



Evaluation of reservoir sedimentation using bathymetry survey: a case study on Adebra night storage reservoir, Ethiopia

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Abstract

Reservoir sedimentation is a serious challenge that reduces reservoir life. Because it decreases the initial capacity of the reservoir and has an impact on drinking water supply, irrigation, and hydropower activities. Inadequate land activities and poor management techniques cause soil erosion and reduce reservoir storage capacity. As a result, accurate sediment estimation was assist in the adoption of sustainable land-use activities and best management practices that lead to effective reservoir operations. The main objective of this study was to evaluate the rate of sedimentation and remaining capacity of Adebra night storage reservoir (NSR) using a bathymetric survey and Arc-GIS 10.8. A comparison of original and current reservoir capacity was used to evaluate the quantity of sediment deposition in the reservoir. The latter was developed using Arc-GIS 10.8 and a bathymetry survey that was used to develop the TIN surface and evaluate reservoir volume. The Adebra NSR reservoir capacity was decreased by the accumulation of sedimentation from 36,902 m³ in 2012 to 27,722 m³ in 2020. The results of this study showed that the Adebra night storage reservoir had lost on average 24.8% of its capacity due to sedimentation, during 8 years of operation. The average deposition rate of sedimentation in Adebra NSR was estimated to be 1147.5 m³/year, with a loss rate of 3.1% per year. The value of sedimentation rates found in live storage of the reservoir area was 1147.5 m³/year. At the current time, the expected life of the night storage reservoir was reduced due to a lack of proper soil conservation practices in the reservoir catchment areas. In general, the study finding showed that the capacity of NSR was reduced by the accumulation of sedimentation year to year throughout the design period. Therefore, to improve the capacity of NSR should be planning and implementing different techniques of sediment control and removal, depending on the estimation of sediment production from watersheds of inlets and outlets of reservoirs.

Keywords Reservoir sedimentation · Bathymetry · Triangulated irregular network · Adebra night storage reservoir

Introduction

The reservoir has the potential to be used for a variety of purposes, including domestic water supply, irrigation, flood control, and water power; however, it is vulnerable to sediment buildup due to erosion in the watersheds. Reservoir sedimentation is the process of sediment being transported into a dam reservoir by streams, and it is a worldwide occurrence that has been seen as a major environmental hazard in recent years (Adongo et al. 2020; Ayele et al. 2021). Sediment deposition in reservoirs is a significant downstream consequence of soil erosion that endangers the long-term viability of dams built for various purposes in Ethiopia (Froehlich et al. 2017; Iradukunda and Bwambale 2021) and elsewhere.

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Currently, the global loss of storage capacity in surface water reservoirs due to sedimentation is greater than the increase in storage volume achieved through new reservoir buildings (Ayele et al. 2017; Kondolf et al. 2017). Reservoir sedimentation is a major issue all over the world since it decreased the reservoir's original capacity, affecting drinking water supply, agriculture, hydropower, flood management, and recreational activities. The sedimentation of reservoirs is unavoidable due to a lack of reservoir management measures such as reservoir sediment routing, periodic sediment flushing, and catchment management to decrease soil erosion, and it has steadily become a major issue for many countries across the world (Adongo et al. 2021; Michalec and Cupak 2021).

As a result, evaluating the sedimentation rate and the time period before silt accumulation interferes with the reservoir's effective operation is critical. Estimating catchment erosion and sediment delivery processes can be done in a variety of ways. Physically based models that predict watershed erosion are becoming increasingly prevalent (Abbasi et al. 2019; Sultana and Naik 2016). A Bathymetric survey of existing reservoirs is another method for determining sediment yield. This method compares the height of the sediment level in a reservoir before impoundment with the elevation of the current sediment level. Another method for evaluating sediment yield is to measure the thickness of reservoir sediment deposits using sediment pits (Hassan et al. 2017; Maina et al. 2018). Because measurements of sediment deposits do not include generalized statistical models of sediment erosion and transport, reservoir sedimentation survey methods are more useful and representative than the other approaches (Bombino et al. 2022; Issa 2015). A bathymetry survey is a more exact indirect approach to evaluating the volume deposited and its pattern in reservoirs than a geophysical survey (Maina et al. 2018; Zarris and Lykoudi 2017).

To guide targeted management, it is vital to identify the key causes of erosion and other factors that increase siltation in reservoirs. For the prediction of storage losses and the reservoir's likely economic life, a progressive evaluation of reservoir siltation is required information (Adongo et al. 2021; Moges et al. 2018). It is critical to maintain the reservoir's storage capacity by estimating and analyzing sediment yield, deposition pattern, and sediment dispersion inside the reservoir. With this consideration, the purpose of this study was to examine the change in sediment yield from the original capacity to the current capacity of the Adebra night storage reservoirs, as well as to estimate their usable life. Models that can forecast reservoir sedimentation are required for effective reservoir sedimentation management.

Reservoir sedimentation is a significant grounds result of soil erosion with significant economic and environmental implications. Sediment issues and management approaches differ greatly from one location to another, and

examining individual locations, which can help to understand the intricacy of sediment issues and how they can be solved. Dams are clearly needed to protect people from the negative effects of frequent droughts and to facilitate development in order to assure agriculturally based food security. The main objective of this study was to evaluate the rate of sedimentation and remaining capacity of Adebra Night Storage Reservoirs using bathymetric survey.

Materials and methods

Description of the study area

Adebra Night Storages irrigation development project is located in Amhara National Regional state, West Gojjam Zone, Mecha Woreda. It is found at a distance of 41 km from Bahir Dar town and 7 km to 15 km from Merawi town at the right side on main highway from Bahir Dar to Addis Ababa. The Night Storage Reservoir site is geographically located at 37°08' 00" E and 11°20' 00" N and 1983–1906 m above sea level (m.a.s.l) average elevation (Table 1). The study area map is as shown in Fig. 1.

Materials

The bathymetric survey chart plotter Garmin GPS Map 421 s single beam echo sounder given by Bahir Dar University; Institute of Technology was used to collect depth sounding with their matching location measured in the Koga night storage reservoirs bathymetric survey chart plotter. The echo sounder is mounted on a local boat and is powered by a 12v sealed lead-acid charged battery. Aside from the Etrex, using a Garmin hand held GPS to pilot our local boat through the geo-referenced transect path and to capture the geographical coordinate point of the reservoir's limit. These materials were listed from (Table 2).

Table 1 Salient features of the Adebra night storage reservoir

Name of NSR	Item	Unit	Features
Adebera NSR	Bed level	Masl	1983.4
	level of outlet	Masl	1983.4
	Capacity	m ³	36,902
	Normal crest level	Masl	1986.944
	Full supply level	Masl	1986.675
	Command area	Ha	694
	Area of reservoir	m ²	25,975

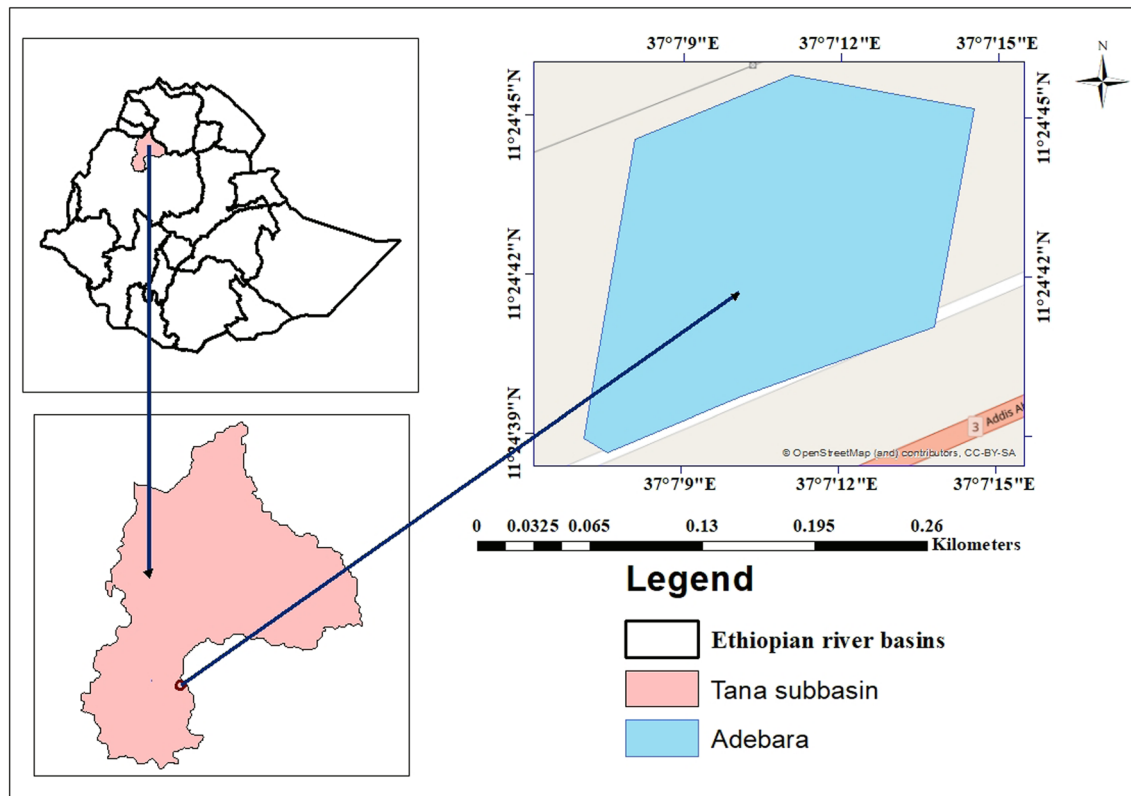


Fig. 1 Map of study area of Adebra NSR

Table 2 List of materials used in the NSR bathymetric survey and sediment sampling

ID	Equipment Name
1	Hand held GPS map 62 s
2	Topographical point data NSR area(during design time) original point
3	Soil Core cutter
4	Garmin GPS421s and echo-sounder to measure the depth of water
5	Local boat
6	Soil sampler and soil container
7	Drying oven
8	Any necessary software such as ArcGIS and computer

Calibration of the sounding instrument

Calibration with local field conditions is required prior to use of the instrument to ensure that it gives reliable readings. As a result, the echo-sounding equipment was initially tested at the Koga night storage reservoir with Garmin TM GPS Map 421 s, and comparisons were performed with repetitive hand measurements using a 5-m long graduated staff and measuring tape (Fig. 2).

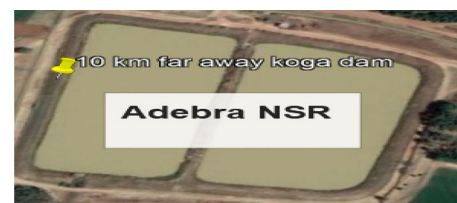
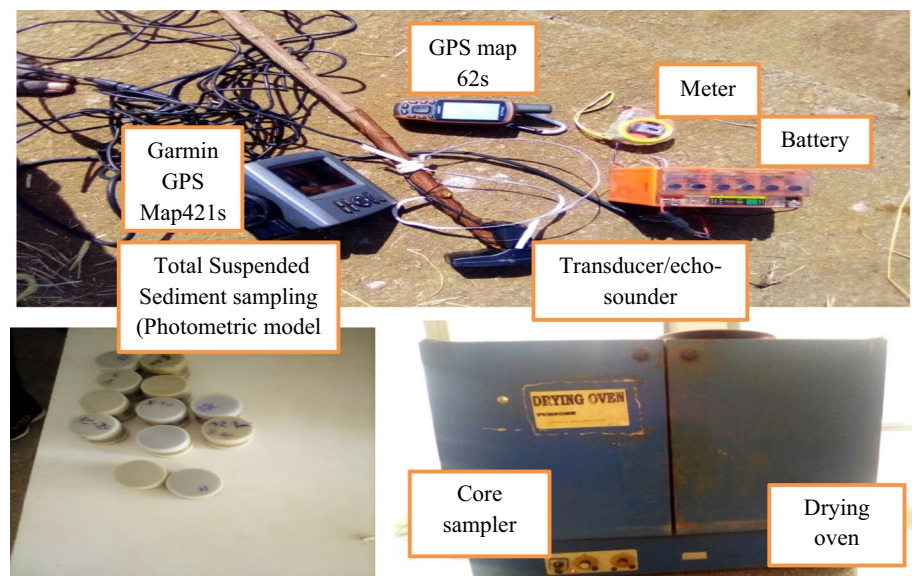


Fig. 2 Location of Adebra NSR area on Google Earth taken 2020

Calibration was done again in the Koga night storage reservoirs to ensure that measurements were accurate. During this phase, the sounder was located at the right point, the GPS Map 421 s was connected to the transducer, the submerged depth of the transducer from the water surface was measured, and the package was checked for synchronization. For the main calibration, some trial sample preliminary measurements were randomly taken, and which included readings from both methods as well as x and y coordinates. During the data collection period, depth calibration was performed twice daily (at the start and end dates) by placing a long graduate staff for a shallower depth at various spots across the reservoir (Fig. 3).

The square Root of the Mean Squared Error (RMSE) was calculated using (Eq. 1) to evaluate the accuracy of this

Fig. 3 Photograph of material used at field and laboratory taken during surveying



measurement. During the bathymetry survey, about 12 quality assurance data points were collected.

$$\text{RMSE} = \sqrt{\frac{1}{n}(\text{ZM} - \text{ZS})^2} \quad (1)$$

where RMSE—root mean square error of Z or vertical component, ZM and ZS are the depth reading by tape measurement on stick and Echo sounder reading depth, respectively, and n is the number of measured points. When the water depth was in the range of 1.5 to 1.8 m within the night storage reservoir, the error values (RMSE) of water depth measurements were 0.0332 m using Eq. 1. To evaluate vertical accuracy at 95% of the confidence interval, a factor of 1.96 is multiplied by the RMSE, yielding a value of 0.136 m, according to the (Moges et al. 2018) guideline. According to them, this inaccuracy was acceptable (Díaz-Gutiérrez et al. 2019; Assfaw 2020).

Estimating reservoir sediment deposition

The reservoir sedimentation evaluation includes a bathymetric survey to determine the rate of sedimentation in Koga night storage reservoirs and the sediment distribution. To gather land surface altitude data up to the escape weir crest level or above, this survey is frequently augmented with some type of topographic survey. It is based on a comparison of reservoir capacity volumes over time.

Before the dam was built, a contour map for the reservoirs was created using a topographic map before impoundment. In this instance, data on the reservoirs' initial capacity must be used as a standard against which the current storage capacity can be evaluated. Then came the acquisition of the original reservoir topography map. Abbay Basin Authority

Drawing Nr KDIP/2004/ included the original design topography data in soft copy.

The original data was initially picked from original map then written in excel and transferred in to Arc-GIS software. Then the topographic data was projected to Arc-GIS 10.8, by Universal Transverse Mercator (UTM) projection, Africa-Adindan. UTM-Zone 37 N' in the Arc-GIS software. Then, it has been imported to Arc-GIS 10.8 and to make workable form in Arc-GIS environment and to export as a shape file Contours and TIN surface has been developed by using 3D analyst tool in Arc-GIS software. This is used to compute original reservoir capacity.

A bathymetric and topography survey was undertaken using echo-sounding instruments mounted on a local boat and a global positioning system to determine existing storage capacity (hand held GPS). A compass was used to find the boat transects line from one end to the other end, and the GPS was utilized to establish the interval of the recording depth. The depth from the water's surface to the top of the silt is recorded using a synchronized echo sounder and GPS Map. When recording each depth measurement simultaneously, it also records the boat's geographic position.

There is a minimum drawdown region in the reservoir area, as well as excess silt accumulation above the water depth. Aside from the nature of the reservoirs for bathymetric survey selection, the best survey pattern is influenced by a variety of factors, including a budget, time, and equipment availability. The survey data was processed by entering it into Microsoft Excel for evaluation and verification. The depth measurement at each position was subtracted from the associated water surface elevation to transform the raw depths recorded by the echo-sounder into elevations.

The current area-capacity curves of the reservoir were produced using 3D tools in Arc-GIS to calculate the storage

capacity and water surface area of the reservoir at each 0.5 m interval. By subtracting the current water storage capacity from the initial water storage capacity before impoundment, the total volume (m^3) of sediment deposition was estimated.

Determine spatial distribution of sediment deposition

The sediment distribution in the reservoir was assessed using two periods of reservoir depth data for the Adebra night storage reservoir area: one before dam construction (2012) and the other in 2020 from the bathymetry survey. For this examination, depth points between 2012 and 2020 were transformed to TIN surfaces using Arc-GIS 10.8 software's 3D analysis tool, and a raster map was created. Then, using the raster math-minus tool in Arc-GIS, the 2012 bed elevation raster layer was removed from the 2020 reservoirs bed elevation raster. The difference between the two raster layers represented the spread of sediment deposits within the reservoirs during their operation.

Estimation of the useful life/ life expectancy of night storage reservoir

The period up to which the reservoir can serve the defined purpose is called useful life. It is an important design parameter of a reservoir which may affect the economic feasibility and sustainability of a water resources project. The useful life of the reservoirs would be estimated by using (Eq. 2) (Pourghasemi et al. 2020; Sang et al. 2016; Roskopf et al. 2018).

$$LE = \frac{DSV}{SR} \quad (2)$$

where LE is the life expectancy of the reservoir (in years), DSV is the dead storage volume of the reservoir, calculated as the capacity loss at the dead storage level and SR is the sediment deposition rate (m^3/year), and calculated by Eq. (3) was shown below.

$$SR = \frac{SV}{\Delta T} \quad (3)$$

where SV is the sediment volume (m^3) that accumulated between the year of construction and bathymetry surveys below the dead storage level and ΔT is the time interval between the two successive reservoir surveys (year).

Methodology of study

The overall work has been carried out in two phases as; the Field Work Phase, and the Office Work Phase. Before carrying out the field work, pre field work preparation made

that includes the selection of suitable research methodology to carry out the study, searching studies related to the topic from different sources, gathering the available data from different sources and collection of materials for field data collection. During field work calibration of instrument bathymetric sediment sample collections in reservoir and in the secondary canals is carried out. The methodology of study shown in Fig. 4 is used to achieve the research objectives.

Reservoir sediment sample collection and dry bulk density estimation

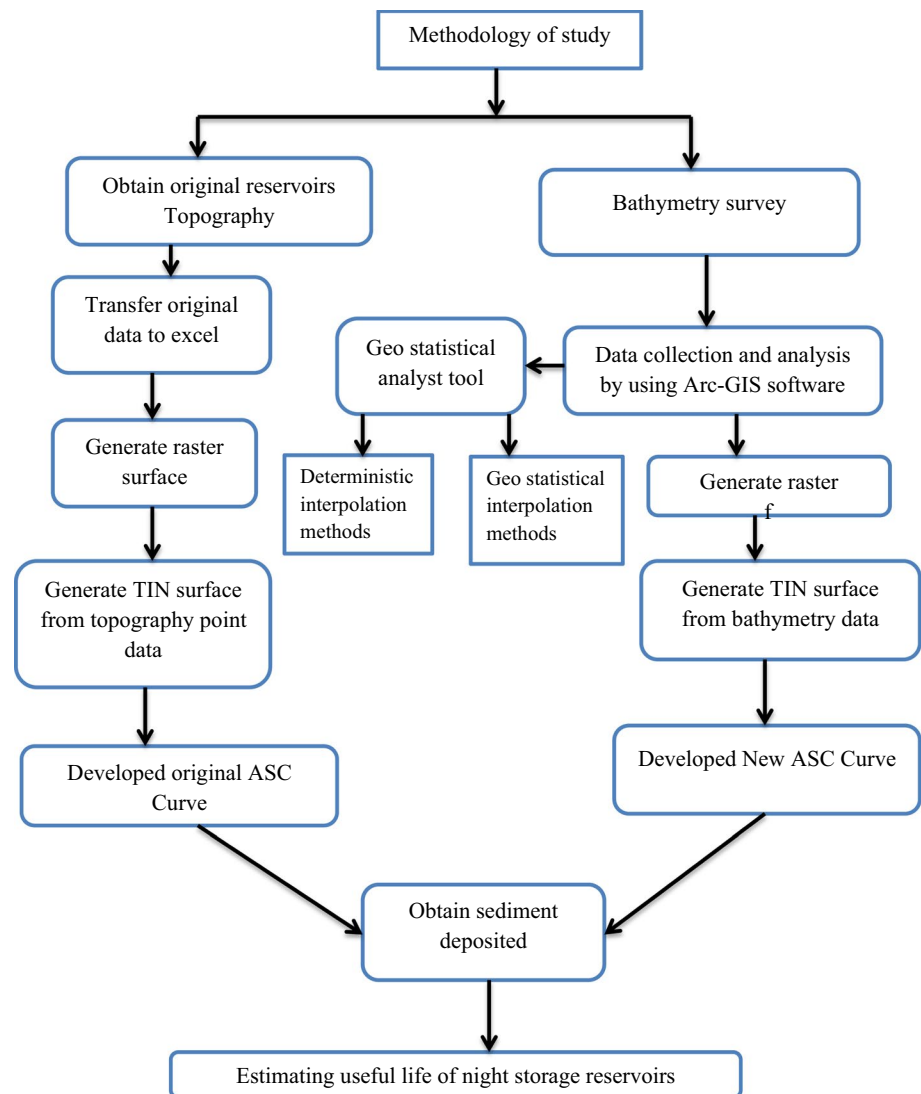
In order to be able to compare sedimentation rate of different reservoirs, it is necessary to convert the measured sediment volume (m^3) to sediment mass (tons) using Dry Bulk Density (DBD) (Rahmani et al. 2018; Annandale et al. 2016). The measured sediment volume was multiplied by its DBD to estimate the sediment mass. Twelve undisturbed sediment samples were collected in core sampler as described earlier and oven-dried for 24 h at 105 °C and the mass of the sediment before and after oven-drying were measured. These samples were selected depends on the kinds of NSRs and the nature of the reservoir's operation. It was collected the time of maximum drawdown area of the reservoirs to obtain undisturbed samples from the different parts of the reservoirs.

The number and nature of sediment sample to be collected depends on the kind of the reservoirs and the nature of the reservoir's operation. Taking those factors in to consideration total 12 Undisturbed known volume of soil samples were collected during the dry period for the analysis of dry bulk density. It was not possible to obtain undisturbed samples from some center parts of the reservoir because lack of the necessary equipment. Soil sample were taken up to a maximum of 70 cm depth (Bombino et al. 2022; Rahmani et al. 2018; Sang et al. 2016), but for this study would be taken maximum 15 cm depth to determine dry density in laboratory, because subsurface layers are not more compacted and have more organic matter, high aggregation and root. On the 10, 11, and 12 February 2020, a sample was taken during reservoir drawdown conditions or when reservoir elevation reaches a minimum level between 9:00 p.m. and 12:00 p.m. for three consecutive days. Figure 5 depicts the spatial distribution of soil sample points. The laboratory results and analysis of the sediment dry bulk density of this sample are presented next sections.

Data types and data collection process

The primary data was gathered by conducting a bathymetric survey and collecting sediment core samples at the reservoir's periphery. Secondary data including topographic,

Fig. 4 Flowcharts of estimating night storage reservoirs sedimentation



hydrologic data was also collected from Amhara Water Resources and Development bureau.

Reservoir bathymetry surveying data

The topography of reservoirs was surveyed in detail by using a bathymetric survey over the entire water surface area by using an echo-sounder over 400 samples were collected from February 20 to February 28, 2020, and additional reservoir boundary data was collected by using etrx-Garmin GPS from March 1 to March 9, 2020.

The elevation of the water surface level on the day of measurement was collected from the escape weir crest level measured by handle GPS or crew gage for this operation. The daily water surface elevation measurement was conducted once a day during this activity because the NSRs had to be closed during data collection time. The depth of the reservoir was measured using an

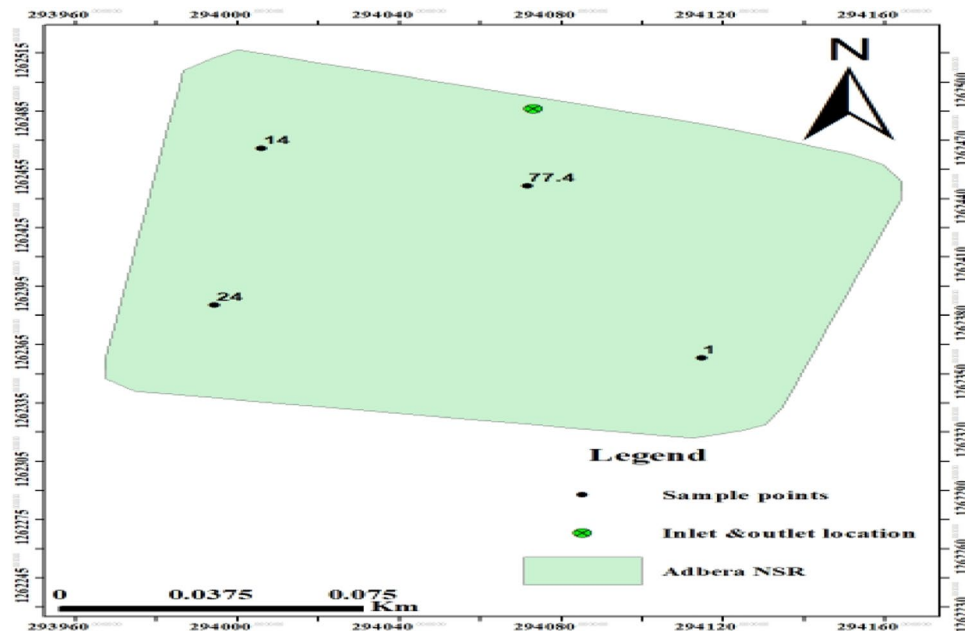
echo-sounder, and the reservoir bed elevations were determined by subtracting the sounder's depth values from the depth of the transducer ($DT = 20$ cm in this survey), this is shown below the water surface (Eq. 4).

$$RBE = WSL - (SD + DT) \quad (4)$$

where RBE = Reservoir bed elevation or sediment elevation (m), WSL = Water surface level (m), SD = Sounding depth (m) and DT = Depth of Transducer from the water surface (m).

The bathymetric survey was carried out over the reservoirs at grid intervals of 15 and 20 m north-east, respectively. However, because the local boat could not precisely follow the previously determined cross-sections, maintaining the predefined route was extremely difficult. Because the bathymetry survey was done in calm situations, the effect of wave height on water depth measurement was

Fig. 5 Location of soil sampling with ID in Adebra NSR



overlooked. More than 400 total sampling points were gathered from all night storage reservoirs using bathymetric techniques (Figs. 6).

Selection of interpolation methods

All bathymetric survey data is structured, processed, and transformed in a way that the Arc-GIS platform can manage. The bathymetric map is then created using a variety of surface interpolation methods. The spatial interpolation was done using four different interpolation algorithms from the Arc-GIS 10.8 Geostatistical interpolation package. The data analysis tool is critical for making the greatest use of observed data and estimating depth characteristics in other locations. These techniques are classified as Deterministic [Local Polynomial Interpolation (LPI), Inverse Distance Weighting (IDW), and Radial Base Function (RBF)] and Geostatistical [ordinary kriging (OK)]. They were chosen because they are widely used in the literature and are frequently used to interpolate bathymetric data in different aquatic systems (Steenhuis 2016). Validation for each spatial interpolation method was conducted using the cross-validation technique, a popular statistical technique used to evaluate interpolation methods (Maina et al. 2019; Ramos-Diez et al. 2017). Validation was performed on each dataset using a training dataset (80%) and test dataset (20%) of each dataset population and the best interpolation method was selected with low root mean square error and high correlation coefficient (Hassen et al. 2022). In addition to the above evaluation methods, coefficient of determination (R^2) value is used to check the performance of the methods on the spatial interpolation techniques.

$$\text{Mean Absolute Error (MAE)} = \frac{1}{n} \sum_{k=1}^n |(Dobs - Dint)| \quad (5)$$

$$\text{Root Mean SquareError (RMSE)} = \sqrt{\frac{1}{n} \sum_{k=1}^n (Dobs - Dint)^2} \quad (6)$$

where n : number of samples points, Dobs = observed dataset and Dint = interpolated value.

Adebra NSR

Among four interpolation methods of tested, the Radial base function interpolation was give the lowest values than RMSE (0.1947), MAE (0.0045), and higher coefficient of correlation with ($R^2=0.9486$).

The findings of these analyses are presented in Table 3 and Fig. 7 respectively. The Ordinary Kriging, Radial base function, and Local polynomial interpolation methods were chosen for spatial interpolations because they work well and produce a good representation of the data in this study.

Result and discussion

Raster map development of Adebra night storage reservoir

To determine the sediment deposition pattern and thickness in night storage reservoir, a raster map was developed

Fig. 6 Adebra NSR bathymetric survey observed points

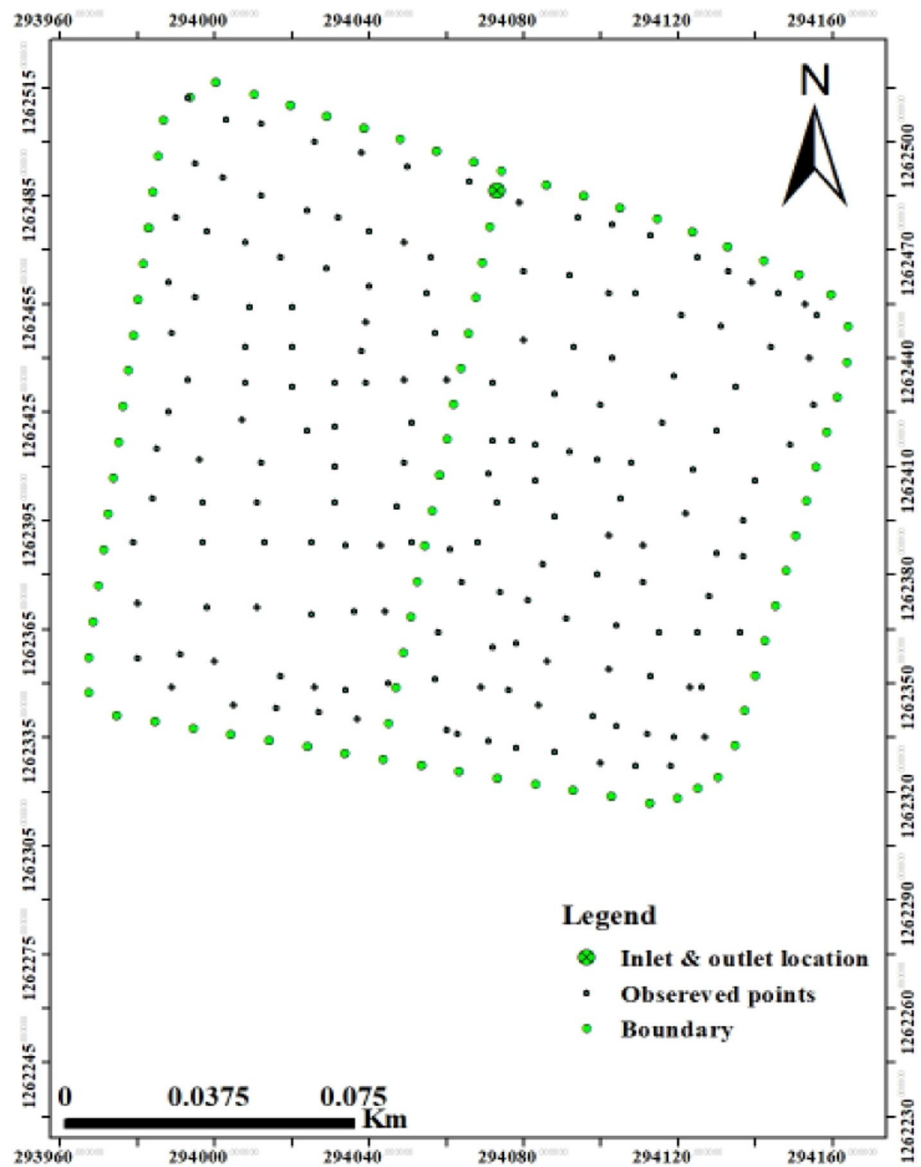


Table 3 Adebra NSR summary of interpolation accuracy analysis

Interpolation method	MAE	RMSE	R^2
Ordinary Kriging (OK)	0.007	0.1955	0.9459
Radial Base Function (RBF)	0.0045	0.19417	0.9486
Inverse Distance Weighting (IDW)	0.0065	0.1977	0.9399
Local Polynomial Interpolation (LPI)	0.098	0.196	0.8965

using Arc-GIS 10.8 and predetermined elevation data from the bathymetric survey, as well as digitized data obtained from original topography data, as shown in Fig. 8 and Table 4. This raster map is used as a starting point for creating a TIN surface map using bathymetry data.

TIN maps development on Adebra night storage reservoirs

The relevant bathymetric maps generated from the bottom elevation data of all fitted night storage reservoirs are exported as raster data. The rasterized map is subsequently transformed into a triangulated irregular network (TIN), a digital representation of surface morphology. The area and volume of Night Storage Reservoir was calculated using the TIN surface generated from the bathymetric survey and digitized points.

The TIN surface is a digital representation of the bed surface of the Night Storage Reservoir, consisting of unevenly distributed nodes produced from point measurements with 3D coordinates (x, y, z) that are grouped into a network of non-overlapping triangles (Arabkhedri et al. 2021;

Fig. 7 Predicted VS measured bed elevation of Adebra NSR test dataset

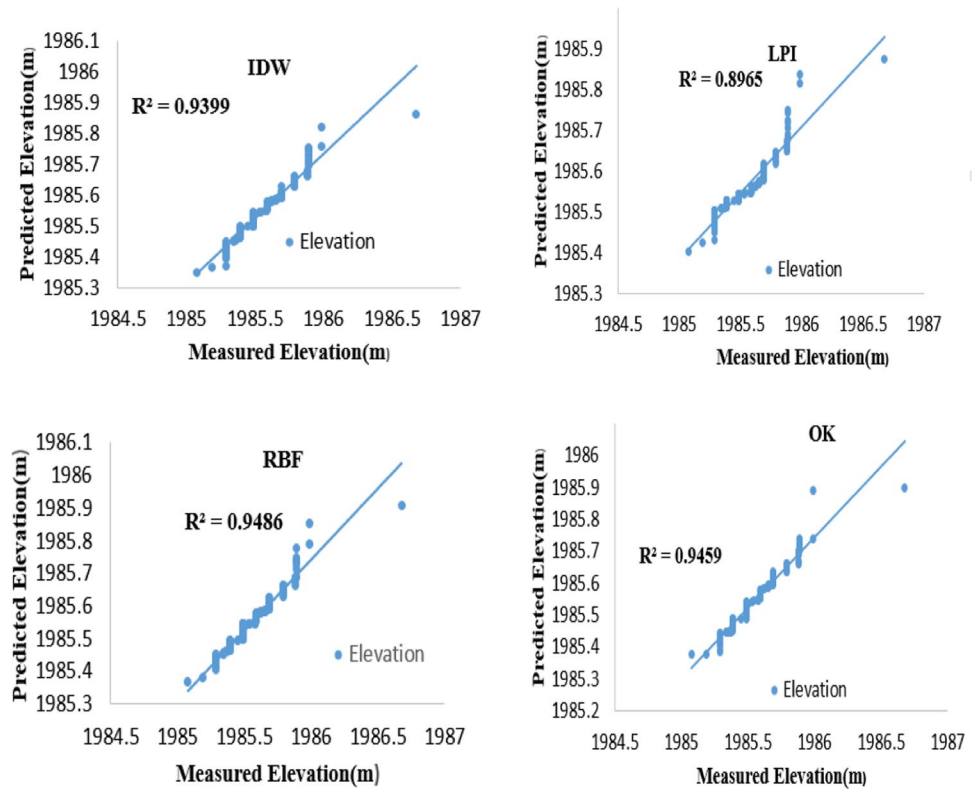


Fig. 8 Adebra NSR 2020 bathymetry survey (raster) map after RBF method by water depth

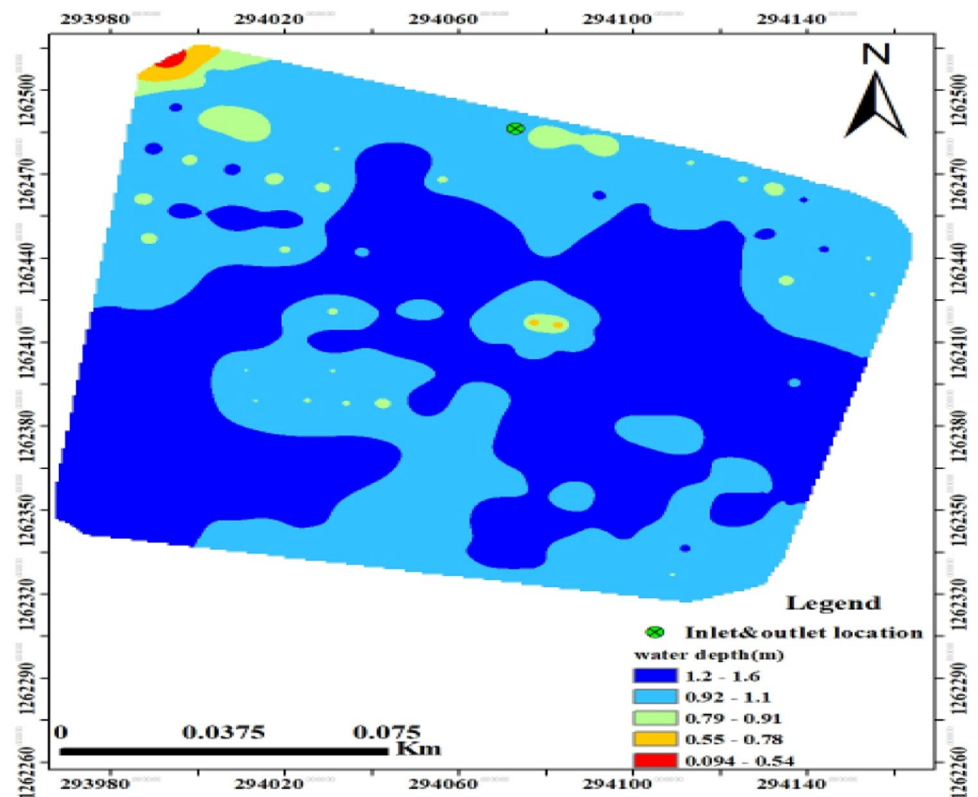


Table 4 Summary of three NSR bathymetry survey water depths in terms of area coverage

Name of NSR	Water depth (m)	Area (m ²)	%Coverage
Adebra NSR	1.3–1.6	3546.82	14.5
	0.92–1.2	20,136	82.4
	0.79–0.91	618.43	2.53
	0.54–0.78	111.29	0.455
	0.09–0.53	18.95	0.0775
	Total	24,431.49 m ²	100

Iradukunda et al. 2020). The silt deposited within the night storage reservoirs is shown by the difference between the 2012 and 2020 surveys. The bathymetric survey and digitized points produced a TIN surface, which is displayed in Figs. 9 and 10.

Computation of area storage capacity curve on Adebra night storage reservoirs by using bathymetry TIN model

The reservoir survey's major goal is to compute the storage capacity of the remaining reservoirs, update the current area storage capacity curve, and estimate sediment distribution inside the reservoirs. As previously stated, the TIN surface produced from 2020-year bathymetric survey data

and digitized data from the reservoir topographical map from 2012 was sufficient to determine the reservoirs' area and capacity. The total amount of sediment accumulated is represented by the loss in storage capacity of the FRL for the two surveys at various dates.

Reservoir storage capacity is gradually diminished as sediment accumulates, causing variations in area-storage capacity curves. For planners, designers, and operators of Night Storage Reservoir, comparisons of capacity in 2020 with initial capacity for Adebra Night Storage Reservoir curves are critical. The 3D Analyst tool of the functional surface was used to determine reservoir volume and area at a 0.5-m elevation interval in Arc-GIS software for the original and current night storage reservoir capacity. New operational curves were designed based on the survey done in 2020 to ensure the safe functioning of Adebra Night Storage Reservoir. The TIN was used to calculate water surface area and storage capacity as a function of water elevation for the surveys of 2012 and 2020, and the results are shown in Table 5 and Fig. 11.

Computation of area-elevation capacity curve on Adebra NSRs by using mathematical method (simple average method)

The storage capacity of a reservoir is one of its most essential physical properties. The reservoir's capacity is calculated

Fig. 9 Adebra NSR TIN map derived from design or original data

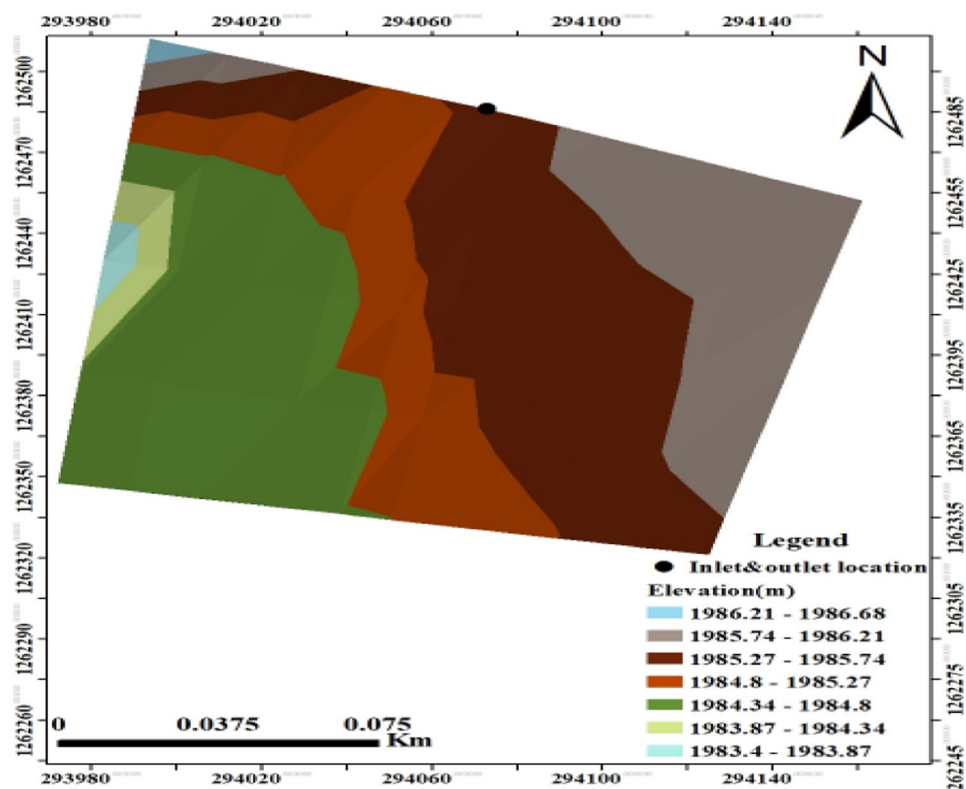


Fig. 10 Adebra NSR TIN map derived from bathymetry survey

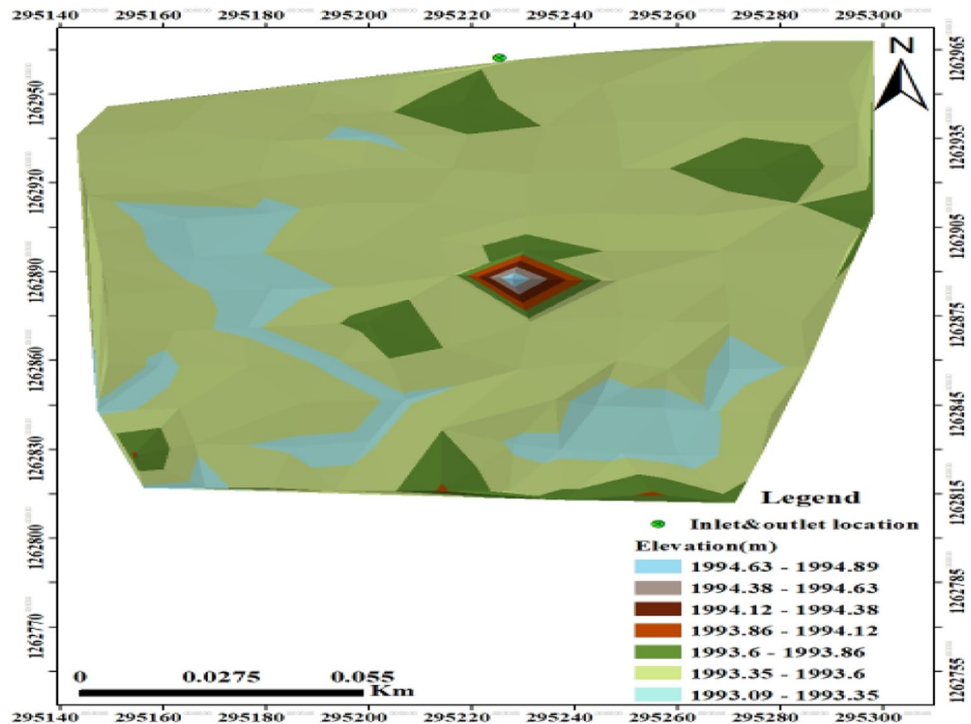


Table 5 Adebra NSR water surface area and storage capacity for 2012 and 2020

Elevation (m)	Area for 2012 (m ²)	Area for 2020 (m ²)	Volume for 2012 (m ³)	Volume for 2020 (m ³)	Remark
1983.4	0	0	0	0	BL
1983.675	60.8	0	5.6	0	
1984.175	483	0	124.7	0	
1984.675	5789.8	0	1081.8	0	
1985.175	11,253.5	22.5	5462.6	0.75	
1985.675	19,094.3	19,047.8	12,825.4	3762.9	
1986.175	25,025.3	24,375.8	24,383.3	15,515.5	
1986.675	25,114.3	24,431.5	36,902	27,722	FSL

using the contour map of the reservoir area on the selected location; the reservoir’s water spread is calculated using a planimeter to measure the area at the contour (Table 6). The following method was used to calculate storage capacity: which is trapezoidal formula (simple average formula).

Comparison of results with TIN model and trapezoidal formula methods

The reservoir capacity of Adebra night storage reservoir is computed in two ways in this study, but as can be seen from the table above, the TIN model is the most valuable technique over the mathematical method (trapezoidal). Even if, when compared to the TIN model bathymetric method, the trapezoidal study of reservoirs does not get near to the initial capacity value that is made below estimate. As a result,

compared to the indirect sediment evaluation approaches, the TIN model bathymetric method is the most valuable in this study. It was used the TIN model's output as a starting point.

Sediment deposit in Adebra night storage reservoirs

During the eight years of operation, the above results were used to calculate the volume of sediment deposited and the reduction in the water spread area for each zone of the reservoir. The capacity of the night storage reservoir at Adebra NSR reduced from 36,902 to 27,722 m³ as a result of silt deposition, according to the results in Table 5. In terms of the volume, the total cumulative sediment for the Adebra NSR is projected to be 9180 m³ between 2012 and 2020, which is roughly 24.8% of the total volume in

Fig. 11 Adebra NSR Area Elevations and Capacity Elevation Curve

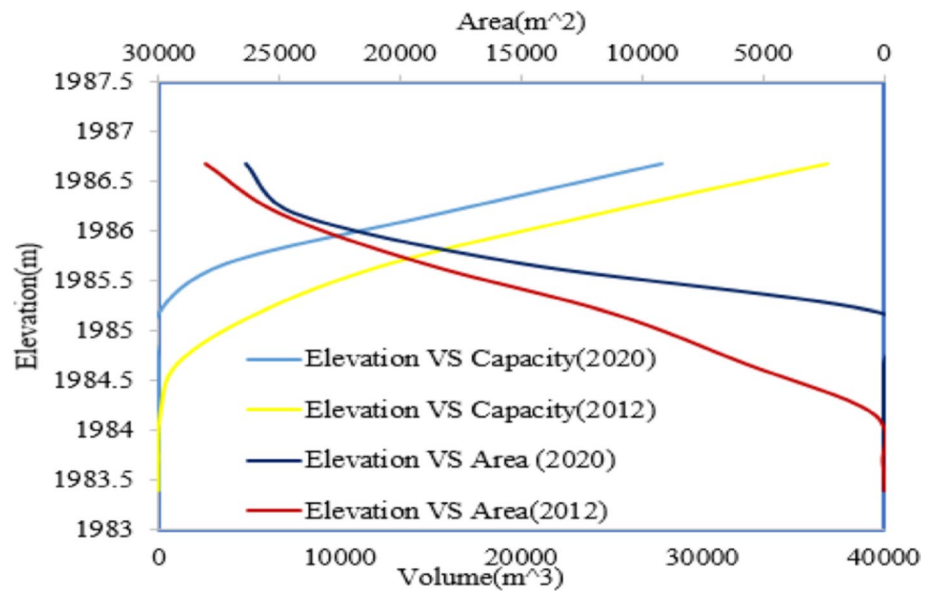


Table 6 Adebra NSR water surface area and storage capacity for 2012 and 2021 average

Elevation (m)	Area for 2012 (m ²)	Area for 2021 (m ²)	Volume for 2012 (m ³)	Volume for 2021 (m ³)	Remark
1983.4	0	0	0	0	BL
1983.675	60.8	0	8.2	0	
1984.175	483	0	135.95	0	
1984.675	5789.8	0	1568.2	0	
1985.175	11,253.5	22.5	4260.8	5.625	
1985.675	19,094.3	19,047.8	7586.95	4767.6	
1986.175	25,025.3	24,375.8	11,029.9	10,855.9	
1986.675	25,114.3	24,431.5	12,534.9	12,200	FSL

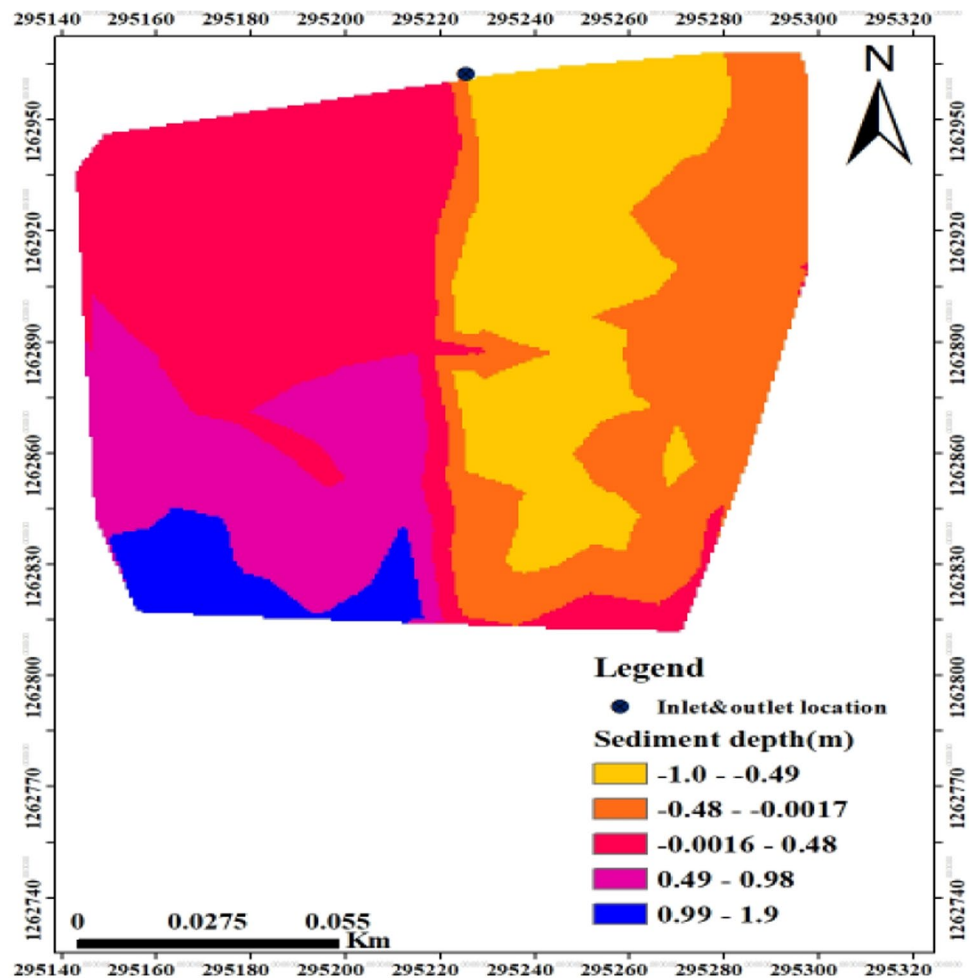
eight years. The yearly sedimentation rate for Adebra NSR becomes 1147.5 m³/year if the rate remains constant during the entire period. According to this rate, annual storage capacity decreases due to siltation are around 3.1% per year. This rate is higher than the projected global average rate of 1% by the Worldwide (Bombino et al. 2022; Froehlich et al. 2017; Zimale et al. 2016).

The results of this investigation revealed that the sedimentation problem in this reservoir is similar to that in most other reservoirs in Ethiopia. Annual total capacity loss estimates of 0.18–4% were recorded by Haregeweyn et al. (2012) for 13 reservoirs in northern Ethiopia. Furthermore, subsequent studies in the same Tana sub-basin revealed a 1.67% annual capacity loss for the Shina micro-earth dam and a 2.295% annual capacity loss for the Selamko dam (Berihune and Moges 2022). When compared to other reservoirs in the basin, this implies that Adebra Night Storage Reservoir had a comparatively high sedimentation rate.

Sediment thickness and distribution pattern in the Adebra NSRs

First, raster layers were constructed from the 2012 and 2020 TINs to determine the sediment thickness distribution in the reservoir. The Raster Math-Minus tool in Arc-GIS was used to subtract the 2012 reservoir bed elevation raster from the 2020 reservoir bed elevation raster. The variations in bathymetry elevations from 2012 to 2020 are shown in the graph below (Fig. 12). The maximum calculated net deposition value was 2.3 m, and the maximum calculated decrease in elevations (i.e., net erosion) were -1, -0.85, and -0.57 m; meaning that the maximum scouring within the reservoir was -1, -0.85, and -0.57 m, and the maximum depositions was 2.3 m in Adebra NSR within eight years of operation. The highest sediment thickness value is typically seen toward the exit of the night storage reservoir. This map can be used to show sediment deposition zones for the management of the night storage reservoir.

Fig. 12 Adebra NSR sediment thickness map



Using the cut/fill function within the 3D analyst tool, it was attempted to highlight locations where sediment has deposited "net gain" or scouring has happened "net loss" in Adebra night storage reservoir from 2012 to 2020. The results are visualized in Fig. 13, and then red areas showing the total deposition, blue areas indicating net scour, and gray areas showing no change.

Analysis of sediment core samples in the Adebra NSRs

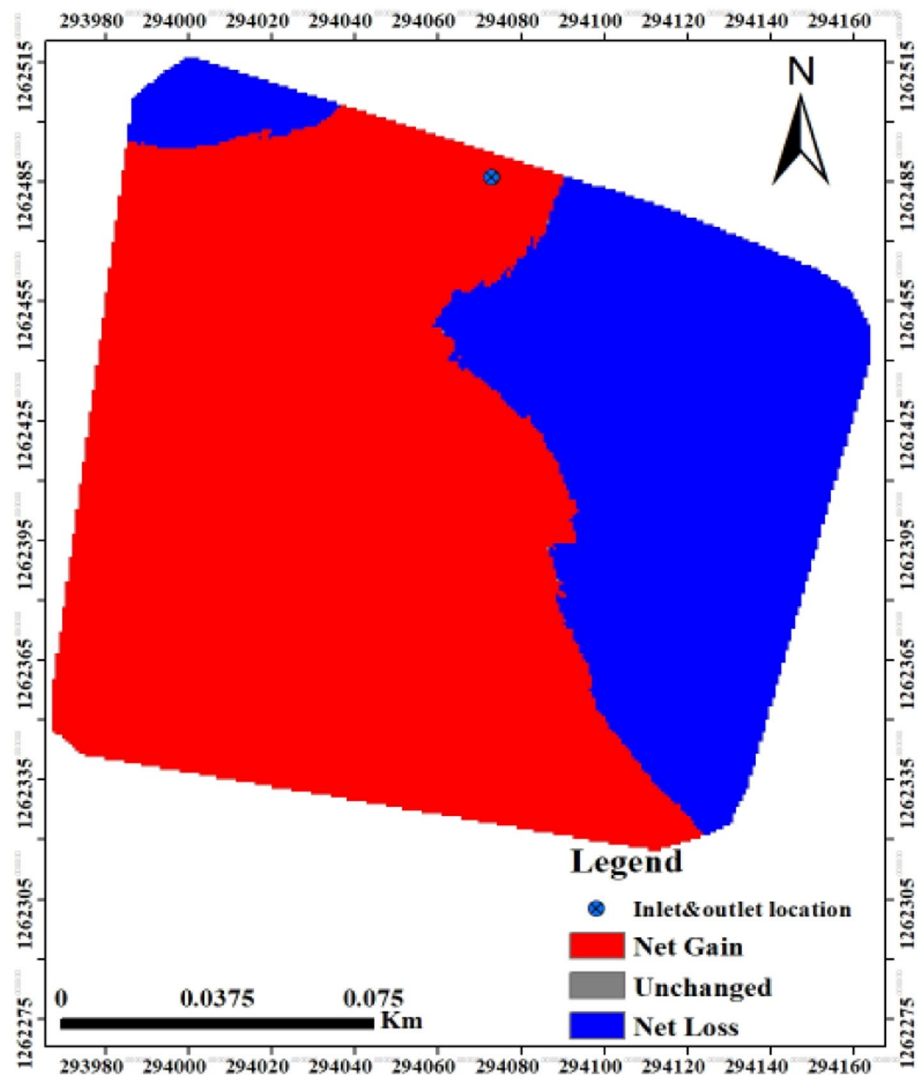
Twelve undisturbed reservoir sediment core samples were taken and evaluated in the laboratory of dry bulk density. To convert reservoir sediment volume to mass, the dry density of deposition is used (Manaze 2019; Mekonnen et al. 2015). The dry bulk density of Adebra night storage reservoir was 1236.75 kg/m³, with a range of 1000–1350 kg/m³. According to Haregeweyn et al. (2012), the dry bulk density of several reservoirs in northern Ethiopia ranges from 1010.18 to 1420 kg/m³. The current study's dry bulk density value is of the same order of magnitude as the preceding one. In general, the lower

dry density of sediment occurs near the dam axis, while the higher dry density of sediment occurs in the reservoir inlet areas.

Estimation of life of the Adebra NSRs

The silting rate in a reservoir is directly controlled by the sediment produced in the catchment areas and the quantity of sediment trapped by the reservoir, which affects the reservoir's life. The bathymetric survey data were used to estimate the reservoir life. The remaining useful life of the reservoirs was estimated to be based on the loss of initial storage capacity. The sedimentation rates or depositional situations of Adebra NSR are dissimilar from ordinary storage reservoir since, are not provided through dead storage space. As a result, the formula for calculating night storage's usable life is simply total storage divided by yearly sediment volume. The life span of Adebra night storage reservoir was 32 years. The life of an NSR is calculated by dividing total storage by the annual sediment volume consumed (Eq. 2).

Fig. 13 Net gain and loss of Adebra NSR sediment volume map



$$\text{Adebra NSR Life} = \frac{36,902}{1147.5} = 32 \text{ years}$$

The NSR has a maximum storage capacity at the start of its predicted life, but at the end storage capacity is decreased day to day. The expected life of the reservoir was reduced due to a lack of proper soil conservation practices in the reservoir catchment areas. Therefore, efficient management practices of reservoir sedimentation needs the models that can estimate amounts of sedimentation in the reservoirs.

Conclusion

This studying focused on the evaluation of reservoir sedimentation by using a bathymetric survey. It evaluates the life of NSR, sediment distribution, capacity loss, and amounts of sediment deposited in Adebra NSRs. The study was done a topographic survey, the development of a map of the initial

reservoir location, the measurement of dry sediment bulk density of deposited sediment, and to evaluate deposited sediment mass in reservoir. The primary objective of this study was to evaluate how sedimentation affects reservoir volume in Adebar night storage reservoir. The simulations were carried out using Arc-GIS software and a TIN map of the reservoir based on bathymetry survey data and topography. According to data analysis, the Adebra NSR's storage capacity reduced by 9180 m³, or around 24.8% of total volumes, over the duration, of its eight-year operation. The average rate of sedimentation deposition was estimated 1147.5 m³/year, which was decreased annual performance of Adebra NSR by 3.1% per year. The findings of this study indicated that the planning and implementation of different techniques to remove and control sediment deposition in the NSRs were the most significant. Because the Adebra NSR was affected direct or indirectly by the accumulation of sediment in the reservoir generated from different directions of the reservoir time to time. As a result, catchment-level soil

erosion management should be implemented. Inflow rates of sediment into reservoir should be decreased by controlling or developing filtration of sediments from conventional crop agriculture to the growth of perennial crops and sediment trapping grass strips. Therefore, planning and design sediment controlling mechanisms depends on estimation of sediments production from watershed of inlet and outlets of reservoir. These mechanisms could be used to supports both restoration of project and watershed management, by providing different indicators for optimizing the design and location of control works, decision-makers and stakeholders, implementing natural hazard mitigation actions in both watershed and reservoir areas, and minimizing the socio-economic and environmental impacts of these structures.

Author contributions As conceptualized and designed the research, gathered and evaluated data, and wrote the paper. YAM contributes to collecting data, analyzing and writing the research and TDM, ANA and YWK, they are contributing to collecting the data and editing the research document.

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Availability of data and materials The required data collected and materials for analysis were included in the manuscript. The corresponding author is ready to clarify the data and provides all the necessary data set as per the request.

Declarations

Conflict of interest The author has no relevant financial or non-financial interests to publish.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants involved in the study. I understand that journals may be available in both print and on the internet, and will be available to a broader audience through marketing channels and other third parties. Therefore, anyone can read material published in the Journal.

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