

Research Article

Assessment of the Impact of Agricultural Activity on Siltation of Meka Dam Reservoir in the Chanco Catchment Using Bathymetric Survey and GIS, Ethiopia Oromia Region Nekemte

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Abstract

Reservoirs are used worldwide supply water for domestic use, irrigation, hydropower generation, and flood management services. Sedimentation affects the sustainability of reservoir operations and overtime, sediments build-up in reservoirs displaces usable storage volume, which in turn negatively affects the beneficial uses of reservoirs and degrades aquatic habitat. An agricultural activity in the chanco watershed is a major issue which increases siltation in the Meka dam reservoir. The bathymetric survey approach is used in the study which is based on a simple comparison of reservoirs morphology at two different time periods, first at the time of the construction of the dam and second at the time of the survey. Bathymetric mapping involves two types of necessary measures: the position and depth measurements. Silt level was directly measured by eco-sound detector. Bathymetric map of the reservoir was done at predetermined 10 m horizontal interval to collect the representative silt level. Echo-sounder was used to measure the depth of silt from reservoir water surface. This device measures the depth of water by sensing and recording the depth of water from surface to top of silt level. Accordingly, 3025 points across the reservoir were surveyed with echo-sounder. The deepest measure was found to be 15.01 m, the shallowest depth is 0.47 m and the average depth of Meka reservoir was found to be 6.67 m. The reservoir capacity was determined by ArcGIS tools. The amount of water that can be stored above the original bed level in Meka dam reservoir is found to be 119,960,000 m³ and the amount of water that is stored above the current level of silt in the reservoir is found to be 9,276,000 m³. The half-life of the Meka reservoir is expected to reach within 42 years. Since its construction in, 2007, it's found that the storage capacity loss of Meka Dam was 17.86%. Therefore, appropriate watershed management strategy should be enforced to alleviate the problem of storage capacity loss of the reservoir due to sedimentation that arises from agricultural activity in the catchment.

Keywords

Meka Dam Reservoir, Silt Level Sensor, Watershed Management, Diga District, Chanco Catchment

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1. Introduction

Water for home consumption, irrigation, hydroelectric power, boating, fishing, flood control, and other recreational activities are all made possible by reservoirs across the world. Reservoirs provide consistent flows that encourage tourism and control seasonal floods.

The sustainability of activities and projects set up in the reservoir or runoff of the river projects is impacted by sedimentation. Degradation of aquatic habitat, irrigation, water supply, flood management services, and hydropower generation are all adversely affected by sediment buildup in reservoirs, which eventually displaces usable storage volume Annandale et al. 2016 [2]; Icold 2009; [6] Rakhmatullaev et al., 2011, [9].

One of the main causes of reservoir sedimentation is anthropogenic activities that affect the watershed. Depending on a variety of elements, including the river basin's features and the hydrology of the catchments, the progressive process of sedimentation progresses at varying rates Kondolf et al. 2014, [7]. Geology, topography, temperature, vegetation, and land use all affect the amount and kind of silt in a drainage basin Dargahi; 2012 [3] Webster, 2010, [10] states that the global sediment output ranges from one to over 1,000 t/km²/year. For basins in China, Java, Kenya, New Guinea, and New Zealand, very large yields in the 10,000-50,000 range have been documented Dargahi 2012, [3].

The results of previous and current bathymetric surveys or the sedimentation rate status are used to calculate the periodic sedimentation rate and the loss of reservoir storage capacity.

Determining the sedimentation of the Meka dam reservoir and the effects of agricultural practices in the Maka reservoir's chanco watershed is the goal of this study.

2. Materials and Methods

2.1. Description of the Study Area

The Chanco watersheds in the East Wollega Zone of Oromia, Ethiopia, were the site of the study. The study region is situated 343 kilometers from Addis Ababa along the major route that connects the two cities. In Diga District, 15 kilometers west of Nekemte town, is the Chanco sub-watershed. About 2 kilometers from Diga town, it is situated at 9°01' North and 36°28.2' East (Figure 1). The majority of the Chanco sub-watershed is covered by agricultural land and rural residents.

A total of 2109 hectares make up the Chanco sub-watershed, including the water bodies; of this, 250 hectares are submerged under water. Meka Dam was built in 2007 G.C. to provide drinking water to the 150,000 residents of Nekemte town, which is situated within this sub-watershed. The reservoir's primary water supply comes from rainfall and one stream, the Meka. The watershed is situated between 2100 and 2260 meters above sea level.

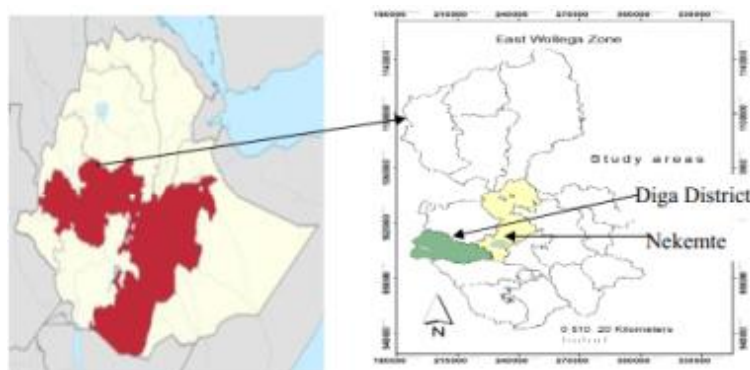


Figure 1. Study Area Map.

2.2. Bathymetric Survey

The bathymetric technique is based on a straightforward comparison of the shape of reservoirs at two distinct points in time: the dam's construction and the survey. Two kinds of measurements are required for a bathymetric map: location and depth observations. In this study, the typical silt level was collected by creating a bathymetric map of the reservoir at predefined horizontal intervals of 10 meters. To determine the

depth of silt from the reservoir water surface, an echo-sounder was employed. This instrument detects and records the water's depth from the surface to the top silt level.. Two kinds of measurements are required for a bathymetric map: location and depth observations. In this study, the typical silt level was collected by creating a bathymetric map of the reservoir at predefined horizontal intervals of 10 meters.

The depth of silt from the reservoir's water surface was measured using an echo-sounder. By sensing and recording the

water's depth from the surface to the top silt level, this instrument determines the depth of the water. The data Digital height Model (DEM) was created by subtracting the collected depth from the water surface height to determine the silt level elevation. The amount of water that can be held above silt was finally determined. Pixel value was multiplied by depth and count to achieve this. Figures 2 and 3 illustrate the acquisition of bathymetric data.



Figure 2. Data collection process including depth measurement.



Figure 3. Water depth data collection.

2.3. Reservoirs Capacity Estimation

Using an echo sounder to measure the water depth at 10-meter intervals allowed for the estimation of the reservoir's capacity. Rakhmatullaev S, 2011 [9]. The capacity of the reservoirs was also approximated using a straightforward computation after the depth of the water from the reservoir's surface to bed was first measured using an echosounder. Hudson, 1998 [4] using the equation that follows

$$C = (A \cdot D) \quad (1)$$

Where A = reservoirs surface area and D = depth of water.

2.4. Soil Loss and Sediment Yield Estimation

The actual soil loss of each land use/cover type in the sub-watersheds was also to be evaluated using the Modified Universal Soil Loss Equation (MUSLE). The reservoirs' final

annual storage loss was calculated by subtracting the total volume of sediment entering the reservoirs from the volume of sediment lost or taken by water out of the reservoirs. This allowed for the prediction of the rate of reservoir sedimentation and the loss of its storage capacity. However, the researchers were unable to quantify the soil loss and sediment yield of the study region because Soil and Water Assessment Tool (SWAT) was not receiving enough input data. The results of a bathymetric survey might be compared with the SWAT model if enough input data were acquired. Other researchers' findings on soil loss and sediment yield are utilized as a point of comparison.

2.5. Sediment Volume and Reservoir Life

The sediment volumes entered in to the Meka reservoir was computed from the differences between the initial storage capacity and the study measured storage capacity using the following formula by Adwubi et al., 2009 [1] given as:

$$SV = RSC_i - RSC_{i+n} \quad (2)$$

Where: SV = Sedimentation Volume (m^3), RSC_i = reservoir storage capacity at an initial year, i (m^3); RSC_{i+n} = reservoir storage capacity n years after i (m^3).

The initial (i) year is the reservoir storage capacity when the dam was constructed and the storage capacity n years after an initial (i) year is the study measured storage capacity. The difference between the two volumes is assumed to be the volume of sediment accumulated in the reservoir.

3. Results and Discussion

3.1. Bathymetric Data Analysis

The position and depth measurements were carried out over Meka reservoir in order to know the volume of silt stored in the Meka reservoir. Accordingly, 3025 points across the reservoir were surveyed with echo-sounder. From this, the deepest measure was found to be 15.01 m, the shallowest depth is 0.47 m and the average depth of Meka reservoir was found to be 6.67 m.

3.2. Reservoirs Capacity Above Silt

This was done by multiplying pixel value with depth and number of counts. The volume of water that can be stored above silt level was calculated and shown in Table 1.

Table 1. Total volume of water above silt.

Object Id	Value	Count	Volume (m^3)
1	0	1501	0

Object Id	Value	Count	Volume (m ³)
2	1	1311	131100
3	2	1905	381000
4	3	1875	562500
5	4	1477	590800
6	5	2086	1043000
7	6	1876	1125600
8	7	1638	1146600
9	8	1636	1308800
10	9	1318	1186200
11	10	1166	1166000
12	11	271	298100
13	12	82	98400
14	13	31	40300
15	14	14	19600
16	15	6	9000
17	29	16	46400
18	30	18	54000
19	31	18	55800
20	32	4	12800
Total			9,276,000

The Figure 4 below shows the DEM of reservoir developed from surveyed point data during bathymetric survey.

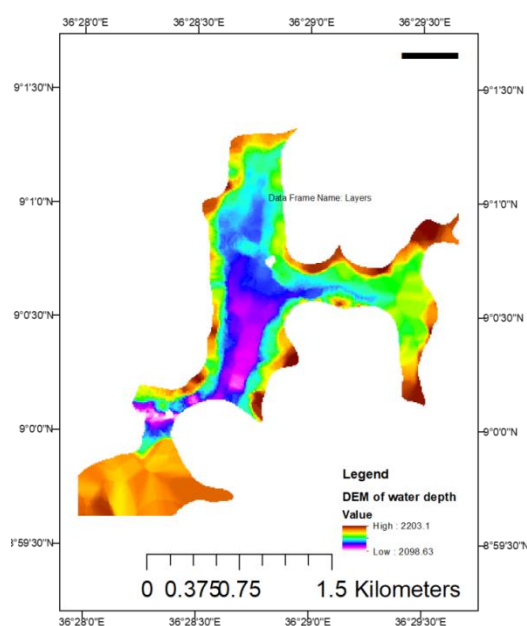


Figure 4. DEM of reservoir developed from surveyed point data.

3.3. Reservoirs Capacity Before Siltation

Contour map with contour interval of 20 m was scanned, geo-referenced and digitized by Geographic Information System (GIS) software. Then, the digitized map was provided the value of elevation. Next the digital elevation model was generated from the contour and the volume of water that can be stored above original bed level was calculated to be 119,960,000 m³.

3.4. Sediment Volume and Reservoir Life

The volume of sediment stored in the reservoir starting from the construction of the dam to 2015 is calculated to be 2,414,400 m³. The dam was completed in 2007 and it has served 15 years since its construction. When we divide total deposited sediment in the reservoir to the reservoir service life, (2,414,400/15) we get 160,960 m³ silt deposition to the reservoir per year. Starting from the time of its construction 2007 to 2022, the storage capacity loss of Meka Dam is 2,414,400 m³ or 17.86%, assuming the rate of siltation per year is constant during the lifespan of the reservoir.

3.5. Sediment Yield from the Watershed

The amount of soil loss from the watershed is generally more than the amount of sediment leaving the watershed at the outlet point. Hence, the sediment yield cannot be estimated from direct soil loss estimates within the watershed unless additional data are available. There is no sediment gauging station on Meka River. The calculation of sediment yield might not be accurate if there is no discharge gauging station in the watershed. There is no gauged sediment data to be used for reservoir sedimentation analysis of the dam. Therefore, the standard practices based on research and previous studies was used to determine the average sediment load at the dam site. An estimate of soil loss rates in Ethiopia Hurni, 1988 [5] is as indicated in Table 2.

Table 2. Estimate of soil loss rates in Ethiopia.

Source	Estimated Yield (t/ha/yr)
Crop land	42
Perennial crops	8
Grazing and browsing land	5
Current unproductive land	70
Current uncultivable land	5
Forests	1
Wood and bush land	5
Countrywide average	12

During field survey, it is estimated that 75% of the watershed is cropland, 15% is grass land, 5% is wood land and 5% is perennial crops. Therefore, in this study an erosion rate of 32 tons/ha/year and a sediment delivery ratio of 60% is considered and annual sedimentation in the reservoir is hence 19 tons/ha and a bed load of 20% will be added. Hence 22.84 tons /ha/year will be assumed to be the total sediment deposited.

3.6. Impacts of Agricultural Activities on Meka Dam



Figure 5. Farm activities around the reservoir area.

Land use/cover has a strong impact on simulated total water yields in the study sub watershed. Surface runoff was increased due to the expansion of cultivated land and urbanization at the expense of vegetation covers. Other studies have also reported the increase of surface runoff due to the expansion of cultivated lands and reduction of vegetation, Weldesenbet T. A., 2017 [11] in Lake Tana catchment and Beles watershed. Meka reservoir is being affected by cultivation of buffer zone. During the data collection it was observed that the farmers are farming very near to the water body as indicated in Figure 5.



Figure 6. Delta stored around the reservoir area.

4. Discussions

4.1. Bathymetric Data Analysis

During the collection of silt depth data, the surface of water is at 2197 m above mean sea level. As it is mentioned in the methodology, the collected water depth was subtracted from reservoir water surface elevation to get silt level elevation and from this point data DEM was generated and the volume of water that can be stored above silt level was calculated.

4.2. Reservoirs Capacity Above Silt

The amount of water that is stored above the current level of silt in the reservoir is found to be 9,276,000 m³. This was calculated by multiplying pixel value (10*10) with count and value (depth). That means storage capacity of the reservoir below the elevation of water surface during bathymetric survey (2197 m) is 9,276,000 m³. However, when the water surface elevation reaches the maximum water level (2198 m), the storage capacity of the reservoir would raise to 11,100,900 m³.

4.3. Reservoirs Capacity Before Siltation

The amount of water that can be stored above the original bed level in the reservoir is found to be 119,960,000 m³. This was calculated by multiplying pixel value (10*10) with count and value (depth) and summing all volumes. This shows, storage capacity of the reservoir at the beginning of the storage at 2197 m elevation is 11,996,0000 m³ and when the water surface elevation reaches the maximum water level (2198 m), the storage capacity of the reservoir would raise to 13,515,300 m³.

4.4. Sediment Volume and Reservoir Life

If sediment delivery from the watershed is assumed to be continues at the same rate from construction periods, the half-life of the Meka reservoir will be reached within 42 years. In addition to this volume of dead storage was calculated and found to be 4,682,400 m³. This means almost half of the dead storage is filled with sediment. This result is different from the result of Megersa et al., 2016 [8], who estimated that the half-life of Meka reservoir to be reached within 293 years. However, the result of this study somewhat agrees with the feasibility study of Oromia water works construction enterprise, which said the Meka reservoir will satisfy completely the demand up to year 2033 including a downstream release of 20 lit/sec. The water demand at year 2038 is failed to satisfy in 10 years out of 34 years simulation period using the 1971-2005.

Based on this study output, Meka reservoir can adequately supply the water demand of Nekemte town up to year 2037

that is for 15 years. The high sediment deposition in to the reservoir may also affect the water quality of the reservoir. To increase the Meka reservoir life water and soil conservation is needed. Hydrology of the study watersheds is mainly impacted by sediment load to surface water and losses of reservoirs storage capacity by sedimentation. According to the output Meka reservoir was highly affected by sediment deposition due to more steep slope land under cultivation including the buffer zone of the reservoir. Human activity has altered the watershed especially during rainy seasons. This is largely due to continuous and steep slope cultivation of land and higher infiltration and low runoff of grass and forestlands.

Therefore, avoiding steep slope and reservoirs buffer zone cultivation and implementing proper soil and water conservation is useful for the longevity of this reservoir. An appropriate watershed management strategy should be also enforced to alleviate the problem of land productivity losses of the upper land and reservoirs sedimentation. In addition to this awareness creation and law enforcement should be done on the surrounding community in order to reduce sediment entry to the reservoir.

4.5. Sediment Yield from the Watershed

The WFP/MERET study WFP/MERET 2005, [12] quotes rates of Sediment Delivery Ratio (SDR) being the ratio of lost soil to eroded soil. From this study, Sediment Delivery Ratios for sheet erosion in eight watersheds (516-1,570 ha) of 0.40-0.46 meaning that some 60-54% of eroded soil is deposited within the catchment was calculated. The SDR is a function of the size of the watershed decreasing as the watershed gets larger indicating that for smaller watersheds a greater amount of eroded soil is lost whilst for larger catchments a larger amount is deposited within the catchment. For dam constructed across a river then in the long run sediment deposited in the upper catchment will be transported and deposited in the reservoir. The slope of the chanco watershed varies from 1% around the reservoir to about 28% up in the escarpments. The distance between the hills and the waterfront of the Maqa River and reservoir is about 1 kilo meter (km).

The total reservoir area 280 ha, which means annual sedimentation rate of 34,260 tons/year at dam site. These results show that in a total sedimentation volume of 1.713 mm^3 in 50 years' time. Assuming 99% trap efficiency, the total volume of sediment that could be deposited in the reservoir is 1.696 mm^3 in 50 years' time. This means 36% of dead storage is going to be filled with sediment in 50 years.

4.6. Comparison of Bathymetric Survey with USLE

Revised Universal soil loss equation (RUSLE) model for the estimation of soil erosion requires the integration of erosion factors including Rainfall erosivity (R), Soil erodibility (K), Slope Length and Gradient (LS), Crop cover (C), and

Management practices (P). Most of these factors were obtained as an output during the simulation of runoff and sediment yield by the SWAT model integrated with GIS. In this research it was planned to calculate sediment yield by universal soil loss equation. However, because of insufficient input data to SWAT model, we couldn't perform this analysis. But we had tried to compare bathymetric result of this study with other researchers on chanco watershed. The resulting sediment yield of Chanco watershed at dam site (outlet) is 8524.34 ton/year. It is stated that starting from the time of its construction in 2007 and until 2016, the storage capacity loss of Meka Dam was 191413.71 m^3 or 1.7%, assuming the rate is constant during the lifespan of the reservoir. If sediment delivery continues at the same rate from construction periods, the half-life of the Meka reservoir will be reached within 293 years. Using this rate, we can estimate sediment volume up to 2022, by multiplying 8524.34 ton/year by 15 years and this gives us 127,865 ton. This value is too small when we compare it with the bathymetric result which is $2,414,400 \text{ m}^3/1.133$ which is 2.13 mm^3 .

5. Conclusions

This research is intended to assess impacts of agricultural activities and determining silt level in Meka Dam reservoir located in Chanco Catchment. Accordingly, bathymetric survey was done with echo-sounder to collect survey data. Soil Loss and Sediment Yield Estimation formula and Sediment volume and reservoir life formula is used to estimate storage capacity and sediment volume. From bathymetric survey, the deepest measure was found to be 15.01 m, the shallowest depth is 0.47 m and the average depth of Meka reservoir was found to be 6.67 m.

The amount of water that can be stored above the current level of silt in the reservoir is found to be $9,276,000 \text{ m}^3$. That means storage capacity of the reservoir below the elevation of water surface during bathymetric survey (2197 m) is $9,276,000 \text{ m}^3$ and when the water surface elevation reaches the maximum water level (2198 m), the storage capacity of the reservoir would raise to $11,100,900 \text{ m}^3$. The amount of water that can be stored above the original bed level (before dam construction) in the reservoir is found to be $11,996,000 \text{ m}^3$. This shows, storage capacity of the reservoir before construction of the dam at 2197 m elevation is $11,996,000 \text{ m}^3$ and when the water surface elevation reaches the maximum water level (2198 m), the storage capacity of the reservoir would raise to $13,515,300 \text{ m}^3$.

The sediment volume is the difference between original reservoir volume and reservoir volume above silt level which is $2,414,400 \text{ m}^3$ of sediment is stored in the reservoir starting from the construction of the dam. As it is known the dam was completed in 2007 and up to now it has served 15 years. Starting from the time of its construction 2007 to 2022, the storage capacity loss of Meka Dam was $2,414,400 \text{ m}^3$ or 17.86%, assuming the rate is constant during the lifespan of the reservoir. If sediment

delivery from the watershed is assumed to be continues at the same rate from construction periods, the half-life of the Meka reservoir will be reached within 42 years. Meka reservoir is being affected by cultivation of buffer zone. Therefore, there should be clear boundary of buffer zone with proper fencing to protect the buffer zone cultivation in order to reduce the impact of farming on the reservoir life.

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Author Contributions

Dereje Adeb: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Writing – original draft, Writing – review & editing

Garuma Negasa: Data curation, Formal Analysis, Investigation, Methodology

Abeya Lencha: Data curation, Software, Supervision, Validation

Abdisa Sandaba: Supervision, Visualization

Habtamu Tilahun: Resources, Supervision, Visualization

Conflicts of Interest

The authors declare no conflicts of interest.

Abbreviations

GC	Gregorian Calendar
DEM	Digital Elevation Model
MUSLE	Modified Universal Soil Loss Equation
GIS	Geographic Information System
Ha	Hectare
SDR	Sediment Delivery Ratio
Km	Kilo Meter
USLE	Universal Soil Loss Equation
NAMSA	National Meteorological Service Agency

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