Original Research Article

Effect of Land Uses and Physical Soil and Water Conservation Practices on Runoff and Soil Loss in Western Tigray, Ethiopia

ABSTRACT

A field experiment was conducted in three consecutive years (2014- 2016) in western zone of Tigray, Northern Ethiopia. It was conducted with the objectives of estimating the runoff and soil loss of four different land uses. Area closure, grazing land, treated cultivated land and untreated cultivated land were selected in a watershed. A total of 12 runoff plots with a size of 15 m x 3 m were constructed in each land use type with the same slope (8.5%). About 25 cm height corrugated iron was constructed for each plot. A runoff collection ditch with dimensions of 2 m length, 1.2 m width and 1 m depth was dug and lined with thick plastic sheet at the bottom side of each runoff plots to collect runoff discharge and sediment yield. After each rainfall event runoff volume in the ditch was measured and subsequently one liter sample was taken to laboratory from each runoff collection ditch after the runoff is mixed vigorously. Samples filtered using filter paper and oven dried at 105 ^oC for 24 hours for sediment concentration calculation. The highest average surface runoff is 7277 m^3/ha/year and the corresponding soil loss 110 t/ha/year were recorded in the grazing land. The lowest runoff (597 m^3/ha/year) and lowest soil loss (2 t/ha/year) were also recorded in the area closure treated with stone bund plus trench and tree plantation. Hence, the actual runoff and soil losses recorded were higher in untreated cultivated land and grazing land than area closure and treated cultivated land which warrant the requirement of more effective soil and water conservation measures. Therefore, area closure treated with the integration of physical soil water conservation measures is the best technology for rehabilitation of degraded land. Stone bund is also the best technology on cultivated land to conserve soil and water.

***Keywords**:* Land use, runoff plots, runoff, soil loss

1. INTRODUCTION

Land use and land cover change through inappropriate agricultural practices, deforestation and high human and livestock population pressure have led to severe land degradation in the Ethiopian highlands [1]. As a result, biodiversity loss and soil erosion are the common occurrences. According to [2, 3] land degradation, which includes the degradation of vegetation cover, soil erosion, and nutrient depletion, is a major ecological and economical problem in Ethiopia. Understanding the complexity of land-use and land-cover and their

UNDER PEER REVIEW

driving forces and impacts on environmental security is important for the planning of natural resource management and associated decision making [4]. According to [5, 6], soil losses in the Ethiopian highlands reach 200-300 t/ha annually.

Performance of soil erosion control measures is location specific [7]. In recent days the idea of area development using an integrated watershed management approach has received recognition in the national development strategy. This must be done by research activities. Different studies have been done to estimate runoff and soil loss using runoff plot method. For example, [8] used 28 plots for daily runoff measurement for two years period in the semi-arid to sub-humid highlands of Tigray to study the effect of vegetation restoration in exclosures and to identify other factors influencing runoff production. Integrated watershed management is expected to improve the interaction between the physical, social, technological, economic and policy dimensions; interdisciplinary approach to solving problems; and the full participation of all stakeholders during problem identification, planning, implementation, monitoring, and evaluation. So the main objectives this study is to estimate the runoff and soil loss of four different land uses and then to recommend the best land use type.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was conducted during 2014 to 2016 at Welkait district, Western Zone of Tigray, Northern Ethiopia. It is located at the west of Mekelle the capital of the Tigray region, at 13.5^{o} - 14.1^{o} N and 36.8^{o} – 37.8^{o} E, with an elevation of 700 to 2354 m a.s.l. (Fig.1). The mean annual rainfall of the area ranges from 700 to 1800 mm. Most of the rainfall is concentrated during the main rainy season which extends from June to September. The average temperature of the area is 21.25 ^{o}C with minimum 17.5 ^{o}C and maximum 25 ^{o}C.

UNDER PEER REVIEW

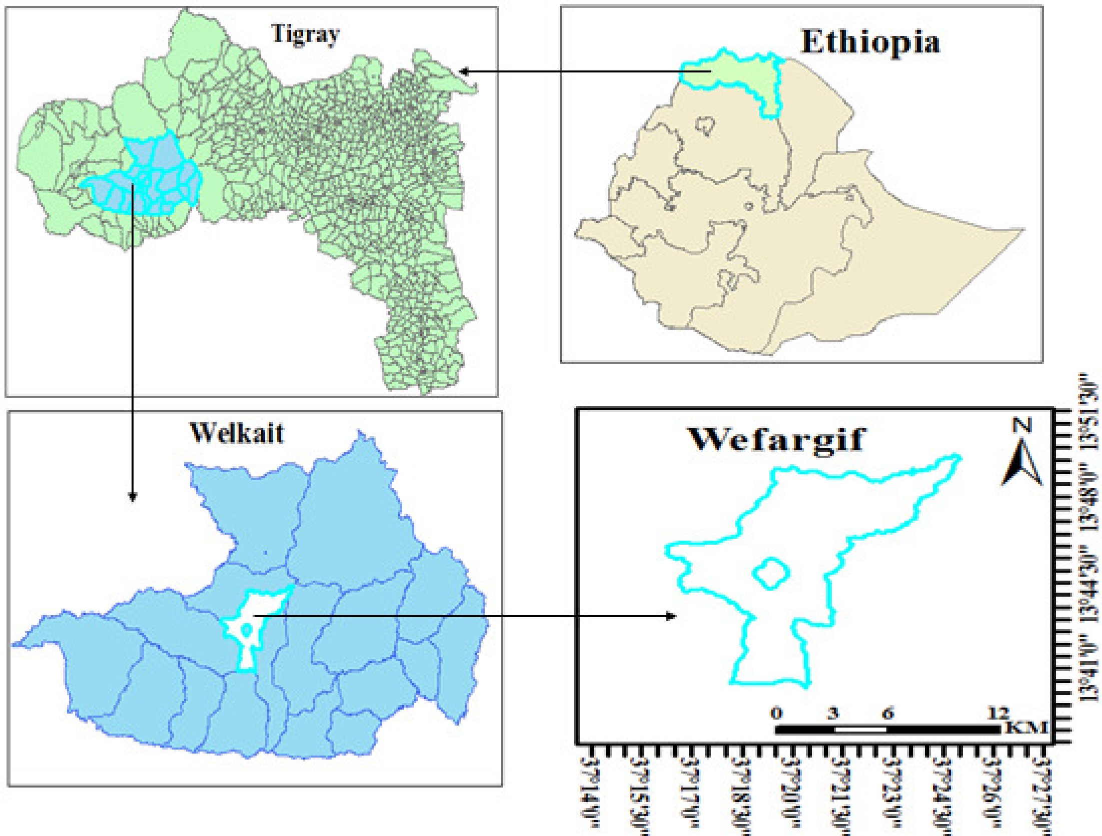

Fig 1. Map of the study area

UNDER PEE

2.2 Experimental Design and Data Analysis Method

A model watershed of different land uses with and without soil and water conservation (SWC) practices was selected. Each land use type was indicated in the model watershed (Table 1). A total of 12 runoff plots with a size of 15 m x 3 m was formulated in each land use types with the same slope (8.5%) in Cambisol soil type. About 25 cm height corrugated iron and stone wall was constructed for each plot. A runoff collection ditch with dimensions of length, width and depth; 2 m, 1.2 m and 1 m, respectively was dug and lined with thick plastic sheet at the bottom side of each runoff plots to collect runoff and sediment. A plastic rain gauge was installed to measure daily rainfall. After each rainfall event runoff volume in the ditch was measured and subsequently 1 liter sample was taken to laboratory from each runoff collection ditch after the runoff is mixed vigorously. Samples filtered using filter paper then oven dried at 105 ^{o}C for 24 hours.

Data analysis was done using Microsoft excel and simple descriptive statistics. Each runoff discharge was summed for each year and converted to hectare. Soil loss was also calculated multiplying the oven dried soil sample obtained form one liter volume of water by the total runoff discharge.

Table 1. Description of the treatments

	Treatments	Description
1	Treated uncultivated (AC)	Stone-faced soil bund + trench in area closure enriched with tree plantation
2	Untreated uncultivated (GL)	Grazing land
3	Treated cultivated land (TC)	Stone-faced soil bund
4	Untreated cultivated (UC)	Cropland

3. RESULTS AND DISCUSSION

3.1 Runoff Discharge and Sediment Yield

The highest discharge (7277 m^3/ha/year) and soil loss (110 t/ha/year) was recorded in the GL and the lowest discharge (597 m^3/ha/year) and soil loss (2 t/ha/year) was recorded in the AC treated with stone-faced soil bund plus trench treated with tree plantation (Table 1a). The grazing land is characterized by different gullies and subjected to uncontrolled grazing which makes the soil susceptible to erosion due to disintegration of the surface soil by by grazing and their traffic. Poor surface cover, and gullies accelerate siltation in the reservoirs due to high soil erosion [9]

However, treated cultivated land contributed about 4 times higher soil loss compared to the treated uncultivated land. Because the treated uncultivated land is covered with vegetation so that the tree vegetation intercepts the rain drops and gives time for infiltration. Similar finding was reported by [10]. According to his finding the positive impact of vegetation cover on runoff reduction is due to direct effect as a canopy cover intercepts raindrops, thus dissipating their energy and creating infiltration pathways. The physical soil and water conservation structures have also conserved more runoff and soil both in the AC and cultivated land. [11] found that various surface water harvesting structures increase the reliability and availability of water by storing runoff. On the other hand the soil on the cultivated land is susceptible to erosion due to the continuous tillage. [12] indicated mean annual soil loss of 12 sites from the foot of the bunds due to tillage erosion. As its name indicates soil water conservation structures conserve not only soil but significant amount of runoff discharge. This study was done using runoff plot method which covers only 181.5 ha; so it is better to do using spatial analysis method in order to cover a large area.

UNDER PEER REVIEW

Table 1a. Average runoff discharge and sediment yield

Treatments	Runoff (m^3/ha)				Soil loss (t/ha)			
	2014	2015	2016	Average	2014	2015	2016	Average
Treated uncultivated	441	306	1045	597	1.3	0.9	2.5	2
Grazing land	6708	6876	8248	7277	133.8	81.0	115.1	110
Treated cultivated	1234	1401	1440	1358	7.9	6.9	10.1	8
Untreated cultivated	5776	5931	7964	6557	104.8	59.3	74.2	79

4. CONCLUSIONS AND RECOMMENDATIONS

Results clearly indicate that area closure treated with tree plantation, can be used to reduce soil loss and runoff volume effectively. Further, stone-faced soil bund was almost equally effective in reducing runoff, soil loss in cultivated land. These two land use management practices were significantly superior to grazing land and cropland in reducing runoff and soil erosion. However, the highest soil loss was recorded in the Grazing Land. Generally, as the runoff increases soil loss also increased.

Area closure treated with the integration of physical soil and water conservation measures is the best technology for rehabilitation of degraded land. Stone bund is also the second-best technology on cultivated land to conserve soil and moisture. This study was done using runoff plot method which covers only 181.5 ha, so other estimation/evaluation methods such as spatial analysis or other models might cover a large area

ACKNOWLEDGEMENTS

The authors acknowledge the financial support by sustainable land management program (SLMP) and the Welkait wereda office of agriculture experts plus the local community who helped us in fieldwork and data collection.

REFERENCES

UNDER PEER REVIEW

1. Samuale T~~.~~, Etefa G~~.~~, ~~A.J.~~Raj AJ, Emiru B~~.~~, ~~and G.~~ Taye G. Land use and land cover change and woody vegetation Diversity in Human-Driven Landscape of Gilgel Tekeze Catchment, Northern Ethiopia. 2014.
2. Sertse S. Study and design guidelines on watershed management with reference to forestry~~.~~ (Unpublished). Bureau of Agriculture and Rural Development (BoARD), Mekelle, Tigray. 2007
3. Darghouth S~~.~~, Ward C~~.~~, Gambarelli G~~.~~, Styger E,~~.~~ ~~and~~ Roux~~,~~ J. Watershed Management Approaches, Policies, and Operations: Lessons for Scaling Up. Source? 2008; 11.
4. Efrem G~~.~~, Mats S~~.~~, Ulf S,~~.~~ ~~and B. M.~~ Campbell BM. Land-use and land-cover dynamics in the central rift valley of Ethiopia. Source? 2009.
5. Herweg K~~.~~, ~~and~~ Stillhardt B. The variability of soil erosion in the Highlands of Ethiopia and Eritrea. Research Report 42. Centre for development and Environment. The University of Berne. 1999.
6. Hurni~~,~~ H. Land degradation, famine, and land resource scenarios in Ethiopia. In: Pimentel D, editor. World Soil Erosion and Conservation. Cambridge Studies in Applied Ecology and Resource Management. Cambridge, UK: Cambridge University. 1993; 27–61.
7. Sudhishri S, Dass A, ~~N.K.~~ Lenka NK. Efficacy of vegetative barriers for rehabilitation of degraded hill slopes in eastern India. Soil and Tillage Research~~.~~ 2008; volume? 98–107.
8. Descheemaeker~~,~~ K~~k.~~, Nyssen~~,~~ J~~.~~, Poesen~~,~~ J~~.~~, Raes~~,~~ D~~.~~, Mitiku~~,~~ H~~.~~, Muys~~,~~ B~~.~~, Deckers~~,~~ S. Runoff on slopes with restoring vegetation: A case study from the Tigray highlands, Ethiopia. Journal of Hydrology~~.~~ 2006; 331~~:~~; 219–241.
9. Tamene~~,~~ L~~.~~, Park S~~.~~J~~.~~, Dikau R~~.~~, Vlek~~,~~ P~~.~~L~~.~~G~~.~~. Analysis of factors determining sediment yield variability in the highlands of northern Ethiopia, Geomorphology~~.~~ 2005; 76: 76–91.
10. Descroix~~,~~ L~~.~~, Viramontes~~,~~ D~~.~~, Vauclin~~,~~ M~~.~~, Gonzalez Barrios~~,~~ J~~.~~L~~.~~, Esteves~~,~~ M. Influence of soil surface features and vegetation on runoff and erosion in the Western Sierra Madre (Durango, Northwest Mexico). Catena~~.~~ 2001; 43: 115–135.
11. Amanuel~~,~~ Z~~.~~, Vanmaercke~~,~~ M~~.~~, Poesen~~,~~ J~~.~~, Verstraeten~~,~~ G~~.~~, Nigussie~~,~~ H~~.~~, Mitiku~~,~~ H~~.~~, Kassa~~,~~ A~~.~~, Deckers~~,~~ J~~.~~, ~~and~~ Nyssen~~,~~ J. Spatial and temporal variability of river flows

UNDER PEER REVIEW

in the degraded semi-arid tropical mountains of northern Ethiopia, Geomorphologie~~.~~ 2013; 57: 143–169.

12. Desta G~~.~~, ~~J.~~ Nysen J, ~~J.~~ Poesen J, ~~J.~~ Deckers J, Mitiku H~~.~~, ~~G .~~Govers G, ~~and J.~~ Moeyersons J. Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray Highlands, northern Ethiopia. Soil Use and Management~~.~~ 2005; 21:~~,~~ 287.

UNDER PEER REVIEW

13.

UNDER PEER REVIEW