Review

The Effect of Upstream Land Use Practices on Soil Erosion and Sedimentation in the Upper Blue Nile Basin, Ethiopia

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In the Ethiopian highlands where more than 86% volume of water for Nile River is originated, soil erosion and nutrient depletion has been one of the most important environmental problems. High population pressure relying on natural resources coupled with poor land management and poverty resulted in severe soil erosion and sedimentation. It is estimated that the Transboundary Rivers that originate from the Ethiopian highlands carry about 1.3 billion ton/year of sediment to neighboring countries whereas the Blue Nile alone carries 131 million ton/year. To reverse these adverse effects, different soil and water conservation technologies have been introduced by the Ethiopian government and NGOs although the adoption was very low. However, as a result of upland management practices, soil loss values of $66 \times 10^6$ ton/year had been reported which is equivalent to 44% reduction compared with no land management where $131 \times 10^6$ ton/year annual soil loss had been recorded. Based on the various findings conducted in the upper Nile basin, soil erosion and sedimentation had been threatened both the upstream and downstream communities for centuries especially the Ethiopians through siltation of dams, nutrient loss, flooding, blockage of irrigation canals, depletion of ground water and reduced agricultural production. Therefore, in order to manage soil and water resources in the upper Blue Nile basin, sustainable investment on appropriate in-situ land management practices has to be implemented cooperatively by the upstream and downstream countries.

Key words: Soil erosion, sedimentation, upstream management, on site effect, upper Nile basin, Ethiopian highlands

INTRODUCTION

In Ethiopia, soil erosion and nutrient depletion has been one of the most important environmental problems (Bekele and Drake, 2003; Nyssen \textit{et al.}, 2010). High population pressure relying on natural resources coupled with poor land resources management practices and poverty resulted in severe soil erosion and sedimentation, this in turn has been a serious threat to national and household food security. However, due to inherently good soils and relatively abundant rainfall, the highlands (>1500 m altitude) have a good agricultural potential (Temesgen \textit{et al.}, 2009). These highlands constitute 43% of the country but account for 95% of the cultivated area and support about 88 and 75% of the human and livestock populations, respectively (Abegaz, 1995). The problem of accelerated land degradation is especially serious in the highlands (FAO, 1986; Hurni, 1993; Grepperud, 1996). The average soil loss rates on croplands have been estimated at 42 ton/ha/year but may also reach up to 300 ton/ha/year in individual fields (Hurni, 1993). This by far exceeds the natural rate of regeneration. FAO (1986) estimated that some 50% of the highlands are significantly eroded, of which 25% are seriously eroded and 4% have reached a point of no return. The Ethiopian Highlands are considered to be the water towers of most East and North African countries especially for Egypt and Sudan with many of the...
Soil erosion is a complex process that involves soil properties, ground slope, vegetation cover, rainfall intensity and land management systems (Nyssen et al., 2004; Pimentel, 2006) which has an adverse impact on agricultural production by depleting nutrients needed for plant growth. Moreover, soil erosion is considered as one of the major agricultural and environmental problems worldwide (Pimentel, 2006) and this is a common feature in the upper Blue Nile basin in the Ethiopian highlands.
Brhane and Vlek (2014) reported that soil erosion by water threatened the environment and the livelihood also in Ethiopia not only through its long term effect on soil productivity and sustainable agriculture, but also as a primary source of sediment that fills reservoirs and pollutes streams (Figure 2). This can lead to severe land degradation in the catchment and eutrophication of downstream reservoirs (Conley et al., 2009). Moreover, water erosion mainly sheet, rill and gully had been the most important process and that in the mid 1980’s 27 million ha or almost 50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation (Berry et al., 2003). The same authors also noted that, erosion rates were estimated at 130 ton/ha/year for cropland and 35 ton/ha/year averages for all land in the highlands which had been regarded as high estimates. In the highlands of Ethiopia, the area of most intense population density, the area of greatest livestock density and the area of greatest land degradation, recorded measurements of soil loss by water erosion range from 3.4 to 84.5 ton/ha/year with a mean of 32.0 ton/ha/year (Hurni, 1993).

Soil erosion research using SWAT model simulation had been done in the soil erosion prone highlands of Ethiopia, in the Upper Blue Nile basin. The scenarios describes that soil erosion extent varies from negligible erosion to over 150 ton/ha/year. The soil erosion level in the basin classified into low (0–20 ton/ha/year), moderate (20–70 ton/ha/year), severe (70–150 ton/ha/year) and extreme (≥150 ton/ha/year) categories (Berry et al., 2003). The low class represents the erosion extent less than the soil formation rates, which is 22 ton/ha/year in the Ethiopian highlands (Hurni, 1993). The moderate class represents erosion level less than the average soil loss from cultivated land, which is 72 ton/ha/year (Hurni, 1985). The extreme class represents one fold higher than the average soil loss and the severe class represents two folds higher than the average soil loss. The extreme erosion was observed in the cultivated land and low erosion was observed in the savannah land.

Soil erosion by water is one of the most important land degradation processes in the highlands of Ethiopia which is the most seriously affected regions in the country where the main water supplier of the Blue Nile basin is located (Tsegaye et al., 2012). The increased land resources demands by rapidly increasing Ethiopian population caused rapid changes in traditional land use patterns.

**SOIL LOSS/SEDIMENTATION IN THE UPPER BLUE NILE BASIN**

Sediment yield refers to the amount of sediment exported by a basin over a period of time, which is also the amount that will enter a reservoir located at the downstream limit of the basin (Moriasi et al., 2007). Soil erosion is a serious problem in the Ethiopian highlands that increased sedimentation of reservoirs and lakes. Sediment export rates in the Ethiopian highlands are characterized by important changes in sediment supply to the downstream basin.
sellers (Descheemaeker et al., 2006; Nyssen et al., 2011). The Ethiopian government has undertaken the construction of more than 50 micro dams in response to the government policy to cope with rainfall variability, periodic drought and food insecurity in the Tekeze and Abbay basin, the main water suppliers of the Nile basin (Belete, 2007). Among others, the Tekeze dam, a 185 m high arch dam with a reservoir length of 60 km, is planned to store about $9 \times 10^9$ m$^3$ of water drained from a 30,390 km$^2$ catchment area mainly to generate 300 MW electric power, the Grand millennium dam which is designed to generate 6000MW hydroelectric power and irrigation development is working (Belete, 2007).

However, the life expectancy of these dams is under question because of severing soil erosion and siltation of the dam as result of poor upland management and land degradation. For instance, few studies realized that most of the smaller reservoirs in Tekeze basin are filled with sediments before their planned life expectancy has passed while some reservoirs harvest much less water than the amount expected (Belete, 2007; Haregeweyn et al., 2006).

Nyssen et al. (2011) also studied the effect of conservation tillage (permanent bed system) in the northern Ethiopia. The result revealed decreased runoff (51%) and soil loss (81%) which allows protection of the down slope areas from flooding. Thus, a continuous investment in water resource management in the Blue Nile Basin suggests a need for efficient and effective mechanisms to improve water capture and agricultural output in the highlands of Ethiopia. Approximately two thirds of the area within the Blue Nile Basin is located in the highlands of Ethiopia. This area receives relatively abundant rainfall (800 to 2,200 mm per year), with the majority falling during the kiremt rains (June-September) that supply the main meher cropping season. Agricultural production in the highlands is dominated by cereal crops, which necessitates frequent soil mixing and provides very little ground cover during the kiremt rains, thus rendering it more susceptible to erosion and land degradation (Haileslassie et al., 2008).

In terms of soil loss due to erosion, estimates vary by location, which reflects the varying Ethiopian landscape, management practices and soil characteristics within and between sub-basins. Hurni et al. (2010) measured soil erosion rates on test plots and estimated a loss of 130 to 170 mt/ha/year on cultivated land. Furthermore, the average annual soil loss in Medego watershed in the north of Ethiopia was estimated at 9.6 mt/ha/year (Tripathi and Raghuvanshi, 2003). Moreover, the average annual soil loss due to erosion in the Chemoga watershed in the Blue Nile Basin (northwest Ethiopia) was estimated at 93 mt/ha/year (Bewket and Sterk, 2005). Shiferaw and Holden (1999) also estimated soil loss in Borena district in south Wollo using the Revised Universal Soil Loss Equation (RUSLE, which allows for spatial modeling of soil loss) and found that annual soil loss ranged from no loss in the flat plain areas to over 154 mt/ha/year in some steeper areas.

A research by Habtegebrial et al. (2007) analyzed...
minimum tillage practices in teff crop fields in the highlands of Ethiopia. Their results suggested that, on average, conventional tillage (leaving land bare for 2–3 months whereby fields are plowed 3 to 6 times prior to planting) provided 4.2 to 6.9 percent higher yields of dry matter and grain compared to the minimum tillage scenario. In addition Kidane et al. (2012) reported that farmers believed strongly in plowing their lands repetitively for a better teff yield and concluded that implementing a minimal or zero-tillage for fields growing teff is not realistic.

A comprehensive investment on terraces and bunds maintained throughout the watershed landscape which provides the greatest reduction in surface flow and erosion. Results suggest that such an investment, if maintained for the next two decades would decrease surface flow by almost 50 percent, increase groundwater flow by 15 percent and decrease sediment yield by 85 percent (Schmidt and Zemadim, 2014).

Betrie et al. (2011) had run SWAT soil loss model to predict sedimentation at different catchment management practices in the upper Blue Nile basin. They had observed the average sediment yield of 131 ×10⁶ ton/year at the outlet of the upper Blue Nile basin. Under relative erosion prone areas, a soil loss values of 66 × 10⁵ ton/ha/year has been reported which is equivalent to 44% reduction. The simulation of stone bunds scenario reduced the total sediment yield to 70 × 10⁶ ton/ha/year from current conditions, which is equivalent to 41% reduction (Figures 3 A and B).

The simulation of reforestation scenario showed the least reduction of sediment loads (104 × 10⁶ ton/ha/year) from current conditions, which is 11% reduction (Figures 3, C and D). The authors argued that, this less sediment reductions under reforestation scenario could be attributed to smaller implementation area compared to stone bunds implementation areas. This means, the effect of reforestation scenario on sediment reductions is masked by greater sediment yields from the agricultural land.

Stone bunds sediment yield reductions were quite comparable to the results reported in literatures (Herweg and Ludi, 1999; Gebremichael et al., 2006). Herweg and Ludi (1999) reported 72%–100% sediment yield reductions by stone bunds at plot scale in the Ethiopian highlands (Figures 3, A and B). Schmidt and Zemadim (2014) reported 68% reductions of sediment yields by stone bunds at the field scale in the northern part of Ethiopia. It is important to note that the reforestation effect is greater at the sub-basin level than at the basin level (Betrie et al., 2011). This is attributed to the reforestation implementation area at the sub-basin level is greater than at the basin level. The potential effect of the BMPs could be obtained by implementing...
re foreclosure in steep slope areas and filter strips and stone bunds in low slope areas of the catchment. These results indicated that applying BMPs could be effective in reducing sediment transport for sustainable water resources management in the Blue Nile basin.

Another dimension of the problem is that the quantity of soil lost each year varies depending on the different agro-ecological zones. Haile et al. (2006) indicated that soil erosion which is particularly severe in Ethiopia is the major indicator of loss and soil fertility decline. However, Amede et al. (2001) and Bezuwerk et al. (2009) report that the degradation and loss of soil resulting from soil erosion in the Ethiopian highlands is estimated at about 200 ton/ha/year.

Tsegaye et al. (2012) studied the effect of land use land cover change on soil erosion in the Central Rift Valley of Ethiopia. The result revealed soil loss amounted to 31, 38 and 56 ton/ha/year in 1973, 1985, and 2006, respectively, indicating a rapid increase. The rate of change in soil loss from 1973 to 2006 (1.2 Mt/ha/year) is a direct reflection of the ongoing reduction of vegetation cover. Similarly Zenebe (2009) documented an annual soil loss varied from 7.49 ton/ha/year in field pea plot in 2007, to 60.44 ton/ha/year in faba bean plot in 2006. Average soil loss in field pea plots was found significantly (p< 0.05) lower than faba bean. Although it is statistically non-significant, the average soil loss from field pea plots is also lower than from wheat plots by 17%. This implies that agronomic measures of soil management has paramount role for enhancing soil fertility which in turn reduced soil erosion and sedimentation.

THE CONSEQUENCE OF UNMANAGED LAND USE SYSTEM

Soil erosion is a challenge for sustainable agricultural development in many developing countries (UNEP and UNESCO, 1980; Eswaran et al., 2001). The problem is more serious in the Ethiopian highlands such as the Tigray region (Hurni, 1993; Mekuria et al., 2007; Vlek et al., 2010). Inappropriate agricultural practices, high population pressure from human and livestock, higher rainfall intensity and rugged topography have been reported as the main facilitators for having severe erosion (Dubale, 2001; Damene et al., 2013). Soil erosion is one of the most severe problems affecting the agriculture sector in Ethiopia. According to the Ethiopian high lands reclamation study (EFAP 1992), over 14 million hectares (or 27% of the area) of the highlands was estimated to be seriously eroded and about 15 million hectares were found to be susceptible to erosion. A preliminary soil loss and run-off study at Melko (Jimma Agricultural Research Center) also indicated that 82.3 ton/ha soil was eroded annually (Kebede and Mikru, 2006). This aggravated degradation in the area resulting in on-site soil erosion and off-site heavy sedimentation (Boru et al., 2012).

Increased exploitation of land resources in the upper parts of the catchments results in increased sediment yield and elevated nutrient loads in runoff that reduces water quality and availability to downstream users (Valentin et al., 2005).

Onsite Effect of Soil Erosion

Decreasing Soil Depth

Most of the land in Ethiopia is exposed to water erosion and the topsoil has disappeared at alarming rate. More than one billion tons soil is eroded in the Ethiopian highlands annually (El Wakeel et al., 1996). Hurni (1988) estimated that a total of about 1.5 billion tons of soil is annually lost in Ethiopia. According to this estimation, around 45% of the total annual soil loss occurred on cropland, with an average soil loss rate of 42 ton/ha/year from crop land. There is a much higher soil loss in cropland areas compared to grassland. This soil loss rate is much higher than the rate of soil formation that ranges between 3-7 tons/ha/year, based on the soil formation rates estimated by (Hurni, 1985).

The Ethiopian Highlands Reclamation Study (EHRS) of 1984 for erosion assessment concluded that 1900 million tones of soil were annually eroded from the highlands, which is equivalent to an average net of 100 tons/ha soil loss, i.e. 8 mm depth annual soil loss (Abdelsalam and Hamid, 2008). The green water storage of the Ethiopian highlands, where rain fed agriculture prevails is diminished because of top-soil loss and this has causes frequent agricultural drought (Hurni, 1993; El Wakeel et al., 1996). Rapid population increase led to fast land-use change from forest to agricultural land and as associated with steep terrain, these changes has resulted in severe soil erosion over the Upper Blue Nile basin (Nyssen et al., 2004). The soil erosion and sediment transport processes have affected the whole Blue Nile basin negatively even though it was nutrient-rich sediment source (Nixon, 2002). The upper Blue Nile basin is losing fertile topsoil, exacerbating impacts of dry spells and drought, a common incident in the area. While, the reservoirs and irrigation canal in the lower Blue Nile are seriously affected by sediment deposition, leading to significant reduction of reservoirs storage capacities and excessive de-silting costs of irrigation canals (Nyssen et al., 2004).

Depletion of Soil Fertility

Erosion and deposition processes can significantly contribute to the variability of fine soil particles and the associated nutrient exports from catchment topography (Stone et al., 1985; Kreznor et al., 1989). Chemical soil degradation processes can lead to a rapid decline in soil
quality. The highland agro-ecosystem of Ethiopia is characterized by intensive agriculture. There is over 63% increase in population in the last 20 years and the size of holding per household has shrunk and will likely continue to shrink unless there is a breakthrough in economic development that will draw most of the labor force from the farm. The topsoil is exposed to severe erosion. Hence, production fields are becoming marginal to every farmer with respect to soil fertility. The farmers are also forced to move onto the valley slopes of 50% gradient or above, despite an extension advice to cultivate only lands with slopes below 35 percent (Tolcha, 1991).

Soil erosion and sediment delivery processes, which are responsible for high sediment transport and the associated export of sediment-bound nutrients to deposition areas in the catchments, are influenced by landscape characteristics (Haregeweyn et al., 2008b). Therefore, the impact of sedimentation is the removal of nutrient rich topsoil in upland areas and subsequent reduction of agricultural productivity in those areas (Ömuto et al., 2009). The on-site effect of erosion, which results in the loss of nutrient-rich top soil and hence reduced crop yields, is chronic in the country (FAO, 1986; Hurmi, 1993; Sonneveld and Keyzer, 2003). The soil nutrient depletion reduces crop production by 885, 330 ton/year, which is about 14% of the agriculture contribution to Ethiopian GDP. About 80% of the losses would result from reduced crop production and the remaining 20% coming from reduced livestock production (Abdelsalam and Hamid, 2008).

Bojö and Cassells (1995) insist that in Ethiopia soil fertility decrease is a more important phenomenon than soil loss by erosion. In this approach, fertility decrease is mainly seen as a consequence of nutrient export through crop harvesting and grazing. It is however often forgotten that sediment-fixed nutrient export, as a consequence of soil erosion is another important process (Verstraeten and Poesen, 2000; Verstraeten and Poesen, 2002; Schilling et al., 2009). Stoorvogel and Smaling (1990) reported for the whole Ethiopia an average N-P-K export through soil loss by erosion of 60 kg/ha/year which compares very high to the 20 kg/ha/year which is taken out of the soil by the crops. This nutrient loss is among the highest depletion rates in sub-Saharan Africa. Haregeweyn et al. (2008a) assessed the nutrient export of 13 small catchments in Tigray and found an average sediment nutrient content of 0.15 % ± 0.04 % for N, 8.13 ± 2.75 mg kg⁻¹ for Pav and 429 ± 164 mg kg⁻¹ for K.

The study by Brhane and Paul (2013) showed that soil nutrient export rates were significantly ($P \leq 0.05$) varied among most landforms. On average, nutrient export rates (kg/ha/year) of 95 for Ca, 68 for OC, 9.1 for TN, 3.2 for K, 2.5 for Mg and 0.07 for P were observed in the landforms. But the export rate from the entire catchment to the reservoir was significantly higher than the average of all landforms and even the values of the individual landforms. They argued that this could be attributed to the fact that the reservoir is the largest sink for sediment attached soil nutrients exported from the hotspot erosion sources in the entire catchment. This was followed by the valley, which received sediment coming from the upstream landforms. Sediment from all other landforms is routed through the valley and then finally to the reservoir. Accordingly their study indicated that, from the erosion source areas, large amounts of soil nutrients are exported to the deposition sites in the same or other landforms. Such erosion processes are aggravated by terrain characteristics (e.g., slope), high gully networks, poor soil cover and conservation measures, which have been reported as the main controlling factors for the rate of sediment yield variability in the Tekeze catchments (Tamene, 2005; Nysse et al., 2008). Similarly, several researchers have reported that aggrading sites contain higher amounts of organic carbon and plant nutrients than the soil from which these were eroded (Stoorvogel and Smaling, 1990; Monke et al., 1977; Zheng et al., 2005).

Depletion of Groundwater Recharge

Soil erosion encourages surface runoff and hinders the infiltration rate and groundwater recharges. However, knowledge of current recharge and levels in both developed and developing countries is poor and there has been very little research on the future impact of upper catchment on groundwater, or groundwater-surface water interactions (Barber, 1984). These are obvious that due to sedimentation of the downstream deposited sand is occasionally harvested for use for construction purposes in the urban areas. Most of the sand harvested is carried away with sizeable amounts of water. This has contributed to drying up of river beds, decreased groundwater recharge and increased soil erosion within the basins where sand is harvested (Nzuve and Mulei, 2014).

Alternation of discharge often shows a decreased discharge amount or frequency as a result of watershed degradation. The latter often includes the occurrence of flash floods, which are short but very intense flood events. Alternation of discharge occurs due to a degradation of vegetation and the acidification of topsoil (Bewket and Sterk, 2005). Furthermore, the process also increases soil erosion due to floods decrease soil moisture and ground water as well as a decrease of groundwater recharge is further features of degradation. Due to the removal of the vegetation cover, the topsoil experiences an increase of evaporation and hence the formation of acidification, which in turn reduces the water conductivity (Haregeweyn, 2006). This leads, on the one hand, to the creation of an evapotranspiration barrier; however, on the other hand it results in a decreasing infiltration rate and thus in increased surface runoff. Changes in soil moisture and groundwater thus not only
Offsite Effect of Erosion

Overland Flow

Deforestation, increased runoff and soil erosion are the serious problems in Ethiopia. Rapid population growth, improper land resource management and utilization are the principal causes of increased runoff and soil erosion in Ethiopia. It has resulted in declining agricultural productivity, water scarcity and continuing food insecurity (Bishaw, 2001). In the highlands of Ethiopia erosion caused by water is severe. It is the main course of erosion in these highlands. The rain is concentrated into three to four month period at the summer time. More than 72% of the highlands receive more than 600 mm of rain between May and September (Braun et al., 1997). As a result, the development of gullies on the downstream has many negative impacts as it normally involves the loss and deposition of a great amount of soil (Figure 4). The loss of large soil masses by gully erosion often stands for the depletion of a basic natural resource. Moreover, the formation of gullies implies an alteration of overland flow, a shortening of runoff lag time and an increase in runoff volume (Billi and Dramis, 2003).

In the lowlands, deposition of soil from eroded uplands causes changes in river channels and subsequent increase in flood vulnerability of the floodplain the farmlands and residential areas (Haregeweyn et al., 2008b). As seen in Figure 4, U-shaped channels in the basin centre once developed from gullies has been wide spread and currently have a total extent of approximately 6.5km (total channel length) Thiemann et al. (2005). The development of these u-shaped channels that makeup a channel network started to develop about 30 years ago in the area where the Dana Dam (Northern Ethiopian Highlands) is located today. As gully development coincided with deforestation of hill slopes and increasing tillage, it can be concluded that gully development was caused by increased surface runoff as a consequence of changes in vegetation cover and land management.

The Northern Ethiopian highlands are a fragile environment, characterized by steep slopes, intense rainfall and a sparse vegetation cover. Poverty and stagnating technology in this vulnerable environment induce severe soil erosion. This leads not only to lower crop yields and higher food insecurity, but also to important off-site effects: e.g. flooding and the deposition of sediment in reservoirs (Haregeweyn, 2006). The intense convective rainfall combined with the steep topography and often poor soil cover leads to a hydrologic regime that is characterized by flash floods. While runoff discharge is very small during most of the time, the majority of the water in the tributaries of the Geba River is exported during flash floods. These floods mostly occur in the evening or night and often have a steep rising limb with flow depths rising from several centimeters to 3-8 meters in less than one hour (Zenebe, 2009).

Sedimentation

Soil erosion and land degradation in the Ethiopian highlands is a fact that 85% of the Nile River annual flow for downstream countries (Sudan and Egypt) comes from the Ethiopian Highlands via the Blue Nile, Atbara river and Sobat River, while about 65 % of White Nile annual flow is lost in the Sudd area due to evaporation.

On the other hand, several studies concluded that all
types of land degradation occur in Ethiopia. Moreover, stream bank erosion, mass movement, biological, physical and chemical degradation are also taking place in the highlands. The severity of erosion could be noticeable by the formation of too deep, wide and large gullies (Figure 5) everywhere (under cultivated lands or uncultivated one) (Abdelsalam and Hamid, 2008).

Soil erosion by water and sediment transport is a complex process that is influenced by soil type and soil forming factors. In areas where soil, climate and topography are similar, differences in erosion rates are commonly related to land use (Del Mar López et al., 1998). The main driving forces for soil erosion in Tigray are intensive rainfall, erodible soils (low organic matter content), rugged topography, and population pressure; curbing factors are limited soil depth, high rock fragment cover and presence of soil and water conservation works (Belete, 2007). In general, soil erosion varies according to land-uses and agro-climatic zones.

Soil erosion and sedimentation are an immense problem threatening the live storage capacity of dam reservoirs in Ethiopia. In irrigation projects, soil erosion and sedimentation cause reduction of irrigation conveyance capacities and reservoir storage volumes (Nyssen et al., 2004). They also reduce irrigation water quality by increasing water turbidity (Omuto et al., 2009). In south Somalia, rivers Juba and Shabelle are the main rivers supplying irrigation water for many agricultural activities in the region. However, over many years and more specifically in the last 20 years, the irrigation projects have experienced high sediment loads which hamper their operation. Upland soil erosion is believed to be the major cause for this high sediment load (McDonald and Partners in collaboration with Institute of Hydrology, 1991). The rapid siltation of the reservoirs has resulted in the loss of their intended services and a large amount of money spent on their construction. Accelerated siltation is also responsible for the storage capacity loss of hydro-electric power dams resulting in frequent power cuts and rationing-based electric power distribution (Ayalew, 2002).

Ethiopia has a large potential to generate electricity by hydropower. However, the large sediment yields are a threat for the life expectancy of many reservoirs used for hydropower electricity generation (Zenebe, 2009). This in turn reduces the power generation capacities of hydropower reservoirs. The high rate of soil erosion/ sedimentation threatens the lifespan of Gilgel Gibe-1 hydropower reservoir. The problem of sedimentation in Gilgel Gibe-1 will also affect Gilgel Gibe-2 which uses the water released from Gilgel Gibe-1 (Adugna et al., 2013). Studies indicated that there is a rapid loss of storage volume due to excessive soil erosion and subsequent sedimentation in Gilgel Gibe-1 dam reservoir. Devi et al. (2008) conducted a cross sectional study and assessed the siltation and nutrient enrichment level of Gilgel Gibe-1 dam reservoir. From their study, they found that siltation and nutrient enrichment were the major problems in this reservoir.

The rapid loss of storage volume due to sedimentation is the major problem of all reservoirs. Some preliminary studies indicated that, the levels of some reservoirs (e.g., Koka reservoir) and many lakes e.g., Alemaya, Awassa, Abaya and Langano have decreased. The process is so challenging that the initial water carrying capacity of the dams has reduced due to progressive silt accumulation. For example, the Koka dam has accumulated about 3.5 million m$^3$ of silt within 23 years (Gizaw et al., 2004; Zemadim et al., 2012).

The Blue Nile River basin, which originates from the steep mountains of the Ethiopian Plateau, is the major source of sediment loads in the Nile basin. Soil erosion from the upstream of the basin and the subsequent sedimentation in the downstream area is an immense problem threatening the existing and future water resources development in the Nile basin (MoWR, 1993). In addition, the amount of soil loss due to gullyming has become a very serious problem in the recent decades as it was associated to remarkable depletion of cultivated land (Billi and Dramis, 2003; Temesgen, 2007).
Another study by Thiemann et al. (2005) shows the Dana reservoir was built in 1998 to supply water for irrigation of the downstream located farmlands. The capacity of total sedimentation of the reservoir was calculated for a lifespan of 10 years, but already after three years high sediment yield of the head waters caused lasting siltation. Similarly, in Tigray (Northern Ethiopia), significant achievements were made, mainly from 1994 to 2002, on the development of agriculture through irrigation by using seasonally harvested runoff using earth dams. However, most of the implemented schemes are not serving the intended purpose well because of these sedimentation problems. Many reservoirs are filled with sediments much sooner than expected. Without these water reservoirs, irrigation becomes impossible which leads to lower crop yields in the region (Haregeweyn, 2006).

As sediment transport in rivers is associated with a wide range of environmental (e.g. chemical transport of nutrients) and engineering issues (e.g. reservoir siltation), the highly appreciated efforts on water resource development interventions usually face problems. Therefore, the sediments, organic and inorganic fertilizers from the agricultural fields that enter the lake by runoff may result in eutrophication of downstream reservoirs (Figure 6). So far no effective measures have been taken to combat flooding, soil erosion and sedimentation problems (Conley et al., 2009; Gebriye et al., 2009).

Heavy sedimentation has been experienced by Ethiopia’s existing dams and is a very real risk to the lifespan of new hydroelectric power dams as well as dams for irrigation and water supply. The withholding of such sediment by Ethiopia’s dams is likely affecting downstream ecological functions and may be exacerbating the rate of downstream erosion. In 2000, Addis Ababa suffered further power outages during the rainy season after turbines at the Koka Dam became clogged with sediment. According to a recent academic study, four irrigation dams constructed in the 1980s had to be abandoned due to sedimentation. Ayalew (2002) noted that siltation had greatly reduced the lifespan of the Angereb and Melka Wakena dams and could greatly impair the soon to be commissioned, Tekeze Dam. According to the Gilgel Gibe I 1997 Environmental Assessment, a high sedimentation load was anticipated. High rates of sedimentation are also anticipated in the Gilgel Gibe III reservoir, where one-third of its space is reserved for sediment to accumulate over time (Hathaway, 2008).

**Conclusion and Recommendation**

Soil erosion and soil loss are the major challenges for sustainable agricultural development in the upper Blue Nile basin. The problem is more serious in the Ethiopian highlands. Inappropriate agricultural practices, high population pressure from human and livestock, higher rainfall intensity and rugged topography have been reported as the main facilitators for having severe erosion and sedimentation. To curb the severity of soil erosion and its associated effects, the Ethiopian government and NGOs have been introduced various soil and water conservation technologies though the adoption had been disappointed. Therefore, soil erosion has been adversely threatening the upper Nile basin particularly in the Ethiopian highlands and the effect has been both onsite and offsite to the upstream and downstream countries, respectively. Siltation of reservoirs, water pollution, distraction of conservation structures, eutrophication, nutrient loss, reduced agricultural productivity and depletion of ground water have been among the effect of soil erosion and sedimentation.
However, some of the adopted conservation and upland management technologies has been effective in reducing soil erosion and sedimentation. Hence, continuous investments in water resource management in the Blue Nile Basin suggest a need for efficient and effective mechanisms to improve water capture and agricultural output in the highlands of Ethiopia. The soil erosion/sedimentation controlling mechanisms and the mitigation measures play an indispensable role for the sustainable water resources development such as encourage tree planting as a means of reducing soil erosion, sediment load detachment and deposition as well as increasing groundwater recharge. To implement such strategies, it is necessary to understand the magnitude of the problem and factors responsible for it. Knowledge of cause effect relationships and their spatial patterns are also essential to plan integrated watershed management schemes and to design necessary management precautions. This will improve the understanding of the upstream-downstream linkages/interdependence for better and equitable land and water management and utilization. The overall reviewed papers indicated that soil erosion, sedimentation, upstream management and its associated effects are interrelated issues in the upper Blue Nile basin. To tackle the onsite and offsite threats of erosion, there is an urgent need for implemented (BMPs) improved catchment-based erosion control and sediment management strategies.

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