Effect of Terracing on Combating Soil Erosion by Water: Case Study In The Beribere Catchment, Northwest Ethiopia

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Abstract

Accelerated soil erosion by water is a critical problem for Ethiopia, where population is rapidly growing and extensive farming systems are very common with little or no preventive measures. This paper presents the results of a study on the effects of terracing practices in reducing the magnitude of soil loss by using rill survey technique at cultivated field scales in relation to crop type and topographic position of the fields in the Beribere catchment, northwest Ethiopia. The study also assessed the factors accelerating rill erosion in the focused area. Rill erosion in the terraced fields was reduced by 53.5% as compared to the non-terraced control fields. In the terraced areas, terrace damages are the main contributing factors to soil loss due to rills. In the non-terraced fields, the slipage of concentrated runoff from up-slope areas and damage of drainage ditches were observed as the principal accelerating factors for the initiation and development of rill erosion, whereas they had insignificant effect for rill erosion in the terraced fields. Moreover, rill erosion shows spatial differences in terms of crop covers and relative topographic positions in the study site. Hence, there should be adequate platform to effective communication between farmers and extension staff to design site specific erosion control activities for addressing the problem. The study verifies that rill surveying is a significant method to pragmatic assessment for the effectiveness of terracing structures in arresting soil erosion by water.

Keywords: Soil erosion by water; Terracing practices; Rill surveying; Ethiopian highlands

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Introduction

Accelerated soil erosion is a critical problem and will remain too during the 21th century in developing countries (Lal, 2001; Pimentel et al., 2003). Pimentel (2006) estimated that on an average, the ratio of soil erosion is the highest (ranging between 30 and 40 t $ha^{-1}yr^{-1}$) in Africa. Accelerated soil erosion by water is too a critical problem for Ethiopia, where population is rapidly growing and extensive farming system is the backbone of the country's economy (Hurni, 1998). Hurni (1993) estimated that soil loss due to erosion by water from slopes amounts about 1493 million tons per annum, out of which 45% is from cropland only. He further estimated the mean soil loss from cultivated fields to be about 42 t $ha^{-1}yr^{-1}$.

Highest soil loss rates were measured in Gojjam, in the north-western highlands of Ethiopia due to combination of factors of high rainfall and erosivity, and intensive cultivation along with non-conservation based land management and cropping systems (Haile *et al*., 2006; Amdihun *et al*., 2014). For example, based on the field assessment of rill erosion, Bewket and Sterk (2003) indicate that the rate of soil loss from cultivated fields ranges between 18 and 79 t $ha^{-1}yr^{-1}$ due to rill and sheet erosion in the Chemoga watershed. By using the same method, Bewket (2003) also estimated around 37 t $ha^{-1}yr^{-1}$ of soil loss due to rills and sheet from croplands in the Digil watershed. Fisseha *et al.* (2011) measured two years amount of soil loss of 141.9 t ha^{-1} from experimental cultivated plots of Debre-Mewi watershed. Belay and Bewket (2012) also estimated 1.26 mm $year^{-1}$ or a 16 t ha^{-1} yr^{-1} soil loss from cultivated fields in northwest Ethiopia through measurement of exposed tree roots.

Other studies estimated the rates of soil loss from cultivated plots in semi-arid environments of the Ethiopian highlands. For instance, Gebremichael *et al.* (2005) estimated a mean annual soil loss rate of 57 t $ha^{-1}yr^{-1}$ by sheet and rill erosion from 202 plots in 12 representative sites of Dogu' Tembien District, northern Ethiopia. Based on eight years (1982-1989) Soil Conservation Research Project (SCRP) data, Tegene (2000) estimated the average rate of soil erosion by water as 35 t $ha^{-1}yr^{-1}$ on cultivated slopes of South Wollo Zone, North-eastern Ethiopia.

In general, all those studies of soil erosion conducted in varied agro-ecologies of the Ethiopian highlands endorse that the magnitude of soil loss is high and revealed the urgent need for intervention in Soil and Water Conservation (SWC) practices. The basic paradigm and approach to SWC has developed through time. The Ministry of Agriculture of Ethiopia and international development agencies like World Food Program (WFP) have been investing considerable resources in encouraging and scaling up of SWC practices like terracing for curbing severe soil erosion by water (Zeleke *et al*., 2006). The practice of effective SWC measures should consider using interdependence between biophysical factors (erosivity, erodibility and slope) and land use patterns (Tegene, 2000).

Numerous studies at micro-watershed level estimated and agreed upon the substantial role of conservation practices (in particular stone terraces) in reducing the magnitude of soil loss in the semi-arid environments of the Ethiopian highlands (Gebremichael *et al*., 2005; Nyssen *et al*.,2007, 2009; Haregeweyn *et al*., 2012; Taye *et al*., 2013). Moreover, few plot level studies indicated the contribution of conservation practices in reducing soil loss in the high rainfall areas of the Ethiopian highlands (Herweg & Ludi, 1999; Fisseha *et al*., 2011; Amare *et al*.,

2014) with regard to emphasis on the actual soil loss from cultivated fields, the principal units for evaluating the effectiveness of SWC practices by the farmers.

Despite substantial progresses in assessing soil erosion using different models since the 1930s, field validation of these models remained to be accomplished (Lal, 2001). The different approaches of soil erosion measurements have their own advantages and limitations. Because of their spatially aggregated nature, measurements using macro-order modelling often do not provide critical information to exactly understand the spatial patterns of erosion and the effectiveness of conservation practices (Stocking, 2001). Contrary to this, some others argue that micro-level measurements at experimental plot levels may not be relevant to draw conclusions at field or large spatial scales as it represents a particular confined area (Boix-Fayos *et al*., 2006). However, erosion shows large spatial variation due to influence of erosivity of rain, effect of relief on such erosion, soil profile, vegetative or plant residue cover and conservation practices. In accordance with, field assessment techniques like rill surveys provide substantial advantages as they are more realistic, simple and practically applicable at field conditions. Such methods of measurement of soil erosion by water and the effectiveness of the conservation practices at actual field levels through integrated views of the ultimate clients for the work, the farmers (Stocking, 2001; Evans, 2002; Morgan, 2005) provide more accurate information about soil losses than that information gathered through the simulated models covering larger areas.

Participatory identification of soil erosion indicators and soil loss computing approaches, like what was done by Belay and Bewket (2012, 2015) in northwest Ethiopia, are quite important to enhance awareness on types of soil erosion by water, magnitude of soil loss and conservation attention to key actors such as farmers and development agents (Evans, 2002; Okoba & de Graaff, 2005). Bewket and Sterk (2003) suggest that rill survey approach is commendable for obtaining useful semi-quantitative information on magnitudes of soil loss in the real situation of different land uses and conservation practices. Therefore, this study was conducted with respect to the actual soil loss from cultivated fields, and the principal units for evaluating the effectiveness of terracing practices by the farmers, using rill survey technique in high rainfall highlands of Ethiopia in which studies have been few in number as far as to the knowledge of the authors.

This study presents the results of the effects of terracing practices in reducing the magnitude of soil loss by using rill survey technique at cultivated field scales with a focus to crop type and topographic positions of the fields in the Beribere catchment, northwest Ethiopia. The paper tries also to assess the factors accelerating rill erosion

2. Materials and Methods

2.1 Description of the study area

The study was conducted in the Beribere catchment, Gonch-Siso-Enese *Woreda*, in the north-western highlands of Ethiopia. The Beribere catchment is roughly located between $38^0$04’49”& $38^0$03’40”E longitudes, and $10^0$56’46” & $10^0$55’19”N latitudes (Figures 1a & b). The major landforms of the catchment are volcanic in origin characterized by gently sloping undulating plains to slightly dissected and rugged plateaus. The mean elevation in the catchment is 2596 m asl. The local climatic condition is moist sub-tropical (*Woina-Dega*), where high annual rainfalls and moderate temperatures are recorded. The mean annual rainfall distribution in the catchment estimated by interpolating a raster surface from points' discrete data (average value of monthly rainfall records) using Arc GIS-version-10.2 software is ≈ 1312 mm. The mean value of erosivity in the catchment is 67 mm. This estimate was made by using Hurni (1985) empirical equation, R=-8.12+0.562P, where R is the total rainfall erosivity factor, and p is the mean annual rainfall (mm), which estimate the erosivity value of the Ethiopian highlands using annual rainfall. More than three-fourth of the total rainfall occurs in the summer season (June - September). Large areas of the study site are covered by steep slope and reddish soils (locally named as *Boda* implying that it is infertile). Under the mixed farming systems of smallholder community, tef (*Eragrostis tef*) and wheat (*Triticum vulgare*) are predominantly grown in the catchment. Tef has more likely sparse canopies with little covers to against soil erosion by water than wheat crop.

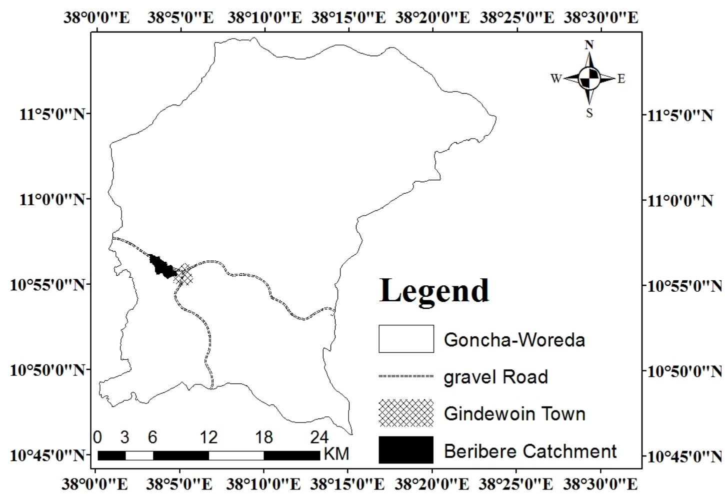

Figure1a: Location of Beribere catchment in the administrative map of Goncha-Siso-Enese Woreda

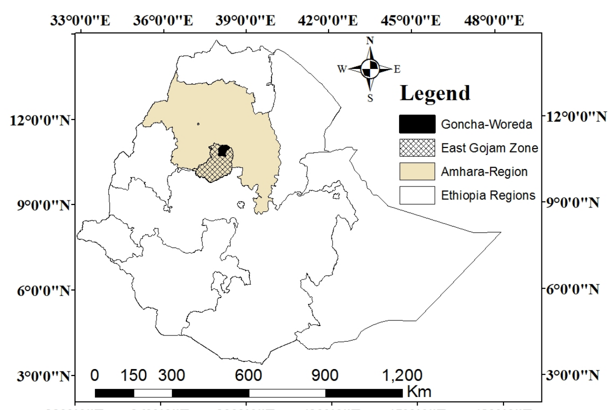

Figure1b: Location of Goncha-Siso Enese Woreda in the Administration map of Ethiopia

2.2 Methods and procedures of data collection and analysis

Monthly rainfall records covering the period between 1994 and 2013 were collected from stations in close proximity to the study area and then used to select the conserved catchment under the highest condition of erosive factor in Goncha-Siso-Enese Woreda. To estimate soil loss on terraced and adjacent non- terraced cultivated fields, primary field data were generated using informal discussions, observations and field rill survey methods. During the transect walks informal discussions with farmers working on their farm plots wre undertaken concerning soil erosion indicators and magnitude on both terraced and non- terraced fields. Frequent observations were also carried out to examine land use types, soil properties (including soil colour and texture), slope length and gradient, erosion indicators (broken terraces and traditional ditches, rills, sheet wash, deposition occurrence, presence of surface runoff entering into the fields from up-slope areas) and the existing status of the SWC measures.

Sample form of 24 representative cultivated fields (commonly identified as infertile and steeply sloping) under terraced and adjacent non-terraced zones were selected in reference to relative topographic positions in the valley sides and fields covered with principal crops (Tef and Wheat) in the catchment for the rill erosion survey. The total area of the selected fields was 76,500 m^2 (7.65 ha) (Table-1), about 2% of 389.9 ha, the total area of the Beriberi catchment.

Table-1: Distributions of surveyed fields by topographic position, conservation status and crop types cultivated in the *Beriberi* catchment

Topographic positions in the valley sides	N0. of cropped fields of terraced zone		N0. of cropped fields of non-terraced zone		Total
	Tef	Wheat	Tef	Wheat	
Up-slope	3(.92)	2(.88)	2(.66)	1(.26)	8(2.72)
Mid-slope	4(1.32)	3(1)	2(.8)	2(.61)	11(3.73)
Down-slope	2(.5)	1(.25)	1(.2)	1 (.25)	5(1.2)
Total	9(2.74)	6(2.13)	5(1.66)	4(1.12)	24(7.65)

Source: Field survey, 2015

Note: Values in parentheses represent total surface area of the surveyed fields in ha

From the selected fields, measuring and recording of the fields' area and rills in the fields were undertaken in the presence of cropland owners and sometimes DAs as well. Rill survey was conducted at different periods of the growing season to increase the reliability of the data. First, frequent visits were made to identify and measure the rills before the crops planting period i.e. between mid-June and early July/ 2015. Second, during the early growing season, between end of July and beginning of September/ 2015 frequent visits were conducted to identify the prevalence of rills following surface area covered with crops. Last, rapid and timely measurements of rills were made between mid-November to end of December /2015, before the rills disappear due to farming practices like free grazing and tillage following crops harvesting from the fields. Section of traditional ditches that washed run-off accompanied with uncovered crop seedlings were also identified, numbered and measured as rills.

In the field assessment of rill erosion, detailed measurements of length and cross-section of rills using tape were considered (Stroosnijder, 2005; Casalı´ *et al*., 2006). Hence, for the study rills were identified and numbered, and their depths, widths and lengths were measured by using tape meter. To enhance the precision and reduce potential error from total volume estimation, measurements of depth and width of each rill channel along its length (Herweg & Ostrowski, 1997) were carried out. Measurements were repeated and averaged with emphasis on keeping track of the actual shape of the rill (often a point of changing width and depth of rill) as widths and depths of rills are seldom constant throughout the length. Moreover, the widths and depths of rills were measured up to 3 times and averaged at a point due to the occurrence of different values. The length of a rill was taken between the origin area of rill formation on up-slope and on the lower slope where the main rill disappeared due to occurrence of sedimentation and confluence with other rills.

Based on the measured depths, widths and lengths of rills, the quantitative data analysis on magnitude of rill erosion like the actual damage of surface area covered by rills, the rill density and volume of soil lost due to rills' were estimated (Herweg, 1996; Bewket & Sterk, 2003). The distributions of the approximate values of actual damage, rills density and volume of soils loss of all identified rills across the surveyed fields were used to analyse spatial variation between homogeneous segments in terms of status of conservation practices, topographic position in the valley sides, crop patterns and accelerating factors of rills initiation and development.

The actual damage of surface area covered by rills was calculated using equation:

$$ADSA = \frac{\sum_{ni}(L_i W_i)}{A}$$

where ADSA- is Actual Damage of Surface Area covered with rills (in $m^2\ ha^{-1}$) in the study year; L_i is rill length in meter; W_i is the mean width of rill in meter; ni is the number of rills of each homogeneous segment; and A is total area of homogeneous fields in ha. Rill density (in $m\ ha^{-1}$) in the study year was obtained by: dividing the total length of all rills (in meter) by the total area of all surveyed homogeneous fields (in ha).
Moreover, the following equation was used to calculate the approximate volume ($m^3\ ha^{-1} yr^{-1}$) of soil removed by the rill channel:

$$V = \frac{\sum_{ni}(W_i D_i L_i)}{A}$$

where: V is total volume of soil loss due to formation of rills from homogeneous fields (in $m^3\ ha^{-1}$) in the study year; W_i is the mean width of rill in meter; D_i is the mean depth of rill in meter; L_i is the length of rill in meter; ni is the number of rills of each homogeneous segment; and A is total area of homogeneous fields in hectare.
The magnitude of soil loss is normally expressed either in unit of mass or in volume per unit area per unit of time (Morgan, 2005). For this study, the rate of soil loss is described in unit of volume per ha ($m^3\ ha^{-1}$) in the study year. The quantitative analysis was substantiated with qualitative data generated using observations and informal discussions. Nevertheless, as sheet erosion is often so inconspicuous and is measured using experimental method, its measurement was excluded from this survey study. Moreover, analysis of temporal variation of soil erosion due to rills was not incorporated in this study since the survey was planned to be completed within only one year due to financial and contract reasons. Data computed using the above models were further analysed using descriptive statistics with support of qualitative information obtained from field observation.

3. Results and Discussion

3.1. Effects of conservation practices on magnitude of rill erosion

Terraced SWC structures stabilized with vegetative supports can reduce the volume, speed and direction of concentrated soil movement along narrow water courses like rills. Run-off in rills is a transitional phase between sheet and gully erosion. Hence, it can be assessed by using intermediary field study in contrast to sheet and gully erosion that need micro and macro modelling, respectively.

Accordingly, results in Table–2 reveal the total number and lengths of rills, and damaged areas and volumes of eroded soils by rills under different conditions of conservation statuses and crop patterns of 24 surveyed fields in the Beribere catchment in the study year of 2015. For instance, the total number of rills was 172 in 4.87 ha terraced fields and 126 in 2.78 ha non-terraced fields. The total length of rills was 406.5 m ha^{-1} in the terraced fields and 710.4 m ha^{-1} in the non-terraced fields. This indicates that 42.8% of rill densities were reduced in terraced fields when compared with non-terraced fields. The total actual surface area damaged was 133.41 m^2 ha^{-1} in terraced fields and 302.7 m^2 ha^{-1} in the non- terraced fields, implying that terracing contributed to reduce damaged area by 55.93% as relatively seen with non-terraced fields. What is more, the damaged area as percent of total in the non-terraced fields was 2.31 times that of the terraced fields. This shows the direct effect of conservation practices in reducing the damage of productive cropping area in the field.

The total volume of all rills was 22.8 m^3 ha^{-1} in the non-terraced fields and 10.6 m^3 ha^{-1} in the terraced fields (Table 2). This entails that 53.5% of rill erosion was reduced in terraced fields when compared with non-terraced (control) fields. In agreement with this, different experimental studies have reported significant reduction in soil loss due to implementation of conservation practices in the high rainfall areas of north-western highlands Ethiopia. For instance, Herweg and Ludi (1999) reported that the majority of SWC treatments showed a significant effect on reduction of soil loss. Results of the study conducted by Amare *et al*. (2014) in Debre-Mewi watershed indicate that 63% of soil loss reduced due to combined effect of soil bunds with elephant grass, compared to the non-conserved plots in similar setting. In the same study site, Fisseha *et al*. (2011) also reported that rill erosion due to the *Fanya-juu* with elephant grass, *Fanya-juu* with Vetiver grass and sole *Fanya-juu* reduced by 75.1, 80.3 and 63.6% respectively, when compared with the non-conserved plots in a similar setting.

Nevertheless, for this study, the measured magnitudes of rill erosion underestimated the actual rates of soil loss since inter-rill/sheet/ erosion was excluded. Sheet wash is the most effective sediment transport agent, in particular when the tilled cultivated field is uncovered before and early after crop sowing time (Morgan, 2005). Govers and Poesen (1988) found that the relative importance of inter-rill erosion ranges between 22 and 46% whereas soil materials transported in rill erosion accounted for 54% to 78% of the total erosion. In contrast to this estimates, Vandaele and Poesen (1995) found that rill erosion in the hill slopes accounted for 33% of the erosion coverage for the three years period in the hammerveld-1 catchment, central Belgium. In the rill survey methodology, there is a probablity to underestimate rill erosion by 10 to 30% since it ignores the contribution of inter-rill erosion to the sediment carried in the rills and depends upon being able to identify conspicuously the edge of the rills (Morgan, 2005). Accordingly, for this study by assuming the contribution of inter-rill/sheet/ erosion as 28% in terraced fields and as 30% in non- terraced fields, the annual actual soil loss due to rills and sheet erosion is estimated at 32.6 m^3 ha^{-1} in the non-terraced fields and 14.8 m^3 ha^{-1} in the terraced fields (Table 2). This, perhaps, indicates that the magnitude of soil loss in the terraced fields was not likely an acceptable level, compared with the mean soil loss of 11 t

$ha^{-1}yr^{-1}$, which generally is considered as tolerance level (Hudson, 1981; cited in Morgan, 2005).

Table-2: Numbers and lengths of rills, and damaged area and volume of eroded soils by rills in 24 surveyed fields of Beribere catchment in 2015

Parameter of rill erosion	Surveyed cultivated fields (7.65 ha)			
	Terraced (4.87 ha)	Non-terraced (2.78 ha)	Tef cropped (4.4 ha)	Wheat cropped (3.25 ha)
Total number of rills	172	126	149	149
Total length (m ha^{-1})	406.5	710.4	441	619.6
Total damaged area (m^2 ha^{-1})	133.41	302.73	193.61	215.3
Damaged area as % of total	1.3	3	1.94	2.2
Eroded soil volume (m^3 ha^{-1})	10.64	22.84	15.34	16.9

Note:

- ✓ *10,000 m^2=1ha*
- ✓ *Minimum mean depth of rill was 2 cm (influenced by ill-ditch practice) in the terraced and wheat-cropped fields, situated in down-slope of valley sides of the catchment*

3.2. Crop type and rill erosion

When the root and shoot densities of crops increase on the topsoil, the concentrated flow of water erosion rates exponentially decrease, particularly for sheet and rill erosion in the early plant growth stages (Gyssels & Poesen, 2003). Table-2 shows the density of rills, affected area and volume of soil removed due to rills in the tef and wheat cropped fields in the Beribere catchment in 2015. Total rill density, proportion of damaged area out of the total area and total volume of soil removed slightly increased in the wheat-cropped fields when compared to tef-cropped fields. For instance, the total length of rills was 619.6 m ha^{-1} in the wheat fields and 441 m ha^{-1} in the tef cropped fields, implying that rill densities in wheat fields were 1.4 times that of the tef fields. Out of the total area, the proportion of the actual damaged cropping area due to rills in the wheat fields was also 1.34 times that of the tef fields.

Moreover, the annual total soil loss due to rills was 16.9 m^3 ha^{-1} in the wheat fields and 15.34 m^3 ha^{-1}in the tef fields; indicating that soil loss due to rills in the wheat cropped fields was 1.1 times that of the tef cropped fields. This is probably, due to more culmination of sheet flow into rills on cropping horizons because of constructing wide spaced ditches and inappropriate gradient of row crop sowing in the wheat fields than in the tef fields. There was initiation of more rills due to poorly designed ditches and cut-off drains in the wheat fields than those of the tef fields. Even the dimensions of rills of wheat fields were larger than those of the tef; that might be due to tearing of tilled surfaces by highly concentrated run-off generated from the widely spaced drainage ditches. In contrast to the results of this study, some studies indicated that soil loss rate in tef-cropped fields was larger than wheat fields. For example, Tefera and Sterk (2010) reported that the highest rill densities observed in the tef fields compared to other fields was because the fields were compacted by animal trampling that reduced infiltration rates and stimulated surface run-off. In this regard, the field observations discovered the trampling of tilled surfaces by animals for tef seedbed preparation in the study district. This probably results in potential prevalence of splash and sheet erosion during the heavy rain storms when the fields are uncovered before and early cropping in the sowing time.

3.3 Topographic positions of the fields and rill erosion

Figur-2 demonstrates that surface area damaged by the rill and volume of soils eroded due to rill in the valley sides topographic positions of the Beribere catchment. In both terraced and non-terraced areas, fields in mid-slope topographic position were more susceptible to rill erosion than other topographic positions in the valley sides. For instance, under the terraced areas, the surface area of actual damage from the mid-slope fields was 1.47 times that of the up-slope and 1.79 times that of down-slop fields. Likewise, the volume of soil eroded from mid-slope fields was 1.47 times that of the up-slope and 1.53 times that of down-slope fields.

In the non-terraced area, the surface area actual damage from the mid-slope fields was 1.72 times that of the up-slope and 1.16 times that of the down-slop fields. As well, the volume of soil removed from mid-slope fields was also 1.47 times that of the up-slope and 1.4 times that of the down-slope fields. This is, perhaps, due to the increasing likelihood of concentrated run-off entering from the up-slope fields. In agreement with this, Bewket and Sterk (2003) reported that mid-slope position in non-terraced area was more vulnerable to rill erosion.

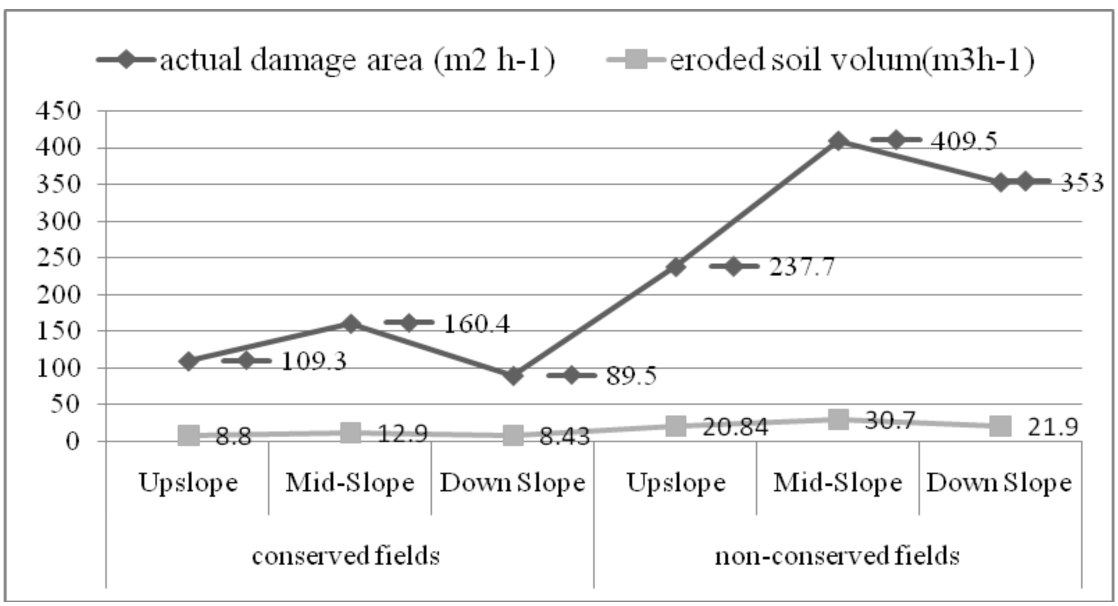

Figure-2: Rill erosion distribution in terraced and non-terraced fields by topographic position in the valley sides of Beribere catchment

Next to fields from mid-slope, fields from the up-slope in the terraced area and fields from the down-slope in the non-terraced area were found to be vulnerable for rill erosion. This may be due to the contribution of terraces to reduce hydrological connectivity (the processes of surface run-off concentration) by reducing surface gradient and diverting course on up-slope and mid-slope positions in the valley sides of the catchment.

3.4 Factors accelerating rill erosion

Based on field observations and measurements, concentrated run-off entering from areas of up-slope direction, damaging of terraces and ditches, poorly designed ditches (which were easily exposed for bed erosion of tilled soils of channel of ditches), growing of sheet flow in-situ were found to be the major factors accelerating rill erosion in the study site.

Table-3 reveals that out of the total volume of soils removed by rills in the terraced fields; almost three-fourth was from damaged terraces. Therefore, in the terraced areas, terrace damage is the most important contributing factor for soil loss due to rills in both tef and wheat cropped fields.

As confirmed from field observation and farmers' views, lack of proper maintenance of bunds and diversion ditches before the first rainstorms and occurrences of loose and bare soils due to repeated tillage practices are most important factors for terrace damages and rills formations in the down-slope parts of cropped fields. For instance, when the first terraces of the upper sections of cultivated fields are well maintained and stabilized, the lengths of the rills on the middle and lower parts of the specific cultivated fields are largely decreased. This perhaps could be owing to the substantial reduction of the velocity and strength of concentrated run-off by the first stabilized bunds. This implies that when terraces on cropping areas are maintained and stabilized timely and properly, the probability of rill prevalence on that cropping field is minimized. Unfortunately, large numbers of farmers often prepare to mitigate erosion which is often more vigorous on bare lands due to concentrated run-off. This probably happens due to inadequate knowledge about the source of initiation of rills along with topographic characters of cropping areas or inadequate labour to excavate soils from terraces and diversion ditches. Moreover, bund destruction by farmers, lack of adapting well-designed terraces (unable to drain surface water) and improper drainage ditches are important factors for the damage of terraces and rill occurrences in the terraced cultivated fields. Because of these interactive factors, the upper section of cropping areas between terraces is more vulnerable to rill erosion than middle and lower parts.

Rill numbers decreased when moving from upper to lower parts of cropping areas between terraces due to the contribution of indigenous drainage ditches or furrows. Even rills usually disappear from the middle parts of terraced areas towards the lower parts. Drainage ditches or furrows play important role to interrupt sheet diagonal growing at their early stages. Moreover, in the fields where terraces are well designed, stabilized (with vegetative measures like *Fanya-juu* bunds), properly maintained and complemented with proper practices of indigenous drainage ditches the occurrence of rills in the terraced cultivated fields often disappears. This perhaps indicates that the combined use of technically fitted indigenous drainage ditches and introduced terraces stabilized with *Fanya-juu* bunds are more likely acceptable to curb soil loss than a single practice.

In the non-terraced fields, entering of concentrated run-off from up-slope areas and damage of ditches were observed as the principal factors accelerating the formation of rills and development of rill erosion, whereas they had insignificant effect on rill erosion in the terraced fields. For example, of the total soil lost due to rills in the non-terraced areas, about 43% was because of entering of concentrated run-off from up-slope fields (Table-3). This indicates that terracing has substantial contribution to control concentrated surface run-off entering from up-slope areas.

Table-3: Factors accelerating rill erosion in terraced, non-terraced, tef and wheat cropped fields

Factors accelerating rill erosion (in m^3) in the fields	Field types			
	Terraced	Non-terraced	Tef cropped	Wheat cropped
Up-field entering	1(1.9)	27.4(43.2)	15.1(22.4)	13.3(24.2)
Terrace damage	38.7(74.7)	-	23.3(34.5)	15.4(28.1)
Ditch damage	2.8(5.4)	27.3(43)	22.3(33)	7.8(14.2)
Ill-constructed ditches	8.1(15.6)	6.8(10.7)	5.8(8.6)	9.14(16.6)
Sheet grown *in-situ*	1.24(2.4)	2(3.1)	1(1.5)	9.3(16.9)
Total	51.84(100)	63.5(100)	67.5(100)	54.9(100)

Note: The values represent soils lost due to rills erosion (m^3) and figures in the parenthesis represented percentages.

From the total volume of soil eroded by rills, damaging of traditional ditches accounted for 43% (Table-3). Based on frequent observations, absence of accompanied control measures (like terraces); lengthiness of ditches along with shallow depths, concentrated run-offs and unsafe gradients of ditches are contributing factors for breakage of traditional drainage ditches and for the prevalence of rills on the down-slope cropped fields. Sometimes, rills are also occurring due to the damage of cut-off drains (locally named as *Tekebikeb*) because of inadequate excavation of tilled soils from channels during construction and maintenance time.

The degree of influence of the factors on rill erosion also differs in tef and wheat cropped fields. On the one hand, out of the total eroded volume of soil due to rills, the combined effect of entering run-off from the up-slope fields, and the damage of terraces and ditches accounted for 89.9% in tef and 66.5% in the wheat-cropped fields. This implies that because of the combined effect of these accelerating factors, the proportion of soil loss due to rills in tef fields is 1.35 times that of wheat fields. This further pointed out that tef crop fields are highly vulnerable to the erosive power of concentrated run-off that enters from up-slope areas initiated by damaging terraces and ditches.

On the other hand, out of the total soil volume removed by rills in the wheat cropped fields, 16.6% and 16.9% accounted for ill-designed traditional ditches and strength of overland flow, respectively. However, of the total volume of soil eroded by rills in the tef-cropped fields, 8.6% and 1.5% was accounted for ill-designed traditional ditches and overland flow strengths, respectively. This indicates that the influence of sheets grown and ill-designed ditches on rill erosion in tef fields was lower than that of the wheat. As learnt from the field observation, when row-direction of wheat seed sowing designed to cause for excessive erosion, rills often generated in tillage paths as the result of strengthened sheet erosion *in-situ*. So, under the conventional tillage, growing of sheet-wash into rills within cropping horizons (between traditional ditches or terraces) was identified. Alternatively, when seed sowing was in contour row, growing of sheet-wash into rills disappeared. Because of considerable proportion of bare tilled surface, particularly in the early stage of crop growth, row crops on sloping fields give rise to more rill and inter-rill erosion problems (Morgan, 2005; Arnhold *et al*., 2014).

Similarly, poorly designed traditional ditches with significantly gradient enough by themselves often accelerated rill erosion through bed erosion on channels of ditches and cut-off drains. The volume of removed parts that are not covered by crop seedlings could be an indication of soil loss from bed surface of drainage ditches. This occurrence was largely observed in the wheat-cropped fields probably due to the flow of high concentration run-off (which generates from relatively wider affected cropping horizons) on the channels of ditches and cut-off drains. However, according to the views of owners of surveyed cultivated fields, a large number of farmers do not recognize the negative effect of poorly designed ditches and cut-off drains for causing soil loss due to rills.

Conclusions

This study assessed the effect of terrace construction on reducing the magnitude of soil loss by using a rill survey methodology on 24 cultivated fields (with respect to crop type and topographic position of fields) and the factors accelerating rill erosion in the Beribere catchment, in the north-western highlands of Ethiopia. Based on the results of the rill survey study, the total volume of soil removed by rills in the study catchment was about 22.8 m^3 ha^{-1} in the non-terraced fields and 10.6 m^3 ha^{-1}. This indicates that 53.5% of the rill erosion reduced in the terraced fields compared to the non-terraced fields. Nevertheless, for this study, the measured magnitudes of rill erosion underestimated the actual soil loss since sheet erosion was considered. Hence, supposing sheet/ inter-rill/ erosion contribution of 28% in terraced fields and 30% in the non- terraced fields, the actual soil loss due to rills and inter-rill erosion is estimated at about 32.6 m^3 ha^{-1} in non-terraced fields and 14.8 m^3 ha^{-1} in the terraced fields. This indicates that the absolute soil loss in the terraced fields was still high (not at acceptable level). In the terraced area, terrace damage is the most important contributing factor for soil loss due to rills. In the non- terraced fields, entering of concentrated run-off from up-slope areas and ditch damaging observed as principal accelerating factors for formation and development of rill erosion, whereas they had insignificant effect for rill erosion in the terraced fields.

Moreover, soil erosion demonstrated spatial difference in terms of crop cover and relative topographic position of the fields in the Beribere catchment. For instance, tef cropped fields were less vulnerable to rill erosion as compared to the wheat cropped fields. This is probably due to the higher contribution of sheet erosion and erosion on beds of ditches to the magnitude of rill erosion in wheat fields than tef. Sheet flow grown in-situ and ditches bed erosion mainly occurred as a result of inappropriate gradient of row crop sowing and widely spaced ill-designed ditches, respectively. All surveyed fields from mid-slope of the valley sides were the most susceptible to rill erosion than other relative topographic positions.

It is concluded that in spite of their advantages on considerable soil loss reduction, terracing structures are inadequate to curb soil erosion by water effectively. Erosion control activities (especially terracing and traditional ditches) often cause rill formation unless they are properly designed, maintained and stabilized. This aspect makes them site specific erosion control activities for addressing the problem. Improving farmers' skills of designing and practicing indigenous and introducing conservation activities through effective communication between farmers and extension staffs should be accentuated. Furthermore, it is suggested that since erosion control practices can do little to prevent detachment of soil particles, they need to be complemented with considerable agronomic SWC measures to reduce soil, water and nutrient losses at acceptable levels and thus enable the cultivated fields to sustain crop yields. Eventually, the study corroborates that rill surveying method provides significant semi-quantitative information on the magnitude of soil erosion and is important for pragmatic assessment of the effectiveness of conservation measures.

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