



Review, impact of land use/cover change on soil erosion in the Lake Tana Basin, Upper Blue Nile, Ethiopia

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Abstract

Lake Tana Basin is located in upper Blue Nile Basin which is comprises a total area of 15,096 km² of which 3063 km² is covered by the Lake which is the source of Blue Nile river. Lake Tana Basin and Blue Nile River provide various benefits also for downstream countries. The basin is highly degraded by different natural and manmade problems and it influence both Ethiopia and downstream countries. The main cause of basin degradation is inappropriate LULC. Huge area of cultivated land using without suitable management is the major basin problem. It is due to insure food security coming from unprecedented population growth rate. Forested land has encouraged the infiltration capacity and permeability of the land. It helps to increase the recharge capacity contribute to base flow whereas it is vice versa for cultivated land which is quick overland flow and significant soil erosion have observed. Besides, the soil erosion from agricultural land is the main source of nutrient enters to the lake which is the cause for eutrophication. To combat such problems both up and downstream countries should discuss together and design and implement appropriate basin management strategies to sustain the biodiversity and hydrological system of the basin.

Keywords Lake Tana · LULC · Soil erosion · Lake Tana Basin

Introduction

Ethiopia, mostly dominated by mountainous topography is the source of water for east Africa which is from rainfall-runoff process (Derib et al. 2009). Understanding rainfall-runoff process is essential to control problems and improve productivity of the watershed. Erosion is the major problems in the basin and it is high in early period of the wet season, and sediment concentration is frequently recorded before peaks of discharge is observed in a given rainfall season (Steenhuis et al. 2009).

In the Lake Tana Basin, effective utilization of the land and water resource is needed to improve the livelihood of the basin. Both natural and manmade activities are significantly affected existed natural resources of the basin (Setegn et al. 2009). Hydrological process research in the watershed is a vital to identify and provide solutions to save the critical degradation of soil and water resources in the

catchment (Easton et al. 2010; Setegn et al. 2008). The lack of resources used to researching problems on the watershed are challenging to overcome significantly the research and development in the area (Setegn et al. 2009). To solve the existing soil erosion problems there is a need to identify the most erosion sensitive areas in the region, so that effective conservation measures can be taken.

Area description

Lake Tana is largest lake in Ethiopia and the third largest in Nile Basin is located in upper Blue Nile Basin, Ethiopia. It is stretched between 10.95° and 12.78°N latitude and 36.89° and 38.25°E longitude with a drainage area of about 15,096 km² of which, 3063 km² of land is covered with Lake Tana (Fig. 1). The climate of the Lake Tana sub-basin is dominated by tropical highland monsoon with most of its rainfall occurring between June and September. The lake is receiving more than 93% of flow from four major rivers which are Gilgel Abay, Gumara, Ribb, and Megech (Setegn 2010). Gilgel Abay is the largest contributing river with a catchment area of 3822 km². The south-east part of the watershed is high (3524 masl) in elevation and it becomes

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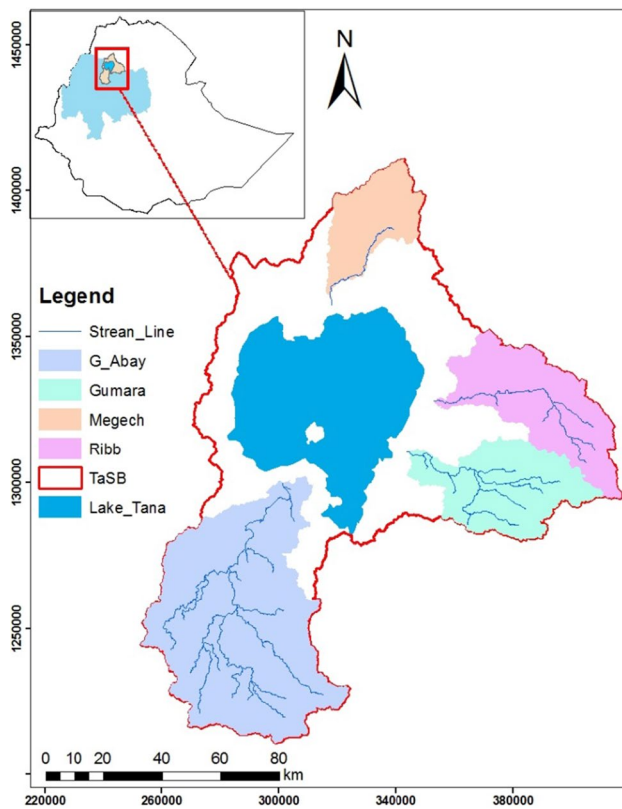


Fig. 1 Location map of review area

decrease to the north which is the river mouth of the lake (1790 masl). Whereas, Gumara and Rib watersheds are adjacent rivers which are flows from east to west contributing to the lake. The elevation ranges from 1784 m to 4109 m above mean sea level (amsl). The contributing area of the watersheds is 2960 km². Another tributary watershed is Megech which is contributing 844 km² area of land. The watershed is elevation difference from 1787 to 2972 masl. All watersheds characterized as a mountainous and terrain with steep slopes at the upper part of the basin and undulating topography with gentle slope from the downstream part of the watershed is the common character of all watersheds. Blue Nile River is the only outlet of the lake which is the source of the River.

Factors affecting soil erosion

Inappropriate land use and management system with lack of soil and water conservation implementation have significant to land degradation problem in Ethiopia. Ethiopia losses \$1.9 billion due to soil erosion between 1985 and 2010. To tackle this problem, Ethiopian government with funding organization takes immediate soil and water conservation implementation (Setegn et al. 2009).

Understanding soil erosion factors are significant to formulate effective soil and water conservation structure. The four major factors discussed below are erosivity of rain, erodibility of the soil, topography and land cover (Mekonnen and Melesse 2011).

The amount, duration and intensity of rainfall are important elements in soil erosion (Hurni 1985b; Lal 1984; Morgan and Erosion 2005; Wischmeier and Smith 1978). Soil erodibility is the capacity of soil to transport and detachment. It is a function of Soil texture, structure, organic matter content and permeability (Renard 1997; Wischmeier and Smith 1978). It determines the soil erosion vulnerability (Lal 1984; Morgan and Erosion 2005).

Land topography is another important consideration to understand rate of soil erosion (Wischmeier and Smith 1978). When the length and steepness of the land increase the soil erosion will increase due to increasing the volume of runoff and gathering speed and energy of runoff (Wischmeier and Smith 1978).

Land cover has potential to change watershed characters such as infiltration capacity of the soil, intercepting agent of rainfall, reduce rainfall and runoff energy by improving rainfall erosivity index, improve soil erodibility factor by increasing cohesive or bonding character of soil type which are affect soil erosion vulnerability. According to Hurni (1985a, b) study in Ethiopia, soil erosion in bare land was higher than other land covered by different use. The average rate of soil erosion from bare land is 70 ton ha⁻¹ yr⁻¹ whereas erosion rate from different land covers was between 0 and 42 ton ha⁻¹ yr⁻¹ (Hurni 1985b).

Soil erosion increases with increasing runoff and where soil depth is shallow and heterogeneous (Easton et al. 2010; Mekonnen and Melesse 2011). Lake Tana sub-basin, one of the major basins of the Blue Nile is predicted to have some of the highest sediment yields in the basin, 15 as high as 200 ton ha⁻¹ resulting from cultivation on the steep slopes, and the relatively high runoff losses that prevail in the region (Easton et al. 2010). Easton et al. (2010) (Mekonnen and Melesse 2011) reported that, cultivated land with steep slope next to grazing land in addition to saturated soil is aggravating soil erosion.

Effects of land use land cover on soil erosion

Watershed characters and climate change are significant to alter the hydrological process (Fohrer et al. 2001; Huang and Zhang 2004; Laurance 1998; Richey et al. 1989; Schulze 2000; Tu 2009; van Roosmalen et al. 2009; Zhang et al. 2001). As Ethiopia dominated by mountainous topography, high runoff was observed due to steep slope (Derib et al. 2009), and thus, investigating the rainfall-runoff processes is critical to controlling erosion (Easton et al. 2010). Runoff

losses from upland area become decrease with decreasing drainage basin and thus, increase base flow. It is due to the variation of saturation fraction depending on the drainage area (Easton et al. 2010).

Studies on effect of land use land cover change on hydrological regime as well as soil erosion are not enough (Andréassian et al. 2004; Bosch and Hewlett 1982; Cosandey et al. 2005). Researchers work on effect of land cover changes on hydrological regimes on experimental watershed of small scale ($<1 \text{ km}^2$) (Bosch and Hewlett 1982; Guillemette et al. 2005; Iroumé et al. 2005; Lavabre et al. 1993; Troendle and King 1987). However, studies in large-scale level ($>1000 \text{ km}^2$) are a key to design effective soil and water resource management system. So the impact of any disturbance will be minimal when catchments are of regional or larger scale. The dynamic of land use land cover is primary cause to altering the watershed hydrology (Chakilu and Moges 2017).

Land use and land cover of the catchment play a significant role to soil erosion than other catchment characters (Halefom et al. 2019a). Study by Abebe and Minale (2017); (Ayalew and Angelidis 2019) estimated the land use/cover change between 1986 and 2013. In the years between 1986 and 2013, most parts of the watershed covered by forest and grassland were changed to cultivated and settlement. The cover size of the cultivated land was nearly doubled between 1986 and 2013 which was 19% and 32%, respectively, whereas settlement was increased significantly from 0.3% to 19% (Abebe and Minale 2017). It is the reason why the runoff and erosion increase time to time.

Hydrological regime and land use/cover relation of the basin

Influential LULC changes were reviewed in different articles. Agricultural land is highly accelerated with time whereas shrub and grassland also reduced simultaneously concluding that the demand for agricultural lands has increased. These LULC change is significantly changed hydrological regime of the watershed. Many studies suggested that significant change of rainfall and stream flow was observed and they conclude that soil erosion is becoming serious issue due to such hydrological change. Rainfall in general has decreasing but it increase in wet season whereas it has decreasing in dry season. In the same manner, the mean annual flow has significantly reduced. Contrary to decrease in low and annual flow, high flow index has increased. Obviously high flow was occurred in wet season (Rientjes et al. 2011). It is likely due to change of land cover and seasonal and annual change of rainfall distribution in the catchment. In terms of land cover, huge area of forest land is converting to agricultural land. Forested land has potential to conserve rainfall

and increase infiltration capacity of the surface to encourage subsurface water availability whereas deforestation and land degradation process are susceptible to overland flow and reduce infiltration and recharge flux. This consequently results in quicker runoff responses were flow rates increase and we presume that this partly causes the increase in the high flow index and aggravate soil erosion.

Land use/cover change and hydrological condition of Gilgel Abbay catchment

Studies by Minale (2013) reported that significant land use land cover change was observed. Most of the watershed covered by forest was changed to cultivated land. In this study, 9328 ha (1.2%) of land was covered by the forest in 1973 whereas only 2581 ha (0.3%) was covered. In the same line, results of the supervised land cover classification analysis indicated that 20.6% and 9.3% of the catchment area was covered by grass land in 1973 and 2008, respectively. It indicates that, the catchment areas were reduced from forest and grass to cultivated land by 3387 ha yr^{-1} . According to Minale (2013) during the last 35 years, cultivated land was increased from 26.1% to 41.2% between 1973 and 2008. The forest, grass and shrub land quickly changed to agricultural land. LULC change (to agricultural) becomes highly accelerated through time (Rientjes et al. 2011). These significant changes in forest and grass land were mainly due to expansion of agricultural land because of unexpected population growth. In the Gilgel Abbay, upland area of the watershed is not sensitive to gully erosion which is the most critical form of soil erosion and sheet and rill erosion are mostly common in this part of the watershed. Stream power index is powerful indicator of gully susceptible area. In large catchment with steep slope, volume and velocity of runoff generated from upslope area will increase. Hence SPI and gully erosion risk becoming increase. Gullies were observed in saturated bottomlands where the most important erosion prone parts of the watershed (Mhired et al. 2019). The SPI was in the range of 2–16 of which gully potential area where the SPI >7 (Mhired et al. 2019).

Land use/cover change and hydrological condition of Gumara catchment

Studies on hydrological characteristics of the watershed are basic to tackle the hydrology problems. Absence of accurate data is hampers to conduct such studies. Land use land cover of the watershed is interesting character to explain the hydrological process of the watershed. The extent and rate of land use/cover change between 1973 and 2013 were studied by Chakilu and Moges (2017). Chakilu and Moges (2017);

(Wubie et al. 2016) reported that significant change of other land use (grass, bush and forestland) to cultivated land was observed. It is in order to meet food demand following population increase. In this point, the forest, bush and grassland were changed to cultivated land. Only 479.36 km² (37.7%) of land was covered by cultivated land in 1973 whereas it was about 961 km² (75.6%) in 2013. The annual change of the watershed from other land use to cultivated land was 1204 ha yr⁻¹ (Chakilu and Moges 2017).

Land use/cover change and hydrological condition of Ribb catchment

The largest portion of Ribb watershed was covered by cultivated land (61.3%) followed by grass land (22.8%) in 2014 which has significant effect on soil erosion (Estifanos 2014). Whereas studies by Moges and Bhat (2018) reported that about 88% of land was covered by cultivated land and only 6% was for grass land in 2016. We observed significance difference of land use/class classification result between different researchers. It is due to LULC maps generated from satellite images always contain some sort of errors originated from several sources, such as classification techniques and methods of image acquisition. As a result, post classification refinement is needed to improve classification accuracy and reduce errors (Butt et al. 2015) and increase the quality of the information. Potential annual soil loss of Ribb micro-watersheds ranges 10.93–95.5 ton ha⁻¹ yr⁻¹ which is agreed with the annual soil loss of the highlands of Ethiopia (16–300 ton ha⁻¹ yr⁻¹). When it is compared to soil loss of the neighboring Gumera watershed ranging from 11 to 22 ton ha⁻¹ yr⁻¹, it is very large value. The mean annual soil loss rate of the whole study area is 39.8 ton ha⁻¹ yr⁻¹; which is much greater than the tolerable level of 10 ton ha⁻¹ yr⁻¹ (Estifanos 2014; Hurni 1983). The annual soil loss of the highlands of Ethiopia ranges from 16 to 300 ton ha⁻¹ yr⁻¹, of pasture, ranges and cultivated fields throughout Ethiopia (Steenhuis et al. 2009). The study by Estifanos (2014) was proved within the findings of FAO. When we compare this result with the predicted annual soil loss rate in Lake Tana Basin which is >60 ton ha⁻¹ yr⁻¹ in rugged topographies and it decreases up to 15 ton ha⁻¹ yr⁻¹ on the area with better catchments characteristics (Yitaferu 2007). Ribb becomes one of the watersheds that contribute a large amount of soil loss in Lake Tana Basin. Like Gilgel Abay and Gumara watersheds, land use land cover was potentially changing the extent of soil erosion. And major area (89.71%) of land in the Ribb watershed is cultivated land (Halefom et al. 2019b). Very sensitive areas are concentrated mainly in the upper and saturated bottomland part of the watershed land (Halefom et al. 2019b). It is likely due to gully initiation at the saturated bottom land and rill and sheet erosion by quick

overland flow at the upside part. Stream power index is significant parameter to identify gully erosion vulnerability of the watershed. Many researchers conducted on role of stream power index on susceptibility of gully erosion (Jetten et al. 2003; Lulseged and Vlek 2005; Zegeye et al. 2016). The higher stream power index (SPI) with in the range of 6.1–8 in the field was identified as areas that have linked up with stream channels. Based on this truth gully potential areas other than the natural stream channels are areas with stream power index from 2 to 6 (Estifanos 2014). In rib watershed, 7.4% of the sub-watershed is gully potential areas where as only 2% of the watershed is potentially susceptible to gully erosion risk (Mhired et al. 2019). Based on soil erosion susceptible classification, saturated bottomland is significantly potential to gully erosion, whereas upland part of the catchment is sensitive to sheet and rill erosion due to quick overland flow generation (Abiy 2009; Tebebu et al. 2010; Zegeye et al. 2016).

Land use/cover change and hydrological condition of Megech catchment

Land use classification map of Megech watershed shows 47% of land was erosion potential area which is covered with cultivated and bare land whereas only 3% of land was covered with dense forest where soil erosion is low in 2018 (Balabathina et al. 2019). In Megech watershed, 75% of land was SPI in range of 2–13 which is most powerful to gully erosion (Balabathina et al. 2019). SPI will increase with increasing area and steepness of the catchment. Major area of Megech watershed is steep than other Lake Tana sub-basin. 52.2% of land is slope greater than 10% which is quick runoff is generated. Total amount of soil loss accounts in the catchment of Megech River with an average soil erosion rate of 41.54 ton ha⁻¹ yr⁻¹. Estifanos (2014) estimated the average rate of soil loss as 39.8 ton ha⁻¹ yr⁻¹ in the Ribb watershed that is adjacent to the Megech watershed. Sever soil erosion was occurred at the upper hilly and mountainous catchment of the watershed, particularly along the main streams and downslopes, It is may be due to gully and rill initiation.

Research gap

Many studies on soil erosion factor are carried out. Most studies conclude that land use/cover have significant potential to soil erosion. Inappropriate cultivated land use is the major source of soil erosion. Most of researches assessed the land use land cover change to investigate soil erosion hotspot area. It is due to land use/cover have the main factor affecting soil erosion. Various studies result on LULC

change and its impact on basin hydrology have no clear and common conclusion. It is likely due to map generated from satellite image have some sort of error originated from various source such as method of image acquisition and classification. As a result, post classification refinement is needed to improve classification accuracy and reduce errors such as visual interpretation of unclassified satellite image, farmers' memory of land use history and several ground control points consisting of different LULC features and their location points collected will increase level of accuracy of image classification. In addition, intensive researches about root cause of soil erosion and to design appropriate control method are not clearly known.

Conclusion

Soil erosion is the major threat in Lake Tana Basin. Sediment transported to the lake is not only reducing the agricultural productivity but also disrupt lake's biodiversity due to reduce reservoir capacity and presence of eutrophication. Cultivated land is the major kind of land use which is the main factor contributed to soil erosion. It is due to quick runoff generation from agricultural land next to bare land. Even though, significant difference was observed between research findings on land use/cover change, many studies were conducted on impact of land use/cover change on soil erosion. Huge areas of land were changed to cultivate and settlement land from forest, grass and bush and shrub land. It was due to significance increase in population growth and to secure their livelihood. Improper cultivated land use with steep slope was the aggravating soil erosion in the Lake Tana Basin. To save the lake and basin biodiversity, different stakeholders such as government and environmental management NGOs should design appropriate type of land use and other source of income to ensure population livelihood. It helps to reduce expansion rate of land, exposed to inappropriate cultivated land use which is significant for accelerating soil erosion.

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Compliance with ethical standards

Conflict of interest The author declares that he have no conflicts of interest.

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