

Report

Impact assessment of soil and water conservation measures at Medego watershed in Tigray, northern Ethiopia

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Abstract: The aim of this study is to assess the impact of various physical and biological soil and water conservation (SWC) measures implemented during the past 2-3 decades in combating land degradation caused by soil erosion in the Medego watershed, northern Ethiopia. Such evaluation is essential to understanding the success or failure of previous conservation measures and readjusting accordingly in the future planning. Data collected through semi-structured interviews, transect walks, field observation and field measurements demonstrated that terraces and check dams were filled with soil up to 1.5 m deep, gullies started to stabilise, irrigation and other water supplies increased many folds, the seedling survival rate rose to over 45%, and the vegetation composition and coverage density improved by more than 30%. Water levels increased in hand-dug wells by up to 2 m, and in a number of springs and shallow wells by more than 100 times as a result of the positive impact of SWC measures implemented in this watershed. Existing SWC measures should be improved for continued maintenance and also expanded further to restore critically degraded areas to their full potential through integrated intervention.

Keywords: land degradation, impact assessment, soil and water conservation, Medego watershed, northern Ethiopia

INTRODUCTION

Land degradation is a serious global problem. Of the world's 8.7 billion ha of agricultural land, pasture, forest and woodland, nearly 2 billion ha (22.5%) have been degraded since 1950 [1-2], and 5-10 million ha (0.36–0.71% of global arable land) are lost every year to severe degradation [2-

3]. If such a trend continues, 1.4-2.8% of the total agricultural, pasture and forest land will be lost by 2020 [1]. In addition, estimates show that degradation of crop land and pasture appears to be most extensive in Africa, affecting 65% of crop land area and 31% of pasture land, compared to 51% and 14% in Latin America and 38% and 20% in Asia respectively [1].

It has also been indicated that nowhere is the severe effect of poverty and environmental degradation more evident than in Ethiopia [4]. In this country, out of the estimated 60 million ha of agriculturally productive areas, nearly 27 million ha experience erosion, 14 million ha are considered eroded and requiring rehabilitation, and 2 million ha are considered lost with an estimated total loss of 2 million m³ of top soil per year and with an average annual soil loss from cultivated lands of 100 t ha⁻¹ [4]. The economic impact of soil erosion is more significant in developing countries such as Ethiopia due to lack of capacities to protect existing nutrients and replace lost nutrients [5]. If land degradation continues at the present rates, the consequence will be a challenge for sustainable future productivity and food security of many developing countries [1]. Soil erosion is the main cause of land degradation that affects soil properties and ecosystems in Ethiopia more than anywhere else [6-7].

The immediate consequence of land degradation is reducing crop yields, which leads to economic decline and increasing social stress [6, 8-9]. Periodic low soil moisture due to erratic and poorly distributed rainfall, severe soil loss by run-off and resultant low soil fertility are the prominent factors associated with land degradation causing low agricultural production [7]. In addition, subsistence agriculture that has extended into marginal lands due to increasing population is also aggravating land degradation as well as damaging and threatening the long-term viability of the environment and agricultural production [10]. Soil erosion, which affects about 30 per cent of the cropland, leads to a grain loss of about 7,000 tons per year in Ethiopia [11]. According to Bojö and Cassells [11], the value of grain lost in 1994 due to soil erosion was estimated to be about 10 million Ethiopian Birr (1 USD ~ 2 ETB at that time). The cost of decreased livestock feed availability due to soil erosion leading to lower crop yields was estimated to be 0.8 million ETB in 1994. The total gross annual loss due to both erosion and nutrient loss was estimated at 637 million ETB, which amounted to 3 per cent of the agricultural gross domestic production at that time [11]. Land degradation in the form of soil erosion and declining soil quality seriously challenges agricultural productivity and overall economic growth of the country [12]. The Tigray region, which is in the northernmost part of Ethiopia, suffers from extreme land degradation since steep slopes have been cultivated for many centuries and are subjected to serious soil erosion [13-14].

In coping with these problems, soil and water conservation (SWC) measures have been implemented to alleviate both the problems of erosion and low crop productivity, which are symptoms of two different extremes of rainfall conditions in Ethiopia since the 1970s. The impacts of physical SWC measures can be classified into short- and long-term effects based on the time needed to become effective against soil erosion [15-16]. According to Bosshart [16], the short-term effects of stone bunds are the reduction in slope length and the creation of small retention basins for run-off and sediment. These reduce the quantity and eroding capacity of overland flow. Such effects appear immediately after construction of the stone bunds and reduce soil loss. The medium- and long-term effects include the reduction in slope angle by formed bench terraces, development of vegetation

cover on the bunds and gullies, and change in land management [16]. Based on the studies of the soil conservation research project in other parts of Ethiopia, Herweg and Stillhardt [17] stated that well-established mechanical SWC measures retain most of the soil eroded in between the structures. Such studies, however, may not be applicable to old conservation measures on a catchment scale as most of these studies were conducted on erosion plots that concerned well-managed and young structures.

Several studies have shown that methods employed to reduce soil loss and run-off to negligible amounts are usually based on a combination of practices that help to maintain soil infiltration rates at sufficiently high levels and efficient water run-off [18-20]. Other studies also indicated that SWC practices undoubtedly have a significant role in increasing agricultural production in arid and semi-arid areas where agriculture is hampered by drought, erosion, low soil fertility and moisture stress [7-8, 21]. Such practices have been implemented in the semi-arid areas of Ethiopia since the 1970s. However, little information is documented on the impact of the various long-term SWC measures implemented in watersheds in northern Ethiopia. The objective of this study is to assess the impact of the SWC measures implemented to reduce land degradation in the Medego watershed, northern Ethiopia, and to realise the results so far achieved. This could lead to further improvement of policies implemented in the future.

STUDY AREA DESCRIPTION

This study was carried out from August 2007 to June 2008 to assess the various impacts of SWC measures implemented in the Medego watershed in the Tigray region, northern Ethiopia (Figure 1). Elevation varies between 2000-2700 m above sea level and the watershed has a total area of 1090 ha. The number of households and total population in the watershed were 97 and 637 respectively. The land holding size of most farmers in the study area was less than 1.3 ha. The rainfall is unimodal but erratic in variability and amount within and among seasons. The main rainy season is very short and extends from June to the first week of September. The mean annual rain fall is 700 mm and the mean monthly temperature during the growing season ranges between 15-20°C [22].

Medego watershed is characterised by different landforms which range from flat or undulating plains and rolling land to steep mountains and very steep escarpments (Table 1). This topography terminology is adopted from the slope capability classification by Chekun [23]. The slope aspect and area are also presented in Table 1. Topography influences the type and intensity of SWC measures to be used. The degradation severity also varies as one moves from flat to steep areas. The bedrock of the watershed is mostly of volcanic origin. Alluvial and colluvial deposits on flat plains are also common in the watershed. The soil types vary according to the landform. The main soil types are cambisols on undulating plains and rolling land, lithosols on hilly and steep to very steep lands, and vertisols on flat and plateau landforms [22].

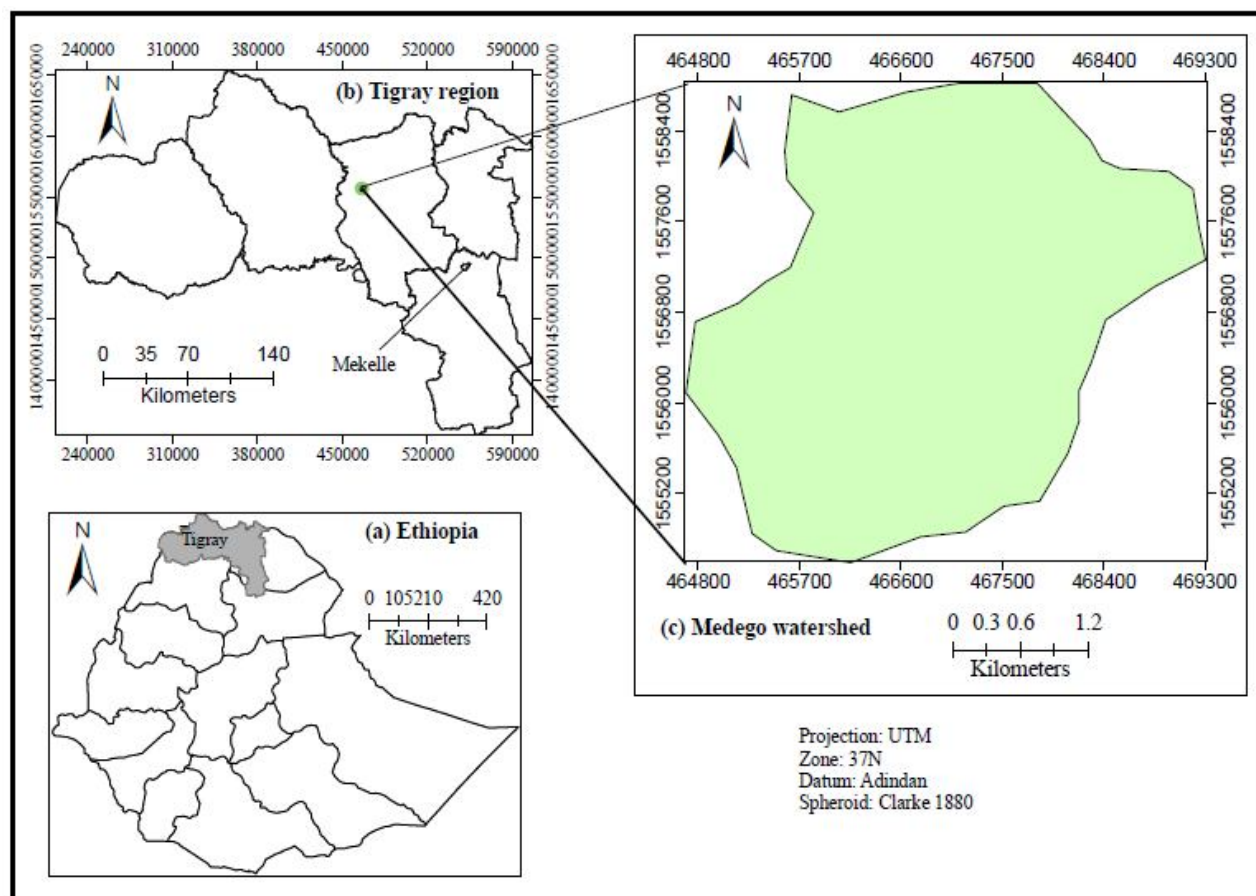


Figure 1. (a) Map of Ethiopia, (b) Tigray region, and (c) Medego watershed

Table 1. Landforms and their area coverage in the Medego watershed

Landform	Slope range (%)	Area (ha)
Flat plain	< 2	200
Undulating plain	2-8	300
Rolling land	8-15	50
Hilly to rolling	15-30	290
Steep mountains	30-50	200
Very steep escarpment	>50	50
Flat, flood-prone area	< 2	1.50
Total		1091

According to the respondents and our field observation, the farming system is principally crop-oriented. Teff cultivation (*Eragrostis tef*) accounts for the majority of the cultivated lands followed by wheat (*Triticum vulgare*). Other crops such as faba bean (*Vicia faba*), field pea (*Pisum sativum*), lentil (*Lens culinaris*), chick pea (*Cicer arietinum*), flax (*Linum usitatissimum*), barley (*Hordeum vulgare*) and maize (*Zea mays*) are also important crops. Irrigation is also widely practiced here. Despite the high crop diversification in the watershed, we observed that there is still a

need for crop productivity to be improved using appropriate cropping systems and soil and water management practices. Livestock rearing is also essential in the farming system, but stock numbers are being reduced due to feed shortages.

The vegetation is sparse and has been overexploited for centuries and consists of shrubs and small trees with little economic value. The vegetation in the study area includes 'seraw' (*Acacia etbaica*), 'chea' (*Acacia abyssinica*), 'acacha' (*Acacia decurrens*) and 'awhi' (*Cordia africana*) on most uncultivated land, and 'momona' (*Acacia albida*), 'tambock' (*Croton machostachys*), 'keyih bahrizaf' (*Eucalyptus camaldulensis*) and some 'seraw' (*Acacia etbaica*) in both cultivated and marginalised areas. *Leucena* (*Leuceana leucocephala*), *sesbania* (*Sesbania sesban*) and some grasses are also commonly found in gullies.

METHODOLOGY

Primary and secondary data were collected related to the environmental impact assessment of SWC measures in the watershed. Primary data were gathered from farmers (topographic transect walks, semi-structured questionnaire interviews, group discussions) and field measurements and observations. The approaches described in Table 2, such as before and after or with and without SWC, down stream and upper stream, and comparisons of indicators of environmental impact, were used during data collection. Secondary data such as climate, demographic and other related data in this study were collected from the Bureau of Agriculture.

The topographic transect walk method was employed for the assessment of natural resources and existing SWC measures in the watershed. In order to obtain as much information as possible, the transect walk was done in two direction: east to west and south to north. In both directions, the walks started at the top margin (divider) of the watershed and then all the way downhill to the other side of the watershed. During the transect walk, observations and appraisals of the vegetation and density, impact of the existing SWC measures, level of erosion before and after the SWC program, and levels of SWC measures at different parts of the landscape were recorded. Land use and slope was taken into account during these walks. The transect walks also provided an opportunity for informal discussions with farmers working on their land. Informal interviews of the farmers were carried out using a combination of participatory rural appraisal (PRA) techniques such as semi-structured interviews and group discussions. The focus group discussions were supplemented by secondary data from knowledgeable people in the Bureau of Agriculture.

A total of 49 household heads were used for the semi-structured interviews. The observations and informal participatory discussions with individuals and groups that represented men and women from different socio-economic categories led to the formation of focus groups. Such groups met as a team for discussions for three consecutive days during the holidays. Among the samples, six women-headed households were purposely involved throughout the interviews and group discussions. These were the only women household heads in the watershed. The distribution of men respondents were 15, 15 and 13 for low, medium and high wealth status respectively, on the basis of the local wealth criterion. These were selected randomly from each wealth category. Economic status and sex difference did not show any significant difference in this study. The aim of the semi-structured interview was to assess the role of the existing SWC measures on environmental degradation

Table 2. Ideal and operational performance indicators of the SWC measures after and before implementation in the Medego watershed

Performance criterion	Ideal indicator	Operational indicator used in this study
Level of soil erosion	<ul style="list-style-type: none"> - Measurement of erosion and associated yield loss - Sediment deposition rate - Presence, expansion and development of new active erosion features by slope, soil and land use types 	<ul style="list-style-type: none"> - Visual assessment of rill and gully erosion status - Impact on soil fertility and soil moisture through vegetation and yield indicators - Qualitative comparison before and after the SWC program implementation - Quantifying sediment deposits
Measures taken to arrest erosion	<ul style="list-style-type: none"> - Inventory of the types of soil and water conservation practices 	<ul style="list-style-type: none"> - Visual assessment of SWC investments - Intensity or level of the SWC measures across the landscape using farmer view and apparent effectiveness on rehabilitation
Water recharge	<ul style="list-style-type: none"> - Surface water storage amount - Levels ground water before and after SWC measures 	<ul style="list-style-type: none"> - Approximate change in number of wells - Change in well depths to get water - Change in irrigated area - Change in village level water supply
Soil moisture retention	<ul style="list-style-type: none"> - Time series, intra- and inter-year variations in soil moisture using measuring instruments 	<ul style="list-style-type: none"> - Change in cropping patterns - Change in cropping intensity - Relative change in yields and biomass using farmer opinions and field observations
Productivity of non-arable lands	<ul style="list-style-type: none"> - Change in production of plantation lands (actual biomass quantities) - Value added to social, economic and environmental situations 	<ul style="list-style-type: none"> - Relative change in farm land area, biomass and soil cover (more than, same as or less than the pre-program) - Extent of erosion and SWC in such areas using local farmers' views

rehabilitation and find out ways that improve its role in the watershed in particular, and in other similar semi-arid areas in general. The potential and limitations of the existing SWC measures in the watershed were evaluated from environmental factors' (soil, water, microclimate, irrigation, vegetation) points of view.

In support of the data collected using Table 2, the transect walk field observations, and the interviews and group discussions, the accumulated sediment rate ($\text{t ha}^{-1} \text{yr}^{-1}$) behind stone bunds was estimated by adopting the equations described by Gebrermichael et al. [24] as:

$$A_A = 10M_A/(T*D) \quad \dots\dots\dots (1)$$

$$M_A = BD*V_A \quad \dots\dots\dots (2)$$

$$V_A = W_A*H_A \quad \dots\dots\dots (3)$$

where: A_A is the annual sediment accumulation behind stone bund ($\text{t ha}^{-1} \text{yr}^{-1}$); M_A , mass of accumulated sediment per unit length (kg m^{-1}); T , age of stone bund (yr); D , average spacing between stone bunds (m); BD , dry bulk density of sediment accumulated behind stone bund (kg m^{-3}); V_A , the unit volume of accumulated sediment ($\text{m}^3 \text{m}^{-1}$); H_A = depth of the accumulated sediment (m); W_A , width of the sediment zone; and *, multiplication symbol.

The value of D was calculated as a mean of the spacing between consecutive bunds on different fields in the watershed. The mean value of D was taken as 70 m between consecutive fields for gentle sloping areas in this study. The average bulk density value of 1143 kg m^{-3} for deposited sediment behind bunds was adopted from a similar condition in the Tigray highlands as reported by Nyssen [25]. The H_A was determined at field level as a mean of the sampled plot lands having stone bunds of similar age and topography on the cultivated lands of the watershed. Similarly, the width of the sediment zone (W_A) was also calculated as a mean of the field measurements. A mean value of 0.80 m for H_A and 6 m for W_A was observed with the aged stone bunds (average of 12 years).

Different field materials were used, e.g. a GPS receiver to locate ground control points, elevation and delineated area, a metric tape measure for measuring changes in sediment depth accumulated behind the SWC facilities and water level differences in the wells, a clinometer to measure slope gradient, and a digital camera to take photographs. The data were subjected to analysis using SPSS 17.0 version software [26]. Percentages, cross-tabulations and nonparametric test (chi-square/ χ^2 test) were used. The data were also subjected to qualitative analysis and interpretation.

RESULTS AND DISCUSSION

Experience of Land Management in the Watershed

Under the SWC program, various types of physical and biological SWC measures have been undertaken in the watershed with full participation of the communities since the 1980s. According to the survey results, most (90%) of the respondents had a positive response on check dams installed to stabilise gullies and transported 0.25 m^3 of stones per person to build them. This was organised by the Food for Work campaign program as part of the contribution to food security for SWC with voluntary labour from the farmers. According to the respondents, farmers were not only taking some incentives, but also developed more commitment and awareness to rehabilitate as well as stabilise gullies in order to reduce soil loss and stop gully development and expansion.

According to our field observation, some of the check dams constructed in both the up-stream and down-stream parts of the landscape collapsed due to faulty construction. There was less tendency to integrate the physical and biological SWC measures, particularly in the up-stream part of the watershed. Most respondents (80%) felt that the Bureau of Agriculture as well as the Food for Work campaign program coordinators did not give enough follow-up and monitoring of check dam maintenance. The local community did not adopt participatory feelings to repair these community resources. In spite of this, many farmers believed that they had benefited much from check dams constructed in the watershed. Some of the farmers (~30%) planted vegetable crops such as tomato, potato, onion and carrot as well as citrus with water accumulated on the check dam floor (Figure 2). Farmers not having land near a water supply used shallow and deep wells with increased ground water as a result of improved soil conservation measures.



Figure 2. Small-scale irrigation expansion: (a) fruits; (b) vegetables intercropped with maize after implementation of SWC measures using water retained in check dams and shallow and deep wells (March 2008)

The recommended spacing between check dams is 4.6 m, but actual spacing was up to 30 to 80 m even if the height and width of the check dam correlated well with the recommended spacing. As a result of this, the amount of run-off from the up-slope areas of the watershed could not be readily dissipated by the existing check dams, which caused their collapse. This also led to the formation of incisions on the gully floor and sides. According to the field observation, many of the check dams were not constructed well in that the spill way was too wide, an apron was lacking, and also the head was apart from the wall of the gully (Figure 3). Figure 3 shows that the depression behind the check dam and bund has been filled with soil so there is no more space to trap sediment. Lack of available rocks to increase the height of the dam above ground level in the cultivated fields was also a problem. Other biological conservation measures such as planting perennial grasses should be done to increase the sediment trapping efficiency of the bunds. Regular maintenance and appraisal of SWC measures is necessary to maintain the effectiveness of the programme.

Information from the respondents and development agents showed that the check dam and the stone bund in Figure 3 were constructed more than 12 years ago. At that time the check dam was constructed with an apron, which had been buried by soil deposits. This was due to a lack of maintenance and the fact that SWC measures were not targeted to the sources of high run-off and sediment in the upper part of the watershed. Wide spacing between check dams was also a cause. As shown in Figure 3, the space between check dams is wide so that the check dam above it cannot be seen. Generally, gullies become stabilised as vegetation grows on the sides and floor. However, the risk of damage by erosion is still possible since the check dam can be destroyed by water erosion. Preventive maintenance is essential to help conserve soil resources rather than investing heavily after erosion occurs.

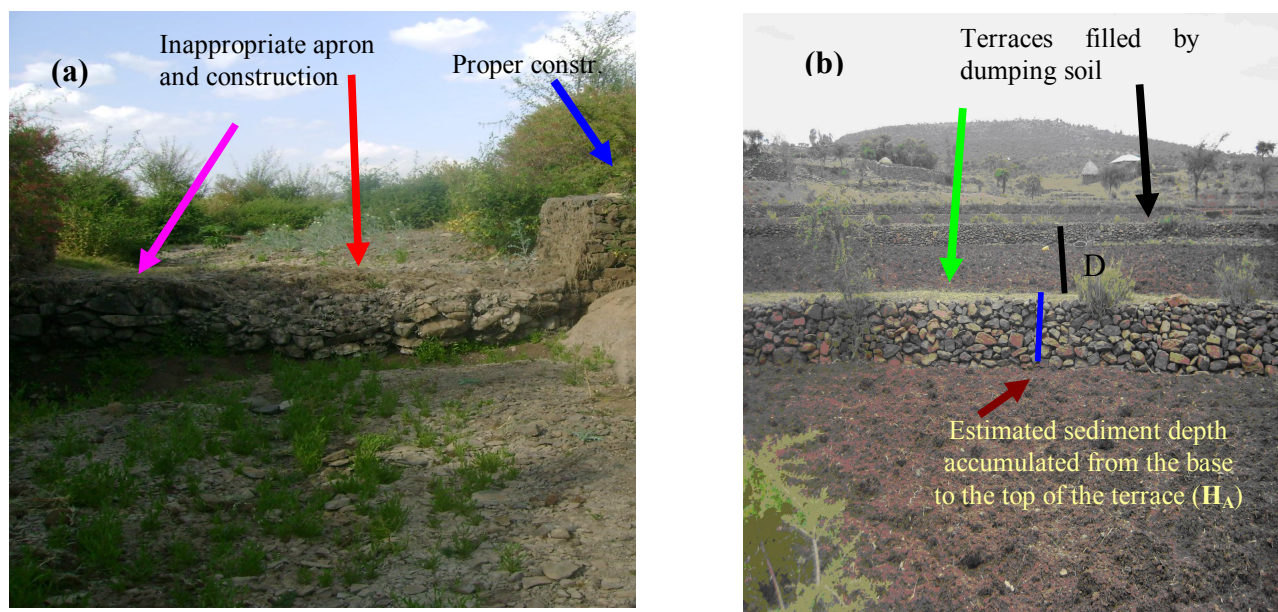


Figure 3. Watershed rehabilitation after the implementation of SWC measures: (a) check dam without apron and proper construction caused collapse; (b) stone bunds around a village filled with soil (indicated by arrows). D is the space between two consecutive bunds. (January 2008)

The farmers in the area noted that the gully did not stabilise and had no vegetation before the implementation of SWC measures, which resulted in high biomass productivity. This clearly demonstrated the advantages of using SWC measures for environmental rehabilitation. Other SWC measures on cultivated land also showed that terraces that can accumulate much soil (Figure 3b). A rough calculation to estimate the sediment accumulated in the stone bunds in Figure 3b was carried out. It was about $65.3 \text{ t ha}^{-1} \text{ y}^{-1}$. This is higher than the $59 \text{ t ha}^{-1} \text{ y}^{-1}$ estimated from a similar environmental condition in the Tigray region reported by Gebrernichael et al [24]. This difference might be attributed to fewer sample plots used in our study. In addition, the annual sediment accumulated could be large after installation of the bund because of the capacity (space) to retain soil (Figure 3b), which older bunds lack. The inclusion of some older stone bunds that do not have the capacity to accumulate sediment could also reduce the annual rate of sedimentation. Further studies on the differences between young and old bunds in the same slope range, soil and land use types should be conducted to evaluate the impact in order to help decision makers to improve SWC implementation.

Since stones were cleared from cultivated fields for other purposes, no terrace height increment was observed for many fields. In such situations, the integration of biological SWC measures with terraces could help conserve the soil and increase biomass production. All respondents agreed on the point that farmers having farmland on flat plains in the watershed were more reluctant to use SWC measures compared to those on steep areas. They even destroyed improvements constructed for fear of being waterlogged during heavy rainfall. If the SWC measures on the steep parts of the watershed were good enough to reduce run-off, waterlogged and related problems of erosion on flat areas could be minimised. Our study revealed that there is still room for

further implementation and intensification of SWC measures in the Medego watershed. The farmers should be made to realise how to increase overall biomass production by integrating grasses or fruit trees in the bunds and improve crop yield by SWC.

Our analysis of the opinions generated a Chi-square (χ^2) test which revealed that there was a significant difference ($P < 0.05$) among the levels of SWC measures implemented in the studied catchment (Table 3). The level of SWC measures in the watershed was rated by more than half of the respondents as low in flat slope ($< 3\%$) and moderate in high slope ($> 15\%$) areas. The respondents who rated SWC measures as intensive were few in number, and no respondent rated the existing SWC level as very intensive. Table 3 also indicates that the high number of respondents perceived that SWC measures were more commonly implemented on higher slopes than on lower slopes. This is logical because steeper areas are the sources of erosion. Despite this fact, even in higher slopes the conservation measures were not intensive and not good enough to stop run-off and erosion. This implies that there is a need to implement intensively or very intensively the physical and biological SWC measures in the Medego watershed in particular and the northern Ethiopia in general. Several studies have shown that watershed management using integrated SWC measures can increase infiltration, directly decrease run-off and improve soil productivity [27-29].

Table 3. Rating (%) by the farmers on the level of existing SWC measures on different slopes in the Medego watershed

Average slope (%)	Estimated level of existing SWC measures				χ^2 probability
	Low ^a	Moderate ^b	Intensive ^c	Very intensive ^d	
2	75	23	2	0	0.005
7	52	41	7	0	0.002
15	43	55	2	0	0.001
30	36	55	9	0	0.002
60	24	64	12	0	0.04

^a This is rated as low by farmers if there is no practice or if the spacing between consecutive measures is too wide.

^b Implies SWC measures are addressed only to the degraded areas.

^c Implies many conservation measures are constructed regardless of the appropriateness in spacing.

^d Implies the conservation measures are appropriate in space so as to solve soil erosion.

Impact of SWC on Soil Moisture, Soil Depth, Soil Fertility and Crop Yields

For the last two decades, the problem of soil erosion has been of great concern in the Tigray region in general and the Medego watershed in particular. This is due to the fact that inappropriate land management practices coupled with intensive rainfall and steep terrains resulted in big gullies, topsoil erosion and poor soil fertility. To minimise the effects of soil erosion, the governments of the region and country have allowed the implementation of SWC programmes at a watershed level. The consequences of different measures were assessed in this study in different land uses to evaluate the positive impact on soil, water (moisture), fertility, biomass and reduction of soil and water losses with run-off by comparison with the situation before/without the programme (Table 4).

Table 4. Measured, observed and farmer-rated impact of SWC measures on soil, moisture, fertility, biomass and erosion (run-off, soil loss) in the Medego watershed

Land use	Performance indicator			
	Soil conserved	Moisture conservation	Soil fertility	Erosion reduction
Cultivated	Terraces filled by soil ranging from 0.2-0.90 m (e.g. see Fig. 3b)	Yield increased by 25% while rainfall is similar as before	Yield increment of 25% with some fertiliser input	Formation of rills and inter-rills decreased by 60%
Natural forest	Soil deposition increased by 0.3-0.9 m after implementation of SWC measures	Greenness increased from time to time by 50% compared to before SWC implementation	Regeneration rate of plant species increased by 5-58% depending on soil conditions	Expansion of gullies decreased by 95% compared to before SWC implementation
Reforestation	Erosion decreased but soil deposition increased by 0.3-0.9 m depth	Survival rate of seedlings increased by 55%	High survival rate of seedlings (increased by more than 55%)	Rainfall drops dissipated by soil cover increased
Grazing	Extent of soil loss by erosion decreased by soil deposit of 0.2-0.6 m	Growth and species diversity of the grasses increased by > 30%	Biomass of grass species increased by 65%	Infiltration increases due to water stored in SWC measures
Area closure	Extent of soil erosion decreased as evidenced by 0.3-1.2 m soil depth deposition	Grass, trees and bush biomass and diversity increased by 18-87% depending on slope	Grass, trees and bush biomass and diversity increase by 18-87%	No further new erosion channels are created or expanded.
Marginal land	Poorly maintained terraces but contributed to soil accumulation from 0.1-0.4 m depth	Plant diversity and regeneration increased by 10%	Plant diversity increased by 10% compared to before the program	Low run-off amount decreases the number of erosion channels.
Gully	Check-dam-accumulated soil ranges 0.4-1.5 m depth.	Plants spread for most part of gullies by 5-90%.	Fast plant growth rate and highly diversified species	Little gully expansion and development (Fig. 3)

Soil accumulated along the bunds and check dams was up to 1.5 m deep. The sediment depth varied according to land use, slope and sediment source area. For example, more than 1.5-m soil was deposited in the gullies with check dams integrated with biological SWC measures (Figure 3a). On cultivated land with stone terrace (Figure 3b), sediment depth was more than 0.80 m. In closed areas, up to 1.2 m and in degraded grazing land, about 0.6 m of soil accumulated. Positive effects of individual SWC measures (both physical and biological) on hydrology and soil loss were reported for a variety of agro-ecological zones and under various land uses in the region [30-31]. However, assessing the overall impact of different SWC measures at watershed level seems more appropriate for practical decision-making processes for further improvements of the measures, rather than using a single conservation measure at plot level.

According to the respondents, the impact of SWC measures on biomass yield (grain and biomass) also showed an increment of more than 25% for grain and 30% for biomass (including cover grass) yields. This was as a result of the SWC measures that contributed to enhancing soil moisture and soil fertility (added or restored), and also to reducing the expansion and development of gullies (Table 4). The contribution of the measures varied across different land uses and slopes in

the area (Table 4), which could help identify target priorities. This does not mean that the SWC measures are always appropriate or targeted to achieve the intended goal of sustainable natural resources management. It needs further consideration on spacing, appropriateness and maintenance besides awareness of local farmers to adopt and handle the technologies sustainably by themselves.

Scientifically documented data that described the watershed before the implementation of the SWC programme was not available. As a result, the results of this study were based on our investigation: visually, field measurements and information collected from farmers (Table 4). According to the respondents, the age of most of the SWC measures in Medego watershed ranged from 8-20 years and some of them were younger than this.

The farmers were also able to classify their land into different levels of erosion based on the degree of erosion severity before the implementation of SWC measures (Table 5) and after their implementation (Table 6). These opinions were based on qualitative factors, but this seems to be a quicker and less expensive approach for fact finding and decision making. This study shows that there is a significantly different ($P < 0.05$) chi-square test among the erosion levels described by the farmers in the same slope category (Table 5). The majority of the respondents (>59%) indicated that the level of erosion was severe in the absence of conservation measures at all parts of the landscape, the severity being higher on steepest slopes than on lower slopes (Table 5).

Table 5. Rating (%) of levels of erosion impact *before* the implementation of SWC measures at different steepness from the respondents' point of view in the Medego watershed

Average slope (%)	Level of erosion before implementation of SWC measures				χ^2 probability
	Insignificant ¹	Slight ²	Moderate ³	Severe ⁴	
2	8	11	22	59	0.04
7	7	9	11	73	0.02
15	4	7	9	80	0.003
30	2	4	8	86	0.002
60	0	2	3	95	0.001

¹ Respondents consider the effect of erosion on land productivity as negligence as they assume that erosion is redistributed soils within or among the same fields.

² Somewhat decreased agricultural suitability but is still proper for local farming conditions as the original biotic functions are not destroyed. Restoration can be easily achieved to its full productivity using appropriate soil management practices and measures.

³ Soil highly reduces its productivity but is still continued for use in local farming. Major soil amendments are required to restore original biotic resources that are partially degraded.

⁴ Soil almost denuded of topsoil and is not appropriate for agricultural production as the original soil resources are largely degraded. This needs large investment and/or SWC engineering work to restore to its full production capacity.

We also demonstrated that the chi-square test shows a significantly difference ($P < 0.01$) in the reduction of soil erosion levels after the SWC measures were implemented (Table 6). Most respondents (about 90%) noted less soil erosion after conservation measures. Similarly, most respondents replied that severe erosion was not noticed after the implementation of the conservation

measures in many parts of the watershed. According to 95% of the respondents (Table 5), severe soil erosion was observed on steep slopes before the implementation of SWC measures. The majority of the respondents (>59%) indicated that the degree of soil erosion was less severe in the presence of the existing conservation measures in many places (Table 6). The respondents also understood the most important causes and effects of soil erosion. Deforestation and inappropriate land use and soil management practices were rated as the most important causes of environmental degradation. Among the most frequently reported effects of soil erosion by farmers was an immediate reduction in crop and straw yields.

Table 6. Rating (%) of level of erosion impact *after* the implementation of SWC measures according to the respondents in Medego watershed

Average slope (%)	Level of erosion after implementation of SWC measures				χ^2 probability
	Less	Same	More	More severe	
2	59	31	10	0	0.002
7	87	8	5	0	0.001
15	98	2	0	0	0.001
30	94	5	1	0	0.000
60	100	0	0	0	0.000

Water Resource Development

The impact of the SWC measures such as bunds and check dams increased the availability of surface and subsurface water for traditional irrigation and other uses. The same trend was also observed for available soil water for rain-fed crops. Water availability by rehabilitating the gullies using check dams was the main source of surface irrigation water, which was supplemented by shallow and deep ground water wells. All of the respondent farmers were convinced that bunds and gullies greatly increased the amount of surface water. Groundwater levels in the wells increased up to 2.5 m while irrigation area increased many times and the number of hand-dug wells also significantly increased (Table 7). Newly emerging springs and irrigated fields as well as increasing crop diversity and yields were some of the indicators for the improved water resources and supply as a result of SWC measures. Arid condition of the area has also been changed to a moister one because of improved water resources in the watershed (Figure 4). The areas in Figure 4 used to be bare land with barren gullies, without water, and with sparse vegetation before the implementation of SWC measures. Livestock in the areas in Figure 4 is strictly forbidden, which has enhanced its successful rehabilitation. Achievements are noticeable but are more concentrated along gullies. More effort should be done to expand and sustain the watershed and other similar areas to achieve successful SWC measures.

Table 7. Indicators of the impact of SWC measures on water resources development according to farmers in the Medego watershed

Performance criterion	Indicator *
Surface water storage capacity and spring development	Increased many times from almost nil to the present situation
Extent of irrigated area	Increased by more than 300 times
Water level in wells	Increased by 0.5 m to 2.5 m
Ground water recuperation rate	Increased 15 times

* Comparing between pre- and post-implementation of the SWC measures according to farmers' qualitative evaluation

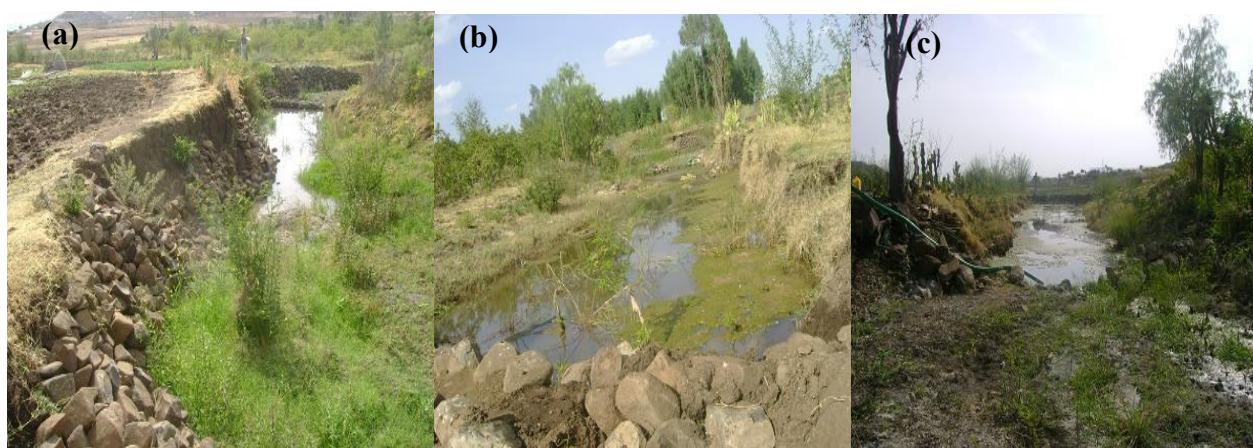


Figure 4. Water resources developed and used for small-scale irrigation and other purposes as a result of long-term impact of the SWC measures implemented in the Medego watershed: (a) deep gully rehabilitated; (b) shallow but wide gully rehabilitated; (c) deep and wide gully after rehabilitation (January 2008)

The increases in crop yield, biomass and diversity are due to more water availability and soil fertility restoration after the SWC measures for both irrigation and rain-fed crops. The duration of rain-fed crops and grass cover is also prolonged by improvement in soil water content as witnessed by the farmers in the area. Additional indicators of the positive effects of the SWC measures are the rapid recharge of the water table and development of new springs. This is because the time for infiltration has increased after installation of the stone/soil bunds and check dams, which raises the water table level. Farmers described this fact as follows: “Ten years ago, it was difficult to get water by digging 3-4 metres deep, but now the possibility of having water at this depth is high”. There are many more opportunities for farmers to use their natural resources sustainably by introducing appropriate plant species on the steep slopes and degraded areas to enhance soil fertility and also as a source of fodder for livestock and pollen for bees. Apiculture is possible in the area and needs to be proven so that farmers can enhance their incomes and at the same time improve the ecosystem in severely degraded landscapes.

Greenness of the Environment

After the implementation of different SWC measures, especially check dams in gullies and bunds in steep streams, the climate of the area improves as a result of increasing vegetation cover (Figures 2-5). The respondents confirmed that the hot and dry air that previously dominated the watershed has been replaced by moist and cooler air. This is because by of increasing vegetation cover in the catchment, which is a direct reflection of the improvement of available water and soil fertility in the area. More biomass after SWC conservation measures has resulted (Figure 5). The vegetables and fruits cultivated in irrigated fields in the watershed have also contributed towards the greenness and humidity in the area.



Figure 5. The impact of SWC measures on greenness, increasing biomass and climate improvement after gully rehabilitation in the Medego watershed (February 2008)

Impact of SWC Measures on Seedling Survival

The farmers were fully dedicated and inspired to work hard towards environmental improvement by planting more trees and vowing to maintain the naturally-growing ones. The respondents (93%) had indicated the low survival rate of newly planted seedlings due to moisture stress and the associated poor soil fertility. However, they said that such problem started to reduce after the implementation of some SWC measures in the area. Barbier and Bishop [32] reported that increasing seedling survival is an advantage of SWC as a long-term incentive to farmers.

Table 8 demonstrates a trend in the increasing survival rate of seedlings for different plantations. The survival rate of seedlings planted in the community and private plantations during 1993-1999 was about 53% and 68% respectively, whereas in 2005 it increased to about 88% and 89% respectively. The 35% increase in survival rate for community plantations and 21% for private plantations was due to the implementation of SWC. Such an achievement is encouraging and offers hope to the people living in this watershed. Poor management of the plantations, such as human and animal interference, has destroyed many of the seedlings. Regulation and rules should be made with the involvement of local communities to successfully maintain planted trees.

Table 8. Inventory of survival rate approximation of tree seedlings planted at the administrative unit of Laelay Maychew where Medego watershed is located [22]

Year	Afforestation/Community			Individual plantation			Agro-forestry plantation		
	Number of seedlings planted	Surviving seedlings		Number of seedlings planted	Surviving seedlings		Number of seedlings planted	Surviving seedlings	
		Number	%		Number	%		Number	%
1993-1999	2,599,497	1,366,884	52.9	3,716,261	2,672,298	68.0	21,822	7,394	72.7
2000	695,611	475,696	68.4	594,781	468,593	78.7	14,576	10,728	73.6
2001	608,899	420,141	69.0	547,004	421,193	77.0	18,117	16,015	88.4
2002	579,209	411,239	71.0	396,588	310,132	78.2	96,488	86,743	89.9
2003	419,811	335,796	79.9	282,070	237,821	84.3	- *	-	-
2004	257,312	210,934	82.0	484,481	428,249	88.4	-	-	-
2005	985,778	867,485	88.2	374,188	333,028	89.0	-	-	-
Total	6,146,117	4,088,175	-	6,395,373	4,871,314	-	51,003	130,880	-

* Not applicable or data not available

CONCLUSIONS

This study assessed the impact of various SWC measures implemented for soil, water, vegetation and climate qualitatively and quantitatively in the Medego watershed, northern Ethiopia. The study indicated that there has been success in maintaining and improving land resources, viz. soil, water, vegetation and humidity due to the implementation of SWC measures. Many issues need to be improved on the existing SWC measures, such as maintenance of terraces, appropriate spacing and integrating with biological conservation measures, in all parts of the watershed landscape in order to restore degraded land to its full potential. A long-term solution in improving infiltration, spreading run-off, and increasing biomass production requires an integrated effort with the full involvement of farmers. More efforts should be directed towards increasing the water retention capacity and improving the organic matter content of the soil, along with the restoration of flora and fauna for ecological and economic benefits in many parts of the watershed. This is because a soil rehabilitation should go beyond the application of natural fertilisers to replace chemical ones or only terraces to reduce soil loss. Such community-based watershed rehabilitation programmes can transfer sustainable and restored landscape to future generations. Development and research work should be focused on introducing alternative management options that can rehabilitate degraded areas to its full potential by considering the existing weaknesses of the SWC measures. This research should include testing techniques appropriate to specific local conditions to identify areas prone to severe degradation, sources of high run-off, and sedimentation that has priority, while taking action using the limited resources available.

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