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A Review on Reservoirs Sedimenation Problems in Ethiopia

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Environmental impacts and long-term morphological changes on the natural water course and mainly through soil erosion (water erosion) due to human intervention, the reservoirs handled by sedimentation. Soil erosion and sedimentation are natural phenomena involved in landscape formation. Cumulative sediment yield is influenced by the combination of factors including soil erodability, soil textural class, organic matter content, watershed area, topography and vegetation cover. In Ethiopia, accelerated sedimentation in reservoirs providing hydroelectric power and irrigation water has resulted in loss of these intended services. The frequent power-cuts and rationing-based electric power distribution recently experienced in the country are also partially attributed to the loss of storage capacity of hydroelectric power reservoirs. Sediment derived from soil erosion and delivered to rivers is a major source of various environmental problems such as sediment deposition in river channels and reservoirs which deteriorates water quality. Sedimentation is a critical pollutant in surface waters that adversely affect water quality and contains other important contaminants including nutrients, pesticides and heavy metals. Some minerals transported with sediments like Cu, Pb, As and Hg are extremely toxic even in small concentration and affect quality of water in dams for various purposes. The suspended solids in the eroded material increases the raw water turbidity (i.e., water becomes muddy and physically dirty),which increases water treatment costs.

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1. INTORDUCTION

Reservoirs are water collection tanks created through the construction of dams across rivers for the purpose of flood control, hydropower generation, irrigation, navigation, water supply, fishing and recreation. Due to these human interventions, environmental impacts and long-term morphological changes on the natural water course and mainly through soil erosion (water erosion) the reservoirs handled by sedimentation. Construction of dams to collect surface water for irrigation, human and animal consumption and electric power generation is carried out at an increasingly fast rate all over the world, resulting in more than 45,000 registered large dams (WCD, 2000; ICOLD, 2007), together storing 11,000 km^3 of water [1].

However, many dams are seriously threatened by sedimentation and are losing their water storage capacity; with an estimated yearly average of 0.5-1% [2], Basson, 2018. Water erosion plays a large role in transporting sediments from upstream catchments to downstream reservoirs. Although any slope, and any place where water flows is potentially a sediment transfer pathway (STP), rivers, gullies and roads are important STPs [3,4,5] Soil erosion is a major watershed problem in many developing countries [6]. Tamane et al. [7] stated that reservoir sediment deposition is a reflection of watershed erosion and deposition processes which are controlled by terrain form, soil type, surface cover, drainage networks and rainfall-related environmental attributes.

In Africa deforestation, mainly from agricultural expansion and land degradation are the leading causes of soil erosion and sedimentation [8]. Degradation of the Ethiopian Highlands have a negative impact on the downstream catchments [6,9]. Sedimentation problem is also widespread in Ethiopian reservoirs in which many lost storage capacity of the reservoirs and quality of water. In Ethiopia, the rates of on-site soil erosion and downstream sedimentation in water reservoirs are alarmingly high [10,7]. Many reservoirs which have been established for hydroelectric power, drinking water supply and irrigation accumulate larger amounts of sediment than expected [11,12]. These is mainly through human induced environmental degradation greatly related with agricultural activity.

Sedimentation is a result of sediments which are defined as particulate matter that can be transported by fluid flow and eventually are deposited as a layer of solid particles on the bed or bottom of water body such as reservoirs (Wikipedia Free Encyclopedia, 2017).Sediment transport is the movement of organic and inorganic particles by water. In general, the greater the flow, the more sediment that will be conveyed. Water flow can be strong enough to suspend particles in the water column as they move downstream, or simply push them along the bottom of a waterway. Transported sediment may include mineral matter, chemicals and pollutants, and organic material.

The total load includes all particles moving as bed load, suspended load, and wash load. Sediment deposition is the geological process in which sediments, soil and rocks are added to a landform or landmass. Wind, ice, and water, as well as sediment flowing via gravity, transport previously eroded sediment, which, at the loss of enough kinetic energy in the fluid, is deposited, building up layers of sediment (https://en.wikipedia.org/wiki/Deposition_ (geology). Sediment deposition can be found anywhere in a water system, from high mountain streams, to rivers, lakes, deltas and floodplains. Reservoir sedimentation is filling of the reservoir behind a dam with sediment carried into the reservoir by streams.

According to *(water.wikia.com/wiki/Reservoir sedimentation),* the flow of water from the catchment upstream of a reservoir is capable of eroding the catchment area and of depositing material either upstream of the reservoir, or in the still water of the reservoirs. The susceptibility of reservoir sedimentation depends on the sediment delivery of the water courses, the retention characteristics of the reservoir and the manner in which the flow is delivered from the natural source to the reservoir (Hal crow, 2001). Hughes and Prosser (2003:12), stating that river erosion is the most uncertain of the sediment sources in terms of river budget modeling.

According to the study, it is known that degradation of riparian vegetation and other impacts on the rivers have resulted in greatly increased rates of riverbank erosion, to the extent that this erosion process cannot be ignored as a sediment source in regional assessment. Ainsworth, (2005) states that erosion of the land surface yields sediments which are transported downstream by rivers and eventually deposited in reservoirs while the rate of erosion depends on a complex interaction of: (1) Climate - precipitation and runoff, temperature, wind speed and direction, (2) Geotechnics-geology, volcanic and tectonic activity, soils, (3) Topography-slope, catchment orientation, drainage basin area, drainage density,(4) Vegetation cover, and (5) Land use and human impact.

Topsoil and other light surface particles from a catchment are transported by rain water from land to a reservoir where some of it settles to the floor of the reservoir as a layer of silt. Lindquist [13]; observed that a layer of silt that is only a few centimeters thick is good because it reduces seepage, but thicker layers of silt decrease the water storage capacity, reducing the period during which water can be drawn from a reservoir. Therefore, catchments without soil conservation and ponds or dams without silt traps may result in dam and reservoirs sedimentation that cannot store any water after only a few years. Therefore, the objective of these review paper was to find the extent of sedimentation problems of reservoirs in Ethiopia.

2. SEDIMENTATION PROBLEMS OF RESERVOIRS' IN ETHIOPIA

Sediment yield is affected by the sum of factors including erodability of the soil, soil texture, organic matter content, watershed area, topography and vegetation cover [14]. Sediment can result from point source discharges such as mining and construction processes, non-point sources such as runoff from agriculture and forestry and from bank erosion [15]. Fortunately, much of the eroded sediment deposits only move a short distance. However, a certain proportion of the eroded sediment particles will ultimately be transported to a reservoir [6].

3. REDUCTION IN STORAGE CAPACITY OF RESERVOIRS

In Ethiopia, sedimentation of reservoirs leads to hydroelectric power and irrigation water reduction. The Aba-Samuel dam in Addis Ababa provided one of the first electric power generating stations in the country. Sedimentation is so prolific that the reservoir's initial water carrying capacity has been reduced by half due to silt accumulation (4.45 tons of silt/km2) and eutrophication [10].

Another, estimate indicates that it is losing storage capacity at a rate of 664,980 t/year for the 43 years following construction [16].

The Gilgel Gibe I hydroelectric dam has a capacity of 917 Mm3 water [16]. Hathaway [9] indicated that according to the 1997 Environmental Assessment on this reservoir, a high sedimentation load was anticipated. The expectation has proven to be true because investigation by Devi et al. [16] showed that the reservoir capacity has been reduced by annual sediment loads of 4.50×10^7 t year $^{-1}$ (from which Gilgel Gibe River contributes 277,437 t year $^{-1}$) which could occupy 3.75×10^7 m^3 year $^{-1}$. Based on the results of physic-chemical parameters and data obtained using the observational checklists, these researchers, estimated that the Gilgel Gibe I dam's volume will be reduced by half within 12 years and would be completely filled with sediments within 24 years unless timely remedial measures are taken. The dam was originally expected to serve at least for 70 years.

The Angereb Dam, which was constructed in early 1980 on Angereb River, a tributary of the Blue Nile, was primarily built to adequately supply drinking water to Gondar town, Musa et al. [17]. The dam was feasible in terms of cost consideration and a judicious use of abundantly available local materials. Nevertheless, the Angereb Reservoir has not lived up to the design expectations because of siltation, in which about 1.4 Mm^3 sediment has been accumulated [11,9]. Other estimates by Musa et al. [17] shows that the mean annual sedimentation rate in Angered reservoir is 1200 t/km2/year. They predicted that the reservoir was losing 30% of its volume by the year 2015.

The Koka reservoir also, supplied by the Awash and the Modjo rivers, was formed by the construction of the Koka dam in 1959 (with an original storage capacity 1650 $Mm^{3)}$ for developing hydroelectric power for domestic use [17,18]. In 2000, Addis Abeba suffered power outages, even during the rainy season, after turbines at the Kokadam became clogged with sediment [9], The mean annual sedimentation rate of this reservoir has been estimated or cited by several authors: 2302 tons/km^2/year [16]; 13-20 mm^3 per year [17]: 17 mm^3 per year Amare [18]. It has been forecasted that using the existing operation, this reservoir will not be able to function effectively after some decades in the future [18]. Impacts of the Koka reservoir sedimentation have been well documented.

In Koka dam, 481Mm^3 sediment has accumulated displacing an equivalent volume of water with an estimated economic loss of 60 million birr (displacement of 481 Mm^3 of water by sediments translates into an energy loss of 128 M KWh, considering the average energy price of 0.45 Birr/KWh) [19], Koka reservoir serves as the only impounding reservoir for the Awash Watershed, which is the country's most important river basin in terms of existing developments and associated flood management [19,20]. Flood control capacity is being reduced due to sedimentation, limiting the amount of retained water during the rainy season.

Many dams constructed to store water for irrigation and /or drinking purposes were being silted up while under construction Amare [11]. There were extreme sedimentation cases in Ethiopia such as Borkena Dam in Wollo, which cost $35 million US dollars in 1991 and Adrako Dam (Ibenat, North Gonder) where the dead storage volume of the reservoirs silted up before their construction ended [10]. An earth dam in the headwaters of Modjo River was completely filled with 96000 m^3 of silt only two years after construction as result of sheet and gully erosion from agricultural lands in the watershed area [19].

Legedadi reservoir supplies 60% of water demand to Addis Abeba city, delivering 165,000 cubic meters of water per day. A 20 years bathymetric survey (1978-1998) of this reservoir shows an average silt accumulation of 26,000m^3 per year, which results in a water shortage for the rapidly increasing Addis Ababa city residents (over 4 million people) [22].

The Gilgel Gibe III hydroelectric power project, which will dam the Omo River, creating a reservoir with a live storage of about 11,750Mm^3 and a total surface area of 200km^2 at normal operating level (889 masl) [23]. The reservoir is expected to be 155 km in total length with a catchment area of 34,150km^2. High rates of sedimentation are anticipated in the Gilgel Gibe III reservoir where one-third of its space is reserved for sediments to accumulate over time [9]. Various estimates have been forwarded estimating sedimentation for the newly built Tekeze dam. Siltation could greatly impair this soon to be commissioned dam and reservoir [9]. Although, the catchment area of this recently built reservoir, which has total storage capacity of 9.3 billion m^3 and anticipated sedimentation rate of 30 Mm^{3}years, is highly susceptible to erosion, the sediment load will largely be suspended and deposited at far of the reservoir where flood velocity approaches zero.

To mitigate agricultural crisis from recurrent drought and erratic rainfall, the government of Ethiopia, in collaboration with other organizations, constructed more than 50 micro-dams (for irrigation scheme) in the Tigray region between 1994 and 2002 [24]. Investigation of these micro-dams by Tamene et al. [7], showed that the area specific sediment yield of the reservoirs ranged between 345 and 4935 t km^{-2}year^{-1} with a mean of 1900 t km^{-2} year^{-1}. This is somewhat higher than the Global and African averages, about 1500 1000 t km^{-2} year^{-1}, respectively.

Thus, it was concluded that most of the reservoirs will be sediment clogged in less than 50% of their intended service time. A related study in this region by Haregeweny et al. [3] showed that 50% of the studied irrigation micro-dam reservoirs have a siltation problem that will shorten their economic life by half of the design period and another20% of the reservoirs will lose their effectiveness between half and 100% of the design period.

Thus, the researchers concluded that only 30% of the reservoirs are expected to last for entire design period. Thus, planned benefits such as increased food production, easy access to drinking water for people and livestock, a rise in the ground water level and issuance of new springs by the construction of micro-dams are all threatened by the rapid loss of the water storage capacity of the irrigation scheme dams, mainly due to siltation. Since, these reservoirs have been constructed to support food self-sufficiency programs, the target have been obscured due to sedimentation. Heavy sedimentation experienced by Ethiopia's existing dams is a very real risk to the lifespan of new dams. The soon to be constructed on Blue Nile Renaissance Dam, which will be the largest hydroelectric dam in the country, is expected to experience a high sedimentation rate. These sediments are currently being captured in the Egypt and Sudan dams but will soon be trapped by the renaissance dam.

Table 1. Impacts of sedimentation on some Reservoirs of Ethiopia

Reservoir	Capacity Reduced/Expected To Reduce	Source
Borkena and Adrako	Silted up before their construction ended	Haregeweny et al. (2006) [10]
Angereb	Annual siltation 1200 t km-2year-1,50% will lost by end of 2010	Musa et al. (2005) [17]
Koka	2302 t/km2/year, 17Mm^3/year	Amare (2005) [11]
Aba-Samuel	50% lost, 664,980 t/year accumulate	Devi et al. (2007) [16]
Gilgel Gibe I	Designed for 70 year but will function for 24 year	Devi et al. (2007) [16]
MelkaWakena	Greatly reduced	Hathaway (2008) [9]
Legadadi	26,000m3 year-1	Gessese (2008) [21]
Gilgel Gibe III	1/3 reserved for sediment	Hathaway (2008) [9]
Tekeze	30 Mm3 year-1 is expected, not threatening	http://www.eepco.gov.et/files
More than 50 micro-dams in Tigray	50% of the studied reservoirs will lose their economic life before half of the design period	Haregeweny et al.(2006) [10]

4. PROBLEMS ON WATER QUALITY AND AQUATIC LIFE

Soil erosion is a major source of sedimentation in reservoirs which negatively affect water quality [25]. Sediment contains contaminant nutrients such as pesticides and heavy metals [11] and minerals transported with sediments like Cu, Pb, As and Hg are toxic and affect quality of water in dams [3].

For instance, for Addis Ababa' Legadadi reservoir, the cost of water treatment increased from 7.7 in 1993 to 21.4 million in 2001 due to the increasing rate of reservoir sedimentation. On the average, the state incurs water treatment cost of 12.6 million birr/year [22,19], which can be reduced by minimizing incoming sediment. Nutrient loss through runoff also has considerable adverse environmental impacts on water quality [26]. Nutrients (mainly nitrogen and phosphorus) supplied by sedimentation often leads to excessive plant growth the process is called eutrophication) and higher sediment deposition which can create increased levels of non-living periphyton [27,15].

According to their report, the high turbidity of silted reservoirs prevents sunlight from penetrating the water, reducing photosynthesis and thus, the survival of the submerged aquatic vegetation; degrades the fish habitat(muddy water fouls the gills of some fish) and upsets the aquatic food chain. Furthermore, sedimentation can directly result in higher drift of invertebrates and decreases in macro-invertebrate abundance and behavior.

In general, the process of eutrophication affect aquatic ecosystem in reservoir by enabling rapid plant growth and adversely influencing the habitats fish and other organisms. In Ethiopia, eutrophic occurrences have been reported at Legedadi, Aba-Samuel and Gilgel Gibe I reservoirs [11,22,16].

5. CONCLUSION AND RECOMMENDATION

This review indicates that sedimentation is a serious problem that undermines the economic life time of reservoirs. Lack of proper study or adequate data on reservoir sedimentation in the country was a problem in estimating the economic life time of the reservoirs. This study attempts to provide quantitative information related to the rate of sedimentation and its impact on the economic life of example reservoirs. Sediment yield is dependent on factors of soil erosion (mainly rainfall, soil condition, land use, topography) and the capacity of transportation [28,23]. Soil erosion will ultimately fill a reservoir with sediment but the rate of this process will depend on the design of the reservoir and manipulation of the erosion factors in the catchment. Sediment deposition in reservoirs for irrigation schemes, hydroelectric power supply and urban water supply reduces their capacity, shorten lifespan, reduce water quality and requires costly operations for removal and treatment [23,28].

Heavy sedimentation has been experienced in most of Ethiopia's existing dams such as Gilgel Gibe I, Aba-Samuel, Koka, Angereb, MelkaWakena, Borkana, Adrako, Legedadi, Koga (in Amhara region) and Many irrigation Micro-dams (in Tigray region).Ethiopia is planning to export electric power to Kenya, Djibouti, Sudan and Yemen, which is expected to become the country's biggest export replacing coffee (http://nazret.com/blog/index.php). To realize the vision and to sustain water supply from these reservoirs, based on reviewed sources, the following practices should be use:

- ❖ Integrated Watershed Management, including various types of soil and water conservation measures, should be practiced in the upstream areas of river basins and Vegetation cover of the reservoirs' buffer zones of all reservoirs in the country should be increased to protect the entrance of sediment loaded runoff.
- ❖ During the design phase of new dams and reservoirs, more emphasis should be given to watershed based soil conservation and ongoing efforts should be strengthened and continued through incorporating new research. As well as national strategy and policy should be technically exercised regarding to the solution of these problem.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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