Impact of Land Use and Landscape on Runoff and Sediment in the Sub-humid Ethiopian Highlands: The Ene-Chilala Watershed

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Abstract. The effect of land cover and landscape on runoff and sediment yield was evaluated in the Ethiopian highlands. We selected three small catchments: agriculture dominated watershed, bush & agriculture dominated watershed and agriculture dominated but with higher coverage of bush & grass watershed compared to the other two watersheds with in 399 ha Ene-chilala watershed. Hydrometric, sediment concentration and rill erosion data were measured for two years (2015 and 2016). The result showed that; sediment yield were statistically significant different between watershed one and watershed two. Moreover, the sediment concentration in watershed three varies statistically when compared with watershed one and watershed two. The greater runoff, suspended sediment concentration and yield in the agriculture dominated but with higher coverage of bush & grass catchment (WS3) results from saturated areas and gully erosion in the bottomlands. Since the agricultural land is highly degraded no more soil is transported due to rill erosion (detachment limited) by generated runoff. The bedrocks at the upland of these watersheds generate high runoff. Shallow and deep active gullies at the bottomlands contributed for higher sediment concentration. Our results support that watershed management that involve gully treatment on bottom lands and increase ground cover on degraded agricultural areas to reduce runoff and soil loss.

Keywords: Ene-chilala watershed · Erosion · Ethiopian highlands · Landscape land use

1 Introduction

Soil erosion hinders agricultural productivity in the Ethiopian highlands (Hurni et al. 2005; Mitiku et al. 2006; Vanmaercke et al. 2010). Rill and gully erosions are typical form of soil losses that reduced soil productivity, sedimentation of water infrastructures

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and water-quality deterioration in streams and reservoirs (Sun et al. 2013). Around 1.5 to 2 billion tons yr-1 soil is lost from Ethiopia highlands it is equivalent to 35 to 42 tons ha-1 yr-1 (Constable and Belshaw 1986; Hurni 1978; Hurni 1983; Hurni and Tato 1992; Tamene and Vlek 2008). Crop production is decreasing due to the removal of fertile soil by erosion (Sertsu 2000). Soil degradation can be regarded as a direct result of a change in the landscape within the Ethiopian highlands.

Land use and land cover has largely influenced runoff and soil loss dynamics in a watershed (Dagnew et al. 2015). The increased demand for land resources as a result of increasing population changes the natural state of land cover distribution in the highlands of Ethiopia. Soil erosion is highly influenced by land uses and land cover as compared to other factors (Kosmas et al. 1997; Thornes 1990). Degraded highland areas are subjected to high surface runoff and low infiltration capacity (Steenhuis et al. 2009). Land use changes like deforestation aggravates soil erosion (Ayele et al. 2016; Dagnew et al. 2015; García-Ruiz 2010). The cause for the excessive rate of soil loss is the unsustainable use of the land resource (Bewket and Sterk 2003). Land use change after deforestation affects rates of runoff (Bewket and Sterk 2005; Symeonakis et al. 2004).

Rill erosion is a result of surface runoff and associated sheet wash, which is a process that selectively removes fine material and organic matter (Bewket and Sterk 2003). Upland rill and sheet erosion rates can contribute up to 125 t ha-1 y-1 in the humid areas (Bewket and Teferi 2009). Rills and gullies are erosion features that often indicate hot spots and affected by soil erosion (Mitiku et al. 2006). Rills are temporary features and can be easily destroyed during plowing but gullies are more permanent features in the landscape (Zegeye 2009). Rills from wetted agricultural fields or gullies from local saturated areas are sources of sediment (Tilahun 2012).

Runoff and soil loss from a given catchment vary depending on the type of land uses (Adimassu and Haile 2011; Girmay et al. 2009; Taye et al. 2013). Understanding the effect of land uses on runoff and soil erosion processes is used for sustainable land use management (Kang et al. 2001). In Ethiopia mostly the land use change is caused by human activities for the expansion of agricultural area, for forest production purpose (Zeleke and Hurni 2001). Moreover, other studies focused land use changes in a watershed can impact water supply by altering hydrological processes (Ndulue et al. 2015) and results land degradation (Bewket 2002; Tekle and Hedlund 2000; Zeleke and Hurni 2001).

This study is focused on comparing and evaluating the effect of land use and landscape on runoff and sediment yield based on measured data collects in different three sub catchments. The overall objective of this study is therefore to understand how land uses and landscape affects runoff and soil losses within the Ene-chilala watershed. The specific objectives are to: (1) assess the effect of land uses and landscape on runoff and sediment/soil loss from three sub watersheds in Ene-chilala watershed, (2) understand the spatial differences of runoff and sediment losses among three small watersheds, and (3) quantify the rate of soil loss due to rill erosion in the three small watersheds.

2 Materials and Methods

2.1 Description of Study Area

Ene-chilala is a small watershed is located in the upper Blue Nile Basin, in the sub-humid Ethiopian highlands (Fig. 1). The watershed has an area 399 ha and characterized by highly rugged topography ranging between 1996 m and 2414 m elevations. Ene-chilala has three sub water sheds where gauging stations (weirs) installed at the outlets (Fig. 1). The slopes of the three sub watersheds are almost similar. Generally it has an average slope of 35% and steeply upland bedrock (Ayele et al. 2016).

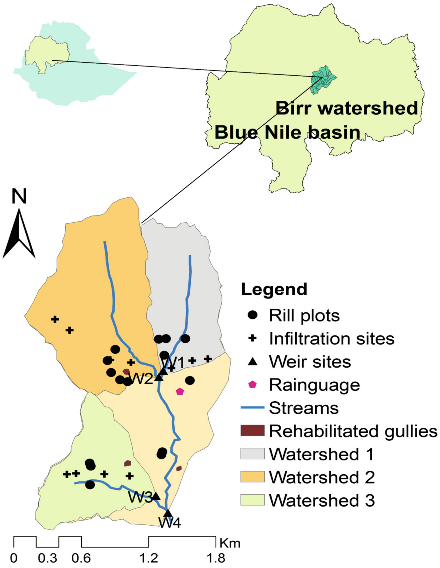

Fig. 1. Location map of Ene-chilala watershed and flow & sediment monitoring (Weirs), Rill and infiltration sites

The average annual rainfall from June to September in Ene-chilala watershed is about 1,225 mm and the dominant soil type is chromic luvisol (Ayele et al. 2016). Ene-chilala watershed had 98 household heads and a total population of 525. The agricultural system is mixed farming system. The dominant crops are ‘Teff’ (Eragrostis tef), maize (Zea mays), barley and wheat (Triticum aestivum), Livestock is the important productive asset for the households. Forest in the watershed was cleared during the Derg regime in the early 1980s, and crop yields have steadily declined since that time (Ayele et al. 2016). Gullies are formed in the periodically saturated bottomlands to carry off the additional direct runoff (both interflow and subsurface water) from agricultural lands (Ayele et al. 2016).

2.2 Data and Methodology

Precipitation, runoff, suspended sediment and rill erosion were measured during the rainy seasons of 2015 and 2016 and infiltration tests were conducted in 2016 (Fig. 2).

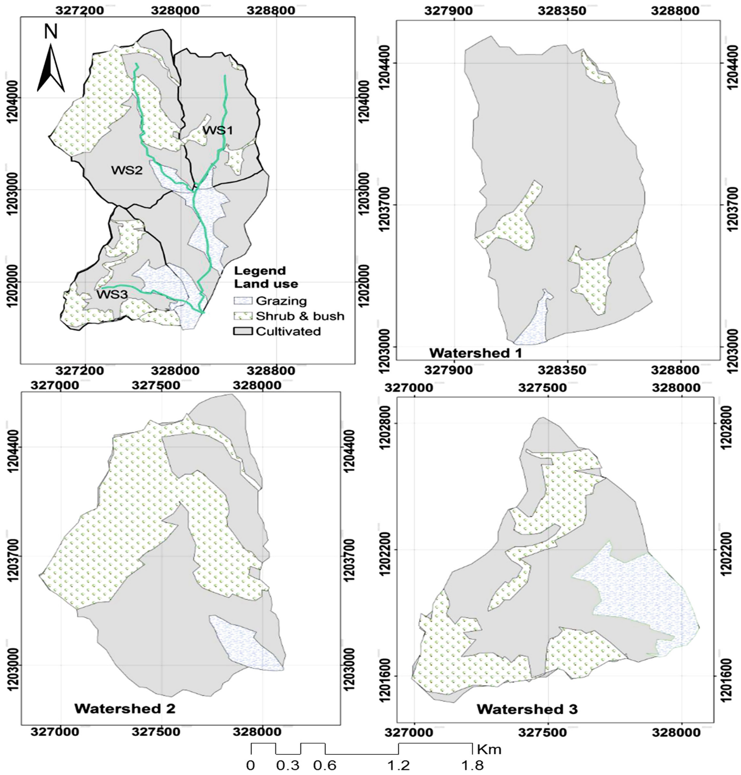

Fig. 2. Land use map of the Ene-chilala watershed and three sub watersheds

The study was conducted in three small watersheds in the Ene-chilala watershed for monitoring runoff and sediment yield. The proportion of land use types of the three watersheds were measured using hand held GPS (Table 1).

NB: numbers in brackets refers to the % coverage of each land use type.

For rainfall measurement a tipping bucket raingauge was installed in the Ene-chilala which recorded in 5-min interval. In addition to this, local raingauge and the nearby "Genet Abo" metrological station data was also used.

Soil infiltration measurements were applied on 11 sites based on land use and landscapes (Fig. 1) throughout the watershed using a 25-cm diameter single-ring infiltrometer in September 2016. A floater was used to read water depth fluctuations in the infiltrometer during the test. The constant infiltration rate at the end of the test was taken as the infiltration capacity of the soil.

The runoff amounts were collected in the three selected sub watersheds after rainfall generates runoff (at the outlets). The observation periods were from June 15th to September 23rd in 2015 and from June 8th to October 1st 2016. The flow velocity was determined by a floating method. The floating materials were released at a fixed distance on the upstream away from the outlet of the weir. The time taken for the floating materials to reach the outlet of the weir was recorded. In addition to this flow depth values were

Table 1. Land use type and area of the three sub watersheds

Land use area (ha)	WS1 area in ha (%)	WS 2 area in ha (%)	WS3 area in ha (%)
Cultivated land	74.2(89.4)	79.6(53.1)	48.5(63.7)
Shrub & bush land	7.2(8.7)	64.2(42.9)	15.8(20.8)
Grazing land	1.6(1.9)	6.0(4.0)	11.9(15.6)
Total	**83**	**149.8**	**76.2**

measured for 15 min time intervals for each storm events. Those measurements were continued until the runoff/discharge has stopped. The mean flow volume was computed by multiplying wetted cross sectional area with two-third of the measured flow velocity (Tilahun 2012).

Rills measurement 15 fields were selected from the 399.3 ha Ene-chilala watershed, based on landscape and land cover types. The erosion rates from rills in these fields were determined after 8 storm events between the periods of June 27, 2016 to August 28, 2016. The total area of the 15 fields was 3 ha (almost 1% of the watershed area, Table 3). The method of rill erosion measurement was conducted similarly as explained in the studies of (Bewket and Sterk 2003; Tilahun 2012; Zegeye 2009). The total volume of soil loss by rill was obtained by summing the volumes of all homogenous rill segments in each field. The total soil loss (t ha^{-1}) was computed by multiplying the computed volume with the measured bulk density (1.31 g cm^{-3}) and then dividing by the area of the agricultural land. Rill density (m ha^{-1}) was calculated by dividing the total rill length (all rill length measurements) by the total area of the agricultural fields.

For Sediment concentration data the sampling periods were similar to runoff. For each three sub watersheds the sediment data were obtained by taking samples using one litter bottles continuously every 15 min from the beginning of runoff to the end (Fig. 1). This sediment sample was filtered by using Whatman 320 mm diameter with a pore size of 2.5 µm filter papers. Finally it oven dried at 105 °C for 24 h and weights it to quantify the sediment weight per liter of sample volume. This was converted to mg/L in each sub-watershed.

2.3 Data Analysis

After collecting the raw data; rainfall, runoff, sediment concentration and sediment yield were analyzed. Stage - discharge (rating curve) was developed from runoff value versus flow depth by using power function. The overall results are described using Statistical Package for the Social Sciences (SPSS) version 20, descriptive statistics like mean, median, mode, minimum, maximum, variance, and standard deviation. Runoff and soil loss data from three watersheds were analyzed separately in order to understand the effect of land use on runoff and soil loss.

3 Results and Discussion

3.1 Rainfall

Ene-chilala watershed received uni-modal rainfall pattern which occurs usually from May to October. Most of the rainfall with higher intensities occurs in July and August. Total precipitation in the four months of the rainy season (June–September) was 588 mm in 2015 and 904 mm in 2016.

3.2 Infiltration Rates of Soils

The average infiltration rates for the upper, mid and downslopes were 85.2, 56 and 23 mm hr^{-1}, respectively at 11 samples of measurement. The maximum measured infiltration capacity was 240 mm hr^{-1} at upslope of watershed two. Moreover in uplands of cultivated lands the soil type is sandy loam which has generally higher infiltration. The median infiltrations were 36 mm hr^{-1}, 63 mm hr^{-1} and 27 mm hr^{-1} for watershed one, watershed two, and watershed three respectively. This also corresponds with the land use type. Watershed two had high median infiltration capacity as compared to watershed one and three.

Low infiltration was measured in bottom landscape positions due to compaction of soils. In bottom landscape of grazing lands the soil type is clay, the infiltration is low. Infiltration rates of the cultivated land in the upland vary greatly. Cultivated land with low infiltration rates represents the degraded soils while the soils with high infiltration rates are not degraded. When the rainfall is intense, the degraded soils produce surface runoff but some amount of runoff might infiltrate down.

Water infiltrated better in the upper fields than the downslope fields (Zegeye 2009). But in this infiltration tests water infiltrated in the upper slopes than the down slope only at watershed one. Due to the presence of impervious layer of shrub & bush land at uplands on watershed two and watershed three, the infiltration rates of midslope were higher than upslope and downslope in the Ene-chilala watershed.

3.3 Runoff

The amount of runoff from all watersheds during the rainy phase of 2015 was lower than the 2016 rainy phase (Table 2). This is due to the lower amount of precipitation in 2015 compared to 2016. WS2 and WS3 have more area coverage of shrub and bush which have impervious layer underneath, which results in large volume of runoff. In both 2015 and 2016 runoff volume generated from WS1 is slightly greater than that of WS2 because WS1 had less median infiltration capacity compared with WS2; these differences were not statistically significant at 1% significance level using F-test.

In addition, the runoff volume generated from watershed three was smaller than watershed one and watershed two in 2015 but it was almost similar in 2016 due to high coverage of locally saturated areas. However the differences were statistically significant at 1% significance level using F-test. In the Ene-chilala watershed, the bottomlands are saturated and runoff source areas. These results indicated that land use and landscape determine the storm runoff process.

Table 2. Monthly runoff, sediment concentration and sediment yield for 3 weirs

Weirs		Storm runoff (mm)		Mean suspended sediment concentration (g l^{-1})		Sediment yield (t ha^{-1})	
		2015	2016	2015	2016	2015	2016
Weir 1	June	1.4	11.3	1.8	12.6	0.0	2.2
	July	10.4	21.3	4.6	3.2	0.6	1.1
	Aug.	35.8	26.5	3.3	2.6	1.5	0.9
	Sep.	4.8	19.1	0.4	2.0	0.0	0.6
	Annual	52.4	78.2	3.6	4.9	2.1	4.7
Weir 2	June	0.2	5.3	6.0	4.2	0.0	0.3
	July	9.6	16.7	1.7	5.7	0.2	1.0
	Aug.	8.9	24.6	3.2	1.8	0.2	0.6
	Sep.	1.3	13.1	0.4	2.2	0.0	0.3
	Annual	20.1	59.6	2.4	3.7	0.4	2.3
Weir 3	June	0.3	3.6	15.5	13.9	0.0	0.6
	July	2.8	29.5	11.5	7.7	0.6	4.1
	Aug.	1.7	13.0	10.8	4.1	0.3	0.8
	Sep.	1.8	10.1	1.0	6.6	0.0	1.2
	Annual	6.6	56.2	10.7	7.2	0.9	6.7

3.4 Rill Measurement as Affected Soil Loss

Rill soil loss and rill density are higher in the early July 2016. The maximum measured rill soil loss was 30 t ha^{-1}. Rainfall intensity has a great role on rill erosion formation. Rills from 15 agricultural fields were filled by inter rill and sheet erosion after only two storm events in 2015 year because of low rainfall volume.

The soil loss rate and the rill density from 15 agricultural fields increase from June 27, 2016 to July 2, 2016 (Table 3). Rills were developed after a higher rainfall storm event and increased rill dimensions up to July 2. The main driving forces for an increase in length, depth and width of rill are head erosion, flow shear and collapse of channel wall, respectively. There was a gradual decrease after July first week until the end of August when rills were filled up by soil from sheet & inter-rill erosions. Therefore we will use the rate of soil loss in July first week as the volume of soil lost when there is maximum rill depth, width and length were recorded.

The cumulative soil loss rate from rills in the watershed is 11 t ha^{-1}. Field 5, 8 and 9 has values of zero soil loss for all days at time of observation (Table 3). Because those fields were sowed at the early rainy season. Upslope fields 1, 2, 11, 12 and 13 which had an average soil loss of 16 t ha^{-1} while the bottom fields such as 3, 6, 14 and 15 were 8.8 t ha^{-1}. This difference between upslope and downslope is not statistically significant at 1% significance level using F-test. The result is not in line with the findings of (Tilahun 2012; Zegeye 2009). This reason rises from Ene-chilala watershed is highly degraded as compared with other watershed. Fields such as 2, 3, 4 and 5 which are located on watershed 1 had an average cumulative soil loss of 10 t ha^{-1}, Fields 6, 7, 8, 9 and 10

Table 3. Soil loss rate from agricultural fields monitored in 2016

Field ID	Crop types	Field size	Cumulative soil loss (t ha^{-1})							
			27-Jun	2-Jul	15-Jul	24-Jul	1-Aug	9-Aug	16-Aug	24-Aug
1	Maize	0.124	0.0	8.4	8.2	5.4	3.9	3.6	4.4	2.8
2	Teff	0.353	3.4	25.1	0.0	4.8	13.8	4.7	7.2	2.9
3	Maize	0.24	0.0	5.0	3.1	0.0	0.0	0.0	0.0	0.0
4	Bean	0.144	0.0	10.8	17.4	11.4	0.5	0.0	14.4	0.0
5	Bean	0.144	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Nut	0.08	0.0	9.3	8.1	3.8	3.8	2.1	4.1	2.5
7	Maize	0.328	5.1	17.3	7.2	9.1	4.2	1.9	2.2	2.0
8	Bean	0.169	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	Barely	0.124	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	Maize	0.161	1.8	21.8	15.1	9.3	4.8	0.0	0.0	0.0
11	Barely	0.327	3.0	2.5	3.2	5.9	1.8	1.3	0.0	0.0
12	Teff	0.137	0.0	30.7	0.0	0.0	0.0	0.0	0.0	0.0
13	Barely	0.189	0.5	14.6	12.1	7.4	1.2	0.6	0.6	0.0
14	Chick pea	0.24	0.0	0.0	0.0	0.0	2.0	1.1	2.2	0.0
15	Teff	0.282	5.7	21.0	23.7	0.0	0.0	0.0	0.0	0.0

which are located on watershed two had an average cumulative soil loss of 9 t ha^{-1}and fields 11, 12 and 13 which are located on watershed 3 had an average cumulative soil loss of 16 t ha^{-1} (Table 3). This difference between sub watersheds is not statistically significant at 1% significance level using F-test.

3.5 Sediment Concentration

The mean annual suspended sediment concentration for watershed one and watershed two during the rainy phase of 2015 was lower than that of 2016 rainy phase (Table 2). This is due to the lower amount of precipitation in 2015 compared to 2016. But the sediment concentration for watershed three is decreased in 2016 due to gully head treatment in 2015. When storm runoff amount increased the sediment concentration also increased. But it in some case suspended sediment concentration was decreased for high amount of runoff from three sub watersheds. Sediment concentration increased at the first rainy season and then gradually decreased particularly at cultivated dominant land use watershed (WS1). Watershed with gullies had higher sediment concentration at the end of rainy season (WS3). Because when water table raised gully was expanded. The main reason was the effect of land use, land cover, rainfall intensity and gully formation within Ene-chilala watershed. Lowering both the water table and protecting the gully heads decreased soil loss due to gully erosion (Addisie et al. 2016). The sediment concentration was greater in WS3 than WS1 and WS2 for both years due to shallow and deep active gullies. The differences were significant. In addition, the sediment concentration for watershed one in two years is greater than that of watershed two due to the contribution of upland rill erosion to WS1; the differences were not significant. Most sediment is generated from the bottom land; because the bottom lands for watershed three has gullies (the shrub and bush land at upper elevation and cultivated land were limited to gully formation in Ene-chilala watershed).

3.6 Sediment Yield

The annual sediment yield for the three watersheds during the rainy phase of 2015 was lower than that of 2016 rainy phase. This is due to the lower amount of precipitation in 2015 compared to 2016 (Table 2). Similarly to the suspended sediment concentration, the sediment yield was greater in watershed three than watershed one and watershed two in 2016 due to shallow and deep active gullies. These differences were not statistically significant. The sediment yield for watershed one is greater than watershed two for the two years. These differences were statistically significant. Because cultivated land dominated watershed contributes rill erosion to the total soil loss. Rill erosion on cultivated land at early rainy season and gully erosion in saturated grazing land at the bottoms were main sources of sediments in Ene-chilala watershed.

The soil loss from Donkorowoniz at bottom slope of watershed two and Lay Enset Bet Village gully on the remaining part of Ene-chilala watershed was 110 and 90 t ha^{-1} respectively (Ayele et al. 2016). The soil losses from gullies are five times or more higher than the average cumulative soil loss from rill erosion (upslope 16 t ha^{-1} and down slope 9 t ha^{-1}).

4 Conclusion

This study was conducted to examine the patterns of runoff, sediment concentration and sediment loads at Ene-chilala watershed. The results showed that upper shrub and bush, saturated grazing land at the bottom and upland rill erosion in the early rainy season were the source of the runoff and sediment. The sediment yield was statistically significant different between watershed one and watershed two. This indicates that the influence of land use was significant impact on runoff and sediment yield. Intensive investigations have been conducted to explain the development processes of rill erosion. In this study, runoff erosivity and soil erodibility have main impacts on rill erosion process.

Sediment yield were generally greater in the mainly grass watershed as compared with watershed with cultivated land and shrub & bush dominance land use. The sources of sediment were rills from agricultural fields and/or gullies from local saturated grazing areas. Gullies on grazing land are erosion hot spot areas in Ene-chilala watershed. Soil conservation practice should be given priority to saturated grazing lands with active shallow and deep gullies than agricultural lands for better soil conservation results in the area. After gully treatment, SWC practices should be done on agricultural fields.

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