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Watershed Management: An Option to Sustain Dam and Reservoir Function in Ethiopia

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ABSTRACT

Inappropriate use of land for agriculture and poor management of its ecosystem lead to environmental problems such as land degradation through soil erosion. Accelerated soil erosion is a major watershed problem in many developing countries including Ethiopia. Climate change, which apparently causes major climatic events such as flooding or drought, also accelerates soil erosion. Soil erosion in various forms such as sheet, rill, gully bank and bed, river bed and bank and landslides provide sediment to critical water bodies. Nutrients and chemicals from cropland and urban sewage are transported into the water systems. Many reservoirs which have been established for hydroelectric power, urban water supply and irrigation accumulate an alarmingly higher level of sediment than expected. Koka, Angereb, Legedadi, Gilgel Gibe I and other reservoirs are threatened by this accelerated sedimentation. Consequences of reservoir sedimentation include the loss of storage capacity and its subsequent effects. These effects include water supply shortages for human consumption, irrigation and hydropower; increased hydro-equipment maintenance and repair; a decline in water quality; the cost of removing sediment; blockage of navigational waters and loss of recreation opportunities. Aquatic ecosystems are modified by increased deposition of sediments and adsorbed or dissolved nutrients and chemicals, which commonly causes eutrophication which in turn negatively influences habitats of fish and other organisms. Some of the techniques suggested to reduce reservoir sediment concentration are technically less feasible as it requires design considerations during construction (which is difficult to implement for the existing dams). Removal of sediment is also economically demanding. Among the approaches and techniques proposed and implemented, integrated participatory watershed management is strongly recommended to reduce sediment inflow in sustainable pattern.

Key words: Erosion, integrated watershed management, soil and water conservation, storage capacity

INTRODUCTION

Soil erosion is a major watershed problem in many developing countries (Awulachew *et al.*, 2008). Tamene *et al.* (2005) 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 general, countries in Africa are experiencing deforestation, mainly from agricultural expansion and land degradation which are the leading causes of erosion and sedimentation (Julien and Shah, 2005). All reservoirs, formed by dams on natural rivers, are subject to some degree of sedimentation, which is continuously supplied by rainfall, runoff, snowmelt and river channel erosion (Randle *et al.*, 2007). The question is: How long will it take before the erosion adversely affects the dam's water control goal. Accumulation of sediment in the reservoir reduces its storage capacity. When this occurs at an accelerated rate, the reservoir's designed life is shortened. Combined with this, chemicals and nutrients from cultivated land, industries and other related sources adversely affect water quality in reservoirs. The cost of removing these sediments and treating the pollutants is enormous.

The reservoirs of many countries are adversely affected by high rate of sedimentation: For instance, Nepal loses approximately 240 million m^3 of sediment per year (Julien and Shah, 2005); and Afghanistan loses 150 million m^3 per year (Seddeqy, 2007). It is estimated that 1.5 billion Mg of sediment are deposited each year in the USA reservoirs (Brady and Weil, 2002). Despite their technological sophistication, which did not consider soil erosion and sediment transport processes, four major Australian dams (Moore Creek, Gap, Korrumbyn Creek, Quipolly) built to provide water supply for domestic, agriculture and mining uses, became fully-silted in less than 25 years (Chanson and James, 1998). Diverse environmental problems and their consequences have been reported for Malaysia (Begum and Pereira, 2008). The deforestation and degradation of the Ethiopian Highlands have a negative impact on the downstream catchments (Awulachew *et al*., 2008; Hathaway, 2008). More than 95% of Egypt's Aswan High Dam's mean annual suspended sediment load (120×10^6 t year^{-1}, Teodoru *et al*., 2006) comes from Ethiopia, in which 72% comes from the Blue Nile and 25% from the Atbara River. Whereas, the White Nile contributes only 3% of the total sediment load (Teodoru *et al*., 2006). Due to this high inflow of sediment, the design life age of the aswan high dam reservoir is estimated to be 265 years, which is only 50% of the reservoir's original design life (Shahin, 1993).

Moreover, land degradation due to anthropogenic factors in the Blue Nile's upper catchment dramatically increased sedimentation in Sennar, Khashm el-Girba and Roseires dams (all in Sudan) (Awulachew *et al*., 2008; Shahin, 1993). Consequently, according to these authors, the Sennar reservoir is no longer used to store significant volumes of water but does generate a limited amount of hydropower, 15 MW). Khashm el-Girba dam lost 55% of its original capacity in 25 years and Roseires dam lost 38% in 28 years. The problem of sedimentation is also widespread in Ethiopian reservoirs in which many lost storage capacity and water quality within a short period of time.

The aim of this study was to review the extent of sedimentation problems and the effects in Ethiopian reservoirs and possible solution for these issues.

SEDIMENTATION: PROCESSES, EXTENT AND EFFECT ON RESERVOIR

Soil erosion and sedimentation are natural phenomena involved in landscape formation (Ndorimana *et al*., 2005). Cumulative sediment yield is influenced by the combination of factors including soil erodability, soil textural class and organic matter content, watershed area, topography and vegetation cover (Imanparast and Hassan panah, 2010). 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 (Klco, 2008). 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 (Awulachew *et al*., 2008). In the process of its transportation, to certain extent, it contributes for meandering of rivers (Javaheri *et al*., 2008) by raising streambeds and reducing depth and capacity of channel (Nikkami *et al*., 2009). Ultimately, sediments in a reservoir greatly reduce the water's velocity and turbulence resulting in deposition of the soil particles at base of the dam (Amare, 2005).

Loss of storage capacity and subsequent effect: 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, a consequence of sedimentation (Elias, 2003; Tamene *et al*., 2006).

The Koka reservoir, 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 (Musa *et al*., 2005; Shahin, 1993). In 2000, Addis Ababa suffered power outages, even during the rainy season, after turbines at the Koka Dam became clogged with sediment (Hathaway, 2008). The mean annual sedimentation rate of this reservoir has been estimated or cited by several authors: 2302 tons/km^2/year (Devi *et al*., 2007); 13-20 Mm^3 year (Musa *et al*., 2005); 17 Mm^3 year Amare (2005). It has been forecasted that using the existing operation, this reservoir will not be able to function effectively after some decades in the future (Shahin, 1993).

Impacts of the Koka reservoir sedimentation have been well documented. In Koka dam, 481 Mm^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) (Elias, 2003). 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 (Elias, 2003; Achamyeleh, 2004). Flood control capacity is being reduced due to sedimentation, limiting the amount of retained water during the rainy season.

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 tones of silt km^{-2}) and eutrophication (Devi *et al*., 2007). Another, estimate indicates that it is losing storage capacity at a rate of 664, 980 t $year^{-1}$ for the 43 years following construction (Amare, 2005).

The Gilgel Gibe I hydroelectric dam has a capacity of 917 Mm^3 water (Devi *et al*., 2007). Hathaway (2008) 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*. (2007) 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 physico-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.

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*., 2005). 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 (Amare, 2005; Hathaway, 2008). Other estimates by Musa *et al*. (2005) shows that the mean annual sedimentation rate in Angereb reservoir is 1200 t/km^2/year. They predicted that the reservoir will lose 30% of its volume by the year 2015.

Many dams constructed to store water for irrigation and/or drinking purposes were being silted up while under construction Amare (2005) 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 Gondar) where the dead storage volume of the reservoirs silted up before their construction ended (Haregeweny *et al.*, 2006). An earth dam in the headwaters of Modjo River was completely filled with 96000 m^3 of silt only two years after construction as a result of sheet and gully erosion from agricultural lands in the watershed area (Elias, 2003).

Legedadi reservoir supplies 60% of water demand to Addis Ababa 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, 000 m^3 year, which results in a water shortage for the rapidly increasing Addis Ababa city residents (over 4 million people) (Gessese, 2008).

Ethiopia is building and planning to build, many hydroelectric power dams hoping electricity will become the biggest export, replacing coffee (URL: http://nazret.com/blog/index.php?title= ethiopia). The Gilgel Gibe III hydroelectric power project, which will dam the Omo River, creating a reservoir with a live storage of about 11, 750 Mm^3 and a total surface area of 200 km^2 at normal operating level (889 masl) (EEPC, 2009). The reservoir is expected to be 155 km in total length with a catchment area of 34,150 Km^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 (Hathaway, 2008).

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 (Hathaway, 2008). 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 year, is highly susceptible to erosion, the sediment load will largely be suspended and deposited at the far end of the reservoir where flood velocity approaches zero. Thus, sedimentation effect may not exceed the expected rate on the reservoir live storage volume for a great many years (URL: http://www.eepco.gov.et/files/ tekeze).

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 (Haregeweny *et al.*, 2008). Investigation of these micro-dams by Tamene *et al.* (2005), 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 and 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.* (2006), 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 another 20% 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 the 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 has been obscured due to sedimentation.

Table 1: Summary of effects of sedimentation on some of reservoirs of Ethiopia

Reservoir	Capacity reduced/expected to reduce	Source
Koka	2302 t/km^2/year	Amare (2005)
	17 Mm^3/year	
Aba-Samuel	50% lost	Devi *et al.* (2007)
	664,980 t/year accumulate	Amare (2005)
Gilgel Gibe I	Designed for 70 year but will function for 24 year	Devi *et al.* (2007)
Melka Wakena	Greatly reduced	Hathaway (2008)
Angereb	Annual siltation 1200 t km^{-2} year^{-1}; 50% will be lost by end of 2010	Musa *et al.* (2005)
Borkena and Adrako	Silted up before their construction ended	Haregeweny *et al.* (2006)
Legedadi	26, 000 m^3 year^{-1}	Gessese (2008)
Gilgel Gibe III	1/3 reserved for sediment	Hathaway (2008)
Tekeze	30 Mm^3 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 loose their economic life before	Tamene *et al.* (2005) and
	half of the design period	Haregeweny *et al.* (2006)
Filiglig	Economic life time reduced 5 times	Aynekulu *et al.* (2006)
Grashito	Economic life time reduced 5 times	Aynekulu *et al.* (2006)

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.

A study on the Tigray region's Filiglig and Grashito reservoirs indicated they had an annual sedimentation of 6928 and 11987 m^3, respectively (Aynekulu *et al.*, 2006). The designed lives of these reservoirs were 30 and 20.6 years, respectively. But, due to excessive sedimentation, they were estimated to serve 5.7 years (Filiglig) and 4.4 years (Grashito) reducing their economic life by 5 times. Sedimentation is also a problem in Migae reservoir (Nigussie, 2003; Julien and Shah, 2005). Details of sedimentation on some reservoirs of Ethiopia is given in Table 1.

Effects on water quality and aquatic life: 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 (Verstraeten *et al.*, 2003). Sediment is a critical pollutant in surface waters that adversely affect water quality and contains other important contaminants (including nutrients, pesticides and heavy metals) (Amare, 2005; Klco, 2008; Phillips, 1989). 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 (Adefemi *et al.*, 2007).

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 (Gessese, 2008). For instance, for Addis Ababa's Legedadi 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 (Gessese, 2008; Elias, 2003), which can be reduced by minimizing incoming sediment.

Nutrient loss through runoff also has considerable adverse environmental impacts on water quality (Lal, 1996). 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 (Brady and Weil, 2002; Klco, 2008). 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 reservoirs 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 (Amare, 2005; Gessese, 2008; Devi *et al.*, 2007).

BENEFITS OF RESERVOIR SEDIMENTATION

Reservoir sedimentation is a phenomenon that also has positive impacts to water usage systems particularly to the downstream river. If contaminants and heavy metals are transported into a reservoir, they will likely settle with the sediments in the reservoir which improves the water quality of the river downstream of the reservoir but the water quality behind the dam may degrade over time as the concentrations of contaminants and heavy metals increase (Randle *et al.*, 2007).

The environmental impact assessment conducted on Gibe III project, which is currently under construction, showed some positive consequences are expected in the medium to long-term downstream due to reservoir sedimentation. These positive consequences include: a substantial degree of annual flow regulation in the Omo River, with avoidance of both disastrous floods and drought extremes and of their consequences on the physical, natural and socio-economic environment; stabilization of riverbanks and potential increase of overall biodiversity values of fluvial and delta natural environments; and reduction of water-logging and water-borne diseases in downstream impoundment (EEPC, 2009). The stated advantages of sedimentation will be realized until the dam impounds the maximum volume of water but their effects will be reduced if heavy siltation occurs.

Decrease in sediment load in downstream Blue Nile dams is also anticipated after the construction of the millennium dam.

OPTIONS TO DECREASE RESERVOIR SEDIMENTATION

In order to increase the life of the reservoir and to best achieve the purpose for which it has been constructed, reducing sediment inflow and removing sediment from the reservoir are substantial activities (Amare, 2005). Sediment inflow can be reduced either by implementing land management methods, particularly integrated watershed management, that reduce sediment yield or by implementing reservoir designs that reduce sediment intake. Haregeweny *et al.* (2006) categorized the causes of threatening sedimentation in Tigray micro-dams in to two main groups: Poor design which is mainly engineering work that did not appropriately consider sediment yield; and absence of initial catchment management prior to dam implementation. The following sub-section presents watershed management, reservoir design and sediment removal to reduce sedimentation.

Watershed management-a sustainable method to decrease reservoir sedimentation: Soil erosion in the upper and middle catchments is the main source of incoming sediment. Thus, soil and water conservation (as a core component in integrated watershed management) is the most fundamental step to reduce the amount of sediment entering a reservoir. Conservation measures generally include increasing vegetation cover through plantation establishment or area enclosure; tillage and crop management; and engineering measures such as terrace construction. These three measures are usually combined to form a comprehensive management strategy for watershed protection. Many investigators support integrated watershed management as a substantial instrument in controlling soil erosion and hence reducing sedimentation in reservoirs. Integrated watershed management measures help in achieving principles of water erosion control indicated by Troeh *et al.* (1980) which includes reducing raindrop impact on the soil, reducing runoff volume and velocity and increasing the soils resistance to erosion.

Watershed development and management is an integration of technology within the natural boundary of a drainage area. The concept of integrated watershed development is that development and management of watershed resources should achieve sustainable production without causing deterioration to the resource base or causing any ecological imbalances. Integrated watershed management encompasses implementation of many physical and biological activities such as physical soil and water conservation, crop management, soil management, forest/vegetation cover management etc. The concept of integrated watershed management needs to be incorporated into soil and water conservation components to obtain the maximum benefit for water resources (Minella *et al.*, 2009). German *et al.* (2006) discussed that integrations in watershed management may include integration of disciplines (technical, social and institutional dimensions) and objectives (conservation, food security and income generation).

Research reports from several countries indicate that implementation of integrated watershed management has reduced soil erosion and sedimentation. A study conducted in twenty seven watersheds of Southeast Asia showed that innovative conservation land-use practices (improved fallow, direct sowing, grass strips and natural vegetation strips, terraces with grass risers) are efficient in preventing erosion not only at the plot scale but also at the watershed scale (Valentin *et al.*, 2006). Investigation by Verbist *et al.* (2009) in Indonesia indicates that on erodible lithologies and steep slopes, forest cover and shade coffee systems are the best land use types to reduce sheet and rill erosion (Verbist *et al.*, 2009). Simulations with a spatially distributed soil loss and sediment delivery model (SEDEM/WaTEM) showed that soil conservation and sediment control measures taken in the framework of an integrated environmental watershed management plan may significantly reduce hill slope sediment delivery to river channels in Flanders (Verstraeten *et al.*, 2003).

Reforestation of denuded areas reduces erosion caused soil loss. Research conducted by Hengsdijk *et al.* (2004) in Ethiopia's Tigray region showed a 14% decrease in soil loss for reforested watershed areas. Mahmoudzadeh (2007) confirmed in his research report in Iran that improving natural vegetation, in his case pasture, by exclosure decreases soil erosion significantly. Gokturk *et al.* (2006) also recommended the use of native plant species for diverse benefits from which erosion control is important. Role of trees such as checking run-off, reducing desiccation of crops, improving physical, chemical and biological properties of soil are substantial in the process of controlling soil erosion (Irshad *et al.*, 2007).

Awulachew *et al.* (2008) emphasized that the most effective sediment control is through upstream conservation through green cover (afforestation) and soil and water conservation measures. To reduce sediments from entering the Angereb reservoir, watershed treatments such as avoiding cultivation of steep slopes and reserving buffer zones have been recommended as necessary measures (Amare, 2005). Tamene *et al.* (2005) recommended that to tackle the on and off-site erosion threats in the Tigray region, there is an urgent need for improved watershed-based erosion control and sediment management strategies.

A study in the Tigray region of northern Ethiopia by Tamene and Vlek (2007) assessed the problem of reservoir sedimentation and evaluated possible land management options as remedial solutions using the Unit Stream Power-based Erosion/Deposition (USPED) model. Based on their findings, they concluded that the most effective way to reduce reservoir sediment deposition is to enclose or afforest areas experiencing high soil loss. In addition, application of management measures to areas with high soil loss and gullies could reduce the rate of potential sediment deposition in half. This would reduce investment losses caused by rapid dam sedimentation of and increase the benefits of water harvesting schemes.

Throughout Ethiopia, soil loss is a critical problem on agricultural land and without careful land management; erosion rates are likely to increase (Awulachew *et al*., 2008). A study conducted by Kebede (2009), in Ethiopia's Gilgel Abbay catchment concerning hydrological response to land cover change, using integrated remote sensing data and GIS techniques, for year 1976-2001 showed that forest cover decreased from 51 to 17% and agriculture increased from 28 to 62%. Following this land cover change, an increasing trend of peak flow (during rainy season) and a decreasing rate of base flow (during dry season) have been recorded. The result of this study implies that during the rainy period the observed increase in flow rate results in a high rate of sediment transport to reservoirs. Thus, he recommended that watershed management measures should be taken to sustain river flow during the dry periods; reduce surface runoff and sediment load during the rainy season; and overall, increase ground water recharge.

Jimma University researchers, Devi *et al*. (2007) investigated the chemical enrichment and sedimentation of Gilgel Gibe I hydroelectric power reservoir. They recommended that the threatening effects of erosion-caused eutrophication and sedimentation can only be mitigated using integrated watershed management intervention. These interventions included maintaining a buffer zone around the reservoir, efficient use of organic fertilizers for different agricultural activities, erosion control through soil conservation activities and finally, creating ecological awareness among the residents dwelling in the watershed.

Various watershed management activities have been implemented to reduce soil erosion and sedimentation. In Ethiopia's Tigray region, in recognition of the sedimentation threat to irrigation reservoirs, soil and water conservation practices have been widely implemented (Haregeweny *et al*., 2006). For this region Tamene *et al*. (2005) reported that from eleven micro-dams reservoirs, three reservoirs using watershed management and conservation practices showed relatively low sediment deposition despite high erosion potential. Haregeweny *et al*. (2006) measured thickness of annual sedimentation rate in the Gereb Segen reservoir before and after soil water conservation practices were initiated in the watershed and obtained observable decreases of sedimentation. Since 1994 efforts have been made by government and non-governmental organizations in treating the Angereb reservoir watershed to reduce siltation issues. Several types of physical measures (bunds, cutoff drain, check dam, etc,.) have been installed in the watershed and some are well stabilized (Amare, 2005). In the agricultural production system of most Ethiopian highlands it is not possible to maintain a year-round permanent vegetation cover due to ecological, economic and social circumstances (Ludi, 2004). Thus, structural measures such as stone terraces are necessary during critical times of the year and an indispensable component of soil and water conservation for the control of runoff and erosion. With this understanding, Ethiopia's government has recently been giving considerable attention to various components of watershed management.

Some technologies in natural resource in the approach of watershed management have multiple advantages. For instance, improvement in crop yield has been reported on uplands on which check dams and related activities practiced (Sadiq *et al.*, 2002). Tonkaz (2006) also suggested better management of natural resources for reducing effect of drought for areas prone to such phenomenon.

Design consideration and sediment removal to reduce sedimentation: Design of the water-holding structure needs to be considered to minimize sediment accumulation. Haregeweny *et al.* (2006) advises that the design of new dams and reservoirs should facilitate sediment management (e.g., providing bottom outlets) to assure long-term reservoir conservation.

Various reservoir sediment removal techniques have been adopted taking into consideration, the different climate, hydrological and geographic conditions (Liu *et al.*, 2002). Awulachew *et al.*, 2008 stated that maximization of sediment through flow (i.e., sluicing), diversion of heavy sediment flow (by passing) and dredging, all help control sediment. Dredging, which most experts consider a costly operation, gathers bottom sediments and disposes of them at a different location. Amare (2005) suggested that the outlet sluice will play a great role in reducing deposited sediment from the Angereb reservoir. Increasing water discharge in high runoff period is an alternative method suggested to reduce sediment retention.

CONCLUSION AND RECOMMENDATIONS

Sediment yield is dependent on factors of soil erosion (mainly rainfall, soil condition, land use, topography) and the capacity of transportation. 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. Heavy sedimentation has been experienced in most of Ethiopia's existing dams such as Gilgel Gibe I, Aba-Samuel, Koka, Angereb, Melka Wakena, Borkena, Adrako, Legedadi 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, through the successful completion of five new dams by 2018 (http://nazret.com/blog/index.php). To realize this vision and to sustain water supply from these reservoirs, based on reviewed sources, the following practices should be strengthened:

- Integrated watershed management, including various types of soil and water conservation measures, should be practiced in the upstream areas of the river basins
- Vegetation cover of the reservoirs' buffer zones should be increased
- Since the cost of desilting is enormous, during the design phase of new dams and reservoirs, more emphasis should be given to watershed based soil conservation
- National strategy and policy should be prepared and exercised with technically acceptable and coordinated approaches to erosion and sediment mitigation
- On going efforts should be strengthened and continued through incorporating new research and continuous feedback

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