. Bathymetry survey data was collected in the reservoir region using a local boat or canoe, digital echo sounder, and a hand-held Garmin GPS as shown in Figure 6. GPS was used to collect the reservoir's X and Y coordinates but not its z or depth. The reservoir's depth was measured with an echo sounder depth measuring device or a VEIXILAR LCO portable sounder (LPS-1). Water depths greater than 0.55 m are measured by the VEIXILAR LCO portable sounder (LPS-1); water depths less than 0.55 m are recorded with a marked stick. The data for the land survey was collected using a total station that was calibrated using known benchmarks. Bathymetric and land surveys were conducted around the reservoir at grid intervals ranging from 3 to 40 m. Following the predefined route, however, was extremely challenging since the local boat or canoe could not precisely track the formerly set cross-sections. The outcome of wave height on water depth extent was ignored because the bathymetry survey was conducted in calm conditions. All reservoir X and Y coordinates were collected using a handheld GPS with a horizontal precision of 3 m–3.8 m. Based on an existing benchmark, this horizontal precision was adjusted (i.e., 324974.17easting, 1147749.92 northings, and 2136.86 m AMSL). Between May 10 and 15, 2021, a total of 1041 sample points were collected (i.e. the data includes both boundary and bathymetry). It was necessary to calibrate the digital sonar depth sensor with local field conditions to ensure that it delivered reliable results. The calibration was done in calm water with a marked stick over the side of the boat. To perform depth calibration, a labeled stick with a shallower depth was placed at various locations throughout the reservoir. A total of 26 water depth samples were measured by hand using a 3 m marked stick. Using Eq. (2.1) below, the root means square error (RMSE) was calculated to assess the precision of this instrument.

$$RMSE = \sqrt{\frac{1}{n}\sum_{k=0}^{n}(D_{GS} - D_{SO})^2} \quad 2.1$$

Where D_{GS} and D_{SO} are the depth readings by graduate stuff and sonar, correspondingly, and n is the figure of measured points, and RMSE is the root mean square error of the vertical component. The RMSE of water depth estimations was 0.049m using equation 2.1. NDEP (2004) used a

Table 2. Watershed slope characterization based on FAO (1989) classification.

Slope (%)	Description	Area (ha)	Coverage (%)
0–2	Flat/gentle	144.517	11.19
2–8	Gently sloping	620.837	48.06
8–15	Moderately steep/gently rolling	429.099	33.22
15–30	Moderately steep	97.0479	7.51
30–50	Steep/Hilly	0.34332	0.03
total		1291.84422	100

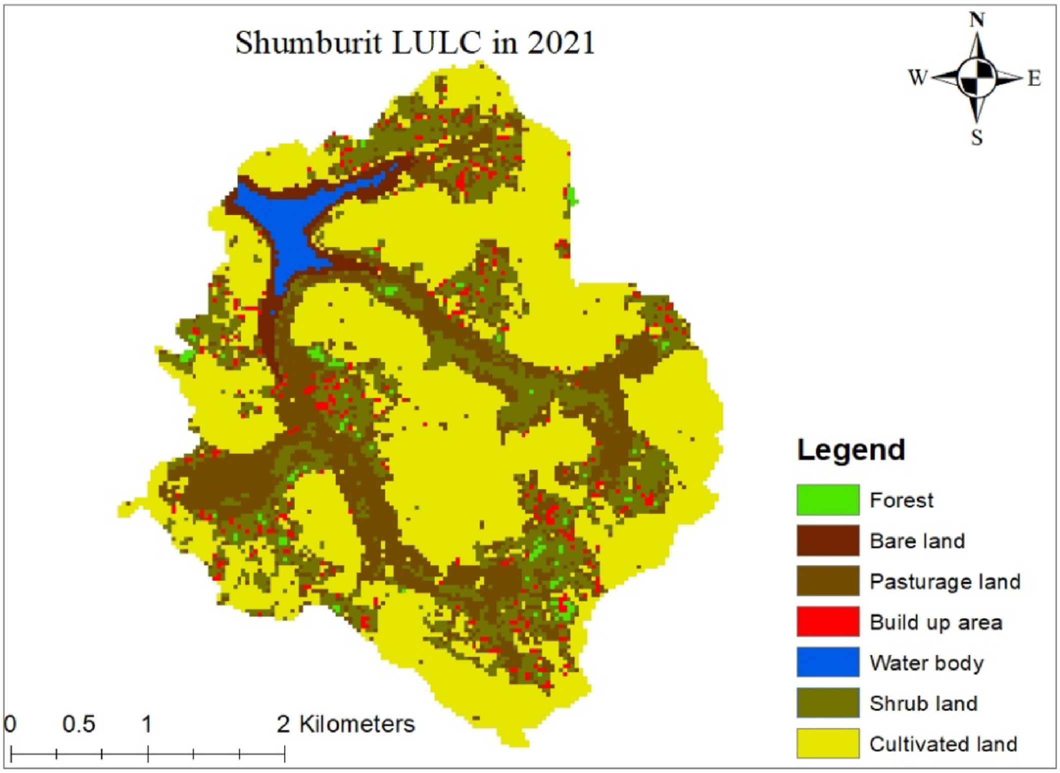

Figure 3. LU/LC map of Shumburit watershed in 2021.

factor of 1.96 multiplied by RMSE to evaluate vertical accuracy at a 95% confidence interval, and the result was 0.096 m, which NDEP considered satisfactory (2004).

2.3.1.2. Soil sample data from reservoir sediment. To estimate the dry sediment bulk density of deposited sediment, eight (8) undisturbed known amount of soil trials were collected in the reservoir area at various locations based on the variation of soil layer/property that differed from the other sections of the sample point while also taking into account the sediment entering a location into the reservoir (i.e., the sediment coming from one sub-watershed may differ from the other sub-watersheds of the Shumburit watershed). On May 16, 2021, samples were taken during a field survey at a reservoir drawdown level or when the reservoir elevation reaches a minimum level. The number and location of sediment samples were determined by the spatial distribution of sediment in the reservoir and the variation in sediment sample property/layer. It was impossible to collect undisturbed samples from several central areas of the reservoir due to a shortage of appropriate apparatus. Soil samples were collected up to a depth of 15 cm to determine the dry density of a sample. Figure 7 illustrates the spatial distribution of soil sample points.

Table 3. The land covers types and area coverage in the watershed.

LULC type	area (in ha)	area coverage in %
Pasturage and Degraded Grass	266.15	19.81
Shrub land	256.6	19.1
build up area	30.07	2.24
Cultivated	720.29	53.63
forest	9.45	0.7
Bare land	33.23	2.47
water	27.39	2.04

2.3.2. Secondary data

The original map and study documents for the study area were acquired from the Este Gojjam zone water resources, irrigation, and energy department office. Downloading a digital elevation model (DEM) from NASA's Earth Explorer, a land use/land cover (LU/LC) image from Earth Explorer, an Ethiopian administrative shape from the DIVAS page, and a soil type from FAO.

2.3.3. Methods of interpolation selection

Interpolation is a technique for estimating values at unknown locations by using known values or sample points. The spatial interpolation, which is accessible in the Arc-GIS 10.8 Geostatistical Analyst tool, uses five (5) different interpolation methods. Geo-statistical data analysis is critical for maximizing observed data and estimating depth characteristics in various locations. Some of the interpolation algorithms that have been compared are Kriging, Inverse Distance Weighting (IDW), Global polynomial interpolation, Local polynomial interpolation (LPI), and Radial Base Function (RBF). These procedures were selected because they are broadly used in the literature and are commonly used to incorporate bathymetric data (Sterling, 2003). The Geo-statistical wizard validated each dataset and compared the results of root mean square error (RMSE) for each interpolation method as shown in Eqs. 2.2 and 2.3. They also compared the coefficient of determination (R2) and finally chose the RMSE with the lowest value and the highest coefficient of determination (R2).

$$\mathrm{MAE} = \frac{1}{n}\sum_{k=1}^{n}\left[\left(D_{obs} - D_{int}\right)\right] \tag{2.2}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{k=0}^{n}\left(D_{obs} - D_{int}\right)^2} \tag{2.3}$$

Where n denotes the number of sample points, D_{obs} is the observed dataset, and D_{int} represents the interpolated value.

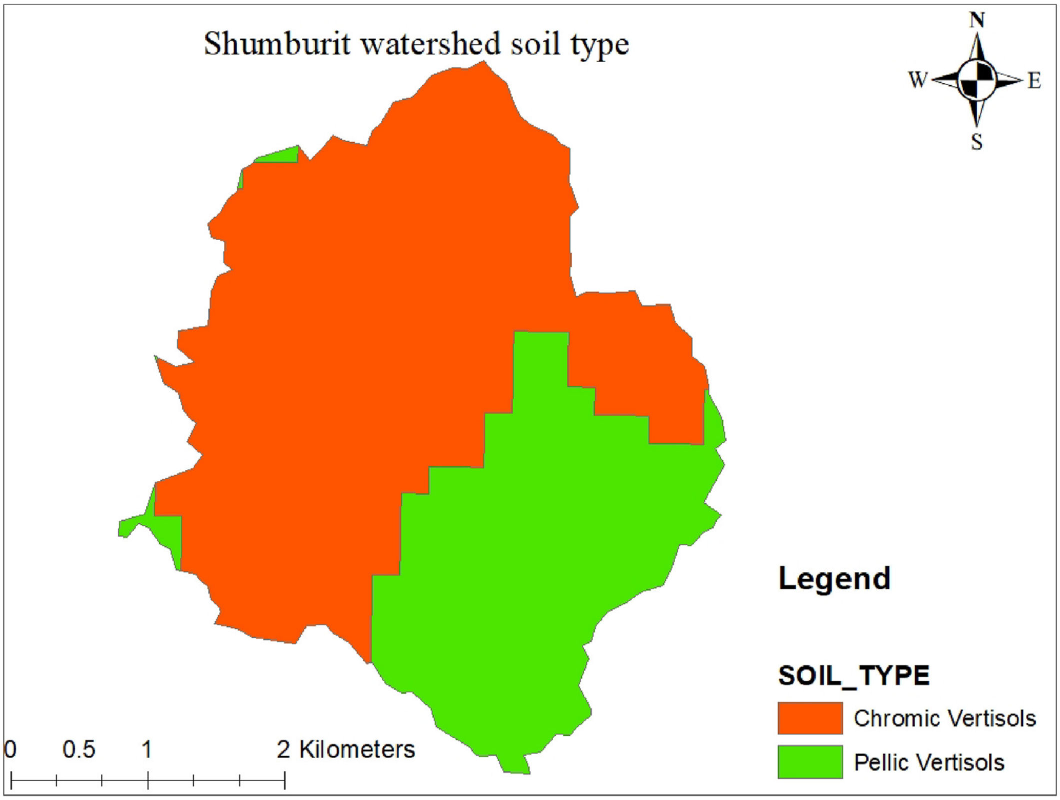

Figure 4. Types of soil classification in Shumburit watershed.

2.4. Research methodology

To achieve the study's objective, the following main procedures were followed: before the field, on the field, and after the field.

Before the field. In this stage, the following tasks were done.

- Gather the relevant information about the study area, like the top sheet, the original design document, and the boat.
- Collect materials such as echo sounders, total stations, GPS, and meters from various universities, government offices, and individuals.
- Download the needed software from Google's link.

In the field.

- Cross-check echo sounder with the study area by measuring the depth of the water with a meter and an echo sounder and comparing them.
- Survey the reservoir or water body using an echo sounder and also survey the surrounding land using a total station.
- Collect sediment samples and metrology data.

After field

- Export the data from the echo sounder, GPS, and the total station into the computer.
- Conduct laboratory tests

Table 4. Soil types and area coverage in the Shumburit watershed.

Soil Type	Area (ha)	Coverage (%)
Chromic vertisol	888.14	66.05
Pellic vertisol	456.42	33.95
sum	1344.56	100

- Finally, arrange all the data and start the main task, or write the document.

2.4.1. Estimation of sediment deposition in the reservoir

Sediment deposition in a Shumburit reservoir was estimated using bathymetry. Bathymetry is the measurement of the depth of the wetted reservoir bed below the surface of the water. It is based on a comparison of reservoir capacity volume over time. In this case, facts on the reservoirs' original volume must be provided as a baseline beside which the current storage volume can be related. A pre-impounding topographic map was provided by the East Gojjam zone water resources, irrigation, and energy department office. The original topo sheet data was found in soft copy, which was prepared using Auto Cad civil 3d software and then converted to JPG format using an Auto Cad civil 3d plotter in the form of publishing to web JPG at Auto Cad civil 3d software. The original map was projected to the Universal Transverse Mercator (UTM) projection at Africa-Adindan UTM-Zone 37N' in Arc-GIS 10.8 software to digitize, to geo-reference, and to compute the original reservoir capacity. It was once imported into ARC-GIS 10.8 and used to create a feasible form in the Arc GIS environment and export it as a shape file. Contours and the TIN surface were created with the 3D Analyst tool in Arc-GIS software. This was used to calculate the original reservoir capacity. A bathymetric survey and topographic survey were carried out using a local boat, an echo sounder (digital sonar or VEXILAR LCD portable sounder (LPS-1), a global positioning system (handheld GPS), and a total station to determine the existing storage capacity. When taking depth measurements, the GPS was used to record the boat's geographic location. An echo sounder (an echo sounder, digital sonar, or VEXILAR LCD portable sounder (LPS-1)) was used to decide the depth from the water's surface to the top of the sediment. A land investigation was carried out using a total station in reservoir areas where sediment accumulation occurs above the water depth and also land survey was carried up to the reservoir's full supply level. The depth readings at each coordinate were deducted from

Figure 5. Materials used during Bathymetry survey and photo taken at data collection period.

the water surface altitude to transform the raw depths documented by the depth measuring device into elevations (i.e., the water elevation was measured using the total station during data collection time and also by comparing the known elevation of the inlet point, the average water surface elevation becomes 2127.3m). Insert the X, Y, and Z data into the Arc GIS window again, project it in the same way as the original data using Arc GIS 10.8 software, and generate a shape file and TIN. The TIN map is usually used by a 3D analyst tool within Arc GIS software to calculate the reservoir's loading volume and water surface area. As a result, the Shumburit reservoir sediment was assessed by deducting the TIN difference between the original data (collected in 2016 or before collecting water) and the current data (i.e., collected using bathymetry in 2021). The reservoir's original or initial and present storage capacities were associated and the changes were the capacity of sediment deposition (m3). Using a representative dry bulk density, the measured sediment volume (m3) was changed to sediment quantity.

2.4.2. Determining spatial distribution of sediment deposition

To determine the thickness of reservoir sediment, two periods of depth data were used one before dam construction (2016) and the other from bathymetry surveys in 2021. To start, raster layers were created using the TINs from 2016 and 2021 to guess the spatial distribution of sediment in the reservoir. Using ArcGIS's Raster calculator tool, the 2016 reservoir bed elevation raster was subtracted from the 2021 reservoir bed elevation raster. The difference in raster layers represents sediment deposits in the reservoir during reservoir operation. The river centerline is also used in this study to assess the change in river bed profile. To do so, the old river centerline was digitized from a reservoir topographic map from 2016 and then interpolated with a raster map from 2016 and a raster map from 2021. Finally, longitudinal profiles were created using the 3D analysis (profile graph) tool in Arc GIS10.8.

2.4.3. Determination of reservoir trap efficiency

Verstraeten and Poesen (2000) define trap efficiency (TE) as the ratio of incoming sediment to deposited sediment, or trapped sediment, in the reservoir. To calculate the regular sediment yield from the arrival of the watersheds, the mass of accumulated sediment must be accustomed for reservoir deposit TE. This assists to account for sediment that may consent the reservoir and avoids underestimating sediment deposition. Reservoir TE can be calculated in a variety of ways (Verstraeten and Poesen, 2000) as shown in equation 2.4. As explained by (Verstraeten and Poesen, 2000) model is one of the most usually used empirical-based models for small reservoirs.

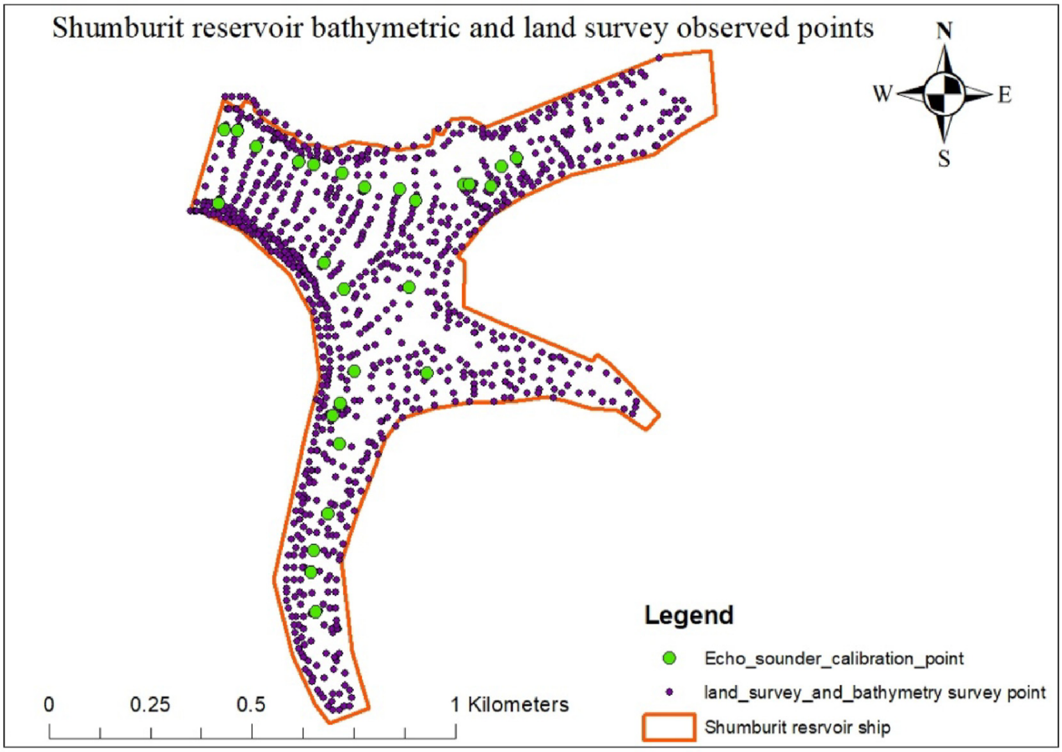

Figure 6. Shumburit reservoir bathymetric and land survey observed points.

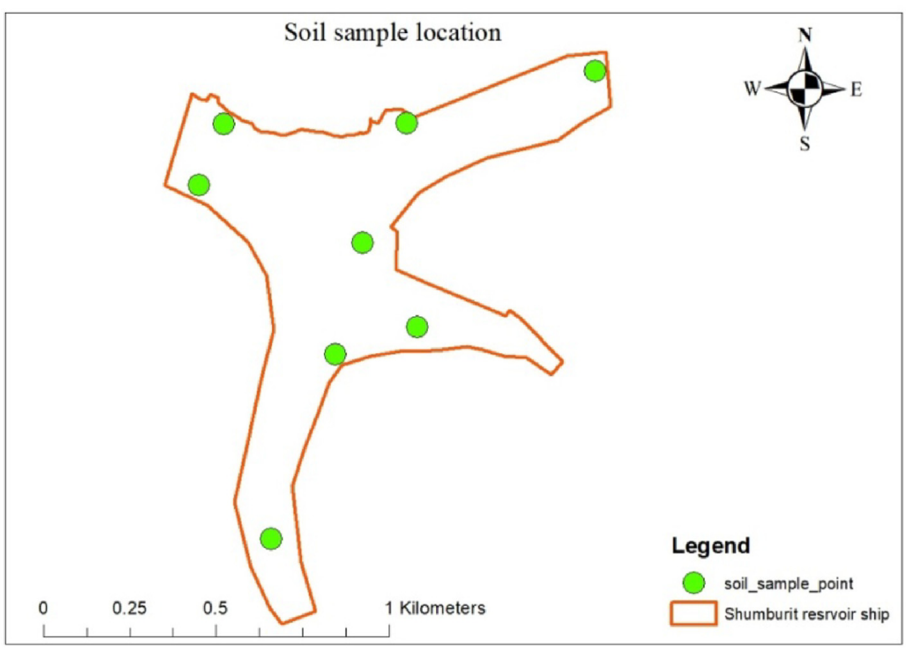

Figure 7. Soil sample location of Shumburit reservoir.

$$TE = 100\left[1 - \frac{1}{1 + 0.0021D^{*}\frac{C}{A}}\right] \qquad 2.4$$

where TE (%) is trap efficiency, C is reservoir storage capacity (m^3), and A is the catchment area (km^2). D has constant values ranging from 0.046 to 1. A value of D = 0.1 is recommended for average conditions, and values of D = 1.0 for coarse sediment; D = 0.1 for medium sediment; and D = 0.046 for fine sediment are also recommended (Gill, 1979). The value of TE depends on the value of D, which depends on reservoir and sediment characteristics. Since the sediment of the study area consists from coarse up to fine size so the value of D was taken as average value 0.1.

2.4.4. Determination of dry bulk density

To compare the sedimentation rates of different reservoirs, the measured sediment volume (m^3) must be changed to sediment quantity (tons) by dry bulk density (DBD) (Verstraeten and Poesen, 2000). The sediment mass was estimated using its dry bulk density (DBD), which was then multiplied by the measured sediment volume. During the field investigation, the sample was taken at random while considering the entering of sediment into different sub-catchments of the reservoir and the soil type/layer variation in the section by visual inspection and inserted into the oven dray. The sediment should then be weighed both before and after it has dried in the oven.

2.4.5. Estimating of sediment yield and specific sediment yield

The total sediment release from the watershed into the reservoir over a given period is referred to as sediment yield. Divide the sediment yield by the catchment area to get the specific sediment yield (Verstraeten and Poesen, 2001) as shown in Eqs. 2.5 and 2.6:

$$SY = \frac{SV*DBD}{TE*\Delta T}*100 \qquad 2.5$$

$$SSY = \frac{SY}{A} \qquad 2.6$$

where SY is sediment yield (ton/year), SSY is Specific sediment yield (ton/km^2/year), SV is the measured volumetric sediment of the reservoir (m^3), TE is the sediment trap efficiency (%), ΔT is the time interval (years) between two successive reservoir surveys, DBD is the average dry bulk density of the sediment (ton/m^3), and A is the watershed area (km^2).

2.4.6. Estimation of the useful life of the reservoir

The useful life of a reservoir is the time taken between depleting 50% of its storage capacity and filling the dead storage with sediment (Gill, 1979). According to Haregeweyn et al. (2012), the useful life of a reservoir is commonly resolute by the rate of dead storage capacity loss rather than the total volume loss and is estimated using the following equation 2.7.

$$LE = \frac{DSV}{SR} \qquad 2.7$$

Where LE is the life expectancy of the reservoir (in years), DSV is the dead storage capacity of the reservoir, considered as the capacity loss at the dead storage level and SR is the sediment Deposition rate (m^3/year). SR is calculated by using equation 2.8

$$SR = \frac{SV}{\Delta T} \qquad 2.8$$

Where SV is the sediment volume (m^3) that was collected between the year Construction and bathymetry surveys and ΔT is the time interval between two consecutive reservoir investigations.

The overall methodology used to estimate sediment accumulation and use full life of the reservoir is summarized as shown in Figure 8.

3. Results and discussion

3.1. Development of raster map

Geo-statistical data analysis is very important to identify the best interpolation techniques and to cross-check observed data or bathymetry survey data with the estimated depth parameters in other locations using ArcGIS software. In this case, five types of interpolation methods were tested that were found in ArcGIS 10.8 version software, and validating each spatial interpolation technique was done using cross-validation to

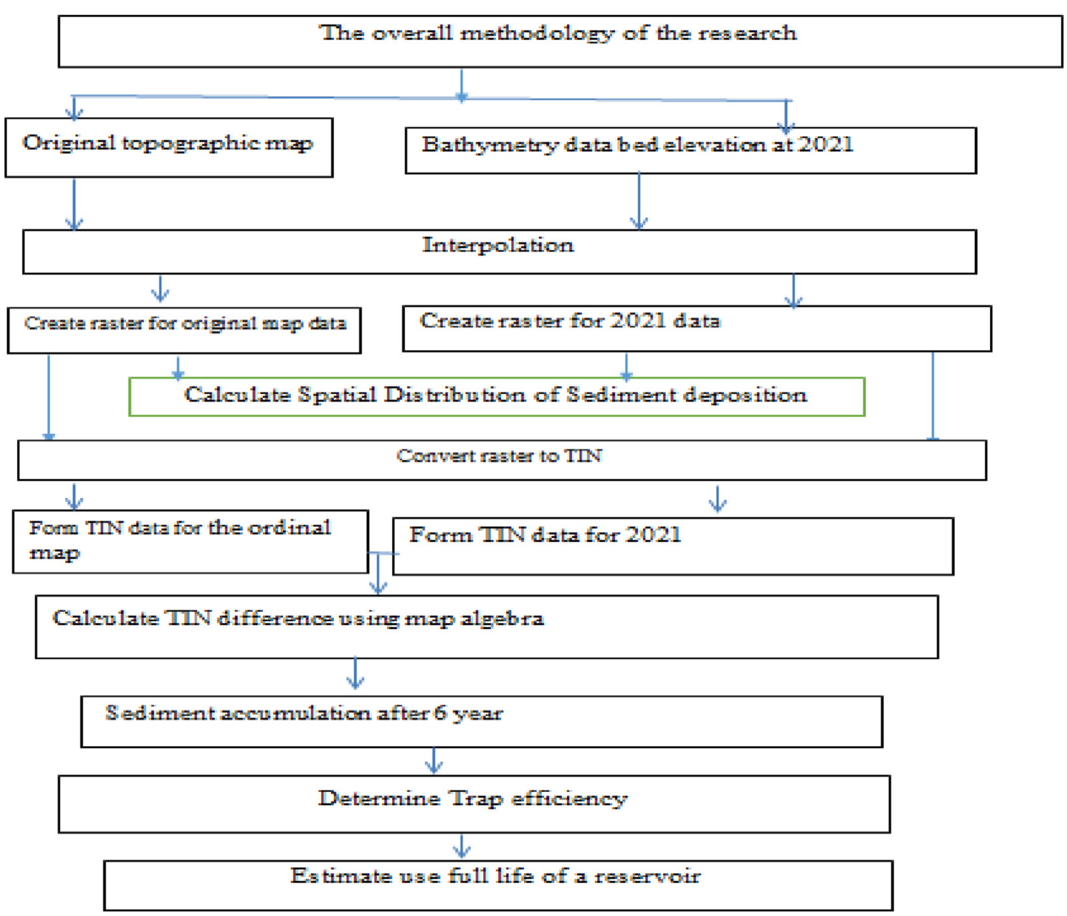

Figure 8. Overall methodologies of the study.

compare the prediction performances. The Kriging interpolation had one of the lowest RMSE (1.116 m) and a higher coefficient of correlation ($R^2 = 0.944$) as compared to the other five methods used. The results of this analysis are reported in Table 5 and Figure 9 as shown below. As a result, the Kriging interpolation method was chosen for spatial interpolation to develop a raster map, as shown in Figure 11 and Table 6.

The reservoir area covers 15.9 ha within a depth range between 2 to 8 m and 0–2 m covers the maximum area (i.e. 40.76 ha) and a small area of the reservoir has a depth of between 8 to 10.1 m as shown in Figure 10. The deepest depth reading within the reservoir was 10.1 m near the dam axis and at the center of the reservoir. 70.08% of the reservoir covers a depth of 0–2 m.

3.2. Development of reservoir TIN map

The creation of a TIN map was critical in calculating the reservoir's volume and area. The TIN surface is a digital illustration of the reservoir bed surface composed of unevenly scattered nodes resulting from contour lines and point extents with 3D coordinates (x, y, z) prescribed in a system of non-overlapping triangles (Stoner et al., 2022). The TIN surface derived from the design topographic survey is shown in Figure 11, and the bathymetry survey is shown in Figure 12.

3.3. Area-storage-capacity curve analysis

Reservoir storage capacity is gradually diminished as sediment accumulates, causing variations in area-storage capacity curves. Dam planners, designers, and operators need to know about these curves. In Arc-GIS software, the 3D Analyst tool of the useful surface was used to calculate reservoir volume and reservoir area at 1 m elevation intervals for the original and current reservoir capacity calculations. The total volume of sediment collected is represented by the decline in reservoir storage volume for the two surveys conducted at different periods. New operating curves were produced based on the investigation done in 2021 to ensure the careful operation of the Shumburit reservoir. The TIN from the 2016 and 2021 surveys was used to compute water surface area and packing volume as a purpose of water elevation, with the results shown in Table 8 and Figure 15. The reservoir capacity was estimated to be 394.7ha-m (3.947Mm^3) and 365 ha-m (3.65 Mm^3) at gross storage level in 2016 and 2021, respectively, based on 3D analysis in ArcGIS. The reservoir's original outer boundary area has been reduced by 2.09 ha in six years, from 42.39 ha before 2016 to 40.3 ha in 2021, due to reservoir area erosion and at the full supply level of water levels at 2132.5m. Table 7 and Figure 13 show the volume and size of the reservoir for each 1 m elevation interval.

The shift of both the area and volume curves of the original map indicates that the reservoir has a reduced capacity or that sediment has accumulated in the reservoir as shown in Figure 13.

3.4. Deposit of sediment in a reservoir

The amount of sediment deposited in the reservoir was estimated using the reservoir capacity difference between 2016 and 2021. Shumburit storage volumes at maximum full supply level or gross storage level were 3.947 Mm^3 in 2016 and 3.65 Mm^3 in 2021, respectively. The storage capacity difference was 0.297 Mm^3 (362000 tons) or deposited sediment in a reservoir over six years of operation. In other words, over the last six years, the overall storage volume loss due to sediment deposition was 7.52 percent. Supposing a persistent rate throughout the period, the annual sedimentation rate became 49500 m^3/year (60390 tons/year), and the annual reduction in storage capacity related to sedimentation was 1.25% of total storage capacity. The findings of this study suggest that the sedimentation problem is similar to that of most other reservoirs in Ethiopia. Haregeweyn et al. (2006) stated yearly whole volume loss values ranging from 0.18 to 4% for 13 reservoirs in northern Ethiopia. This result is also lower than previous research in the Anjeb reservoir, Abrajet reservoir, Tembi reservoir, and the Legemera micro-earth dam reservoir. Menberu Z. et al. (2021) conducted reservoir sedimentation studies in the Anjeb reservoir, and he reported that the reservoir's yearly capacity loss was 11.5%. Mekash Shiferaw (2019) conducted a study on the Abrajet Reservoir in the East Gojjam zone and discovered that the annual reservoir capacity loss rate was 1.66%. Mesfen S. et al. (2018) studied Tembi Reservoir and found that the annual capacity reduction was 1.77 percent each year. Anteneh et al. (2022 investigated reservoir sedimentation at the Legemera micro-earth dam reservoir in northern Ethiopia, and he reported that the reservoir's annual capacity reduction was 6.94% per year. However, the Shumburit reservoir's annual decrease in loading capacity related to sediment was 1.25%, which is higher than the worldwide average sedimentation rate, as estimated by Howard (2000), which was 1%.

3.5. The thickness and distribution of reservoir sediment

The first step was to generate raster layers using the 2016 and 2021 TIN data to define the dissemination of sediment thickness in the reservoir. The 2016 reservoir bed elevation raster was then deducted from the 2021 reservoir bed elevation raster using the Raster Math-Minus spatial analysis tool to generate the 2021 reservoir bed elevation raster. According to the calculated results, the greatest sediment thickness was 4.34 m, the maximum computed elevation reduction was 2.74 m, and the average computed sediment thickness was 0.8 m. The negative 2.74m shows that the depth has been reduced from the original ground level by 2.74m, indicating that they were excavated during construction to be used as core martial after a topo survey was taken. The maximum sediment thickness values are produced by delta deposition near the reservoir's mouth. Table 8 and Figure 14 were used to indicate sediment deposition locations in reservoirs for sediment management.

Table 8 and Figure 14 show the distribution and accumulation of sediment thickness and volume in each zone over the six-year operating period. Dead storage zones have sedimentation rates of 31,666.67 m^3/year (38,633.34 tons/year) and live storage zones have sedimentation rates of 48,333.33 m^3/year (58,966.66 tons/year) (i.e., in this case, the sedimentation rate at live storage is 48,333.33 m^3/year, which means sediment is distributed at each level of elevation depending on the characteristics of the sediment, which means that the heaviness or larger sediment is deposited near to the entrance of each direction, so that sediment is distributed at each level of the reservoir). In other words, Table 9 also demonstrates that the dead storage and live storage zones have lost 40.43% and 11.11%, respectively, of their storage capacity after six years of operation, whereas the gross storage capacity of a reservoir has lost 7.52%. Even though both the dead storage and live storage zones are losing capacity, the dead storage zone has lost significantly more. The reservoir's capacity was lost because the watershed is dominated by fine soil fractions. This indicates that the fine soil fraction was transported to the end of the reservoir, even at lower flow rates. Furthermore, it was discovered that sedimentation had a negative impact not only on dead storage but also on live storage to an even greater extent. This study discovered that the annual sedimentation rate was of the same order as stated yearly entire volume loss values ranging from 0.18 to 4% for different reservoirs in northern Ethiopia when comparing annual sedimentation rates in a regional context (Haregeweyn, 2006). When compared to the siltation problem of the Shumburit reservoir to the

Table 5. Summary of interpolation method.

Interpolation method	MAE	RMSE	R^2
IDW	1.35	1.92	0.938
OK	0.693	1.116	0.944
GPI	3.576	4.288	0.169
LPI	0.696	1.179	0.938
RBF	0.806	1.321	0.922

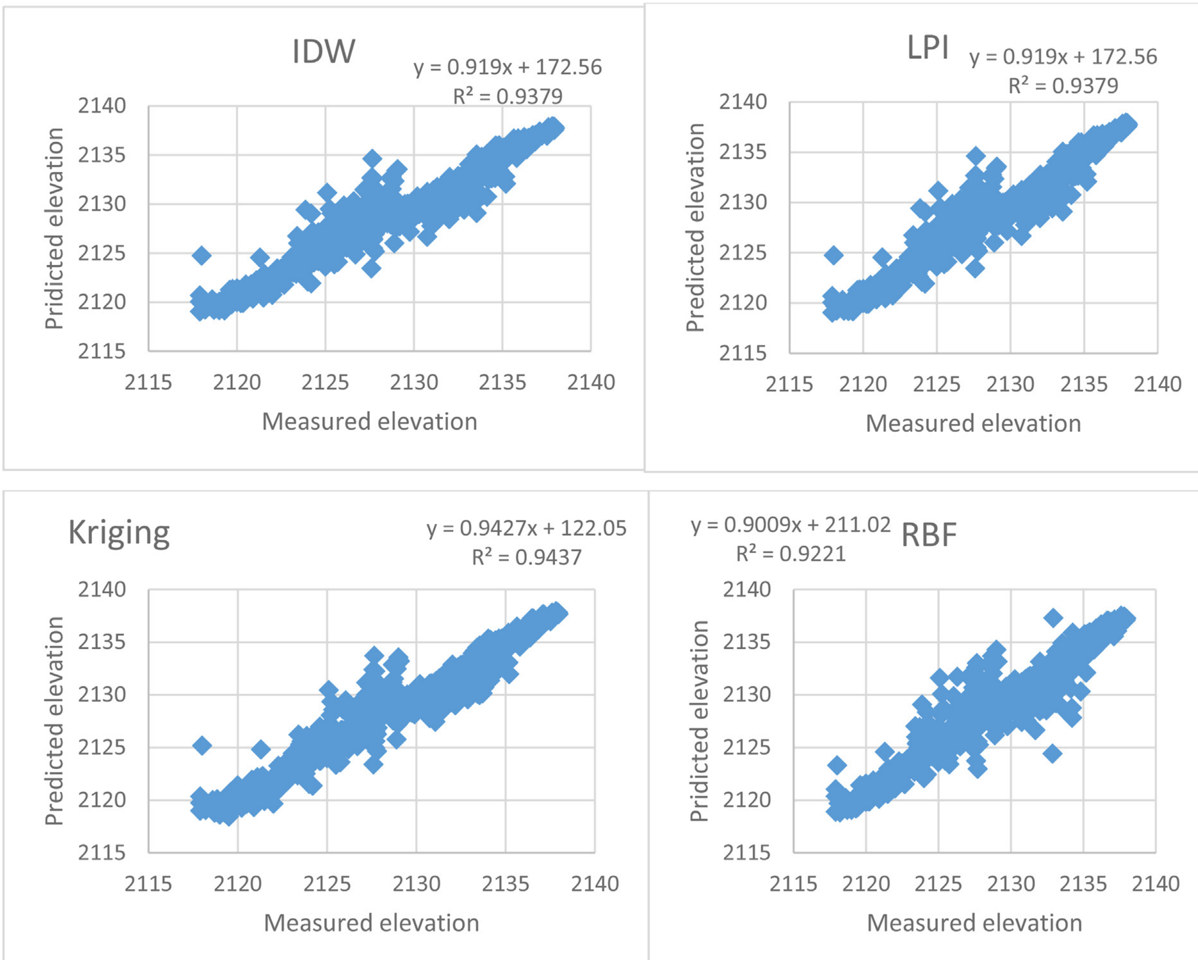

Figure 9. Measured elevation Vs. predicted elevation.

world's average annual rate of storage loss due to reservoir sedimentation, which ranges between 0.5 and 1 percent of total storage capacity, the siltation problem appears to be more severe (Howard, 2000). The use of cut/fill function within the 3D Analyst tool in Arc GIS software was used to show the net sediment deposition and net scouring of the Shumburit reservoir in the last six years. According to the findings of this study, as shown in Figure 15, with blue areas representing net deposition and green areas showing net scour, or the area that is lower than the original ground level, the main cause of scoring in the Shumburit reservoir was that it was excavated during the construction period to use a core material and filling material for dam and canal construction, which was approved during the data collection and observation period. Most of the scoring area was found on the reservoir's periphery or the banks, as shown in Figure 15 and Table 9. The scoring area during construction was expressed and the net deposition of sediment was distributed in different zones of the reservoir, which means that sediment is not only settled in the dead storage, but the sediment inflow also settles on the entire surface of the reservoir storage. During the reservoir's six-year operational period, sediment deposition occurs in all of the reservoir's zones (i.e., the sediment is deposited on both dead storage and live storage).

Table 6. Area coverage at different depth.

No	depth	area in (ha)	area coverage (%)
1	0–2	40.76	70.08
2	2–4	6.9	11.86
3	4–6	5.2	8.94
4	6–8	3.8	6.53
5	8–10.1	1.5	2.58
	total	58.16	100

3.6. Shumburit river's longitudinal profile change

As indicated in Figure 16 below, the longitudinal profile of the Shumburit riverbed was obtained after six years of activity. Before the reservoir impoundment and bathymetry survey, longitudinal profiles were plotted using ArcGIS' 3D analysis (profile graph) tool, and two reservoir topography raster maps were generated. Longitudinal profiles were drawn along the pre-impoundment river, i.e., the river's centerline within the reservoir basin, for both the 2016 and 2021 surveys. The difference between the longitudinal profiles from 2021 and 2016 represents the sediment dropped on the river centerline within the reservoir over six years. The deepest sediment deposition was determined to be 4.34m around the upstream of the dam (i.e., 575m away from the upstream reservoir entry). However, there was no scouring along the river center, and in this study, scoring (below the original level) occurred mostly at the edge of the reservoir. The river's total bed slope changed from 0.87 percent to 0.75 percent within a 1.55-kilometer fetch length.

3.7. Reservoir useful life estimation

The useful life of a reservoir is defined as the time it takes to exhaust 50% of its loading capacity or fill the dead storage with silt. Because the silting rate in a reservoir is straight predisposed by the sediment made in

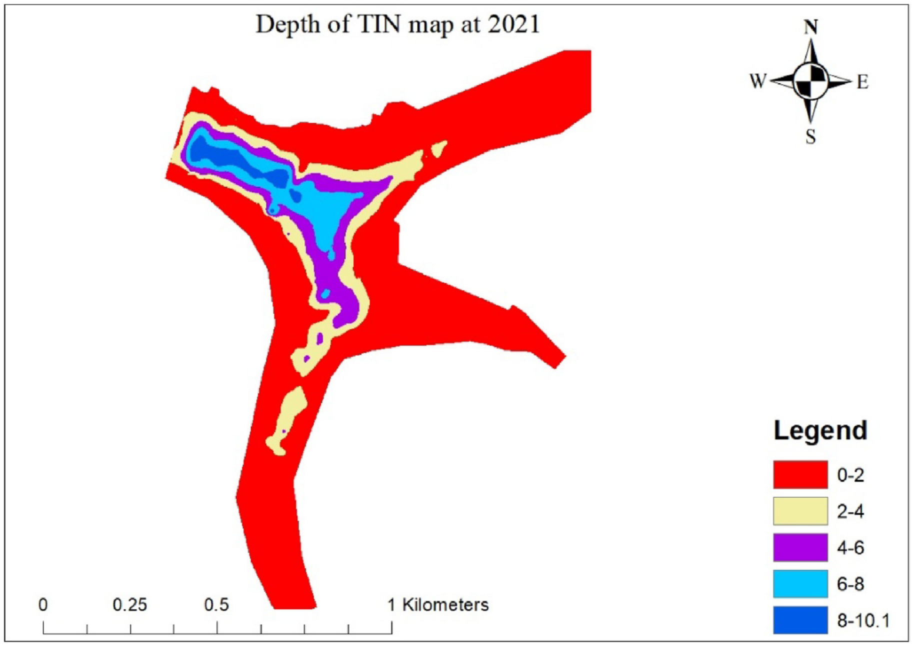

Figure 10. Bathymetry surveys in 2021 using the Kriging method by the depth.

the catchment and the quantity of material contained in the reservoir, the reservoir's life is shortened. In this study, reservoir life was calculated using Eqs. 2.7 and 2.8.

$$LE = \frac{DSV}{SR}\frac{470000}{31666.67} = 14.8 \text{ years}$$

It indicates that the dam gives the function approximately 15 years. Where LE is reservoir life probability (years); DSV is reservoir dead storage volume and.

SR = sediment deposition rate (m^3/year).

The sedimentation rate of the total reservoir was designed as follows:

$$SY = \frac{SV}{\Delta T}\frac{190000}{6} = 31666.67m^3 \Big/ \text{year}$$

SV = sediment volume in dead storage (m^3) collected among the year of process (ΔT) and in this case, the original and the current sediment deposition are discussed in Table 10.

The useful life of the reservoir is projected to be fifteen years based on deposited silt at the dead storage level. However, a review of the design report reveals that the reservoir's useful life is adaptable to 25 years. The reservoirs' failure to attain their design life could be due to a variety of causes. The most common cause of reservoir design life failure is a lack of soil and water management practices in the area.

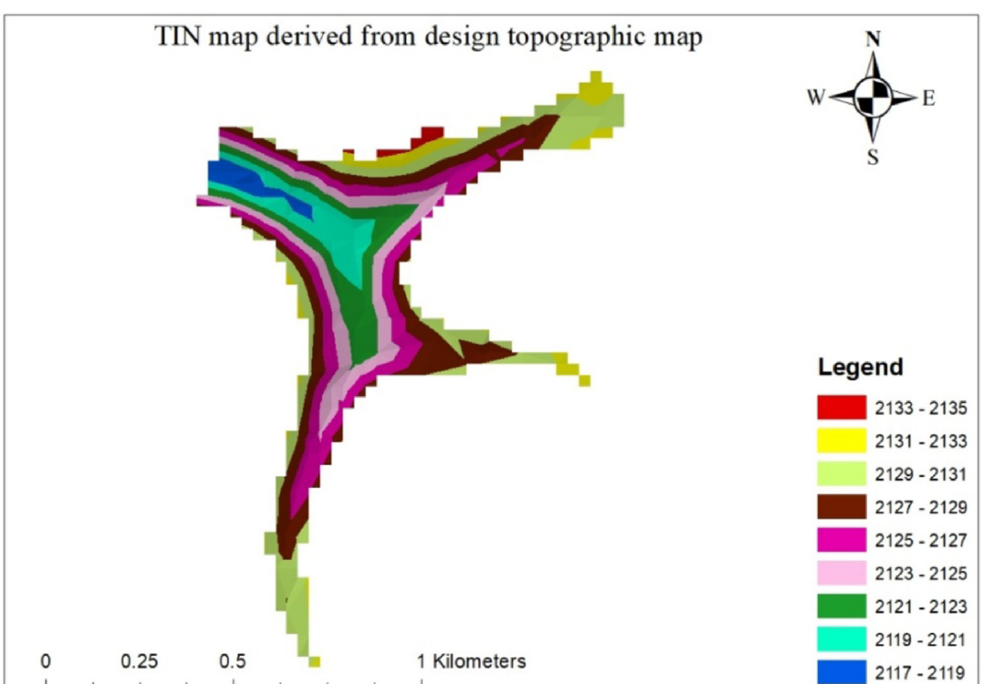

Figure 11. TIN map derived from design topographic map.

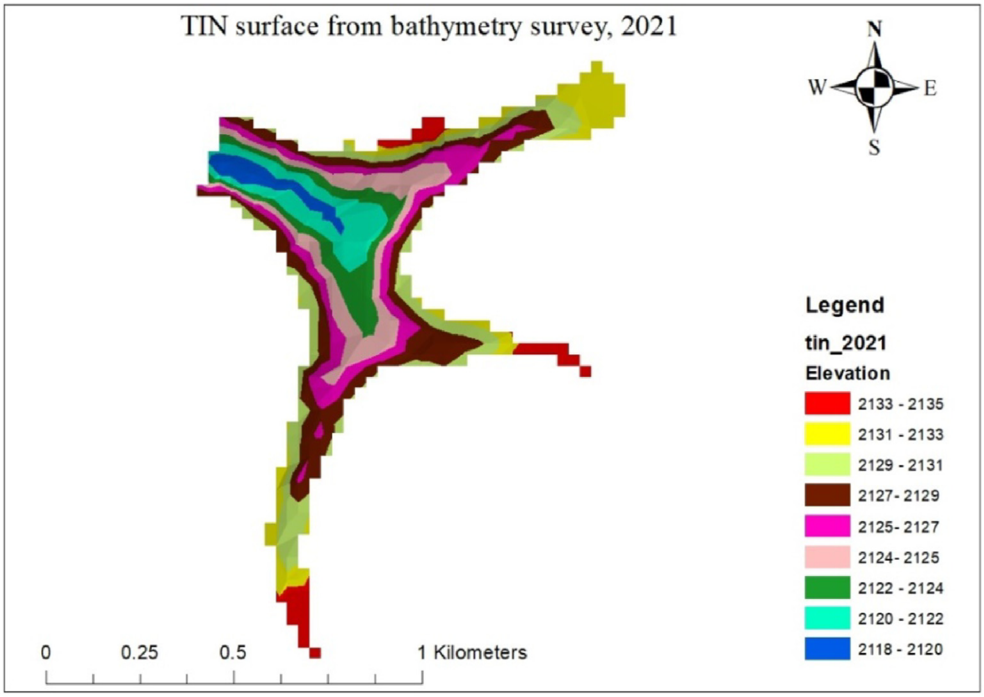

Figure 12. TIN surface from bathymetry survey, 2021

3.8. Reservoir trap efficiency

To calculate the average sediment output from contributing watersheds, the weight of deposited sediment must be adjusted for reservoir sediment TE. This aids in the correction of silt that may exit the reservoir and reduces the possibility of underestimating sediment deposition. The reservoir trap efficiency of the Shumburit reservoir is calculated using Eq. (2.4), as given in the material and methodology section. The trap efficiency was calculated using a 13.5 km^2 watershed area and a reservoir capacity of 3947000m^3.

Table 7. Area and volume calculation summary.

Reservoir area and volume in 2016			Reservoir area and volume in 2021		
Elevation (m)	Area (ha) in 2016	volume (ha-m) 2016	Area (ha) 2021	volume (ha-m) 2021	
2117	0	0	0	0	
2118	0	0	0	0	
2119	0.52	0.17	0	0	
2120	2.04	1.24	0.83	0.3	
2121	3.88	4.11	3.24	2.13	
2122	5.88	8.8	5.3	6.48	
2123	8.33	15.7	7.1	12.58	
2124	11.29	25.56	9.83	20.59	
2125	14.39	47.01	12.37	28	MDDL
2126	17.65	53.99	15.62	45.33	
2127	21.49	73.17	19.11	62.64	
2128	26.15	96.85	23.14	82.97	
2129	31.28	125.71	28.12	108.84	
2130	35.88	159.5	32.25	139.17	
2131	39.83	197.79	35.83	173.8	
2132	42.07	239.46	38.6	211.42	
2132.5	42.39	260.7	40.3	231.36	FSL
2133	42.61	281.96	40.88	270.72	
2134	42.95	394.7	42.82	365	

$$TE=100\left[1-\frac{1}{1+0.0021D^{*}\frac{C}{A}}\right]=100\left[1-\frac{1}{1+0.0021^{*}0.1^{*}\frac{3947000}{13.5}}\right]=98.4\%$$

3.9. Analysis of reservoir sediment core samples

Eight undisturbed sediment samples were taken in core rings (with a known volume) and oven-dried for 24 h at 105° at Debre Markos University's Soils Laboratory for soil mechanics to decide the dry density of dumped sediment. The mean dry bulk density of the reservoir was 1219.9 kg/m^3, ranging from 1219.6 kg/m^3 to 1220.3 kg/m^3. The mean dry bulk density of the reservoirs was found to be within that range when compared to previous research. Haregeweyn et al. (2006) found that the mean dry bulk density of several northern Ethiopian reservoirs ranged from 1010.18 to 1420 kg/m^3.

4. Conclusion and recommendations

4.1. Conclusion

One of Ethiopia's most difficult water-related problems is reservoir sedimentation, which reduces water depth and aids aquatic plant growth. In this case, bathymetry was used to calculate the watershed's specific sediment yield production and the total accumulation of sediment. The capacity loss, sediment spreading, useful life, and mass of put-down sediment in the Shumburit reservoir were examined. Several processes were used for this methodology, including accurate topographical surveying, creating a pre-impounding topography map of the reservoir area, calculating the dry sediment bulk density to convert sediment volumes to sediment masses, and determining the reservoir's sediment trap efficiency.

According to the bathymetric results of the survey, the total deposited sediment between 2016 and 2021 is estimated to be of the magnitude of 29.7 ha-m (297000m^3) or 0.364 M tons, which reduces about 7.52% (i.e., from 3.947 Mm^3 in 2016 to 3.65 Mm^3 in 2021) of the gross storage capacity in six years of operation. Annual sedimentation rates using bathymetry have been 49500 m^3/year by assuming the rate is the same over the entire period, and the annual reduction in storage capacity due to

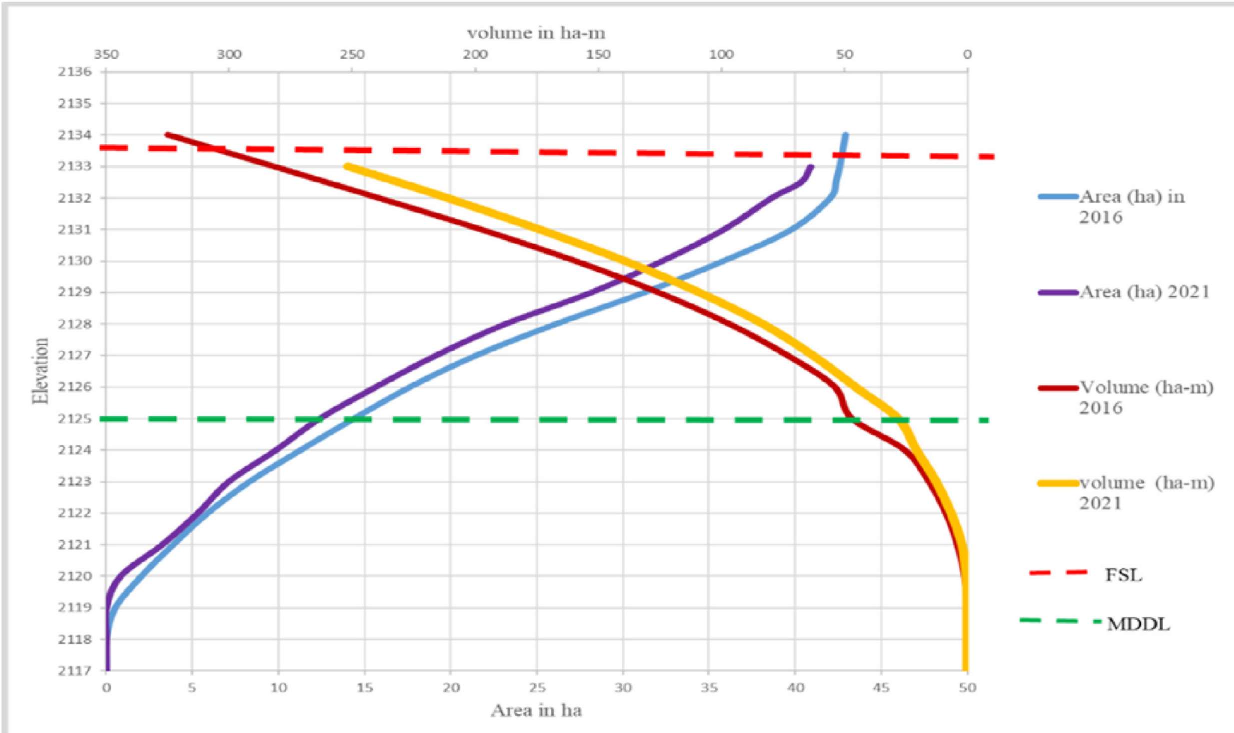

Figure 13. Area Elevation curve and Capacity Elevation curve.

Table 8. Storage capacity for both live and dead storage zones.

Zone	Elevation	Storage capacity (SC)				
		survey 2016	survey 2021	The difference in SC or sediment accumulation	rate of sediment m^3/year	SC Reduction
	m (amsl)	Mm^3	Mm^3	Mm^3		%
Dead zone	2125	0.47	0.28	0.19	31666.67	40.43
Live zone	2125–2132.5	2.61	2.32	0.29	48333.33	11.11
Gross Reservoir capacity	2134	3.947	3.65	0.297	49500	7.52

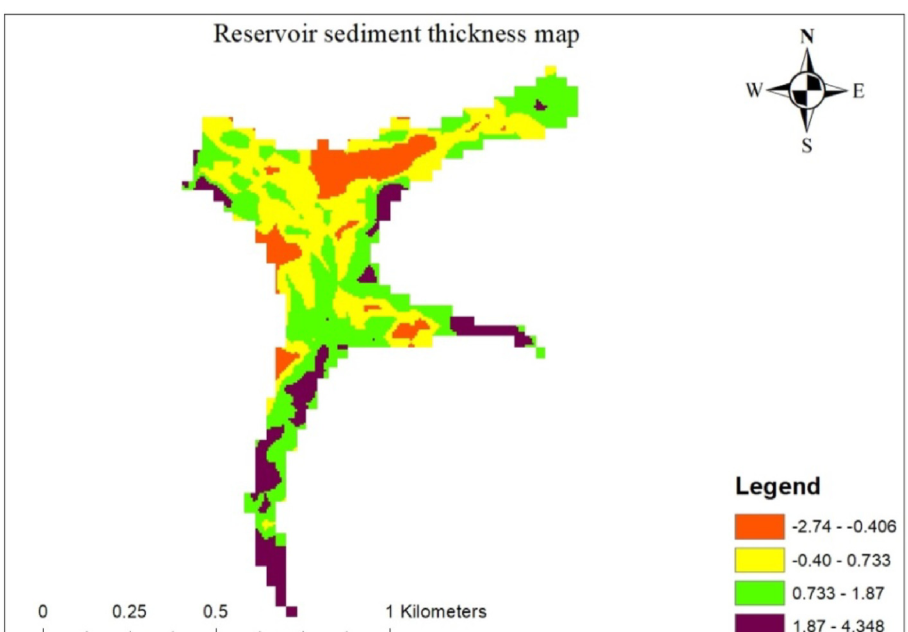

Figure 14. Reservoir sediment thickness map.

Table 9. Area coverage in net gain and a net loss of Shumburit reservoir.

Deposition of sediment	Area coverage (ha)
Net gain (sediment deposition)	33.95
Un changed	0
Net Loss (scoring)	9.07

sedimentation is 1.25% each year. Sedimentation, on the other hand, reduced live storage by 11.11%, or the storage capacity of live storage was reduced from 2.61 Mm^3 to 2.32 Mm^3 in six years of operation. Furthermore, the study's actual specific sediment yield was 45.46 tons/ha/year, which was much greater than the global and African averages of around 1,500 and 1,000 tons/km^2/year, respectively. However, the result is accepted because Tamene et al. (2006) stated that the definite sediment production value in the northern Ethiopian highlands ranges from 3.45 to 49.35 tons/ha/year. The reservoir's useful life is estimated to be 15 years based on bathymetric results. The main source of excessive sedimentation in the Shumburit reservoir is poor watershed management; most of the watershed is cultivated, and there is no buffer surrounding the reservoir.

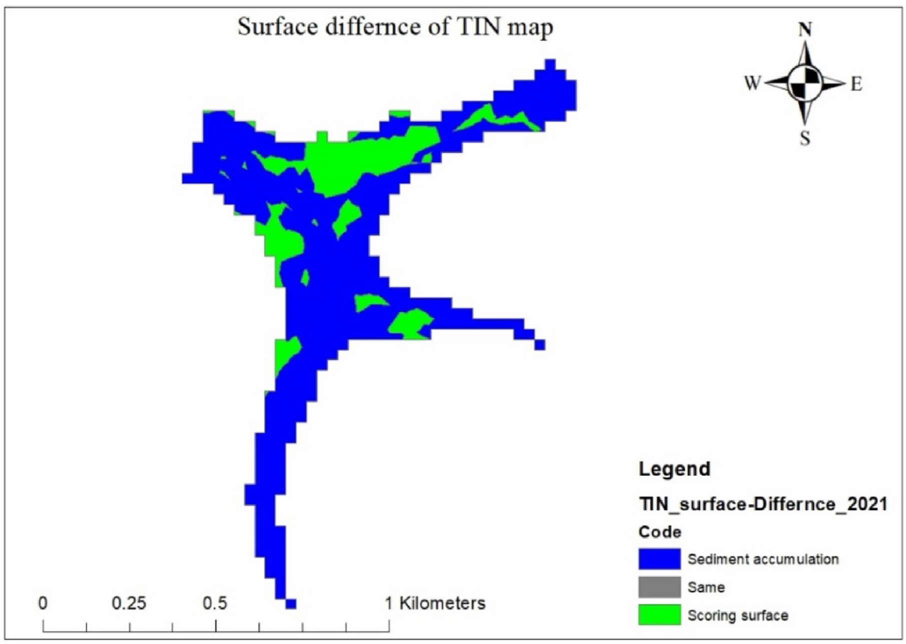

Figure 15. Net gain and loss of reservoir sediment volume map.

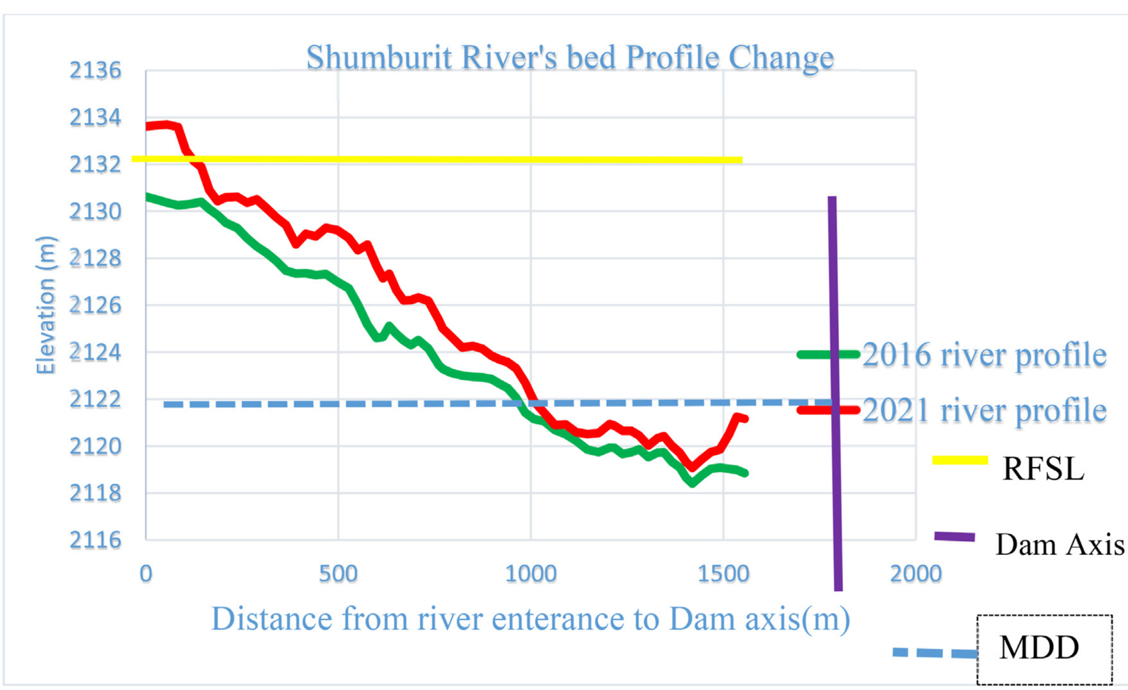

Figure 16. River bed profile comparison.

Table 10. Location of sediment core sampling.

Description	Easting	Northing	Average sediment density (ton/m^3)
Sample 1	325972	1147847	1.2198
Sample 2	325455	1147108	1.2196
Sample 3	325297	1147352	1.2198
Sample 4	325220	1147027	1.2198
Sample 5	325032	1146494	1.2198
Sample 6	324823	1147519	1.2203
Sample 7	324897	1147695	1.2203
Sample 8	325426	1147697	1.2198
average			1.22

4.2. Recommendations

In this study, the following recommendations are suggested for now and next.

To prevent sediment from entering the reservoir, avoid cultivation or agricultural activity around the reservoir and preserve buffer zones around it. Because this project has a relatively small watershed (13.5 km^2), the suspended particles are carried by the runoff a shorter distance to the reservoir without settling somewhere along the way in the watershed. As a result, to decrease soil loss and sediment entry into the reservoir, considering integrated watershed management is critical, the community and the Debre Eliyas worda administrator should implement soil and water conservation measures such as land contouring, terracing in steep slope areas, and planting specific trees and grass in the watershed area.

Dam designers and decision-makers should pay attention during the design stage to provide a bottom outlet for sediment discharge and flushing. Dam designers should also pay attention to providing enough dead storage capacity depending on the watershed characteristics to increase the useful life of the reservoir.

In this project, there is no elevation reader apparatus or gauged instrument. Elevation readers are used to reading the level of water each day throughout the year. This helps to find the information sediment level and is also used to minimize the error of the reservoir level during sediment investigation.

The stakeholders should awareness the community to protect the reservoir as well as the dam to achieve the goal of the project.

Declaration

Author contribution statement

Lake Endalew; Arega Mulu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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