

Chapter 17

Soil and Water Conservation Technology and Sediment Retention Assessment



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Abstract Soil erosion is a common menace to Ethiopian highlands. As a result, mitigation measures were practiced for decades without evaluation of the efforts made on the highlands. Therefore, this field survey was conducted in 34 community watersheds in Amhara region, Ethiopia, to determine the performance of conservation practices with respect to soil erosion and sediment retention. The study used the methodology of biophysical field surveys, and hence, different sites were selected based on agro-ecology, topography, and land use. Different types of structures were identified; vertical intervals, horizontal intervals, dimension of embankments and collection ditches' height, width, and depth were evaluated against the standards provided by ministry of agriculture. Google earth images were downloaded, and structures were digitized for verification using field observations. Stream power index was used to delineate gullies and soil loss with two scenarios, with conservation practices (existing scenario) and without the practices (base case scenario) were estimated, and sediment retained was evaluated. Based on the results, the land affected by gullies was estimated 2% from the total land area. The gullies treated by check dams and plantation of gully sides were estimated about 54.1%. The coverage of the practices in the study watersheds accounts 60.38% and 38.02% by physical and biological measures, respectively. About 42% of the bunds were stabilized with trees and grass, and 16% of the area of community watersheds were delineated for enclosure. The gradients of bunds in humid areas where there is high rainfall, only 27.62% fits the criteria of the standard, but the remaining 72.38% were below the standard. But in most sub-humid areas where the rainfall is lower

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than moist humid areas, 91.25% of structures were constructed based on the recommendation. Average annual soil losses of watersheds before conservation were estimated as 77 t/ha/year and reduced to 34 t/ha/year after conservation was practiced. Thus, the amount of soil retained as a result of the practices was estimated as 43 t/ha/year, and hence 56% (0.37 cm) of soil could be engaged on land resource managed areas. From the analysis, it can be concluded that significant soil was retained as a result of implementation of practices.

Keywords Gullies · Soil erosion · Sediment loss · Soil and water conservation · Amhara region · Sediment retention

Introduction

The livelihood of Ethiopians is supported by the agriculture sector, which is widely considered a sector for improving food security and poverty. However, this sector is highly affected by soil erosion, decrease of soil fertility, and land degradation (Grepperud 1996; Pender and Gebremedhin 2006). Furthermore, climate change impact is shown to affect the agricultural sector in Ethiopia. This has led Ethiopia to be highly vulnerable to food insecurity and hence depend on international aid. In Ethiopia, soil degradation can be understood as a direct result of historical agrarian practices in its uplands (Bishaw 2001). In the uplands, the expansions of deforestation, over cultivation, and overgrazing lead to enhanced soil erosion (Hurni and Pimentel 1993).

Watersheds affected by high degradation tend to hasten overland flow, increases sediment detachment and transportation, decreasing soil moisture and base flow. Several studies used terrestrial cover representing tools and methods to comprehend land use differences, record of natural resources and forest as well as recognize the changes in the hydrologic performance of watersheds (Getachew and Melesse 2012; Mango et al. 2011a, b; Wondie et al. 2011, 2012; Melesse and Jordan 2002, 2003; Melesse et al. 2007; Yesuf et al. 2013).

Numerous studies (Aga et al. 2018, 2019; Defersha and Melesse 2012a, b; Defersha et al. 2010, 2012; Maalim and Melesse 2013; Maalim et al. 2013; Setegn et al. 2010; Melesse et al. 2011; Msagahaa et al. 2014; Wang et al. 2008; Mekonnen and Melesse 2011; Setegn et al. 2009; Yesuf et al. 2015) were conducted to comprehend soil erosion and sediment conveyance. Multi-approach studies indicate that watershed procedures and landscape structures regulate the rate of sediment detachment and conveyance.

Similar to the rest of Ethiopian regions, major economic activities of the Amhara region are largely confined to cropping and livestock farming whose misuses are strongly connected to the degradation of land resources. Various soil and water conservation measures have been conducted over the last 40–50 years. Physical soil and water conservation measures such as soil bund, stone bund, hillside terrace, cut

of drain, check dams, micro basin construction, and biophysical conservation measures such as river bank plantation, gully side plantation, hedge row cropping, area closure, and tree planting on degraded lands are the main soil, and water conservation measures that were implemented for the last decades under Amhara Bureau of Agriculture (BoA).

In Amhara region, soil and water conservation actions are implemented widely, especially in those 4–5 years in the first million development goals (MDG) period, but their impacts were not appraised. The quantity and quality of the structures were not documented. So that, the social, physical, and biological state of the soil and water conservation structures appraisal were done through selected 34 community watersheds chosen based on the agro-climate zonings (ACZ). Soils surrounded by the construction, gully treated by the check dam, physical and biological soil and water conservation structures were evaluated throughout the Amhara region for selected community watersheds of treated and untreated units with the main objective of assessing the performance and effects of soil conservation practices in respective to soil erosion and sediment retention.

Materials and Methods

Description of the Study Area

The Amhara National Regional State (Fig. 17.1) inhabits a territory prolonged within a geographical coordinate between $9^{\circ} 29' - 14^{\circ} 0'$ North latitude and $36^{\circ} 20' - 40^{\circ} 20'$ East longitude. It covers an area of 170,152 km². It is enclosed by Sudan and Benshangul Gumuze in the west, Tigray in the North, Afar in the East, and Oromia region in the South. Thirty-four small watersheds were selected based on the agro-ecology throughout the Amhara region, and evaluations were conducted on the effect of natural resource conservation on biophysical and socio-economic changes.

Data Set

Base Map Preparation

Base maps using Google earth images were prepared showing treated and untreated watersheds. Observation points were selected based on the prepared base map considering conserved and degraded areas of the watersheds under different slope class.

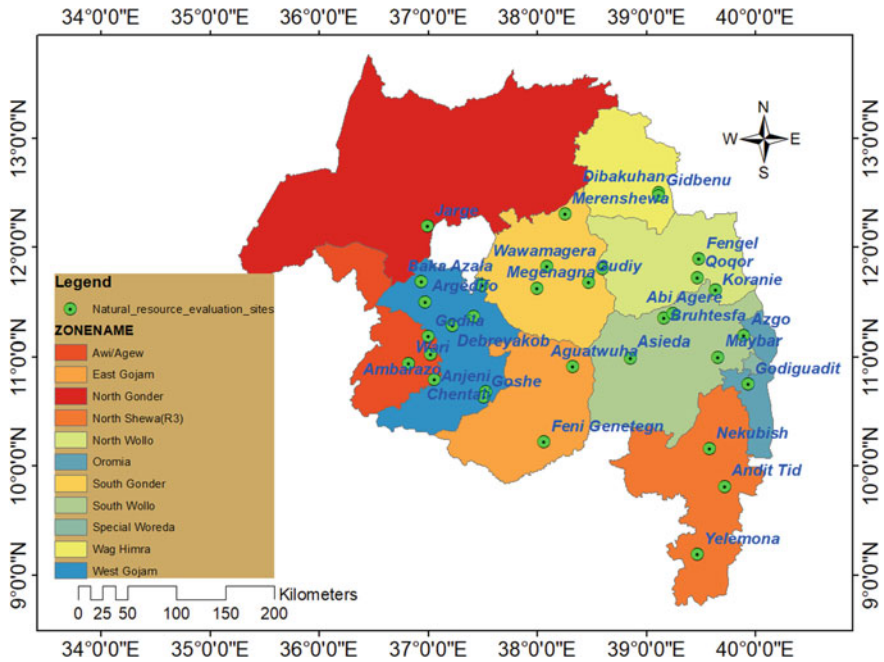


Fig. 17.1 Figure location map of the study area

Preparation of checklists and questionnaires was designed for the assessment of both secondary and primary data on biophysical and socio-economic issues at different levels that enable for gathering preference of farmers and best practices of the watersheds.

Primary Data Assortment

This study was conducted mainly through field observation with the aid of GPS and spatial tools to investigate biophysical data of the watershed. The primary data were also collected from farmers, development agents by using questionnaires and discussions with the concerned experts.

Observation through transect walk and soil and water conservation structures measurements were taken. Field measurements such as vertical interval and horizontal interval between structures, height, depth, and width of structures of embankment and ditch dimensions were taken from field. Key informant interviews were also taken from key persons of each watersheds. Coordinate points were collected to take representative places where soil and water conservation structures were found.

Data Analysis

Assessment of Areas Affected by Gullies

Gullies are formed by concentrated flow of runoff. Area coverage of land affected by gully was assessed with the use of raster calculator as

$$\text{SPI} = \text{LN}([\text{FlowAccum_Raster}] + 0.001) * ([\text{Slope_Raster}] / 100) + 0.001 \quad (17.1)$$

Stream power index (SPI) refers to the flow accumulation raster which is the output from flow accumulation analysis and slope raster from slope analysis.

Soil and Water Conservation of Watersheds

Using image downloaded from Google earth, digitization of constructed structures were done by grouping types of structures such as bunds, bunds with stabilized tree types, hill side terraces, trenches, micro-basins, etc. The coverage of structures was digitized in polygon. Attributes were coded for each construction based on the data collected from field.

Evaluation of Dimension of Structures

Soil and water management structures have their own standards to correctly control erosion. If we decrease the spacing between bunds, it may occupy cultivable land, and in the contrary, if we construct wide spacing, erosion may aggravate and the structure may collapse so that appropriate spacing between structures is necessary. Vertical intervals, horizontal intervals, dimensions of different embankments, ridges, and gradients of structures were evaluated with standards. The actual dimensions were collected during the field trip period, and standards of the dimensions were calculated using the formula from guidebooks or from standards obtained in literatures such as participatory watershed management knowledge compiled by the ministry of asgriculture (MoA). Different structures may be appropriate in different agro-ecological zones, so that this variation of appropriateness was also evaluated.

Vertical interval between bunds (VI) was estimated as

$$\text{VI} = \left(b + \frac{S}{a} \right) 0.3 \quad (17.2)$$

where S = Land slope in (%); a and b are constants, and $a = 3$ and $b = 2$ for medium and substantial rainfall zones, and $a = 2$ and $b = 2$ for short rainfall zones.

Horizontal spacing in between bunds (HI) is given by

$$HI = \left(\frac{VI}{S} \right) \times 100 \quad (17.3)$$

The spacing of check dams is estimated as

$$S = \left(\frac{1.2 \times h}{G} \right) \quad (17.4)$$

where S = the spacing in m , h = the effective height of the check dam (spillway height in m), and G = the gully gradient.

The vertical interval, height, and collection ditch's width and depth were measured at selected points in each structure within the bunds, check dam, micro-basin, and terrace or trench length. The mean height, mean length, and mean vertical interval are computed for each structure and compared with the recommended (standard) value using basic statistics, z -test (when the mean of the population is known and the sample number is greater than 30), and t -test (when the population mean is unknown and sample number is less than 30) to evaluate the quality of the structure.

$$Z = \left(\frac{X - \bar{x}}{\frac{S}{\text{Sqrtn}}} \right) \quad (17.5)$$

$$t = \left(\frac{X - \bar{x}}{\frac{S}{\text{Sqrtn}}} \right) \quad (17.6)$$

where X is the recommended standard value, \bar{x} is the mean of the data set, S is the standard deviance of the data set, and n is the total number of each data set.

Sediment Analysis

The data collected through different methods were organized and analyzed into different forms in line with the nature of issues supported by theoretical and empirical evidence from literatures. In analyzing the data, both qualitative and quantitative methods were applied.

Soil Erosion Estimation Method

The area was assessed using soil erosion hazard as an indicator for quantitative land degradation. To assess soil erosion threat for the project area, Revised Universal Soil Loss Equation (RUSLE) approach was used.

The land degradation maps were developed on ArcGIS environment by using RUSLE params (erosivity of rainfall; erodibility of soil; slope distance and gradient; land cover; and land management practices) as an input to assess average annual soil loss rate of the area. The mathematical equation can be represented on physical-based models in the ArcGIS environment. Each variable was overlaid to make the overall spatial analysis. Mathematical equation of Revised Universal Soil Loss Equation to guess soil loss before soil and water conservation is

$$A = R.K.LS.C.P \quad (17.7)$$

Soil loss after SWC was implemented and estimated using

$$A' = R'.K'.L'S'.C'.P' \quad (17.8)$$

where A = Annual soil loss in tons/ha/yr; R = Rainfall erosivity; K = Soil erodibility; LS = Topographic factor (slope length and gradient factor), C = Soil cover factor, and P = Land management factor.

Soil Loss Before and After Construction of SWC

Soil loss before and after soil and water management practices were implemented is assumed to be calculated by changing slope distance factor, land protection factor, and land management factor.

Rainfall Erosivity factor (R) There are different ways of examining the R -factor for different areas. The factor of the development corridor was calculated on the bases of mean annual rainfall data of each station rendering to the calculation given by Hurni (1985a, b), for Ethiopian circumstances based on the available mean annual rainfall (P). It is given by a regression equation as

$$R = -8.12 + 0.562 * P \quad (17.9)$$

where R = Rainfall (Erosivity) factor unit less, and P = Mean annual rainfall in mm.

To compute erosivity rate of the basin, the mean value at each meteorological stations was taken. To change this point rainfall into areal rainfall, the Thiessen polygon method was used. Areal rainfall of Thiessen polygons was area weighted; the values were mapped in the ArcGIS environment.

The formula used to calculate point rainfall into area based is given by the equation:

$$P_{ave} = \sum_{i=1}^{i=n} \left(\frac{A_i P_i}{A_n} \right) \tag{17.10}$$

where P_{avg} = Average precipitation of the rainfall, A_i = area of Thiessen polygon i , A_n = Sum of Area of “ n ” numbers, and P_i = yearly mean Precipitation of each meteorological station.

Soil Erodibility (K): Erodibility of soils was estimated from the generated soils map of the project area. To estimate the erodibility value, major soil types based on FAO classification were used.

Slope length and gradient factor (LS): The technique used for computing LS requires length of overland flow for a watershed which is assumed to be the surface flow length till the runoff gets channel such as rills and drainage ways. Stream density was calculated with drainage length divided by area of the watershed, and the length of overland flow is the reverse of twice drainage density.

The slope distance and slope steepness can be used in a single index, which expresses the ratio of soil loss as well-defined by

$$LS = \left(\frac{X}{22.13} \right)^{0.5} * (0.344 + 0.0798 * s) \tag{17.11}$$

where X is the length of overland flow (before) and length of spacing between bunds (after) SWC and S is slope in percent.

Land cover factor (C): The land cover feature was planned using the land cover map as an input. Each cover value of the project area (Table 17.1) could be synchronized with the adopted C-value in Ethiopian condition (Hurni 1985a, b). The land cover/use map was developed from the Google earth imaginary by using ArcGIS.

Land management practice factor (P): The land management factor (P) in RUSLE is defined as the ratio of soil loss with a specific management practice to the

Table 17.1 C-factor values

Land use	C-factor
Forestland	0.01
Eucalyptus plantation	0.02
Grassland	0.05
Shrub land	0.05
Cropland	0.15
Waste land	0.5
Built up area	0.09
Water body	0

Source (Hurni 1985a, b)

corresponding soil loss with straight row upslope and down slope tillage. Management factor was taken as unity assuming there was no management intervention in the base case scenario.

Soil Loss After SWC

Slope length and gradient factor (LS): It is well known that the slope length is becoming short with the practice of management measures. Length of overland flow is divided in to short slope length because of bunds and terraces are constructed. Therefore, the slope length factors were obtained from spacing between two constructed practices using the above LS formula.

Land Cover factor: Land cover is expected to be changed in each watershed after soil and water conservation strategies were implemented. Land uses were prepared for both before and after soil and water conservation structures implementation, so that the soil loss cover factor could be changed in estimating the soil loss for both scenarios.

Land Management practices factor: It is clearly known that soil loss is minimized after proper soil and water conservation structures were implemented, so that the management factors were determined based on management type for the given land use for Ethiopian condition. It is assumed that the p -values (Table 17.2) were given to management factor for those areas treated by bunds (Hurni 1985a, b).

Estimation of Sediment Deposition

The change in between the two scenarios (without SWC and with SWC) was assumed to be sediment deposited between bunds in ton/ha/yr, and this soil contains parallel soil depth increment. The soil depth increment is modeled as in

$$D = \left(\frac{m}{a} * d\right) \quad (17.12)$$

Table 17.2 Management factors for some land use types

Land use	p -value
Water body	0
Cultivated land	0.9
Settlement	0.63
Eucalyptus plantation	0.53
Grazing	0.63
Bare land	0.73

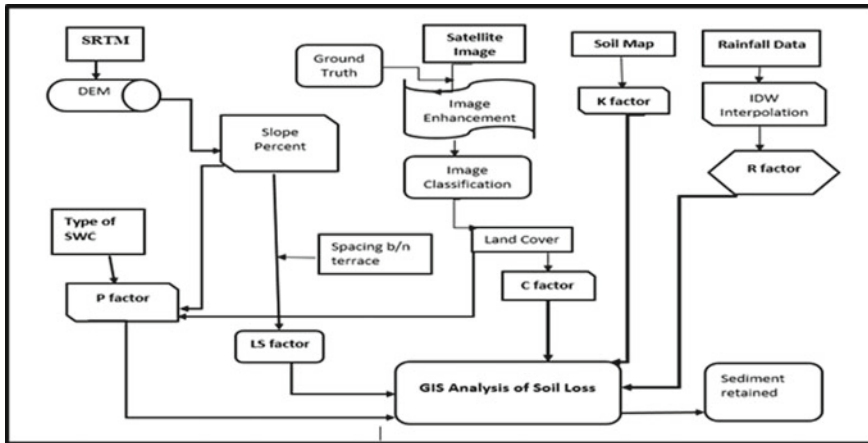


Fig. 17.2 Flowchart of soil loss analysis and sediment retention

where D = soil depth increment, m = mass of soil retained by SWC, a = unit area of grid cell, and d' = bulk density of the retained soil taken from laboratory analysis for samples taken from representative samples for physical and chemical analysis of deposited soil. Figure 17.2 shows the methodology flowchart followed in this study.

Results and Discussion

Soil Erosion

Splash, Sheet and Rill Erosion

Splash, sheet, and rill erosions were seen in all watersheds. Earth smoothing and crusting, which is the effect of splash, are the common phenomena of farmlands. Soil deposit at the high side of obstructions and most lately constructed bunds and hill side terraces formed benching. These indicate the presence of the movement of soil as a sheet flow and indication of soil loss as sheet erosion. Rill erosion as a result of wide spacing of bunds and weakly constructed bunds was observed in all watersheds (Fig. 17.3).

Gully and their treatment coverage

From analysis of stream power index (SPI), a land affected by gully erosion was assessed, and from Google earth image and field observations, the gully treated by check dams and plantations was determined. The land occupied by gullies account 2% of the total land area of community watersheds. This implies that this much



Fig. 17.3 Rill erosion formed in poorly constructed soil bund in Dibakuhan watershed (a). Earth crusting, smoothing of cultivated land and rills formed in Andit Tid watershed (b)

amount of land is affected by gully destruction in the region. From observation and Google earth image, 54.1% of the gullies are treated by check dams and plantation.

Area Coverage of SWC Practices in Community Watersheds

Traditional as well as introduced soil and water management structures are observed in the study watersheds such as contour plowing, traditional ditches, soil bunds, stone bunds, Fanya juu, stone-faced soil bunds, hillside terrace, bench terrace, trenches, micro-basin, eyebrow basin, and percolation pit. Biological measures such as grass strip, area closure, and hedgerow planting were also used. *Trelucern*, *Susbania susban*, *Lucinia*, *Sisal (Erate)*, *Kitikita*, and *Kundo Berberie (Schieness molle)* were plants, and *Vetiver grass*, *Sendedo*, *Densho*, *key Sar*, *Serdo*, *Lime*, and *Guasa* are grasses grown in the bunds of the watersheds.

The coverage of soil and water conservation works in the watersheds were 60.38% of the total area covered by physical measures and 38.02% by biological interventions. This implies that 39.62% parts of the region's community watersheds are not covered by physical and 61.98% by biological conservation measures.

Evaluation of the Technical Standards of SWC Structures

Different types of dimensions and spacing of soil and water conservation structures were evaluated with their standards. Those that are the same types of structures data collected from field are grouped together and evaluated with statistical params.

Table 17.3 Comparison of existing with standard values set for Soil bund

Variable	Existing Av	Standard value	<i>n</i>	<i>p</i> -value	Decision
Height of bund (m)	0.61	0.6	31	0.4588	Ho = accepted
Width (m)	0.71	0.5	10	0.0005	Ho = rejected
Depth (m)	0.29	0.5	10	0.0000	Ho = rejected
Vertical spacing (m)	1.36	1.58	28	0.4071	Ho = accepted

Soil Bund

Soil bund is constructed in slopes ranged from 3 to 33% with 6 to 32-m horizontal distance and 0.7 to 3.45-m vertical interval. As indicated in Table 17.3, the height and the vertical spacing of the soil bund is found to be supporting the hypotheses that there is no a significant difference between the existing and standard one. This implies that the construction of soil bund in watersheds in the region is carried out as per the recommended standards. On the other hand, embankment depth and width of soil bunds are found to be highly significantly different from recommended standard. This implies that the width and the depth of soil bunds are incorrectly constructed in the watersheds throughout the region in the probability of ($p = 0.0005$) and ($p = 0.000$), respectively, at 5% level of significance.

Stone Bund

The mean height of the stone bund is 0.87 m (Table 17.4) with minimum of 0.33 m and maximum of 2.5 m which is observed in old stones that the height is added by frequent maintenance through time. About 25.6% of the bunds have greater heights from the recommended values. The mean value of the stone bund vertical interval is 2 m, but the standard recommended value is 2.13 m.

Statistical analysis also shows that there is no significant difference between height and vertical interval of stone bunds with their recommended standards in 0.05 significance level: the *p*-values are 0.06 and 0.26, respectively, which is greater than 0.05. This implies that height and vertical intervals of the stone bunds were constructed according to the standard in the region.

Table 17.4 Comparisons of existing with the standard values of stone bund

Variable	Existing Av	Standard value	<i>n</i>	<i>p</i> -value	Decision
Height (m)	0.87	0.76	38	0.06	Ho = accepted
VI spacing (m)	2	2.13	34	0.29	Ho = accepted

Table 17.5 Comparison of existing with standard values of stone-faced soil bund

Variable	Existing Av	Standard value	<i>n</i>	<i>p</i> -value	Decision
Height (m)	0.629	0.7	39	0.13422	Ho = accepted
Width (m)	0.76	0.5	10	0.0009	Ho = rejected
Depth (m)	0.35	0.5	10	0.000072	Ho = rejected
VI spacing (m)	2.33	2.4	39	0.40389	Ho = accepted

Stone-Faced Soil Bund

The minimum standard of the height of the stone-faced soil bunds is 0.7, and it can extend up to 1 m according to the topography and availability of quality of stones (Table 17.5). The mean height of the stone-faced soil bund is 0.63 m with the minimum of 0.2 m and maximum of 1 m. However, 77% of the height of stone-faced soil bund is less than the recommended value. Height and vertical interval are not significantly different with the standard at 0.05 significance level, and the *p*-values are 0.13 and 0.40, respectively, but width and depth of the ditches are different from standards.

The mean spacing of stone-faced soil bund is 2.33 m, but the mean of the standard value is 2.4 that means the mean spacing is less wide but not so much different from the recommended mean spacing. About 65% of the bund spacing is less than the recommended value. In lower slopes or gentler slopes, the spacing is less wide compared to the standard, but in higher slopes, it is wider than the recommended value of that slope.

The width is wider than the recommended, and the depth is less deep than the standard. The mean values of depth and width are 0.35 and 0.76 m, but the recommended values are 0.5 m for both structures. The depth may be filled with sediment. The height and spacing are correctly constructed in the region, but the width and depth of ditches are not.

Fanya Juu

Fanya juu is applied in cultivated lands with slopes 2–15% which is constructed in recommended slope with 9–25 m horizontal distance and 0.28– 2.67 m vertical interval. Heights and vertical intervals were not significantly different with the recommended standard at 0.05 level of significance since the *p*-value is 0.207 and 0.17, respectively, which is greater than 0.05. However, the mean height of these bunds is greater than the standard. The mean value of heights of fanya juu is 0.667 m, but the recommended standard is 0.6 m. About 64% of the measured height is less than the recommended and 36% is above 0.6 m. The maximum height was 1.96 m which is very old fanya juu in Anjeni watershed, and the minimum height is 0.2 m.

Table 17.6 Comparison of existing with the standard values of Fanya Juu

Variable	Existing Av	Standard value	<i>n</i>	<i>p</i> -value	Decision
Height (m)	0.66	0.6	25	0.20311	Ho = accepted
Vertical interval spacing (m)	1.65	1.479	24	0.17131	Ho = accepted

Even if there is no difference with *z*-test, the mean spacing between measured fanya juu is 1.65 m, but the recommended value is 1.479 m (Table 17.6). This indicates that the spacing of fanya juu exists in field is higher than the standard. About 63% of the spacing is wider than the standard. In sloppy areas, the spacing is wider than in gentler slopes compared with the recommended value of that slope.

Hill Side Terrace

Hill side terrace was constructed in hill lands and degraded areas to rehabilitate the abandoned lands. It was stabilized with some trees and protected by area closure. Revegetation of natural trees was allowed in hill lands, and plantation was applied in degraded areas together with hill side terrace.

The height and vertical intervals are significantly different from the standard, and the *p*-values (0.042) and (0.007), respectively, are less than the significance level 0.05 (Table 17.7). From the analysis, we can conclude that height and vertical intervals of hill side terrace were not constructed according to the recommendation in the region.

Trench

The value of the constructed trenches was weighed up in terms of minimum.

Trenches were constructed at an interval of 3–5 m depending upon on the suitability of the land. The values of the existing average trench length, width, and depth were not significantly different from recommended standard. This showed that the average height, width, and depth of the already existing trenches in the catchment were up to the MoARD recommended standard (Table 17.8) and can be conclude that they are constructed as per the recommendation in the region.

Table 17.7 Comparison of existing with standards values of hill side terrace

Variable	Existing Av	Standard value	<i>n</i>	<i>p</i> -value	Decision
Height	0.72	0.6	15	0.04194	Ho = rejected
VI spacing	2.23	3.24	16	0.00779	Ho = rejected

Table 17.8 Comparison of existing with standard values of trench

Variable	Existing Av	Standard value	<i>n</i>	<i>p</i> -value	Decision
Length (m)	3.03	3- 5	9	0.4519	Ho = accepted
Width (m)	0.52	0.5	9	0.3642	Ho = accepted
Depth (m)	0.43	0.5	9	0.0546	Ho = accepted

Table 17.9 Comparison of existing with standard values set for bench terrace

Variable	Existing Av	Standard value	<i>N</i>	<i>p</i> -value	Decision
Vertical interval (m)	1.56	2.65	7	0.000125	Ho = rejected
Width (m)	4.5	5.13	7	0.2133	Ho = accepted

Bench Terrace

The spacing between existing bench terraces ranged from 0.85–2.17 m with an average of 1.56 m on 14–50% slope lands. About 86% did not meet the minimum technical standard of vertical interval (Table 17.9). It was significantly different; the null hypothesis is rejected since the *p*-value is less than 0.05 significance level. The analysis shows that it is narrower than the recommended standard.

From the analysis of vertical interval of the bench terraces, we can conclude that bench terrace can be done wider than the existing bench terrace in the region, then it could be possible to get wide farm area possibly to maximize cropping area of high slopes. In Gidbenu watershed, bench terraces were constructed to use the land for youths in order to use for income generation. Hence, there is a possibility to use for the purpose like cropping, afforestation, and apiculture for job creation of youths in the rest watersheds and in the region as a whole.

Check Dam

Check dam are constructed to reduce velocity of runoff and prevent the deepening and widening of gullies. Single brush wood, brush wood together with gabion, gabion check dam, and stone rip rap check dams and in some places like Dibakuhan watershed rock fill dams are also constructed in the study areas. Among collected sample data, 62.5% of the check dams are stone riprap, 18.25% are brushwood, and 18% are Gabion check dams.

Maximum height of check dams is 1.9 m, and the minimum height is 0.3 m. The mean height (1.03 m) is in between the recommended value, 1 and 1.5 m. But 18.75% are constructed above the maximum standard, and 37.5% were constructed below the recommended standard.

Average spacing of check dams is 10.3 m which is greater and wider than the recommended average 9.4 m. The spacing between two check dams was evaluated with *z*-test, and the result showed it is significantly wide with 0.05 significance

level. About 37.5% are narrower than the mean and 62.5% are wider. The maximum length between the check dams is 30 m and also 75% of the check dams have no foundation and 81.75% has no drop structure. Besides the drop structure is less than the recommendation. The drop structure must be 1.5 times the height of check.

The width of check dam should be between 1.5 and 3.5 m but the average width is 1.3 m. The value is less than the recommendation which is shown as 87% the check dams' width deviate from the minimum value of the recommendation.

Gully Rehabilitation Problems

The following difficulties can be taken as the main reasons for the catastrophe of most of the gully rehabilitation schemes in Amhara region as summarized from study watersheds.

- Poor attention for upper catchment treatment.
- Poor fitting of check dams which is related to absence of keying the check dam to the floor and side walls of the gully.
- Absence of apron.
- Absence of spillway.
- Deprived maintenance.
- Inappropriate spacing of check dams.
- Structures are occasionally made too high and the water which pools causes unsteadiness of the soil and piping underneath or around the structure.
- Deprived integration among physical and biological measures.

According to the guideline, recommended bund gradient ranged from 0 (level) for the purpose of moisture retention and 0.5–1% for the draining of surplus runoff for the purpose of flow in permissive velocity based on agro-ecology (Hurni 1985a, b). In moist agro-ecological areas, it has to be constructed up to 1% gradient, because the rainfall is high, excess runoff water has to drain. But in this area, only 27.62% fits the criteria of the standard, while the 72.38% violates the recommendation. But in sub-humid areas, it has to be level in most places because the rainfall is lower than the moist areas the analysis show 91.25% was level which fulfills the standard. Figure 17.4 shows gullies formed due to improper land management.

Biological SWC Measures

Biological measures including protection of existing vegetation or planting of trees and grasses on degraded and stabilization of bunds in cultivated areas were practiced in the study community watersheds (Figs. 17.5 and 17.6). Plantations of up slopes, bund stabilization, gully rehabilitation, and regeneration through plantation of trees and grasses are some activities which were done artificially as biological

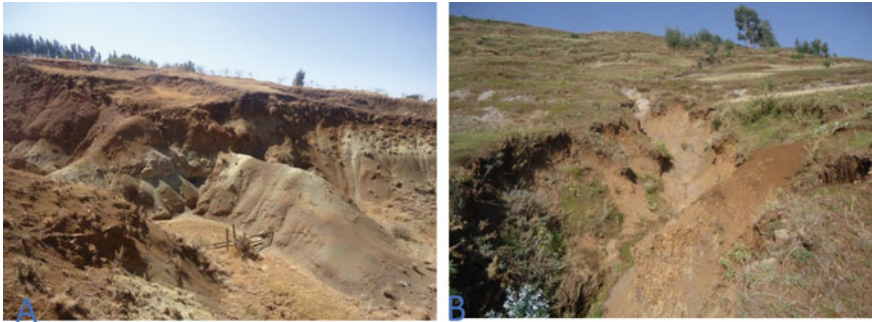


Fig. 17.4 Gully formed by improper land management and concentration of runoff in Deresinilih watershed (a) and gully formed by improper waterway construction in Asieda watershed (b). In these areas, high cattle population and overgrazing constitute a major factor for gully formation



Fig. 17.5 The result of Overgrazing in Baka Azala watershed. Road construction done in steep lands, without adequate delivery for drainage systems, is a main cause of gully erosion

soil and water conservation. Protection of natural vegetation through area closure is practices applied in the study watersheds which are important to regenerate the natural vegetation. Among 34 studied community watersheds, 19 watersheds do have areas delineated for enclosure which have 2657 ha, and it accounts 16.74% from the total area of community watersheds. About 42% of the bunds constructed



Fig. 17.6 Gully formed by road culvert; it is treated by check dam in Abiager watershed

in community watersheds were stabilized with different types of trees and grasses selected according to the agro-ecology (Fig. 17.6). It is shown that in some parts of the study areas footpath was a contributing factor for gully formation (Fig. 17.7).

Fodder trees, shrubs, and grass used for the stabilization of bunds are *Trelucern*, *Susbania susban*, Pigeon Pea, and grasses like Vetiver, Phalaris, Elephant grass, etc. The farmers used these plants as a fodder, the seed for sell collected from ripen trees, and fuel wood and cutting grasses for fodder and to cover the house roof in addition to the purpose they give for conservation of the soil. In addition to grasss and vegetation that are used for gully stablization, soil and stone bunds are also used as a measure for soil erosion reduction (Figs. 17.8, 17.9 and 17.10).

Soil Loss and Sediment Retention: RUSLE model was used to estimate the soil loss of the area in two scenarios; before and after soil and water conservation practices with multiplying erosivity, erodibility, slope steepness, slope length, cover factor, and management factors existed in each parcel of land in the study watersheds. Soil losses before SWC assumes no interventions on lands were applied such as up and down ploughing, with no intervention in degraded communal lands and the length of over land flow unchanged. But when SWC practices were applied, the coverage and management of communal lands were changed, and length of overland flow was decreased in cultivated lands and in some communal lands as a result of bunds and hillside terraces, respectively. The slope length and steepness factor, crop cover management factor, and land management factor on



Fig. 17.7 Gully formed by footpath and cattle trafficking line in Gadila watershed



Fig. 17.8 Soil bund in Andit Tid watershed

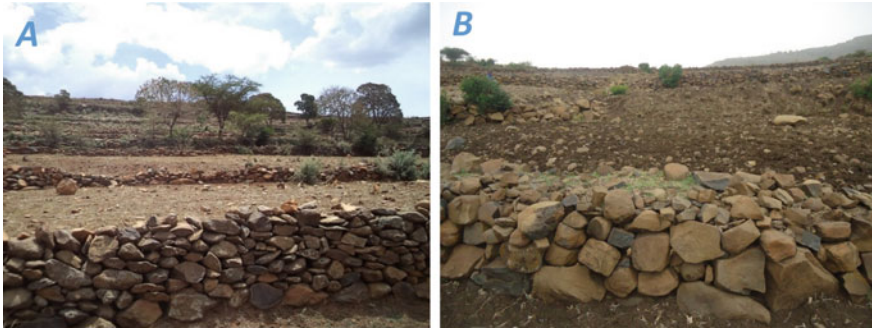


Fig. 17.9 Stone bund in (a) Aguat wuha, and (b) Bruhtesfa watersheds



Fig. 17.10 Stone-faced soil bund in Andit Tid watershed

natural resource managed areas were changed, but rainfall and soil erodibility factor remained unchanged.

Average annual soil loss of watersheds before soil and water conservation was estimated as 77 t/ha/yr, and it became 34 t/ha/yr after conservation was practiced. Thus, the amount of soil retained as a result of physical and biological soil and water practices was estimated as 43 t/ha/yr. On average, there was 0.66 cm depth of soil lost in a hectare each year before SWC structures implementation throughout

the study watersheds but it decreased to 0.29 cm as a result of management practices. Hence, there could be 0.37 cm per hectare per year depth of soil could be remained as a result of soil and water conservation structures implementation. This indicates that 56% of soil could remain in places on land resource managed areas (Fig. 17.11).

Engdayehu et al. (2016) estimated in single watershed in Debre Mawi learning watershed that there was 55% decrease of soil loss after soil and water conservation intervention reducing from 39 to 17.36 t/ha/year. The difference in soil loss decline was most probably due to SWC measures since it has an important effect in trapping soil and decreasing sediment transport. In general, soil loss was found as above the tolerable soil loss value (0.2–12 t/ha/yr) estimated for Ethiopian condition (Hurni 1985a, b) as cited in (Engdayehu et al. 2016). Figures 17.12, 17.13, 17.14, 17.15, and 17.16 show various types of intervention measures used to reverse the soil erosion process and gully formation.

The analysis shows that soil loss is dependent on the area covered with soil and water conservation measures. It was estimated that 18.9 ton/ha/yr from five among studied watersheds which were on average covered with 93% of the total area with soil and water conservation. It was also seen from the analysis that from five selected study watersheds with 29.08% area treated by soil and water conservation, the soil loss is estimated as 46.86 ton/ha/yr. From these five watersheds, the average



Fig. 17.11 Stabilized fanya juu in Argedifo community watershed



Fig. 17.12 Newly constructed hill side terrace in Nekubish watershed

sediment retention was estimated as 73%. Compared to the average watersheds sediment retention of 56%, it is much greater; therefore, we can conclude that if the whole watersheds were covered with SWC, it can retain considerable amount of sediment, and soil loss can decrease substantially.

Conclusion and Recommendation

Conclusion

In this study, watersheds experience different types of soil erosion. Rills and gullies are the visible form of soil erosion which were commonly observed in study watersheds. It was also common to see stream channel erosion and sediments and boulders movement and color of the runoff water which is muddy. This study showed that there is a decrease in soil loss as a result of soil and water conservation implementation, even though the result was far above the soil formation rate in the Amhara region.



Fig. 17.13 Trench in Deresinilih watershed

Sediment retention in watersheds increases as the coverage of watersheds in soil and water conservation increases. Soil loss of watersheds with and without soil and water conservation was estimated, and the result was 77 ton/ha/yr in base case scenario assuming there was no SWC and 34 ton/ha/yr after implementation of SWC where the watersheds were covered with 60% of physical SWC from 34 watersheds. But when the watersheds area coverage increases to 93% as seen in five selected watersheds, the soil loss decreases to 18 ton/ha/yr, and the soil loss increases to 46 ton/ha/yr as the SWC area coverage decrease to 29% based on the average value of five watersheds.

Physical and biological soil and water conservation in study watersheds were identified, delineation of the coverage of implemented SWCs in the map was done, and the standards of the structures were technically evaluated by direct survey compared with the standard. Contribution of soil and water conservation for erosion control was assessed by RUSLE model.

From the survey of watersheds, it was possible to conclude that physical and biological soil and water conservation were selected based on the agro-ecology and land use requirement. Trees used for hedge row plantation are practiced according to agro-ecology, in moist areas suitable trees such as Trelu-cerne were observed and adapted and grown well, likewise *Susbania susban* were grown in humid areas and performed well.



Fig. 17.14 Bench terrace in Godiguadit watershed (a and b), Side view of Bench terrace (c), Front view of Bench terraces Gidbenu watershed (d)

Structures have their own standard, and some SWC structures meet the requirements, but some others did not. The height of the SWC structures after compaction was as per the standard, but the width and depth of ditches were not as recommended for Ethiopian condition. Some structures like soil bund and stone-faced soil bund, the width were wider and the depth were less deep. In most types of structures, the mean vertical intervals were as per the standard, but for low sloppy areas, it was narrow, and for high slopes, it was wider than the recommended. The gradient of bunds violates the standard in some places, especially in wet and humid agro-ecology of watersheds. In gully rehabilitation, some conditions which should aggravate the problem such as constructing without foundation, side key, and apron and spill way were observed. The spacing between two check dams also were wide in most gullies treated by this structure.

Biological measures were implemented according to the agro-ecology, but there was no or few protections from cattle in some watersheds, so that those trees that are planted as stabilization of bunds were not grown well if not, they are stunted in their growth. Some managements such as area closure, control grazing, and gully rehabilitation were seen as a good start in rehabilitation of the land, and they become as a source of income by cutting grasses and selling tree seeds as well. In some watersheds, hilly areas were used as a job creation for youths by constructing

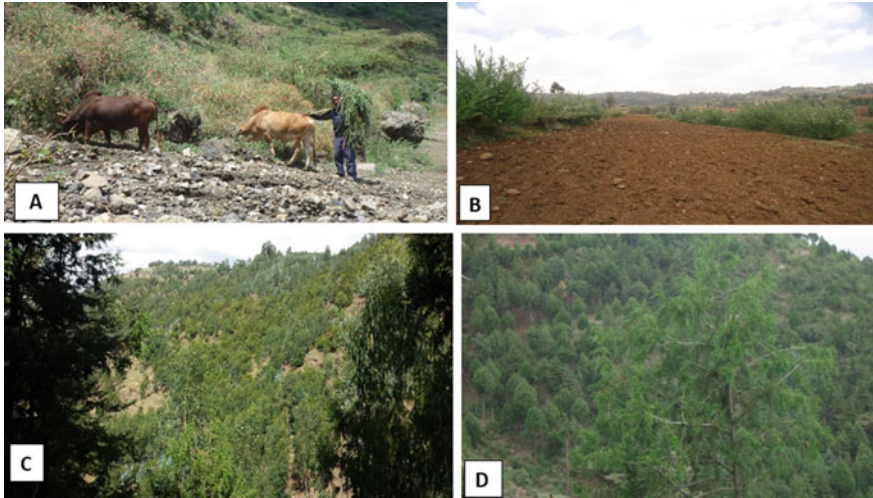


Fig. 17.15 a Area closure and a man used cut and carry system in Abiager watershed, b Hedge row plantation in Aseida watershed, c plantation of Eucalyptus trees in Maybar watershed, and d protected forest in Godguadit watershed



Fig. 17.16 Grass strip in Deresnilih watershed

bench terracing for maximizing crop land, apiculture, and tree planting. These have again indirect positive impact on regeneration of the land unless it could be used unwisely.

When both physical and biological soil and water conservation structures are done rendering to the standard and suitable agro-ecology, the target, minimizing erosion problem can be achieved, but to achieve the intended objective and for sustainability, technical standards such as vertical intervals, dimension of bunds and ditches, check dam dimensions, and gradients of SWC measures need great attention and close follow up.

Recommendation

Based on the results of the study and field observations of community watersheds, the following recommendations are forwarded.

- I. Detailed surveys to map area coverage of soil and water conservation implemented in the region is required.
- II. Farmers should be consulted and should be participated in the selection of SWC measures before application on their farm and maintenance should be taken on their own because it develops the ownership and responsibility.
- III. Indigenous plants should be practiced as bund stabilization, and reforestation was seen in Gidbenu watershed and planting Kitikita in soil bund structure and regenerated better than exotic plants.
- IV. It is better to treat Vertisols farmlands, which are characterized by their properties of swelling and shrinkage according to the moisture availability, that have gentle slopes with only grass strip and other biological measures. Bunds were cut and damaged since farmers used to construct traditional farm ditches by crossing the constructed SWC structure.
- V. If fanyajuu terrace is to be done in gentle slopes, it should be treated for water logging in the upper part, and the mound should be stone faced and slope should be 1%.
- VI. Inter-terrace management practices like ploughing in graded contours, strip cropping, cover cropping, mulching or residue management, and planting in rows along graded contours can be applied in addition to physical practices.
- VII. If bench terrace is also to be done in loose soils, the embankment should be stone faced, and the width is also to be according to the soil depth since it may be unproductivity if sub soils exposed entirely.
- VIII. It is better to avoid using small and round stones when stone bund and stone-faced soil bunds are constructed since they can easily be collapsed. And bunds should not be long enough and must be staggered besides cattle tracks are very important to protect the collapse of bunds.
- IX. Some of the water way selected on natural depression do not much as the depth of bund ditches are deeper than the water way depth and farm

boundary were not done along the slope, and this needs special attention because concentration of runoff can damage the land.

- X. Accuracy of standards should be given great attention when surveying is held such as layout of gradients, embankments, and ditches dimensions like width, depth, and foundation and side keys on the period of implementation of SWC structures, so that they are constructed as per the recommendation.
- XI. Documentation of the data of constructed structures in the community watersheds must be underway in each district since it is very important to evaluate the performance and coverage of SWC.

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