International Scholars Journals

African Journal of Soil Science ISSN 2375-088X Vol. 4 (3), pp. 321-327, March, 2016. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Evaluation of the existing conservation practices on Lake Haramaya Catchment

Zerihun Asad[1]*, Dametew Adem[1] and Abdulaziz Farah[2]

[1]Department of Soil and Water Engineering, Jigjiga University, P. O. Box 1020, Jigjiga, Ethiopia.
[2]Institute of Technology, Haramaya University, P. O. Box 345, Haramaya University, Ethiopia.

Accepted 09 September, 2015

A study was carried out at Lake Haramaya Catchment (5032 ha) to evaluate soil erosion, sedimentation and conservation practices. The catchment has experienced severe degradation due to intensive cultivation, deforestation, unwise utilization of land and water resources which lead to the onset of soil erosion. The Gumbel's Method and MUSLE were employed to estimate the peak flood and catchment sediment yield respectively. SWAT was used to delineate the catchment and to analyse the catchment slope, soil and land uses. Besides, interview and field observation were carried out to collect data regarding the effects of soil erosion and status of existing conservation measures. The average annual soil loss from the study area estimated is to 24.315 ton/ha/year resulted due to the high rainfall erosivity in the area. Moreover, the results showed a direct relationship between rainfall and sediment yield. With regard to the method of soil and water conservation practices, biological conservation measures like mulching and mixed cropping are widely implemented with almost zero or negligible engineering measures. Small mechanical/engineering measures that could better hit the target are not considered. Generally, soil erosion of the catchment is high and integrated watershed management is needed to minimize the erosion problem.

Key words: Soil loss, SWAT, MUSLE, lake sedimentation, erosion, Haramaya.

INTRODUCTION

The poor land use practices, improper management systems and lack of appropriate soil conservation measures have played a major role for causing land degradation problems in Ethiopia. Because of the rugged terrain, the rates of soil erosion, land degradation in Ethiopia are high. The soil depth of more than 34% of the land area is already less than 35 cm (Zemenfes, 1995; SCRP, 1996). Hurni (1989) indicated that Ethiopia loses about 1.3 billion metric tons of fertile soil every year and the degradation of land through soil erosion is increasing at a high rate. In the Ethiopian highlands, soil and water are the most critical resources. Nearly 85% of the population depends on subsistence agriculture. One process that threatens the resource base is soil erosion.

Due to greater population pressure and consequently more intensive cultivation, erosion losses have been increasing to an annual areal average of 7 ton/ha equivalent to 0.5 mm depth (Garzanti et al., 2006). Local erosion rates are spatially variable ranging from less than 1 to over 400 tons/ha/year (Hurni, 1988; Tebebu et al., 2010). The history of Lake Haramaya Catchment is not different from other parts of the country, because the catchment is not properly conserved. There are different causes for detachment of top soil, formation of medium

*Corresponding author. E-mail: zerihun_asad@gmail.com.

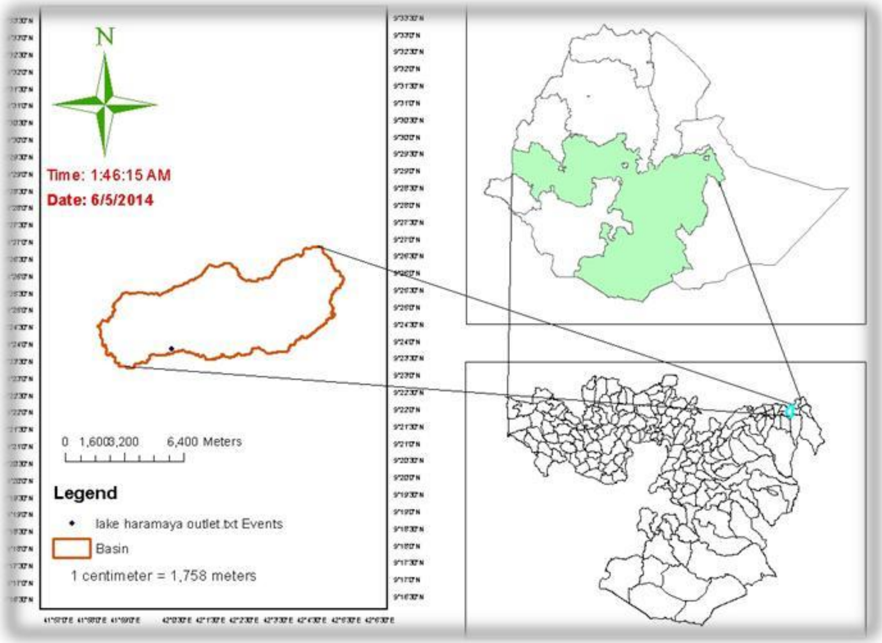

Figure 1. Lake Haramaya Catchment.

and excessively large gullies, erosion, transport and deposition of sediments in the lake area. In addition, the area has suffered from adverse effects of deforestation and unwise irrigation practice, land degradation due to intensive cultivation, conversion of marginal lands into crop cultivation, and climate change induced droughts. The severity of soil erosion is evident in the Lake Haramaya Catchment by the common occurrence of deep and wide gullies that are extreme forms of soil erosion (Tamirie, 1981; Solomon, 2002; Shimelis, 2003; Muleta et al., 2006). The consequences of such extreme forms of soil erosion can be seen from the on-site and off-site impacts of reduced agricultural production, increased volume of flood and siltation leads to drying up of the Lakes in the Watershed.

These call for immediate measures to save the physical quality of soil and water resources, rehabilitate the highly affected erosion areas, reduce the negative effects of soil erosion and siltation of lake area. Thus, as a way towards formulation of management options, soil erosion and sedimentation should be considered as these are concurring environmental processes with varied negative and positive impacts. In the study area, soil erosion and sedimentation cause reduction of fertile top soil from agricultural upland area, reduction in storage capacity of the lake which later became one main cause for disappearance of Lake Haramaya. To tackle the on-site and off-site threats of erosion, there is an urgent need for improved catchment-based erosion control and sediment management strategies (Millward and Mersey, 2001). Thus, in order to reduce the sediment transport into the lake area, contributing areas with high soil erosion rates need to be identified, their sediment yield has to be quantified and targeted for soil erosion control measures. The study was, therefore, conducted with the main objective of analyzing soil erosion, sedimentation and conservation practices on the Lake Haramaya Catchment. The specific objectives are (i) quantify sediment yield of the catchment; (ii) discuss effects of soil erosion on the catchment; and (iii) evaluate the existing conservation practices on the catchment.

MATERIALS AND METHODS

Description of the area

The Watershed of Lake Haramaya is located in Haramaya and partly in Kombolcha districts, eastern Hararghe zone, Oromia National Region State, East Ethiopia. It is located at the upstream part of Wabishabele Drainage Basin. The Haramaya District which the Lake Haramaya catchment found in is situated 505 km away from Addis Ababa to East, about 14 km far from Harar city, and 38 km far from Dire Dawa city. The Watershed lies 9°23' 18" to 9° 26' 48" North of latitude and 41° 58' 30" to 42° 05' 30" East of longitude.

The total area of the catchment is 5032 ha of which the area of the Lake Haramaya is 2.26 km^2 (Setegn et al., 2011). Lake Haramaya catchment encompasses a small part of Haramaya Town, the Haramaya University

Campus, Bate town, three peasant associations; *Damota*, *Ifa-Bate, and Tuji-Gebissa* fully, and another two *Ifa-Oromia* (around 90%) and *Guba-Selama* (around 10%) partially (Edo, 2009). According to the East-Hararghe zone planning and economic development department, Haramaya District with a total of 18,800 stands fifth after Girawa, Deder, Bedeno, and Meta districts in its population size. The livelihood of the community in Lake Haramaya Catchment is mainly based on mixed farming, that is, cropping and livestock production (Muleta et al., 2006).

Based on the agro-climatologically classification, Haramaya woreda has Woina Dega (wet and cool, 70%) and Kolla (dry and hot 30%) areas. The annual rainfall distribution record indicates that the area receives a bimodal rainfall type with the mean annual precipitation of 751 mm (Alemayehu et al., 2007). According to Muleta et al. (2006), the dry period (less than 30 mm per month) extends from October to January inclusive; December with 9 mm is the driest month. The wet season starts in February (37 mm) and extends up to March (67 mm). The monthly rainfall is more than 100 mm from April to September, except June (65 mm). The wettest month is August with an average rainfall of 144 mm. The maximum and minimum mean annual temperatures for the area are 23.8°C and 9.6^{0}C respectively (Tadesse et al., 2010). The mean monthly relative humidity before the year 2003 falls between 53 and 75% (Alemayehu et al., 2007).

Lake Haramaya Catchment covers areas with elevation ranging between 1980 and 2343 m.a.s.l. About 71% of the catchment is characterized by undulating and rolling topography (Muleta et al., 2006). On the basis of USDA soil textural classification scheme, the soil in the watershed was grouped in to four different classes: clay (14.6 km^2), clay-loam (25.7 km^2), sandy clay loam (6.1 km^2) and sandy-loam (5 km^2) (Tadesse and Abdulaziz, 2009).

The six land use types comprised in the study area are cultivated land (78.3%), grazing land (7.6%), forest (0.6%), settlement (4.5%), shrub (4.6%) and swampy area (4.5%) (Tadesse and Abdulaziz, 2009). The major crops grown in the area under irrigated conditions are chat, potato and vegetables (lettuce, carrot, onion, tomato and cabbage). Sorghum and maize are grown under rain-fed conditions (Setegn et al., 2011).

Data collection and analysis

The meteorological data required for this study were collected from the Ethiopian National Meteorological Services Agency (NMSA), Haramaya Branch Office. Complete data of the year from 1997 - 2008 were collected and used as input in the SWAT model. DEM (Digital Elevation Modeling of SRTM_30 Shuttle Radar Topography Mission) with specific spatial x-y resolution of 30 was obtained from Consortium for Spatial Information (CGIAR-CSI) website. Soil Map and Land Use Map of good resolution (30 × 30 m) were obtained from Ethiopian Mapping Agency. In addition, data regarding soil erosion and its negative on-site and off-site effects, status of existing conservation measures was collected by direct field observation and by interview. The collected data were analyzed by different statistical analysis presented by means of tables, graphs, percentages etc.

Catchment delineation

In this study Arc SWAT integrated with Arc GIS was used to delineate the catchment area and process the slope, soil and land use map. The reason for selecting SWAT model was, among others, its computational efficiency, its ability to simulate long-term impacts, its applicability to large-scale catchments. SWAT requires daily values of precipitation, maximum and minimum temperatures, solar radiation, relative humidity and wind speed. In addition soil and land use maps are needed to run the model.

Determination of peak flood

The peak flood was generated using Gumble's method. Gumbel's method extreme value distribution was introduced by Gumbel's (1941) and is commonly known as Gumbel's distribution. It is one of the most widely used probability distribution function for extreme values in hydrologic and metrological studies for the prediction of flood peaks, maximum rain falls, minimum rainfalls maximum wind speed, etc. It is given by the following basic statistical equation.

$$X=\bar{x}+k\delta \quad (1)$$

Where
X = is any variable
$\bar{x}$ = is mean of variate
δ = standard deviation of variate and
K = is constant

Estimation of sediment yield

The sediment yield of the study area, Lake Haramaya Catchment, was calculated by MUSLE (Modified Universal Soil Loss Equation). The MUSLE sediment yield module uses factors that characterize physical conditions on the surface of a catchment as input information. The equation is written as:

$$sed = 11.8 \cdot \left(Q_{surf} \cdot q_{peak} \cdot area_{hru}\right)^{0.56} \cdot K_{USLE} \cdot C_{USLE} \cdot P_{USLE} \cdot LS_{USLE} \cdot CFRG \quad (2)$$

Figure 2. Sub-basins of Lake Haramaya Catchment.

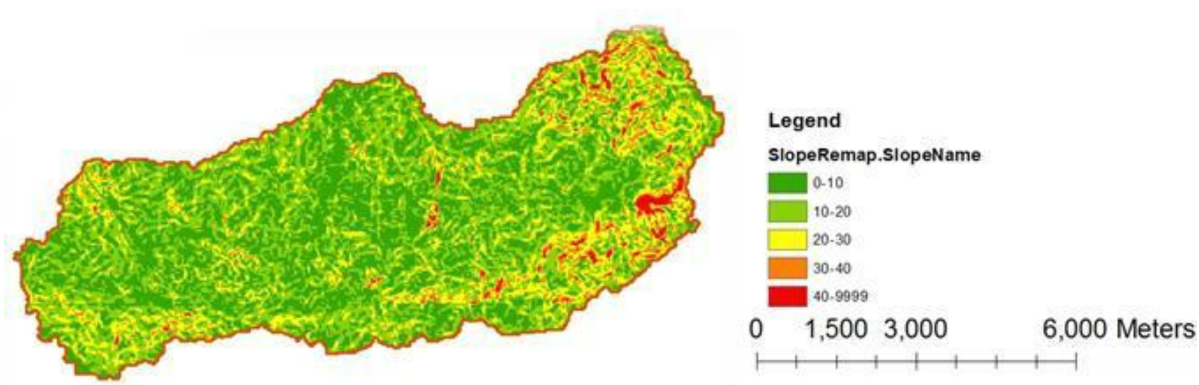

Figure 3. Lake Haramaya catchment slope map.

Where: *sed* is the sediment yield on a given day (metric tons), Q_{Surf} is the surface runoff volume (mm/ha), q_{peak} is the peak runoff rate (m³/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil Erodibility factor (0.013 metric ton m² hr/(m³-metric ton cm)), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor; LS_{USLE} is the USLE topographic factor and *CFRG* is the coarse fragment factor. MUSLE is a method which is generally applicable as predictor of wash load and it is more appropriate to use than the USLE method in semi-arid conditions (Di Silvio et.al, 2008).

RESULTS AND DISCUSSION

Catchment Characteristics

According to the results obtained from Arc SWAT, the total areal coverage of Lake Haramaya catchment (**Error! Reference source not found.**), which comprises 32 sub-basins and 420 HRUs, is around 5109 ha. The catchment is defined at UTM (171212E, 1040190N).

The slope map (Figure) of the catchment processed using ArcSWAT and the topographic reports of the same tool revealed that the lowest slope of the catchment is 0.033% while the highest slope is 43.54%. The eastern part of the catchment, where the peak point (around GaraDamota) is located, is relatively characterized with higher slope which make it more vulnerable to soil erosion than the other parts of the catchment.

The land use of the study area can be categorized mainly as agricultural/ (Row crop and genetic), forest-mixed/ and shrubs, bare-land/settlement and water body. As can be seen from the land use map (Figure), the basin is mainly occupied by agricultural land (AGRL and AGRR) with about 70% of the basin area. There is also a 24.8% of the area covered by forest (FRST), shrubs and pasture. The rest which is about 4.44% is water body (WATR) and bare land/settlement (URML).

The soil types of the watershed gathered from the Ethiopian soil map are classified as Luvisols (LUVSOL), Nitisols (NITSOL) and Cambisol (CMBSOL) as shown in Figure. Nitisols which covers greater than 43% of the watershed soil is the most dominant soils group.

Metrological data processing

The remaining soil groups Luvisols and Cambisols cover 32 and 25% of the study area respectively. Temporal and spatial rainfall (precipitation) characteristics are very important factors that affect runoff generation from catch-

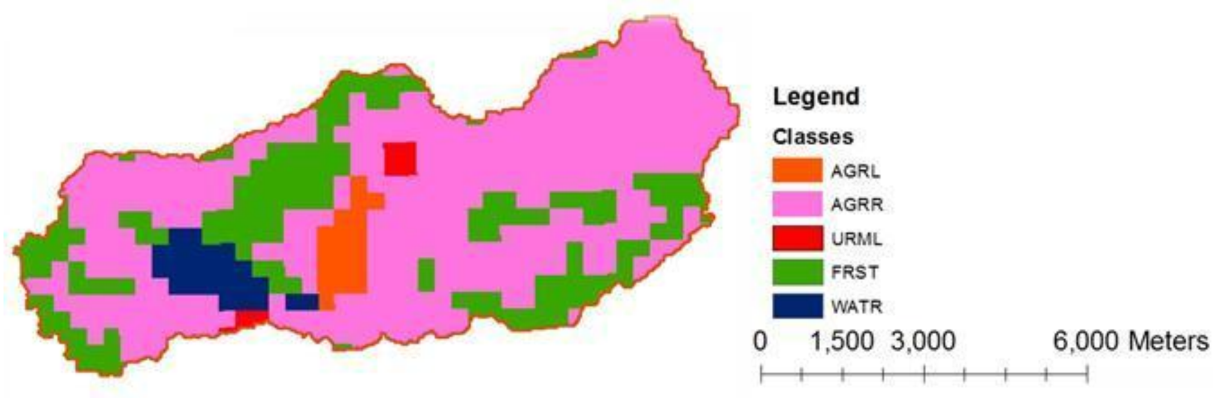

Figure 4. Land use/land cover map of Lake Haramaya catchment.

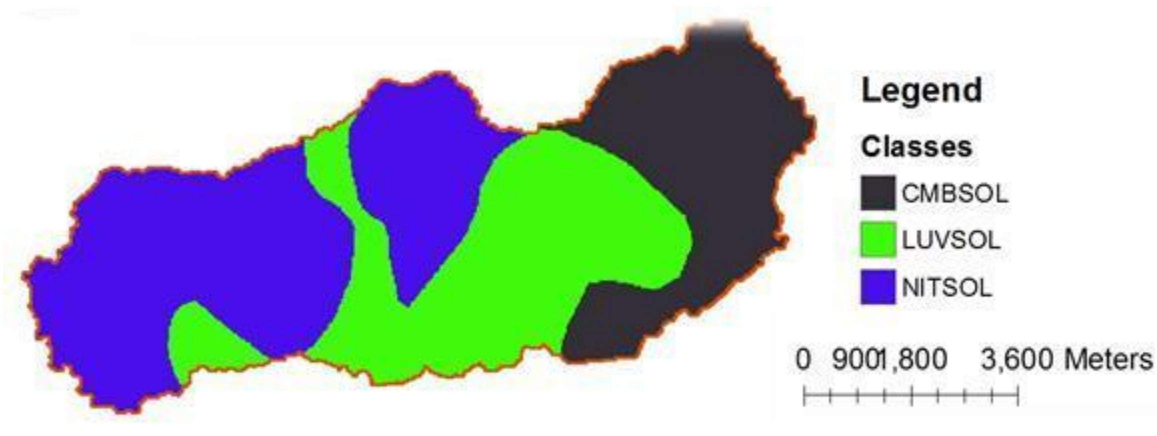

Figure 5. Soil map of Lake Haramaya catchment based on classification system of the Food and Agriculture Organization (FAO).

ments. The average annual precipitation based on 12 years of observation is 813.63 mm and the watershed experiences a bimodal rainfall distribution (Figure). From the rainfall data records obtained, year 2006 is found to have the maximum rainfall amount and the monthly variation is portrayed in Figure.

Peak flood and sediment yield

For this study, the value of variable (x) in Equation 1 is 12 years. Hence, the peak flood that can be generated from the study area can be written as given in Equation 3 and the results are tabulated in Table.

$$X(12) = \bar{X} + K\delta \quad (3)$$

The sediment yield, total amount of sediment delivered to the outlet of the watershed (Julien, 2010), of the area calculated by MUSLE (Equation 2) is presented in Table 1. As shown in Table, the catchment sediment yield reaches its maximum value in the year 2006 and its minimum value in the year 2002.

Similarly, maximum (1104 mm) and minimum (607.10 mm) annual rainfalls occur in the year 2006 and 2002 respectively. This indicates a linear relationship between rainfall and sediment yield in the catchment. Total annual sediment yield of the catchment is 24.315 kg/ha/year.

The particle density of soils in the catchment is 2.45 kg/m^3.Thus, the volume of annual soil loss from the Lake

Haramaya catchment (5109.2 ha) can be estimated as follow.

$$Volume = \frac{Mass\ of\ Particles}{Particle\ Density}$$

$$= 124230.198 * 10^3 kg / 2450\ kg/m^3$$ = 50,706.2033 m^3/year

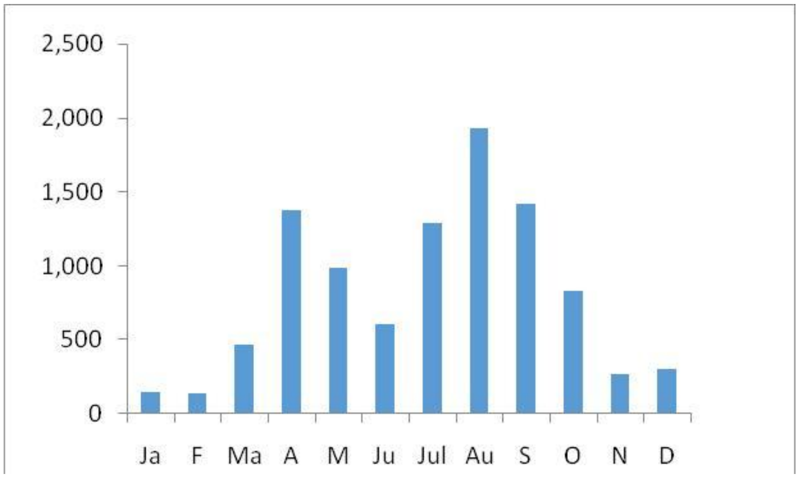

Figure 6. Average monthly rainfall distribution of Lake Haramaya catchment.

Table 1. Annual sediment yields of Lake Haramaya catchment.

Year	Annual rainfall (mm)	Qpeak (m^3/s)	Sediment Yield (metric ton)
1997	1011.80	6.73	148.73
1998	801.20	5.28	111.74
1999	879.70	6.81	136.89
2000	717.10	5.46	106.20
2001	724.10	6.93	121.77
2002	607.10	4.50	85.07
2003	766.10	7.02	127.35
2004	744.90	5.88	113.15
2005	767.30	6.39	120.90
2006	1104.00	7.10	161.88
2007	766.20	6.23	119.07
2008	874.40	6.96	138.05
Sum	9763.90	75.30	1490.79

Sediment yield is dependent on gross erosion in the watershed and on the transport of eroded material out of the watershed. Only a part of eroded material from upland areas in a watershed is carried out of the watershed (Renfro, 1975). The rate of sediment carried out by the natural streams is much less the gross erosion on its upstream watershed.

The bulk of the sediment is deposited at intermediate locations whenever the transport capacity of runoff is insufficient to sustain transport. Between the source and the outlet, varying proportions of the eroded materials are deposited.

In the study area, some of the particles eroded from bare upland areas around Gara Damota are trapped in vegetated areas at its far downstream. Some sediment trapped in floodplain and some are deposited in channels, but a large portion of eroded material transported and ended in the lake.

Assessments of conservation measures and their mitigation

Soil conservation is a preservation technique, in which deterioration of soil and its losses are conserved by using it within its capability and applying conservation techniques for protection as well as improvement of soil. In hilly regions, where land topography has steep slope and is subjected to erosion problem, the vegetation cannot get established. Luck of the vegetative cover on sloppy soil surface, accelerates the erosion and a large amount of soil is transported into the stream through runoff. In addition, the uncovered sloppy land also causes extensive damage to the cultivated land at foothill through deposition of sediments on them. Where sheet or gully erosion exists, erosion control by vegetative means is not completely effective and mechanical control becomes necessary. This measure protects the slopping arable lands from erosion. Sediment deposition covers the top fertile productive soil layer of the catchment in the study area. In addition it gets transported and deposited in the lake body. This and other relative problems facilitate the drying and disappearance of the lake and make the area unsuitable for cultivation especially on sloppy areas of Damota ridges.

The effects of soil erosion on the study area can be considered in two categories. The first one is on-site effect which refers to the consequences of soil erosion on the upslope areas where it occurred. This causes loss of productive soil from upper layer of the soil surface, soil textural change, fragmentation of productive land and others. The second one is off-site effect which refers to the damage out of the areas where soil erosion occurred. This has greatly contributed to siltation (sedimentation) on Lake Haramaya and its surrounding area. Moreover, the sedimentation of sand and coarse materials coming from the upslope areas has damaged the downstream productive farm lands.

According to OESPO (2001) the surface area of Lake Haramaya was 2.25 km^2 with depth of 2.13 meters. However, currently, volume of the lake is on its very minimum volume as a result of continued drought supported by heavy, continued and unwise utilization of its water by farmers irrigating chat and vegetable. Unwise pumping to Harar city, Haramaya and Awaday towns for drinking and other home consumptions also has great contribution in reducing the volume of this water. Peasant associations utilizing this lake for irrigation were; Fuji Gabissa, Mullata, Adellewaltaha, Ifa bate, and Haramaya University. The data collected during interview indicates that most of farmers around the lake believe that the disappearance of the lake is due to pumping of water for Harar town, Harar Brewery, Awaday town, Haramaya town, and Haramaya University. However, they do not count their unwise use of lake water for irrigation and domestic purpose. Moreover, according to the survey data collected by interviewing farmers who have farm land in the dried lake area, 96% of the respondents say the ownership of the lake before lake drying was under the government as well as Pas (peasant associations) and people were using the lakes resource commonly. The remaining 4% perceived the plot as their own land which passed through heritage. Among the respondents who ploughed the dried lake area, 81% were plowing for the purpose of expanding their land and seeking for additional income. The remaining 19% reported that they do not have land other than the dried lake's land. Majority of the respondents (63%), who ploughed the Lake area, agreed to stop plowing while the rest 37% are not willing to stop plowing the land.

CONCLUSION

The factors contributing to the occurrence of high soil erosion are the nature of catchment topography, rainfall, soil characteristics and the lack of adequate conservation practices. Consequently, the Lake Haramaya catchment has suffered as a result of the high sedimentation problem from the highland areas of its sub-basins. The catchment is characterized with undulating topography ranging from 0.03 to 43.5% of slope. Damota sub- basin which has slope ranges between 30 to 43% and highly developed gullies is highly prone to erosion problem and generates maximum sediment yield. There is a direct relationship between rainfall and catchment sediment yield for Lake Haramaya Catchment. With regard to the method of soil and water conservation practices, biological conservation measures like mulching and mixed cropping (alley cropping) are widely implemented with almost zero or negligible engineering measures. The areas that have been conserved by Integrated Lake Haramaya Catchment Project are somewhat promising. But, as mentioned above, it is more of biological. Small mechanical/engineering measures that could better hit the target are not considered.

An integrated physical intervention on managing and conserving the watershed resources in a holistic manner is very crucial. To do so, engineering control measures like bunding, terracing, gully control and stabilization together with changing the land use of steeply area and afforesting of bare lands should be considered. Moreover, this should be integrated with and based on the study of the hydrology, sedimentology, agronomic and other aspects. Measures intended to control and manage the surface flow, should aim at measuring, estimating and temporarily or permanently storing it. The interaction between surface and ground water should have to be studied as well since it would ease the decision in conjunctive water use and efficient water storage mechanism. Erosion, sediment transport and deposition should be precisely estimated. The source, size and concentration of sediments have to be measured or simulated with utmost care. The crops, cropping pattern and irrigation practices of the area has to

be carefully studied. The effectiveness of existing soil and water conservation practices should be surveyed so as to increase the success for future works on finding ways and means to upgrade their effectiveness existing practices and introduce new measures. Finally, the
authors insist that the findings of this manuscript should be supported by intensive field data measurements before using it for any decision making purposes.

ACKNOWLEDGEMENT

The authors would like acknowledge School of Natural Resources and Environmental Engineering of Haramaya University for material and logistics support. The authors would also like to acknowledge the Participatory Integrated Lake Haramaya Watershed Rehabilitation Project team for sharing data and information about the study area. Special thanks go to Dr. Asfaw Kebede and Mr. Abebe Teklu for their technical and material support.

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