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Review Article

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Impact of Physical Soil and Water Conservation Measures on Soil Erosion Reduction and Associated Constraints in the Highland of Ethiopia

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Abstract

Soil erosion is among the most challenging and continuous environmental problems in highland parts of Ethiopia. Highland areas of Ethiopia are receiving high rainfall and are occupied by high population density, and causes soil erosion in the form of water erosion. Soil erosion induced by water had an impact on national food supply, downstream flooding and reservoir sedimentation, and loss of valuable plant nutrients. Physical soil and water conservation measures are identified as the first line of defense that mostly acts as a barrier due to the creation of obstacles against surface runoff, changing the slope gradient of the landscape via sediment accumulation and moisture storage. The key findings in this review showed that soil bund, stone bund, stone-faced soil bund, fanyajuu and integrated with in situ water harvesting structure and biological measures were effective in the reduction of runoff, soil loss, the slope gradient, moisture storage, and crop productivities compared to non-conserved land. However, low adoption and extent of sustainable land management practice, lack of integration of different disciplines, inappropriateness of soil and water conservation measures, low community acceptance and commitment, lack of extension service were the most constraints which hinder to bring expected output in the reduction of continued soil erosion. Thereby, combining Physical soil and water conservation measures within situ water harvesting structures and biological measures were significantly reduced soil erosion. In addition, better understanding of constraints that influence the success of soil conservation implementation is important for a sustainable agriculture in Ethiopia.

Keyword

Runoff, Soil loss, Moisture storage, Soil properties, Crop productivity

Abbreviations

PSWC: Physical Soil and Water Conservation; NGO: Non-Governmental Organization; MOA: Ministry of Agriculture; SWC: Soil and Water Conservation; IWM: Integrated Watershed Management; and SLM: Sustainable Land Management.

Introduction

Land degradation in the form of soil erosion and nutrient depletion threatens food security and the sustainability of agricultural production in Sub-Saharan Africa [1]. For instance, soil erosion is the main environmental and economic problem in the highland of Ethiopia [2-4]. Soil erosion induced by water had an impact on national food supply [5], deteriorate soil fertility and reduce agricultural productivity [6,7], downstream flooding and reservoir sedimentation [8,9] and loss of valuable plant nutrients [10]. In order to solve soil degradation problems in Ethiopia, efforts towards soil and water conservation (SWC) goals were started in the mid-1970s and 80s to alleviate soil erosion and low crop productivity [11,12]. Combating land degradation and investing in the soil and water conservation for future generations is a major

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development task promoting sustainable land management [6]. Currently, at the watershed scale, various recommended physical soil and water conservation (PSWC) measures such as soil bund, stone bund, stone-faced soil bund, Fanya juu, hillside terrace, bench terrace, trench, pit, half-moon and indigenous PSWC such as drainage ditches, contour plowing has been implemented through free community labor mobilization, government, and NGO mobilization to prevent soil erosion and rehabilitate degraded land in the highland of Ethiopia [2,13-21].

Various site-specific studies at watershed scale in Ethiopian Highland areas indicated that various PSWC measures had positive impact sustainable agriculture through;- reduction of runoff and soil loss [22-25]; changing slope gradient [20,26,27]; enhancing moisture storage [28-30]; improving soil quality [27,31,32], and increasing crop productivity [27,33,34]. Yet, this generalization is coarse and inconsistent as there are different factors influencing the effectiveness of PSWC practices. This includes integration of physical and biological activities [35]; type of physical practices [36]; the soil fertility condition of the land at a time when treated with SWC measures and age of structures [36-38]. Thus, taking into account soil-crop-and management type-specific information is relevant for sustainable implementation of soil conservation practices at the watershed level.

In addition, poor adoption, implementation approach, inappropriate of the technologies, and management of the SWC and acceptance and involvement of the community have affected the sustainability of the implemented interventions [2,15,21,39-41]. Hence this study review entails

- The major forms of soil erosion and status of soil loss in highlands of Ethiopia
- Impacts of PSWC measures on continued soil erosion reduction in highlands of Ethiopia
- Challenges and constraints to bring expected outputs in the reduction of continued soil erosion of implemented SWC.

Major Forms of Water Erosion and Status of Soil loss

In practice Ethiopian highlands are vulnerable to various forms of water erosion of which sheet/splash, rill, and gully erosion are common in cultivated, grazing, and degraded bushland [3,42-44]. Highland areas of Ethiopia are receiving high rainfall and are occupied by high population which are likely to be the major reason for soil erosion in the form of water erosion [3,6,45]. Furthermore, the main cause of soil erosion of Ethiopia highland areas are often due to cultivation of the steep and fragile soils, limited recycling of dung and crop residues and overgrazing [46]; agricultural intensification [2,3,22,33,47]. For instance, sheet and rill erosion is the predominant form of water erosion and source of sediment detachment and transport which is initiated by poor tillage, and lack and improper soil and water conservation structure in agriculture land in the highland of Ethiopia [2,42] (Figure 1). Various studies have been reported that sheet and rill erosion had a detrimental impact on soil fertility and crop production in the highlands of Ethiopia [17,48,49]. This is due to that mostly sheet and rill erosion occurs on the surface of cultivated land during intensive and improper tillage systems via raindrop impact and runoff.

Figure 1: Photograph of Rill erosion in Angereb Watershed [2] and Gully erosion in Debre Mawi Watershed [16] respectively in a and b.

On the other hand, gully erosion is the most visible form of soil erosion in Ethiopian highlands [16,43,44,50,51]. The distribution and expansion of gully rate are determined by catchment land use and topography, gully morphology characteristics, human activities such as road construction that lead to a diversion of concentrated runoff to catchment [44,52,53]. For instance, Yazie, et al. [44] reported that gully density was higher in cultivated areas at gentle slope gradients due to poor tillage systems and lack of appropriate land management measures in the Upper Blue Nile basin.

Increasing top fertile soil loss status in the highlands of Ethiopia, particularly in the Upper Blue Nile (UBN) basin of Ethiopia is the main threat and concern for environmental sustainability and crop productivity [3,4,56]. Ebabu, et al. [9] reported that the sediment yield of Akusity and Kasiry paired watershed were varied spatially and temporally of which, in 2014 and 2015 was 7.6 and 27.1 tha^{-1} in Kasiry with corresponding values of 25.7 and 71.2 tha^{-1} for Akusity watershed. This implies that in the consequent year 2014 and 2015, the sediment loss is increasing in both catchments whereas the relative reduction of sediment yield of Kasiry watershed is due to its soil and water conservation practice (SWC). And also in the northwestern highlands of Ethiopia, in the Geleda watershed of the Blue Nile basin, the soil loss in the steep areas of the watershed extends up to 237 $tha^{-1}yr^{-1}$ [57]. Habtamu, et al. [4] also revealed that maximum soil loss which is 100.62 $tha^{-1}yr^{-1}$ found in steep slope cultivated land and the average soil loss in Yasir Watershed was 50.31 $tha^{-1}yr^{-1}$. Likewise, Belayneh, et al. [58] also found a total of 9.683456 million ton of gross surface soil lost annually, with an average soil loss of 42.67 $tha^{-1}yr^{-1}$ of which 62.1% was generated from cultivated land, and high spatial variability of soil erosion within the Gumara watershed. This implies that according to Hurni [59] reckoning the maximum (18 $tha^{-1}yr^{-1}$) soil loss tolerable limit, the majority of the Ethiopian highland areas were highly affected by soil erosion in the form of water erosion due to various reason such as the cultivation of steep slope, high rainfall, and poor land management practice.

Impact of PSWC Measures on Hydrological Responses and Soil Erosion

Runoff and soil moisture retention

Physical soil and water conservation measures (PSWC) are impermeable structures that are intended to retain surface runoff and enhance soil moisture storage capacity and drain the excess runoff (Table 1 and Table 2). Though the effectiveness of various PSWC measures on runoff reduction and moisture storage various in soil type, land use, slope gradient, several studies in a different part of the countries have been reported that implementation of PSWC measures reduced the surface runoff and enhanced soil moisture storage compared to non-conserved land.

A study made by Dagnew, et al. [16] indicated that the total runoff volumes before the implementation of soil bund accounted for 32% and 20% in 2010 and 2011 rainfall season while after PSWC implementation, estimated runoff accounted for 10% and 11% in 2012 and 2013 respectively. This implies that the implementation of soil bund on cultivated land reduced runoff by 69% and 45% compared to non-conserved land in the respective rainy season. Abrha, et al. [24] also observed that stone-faced soil bund reduced runoff by 79.2% in Welkait district Tigray Ethiopia; Mengistu, et al. [60] reported that graded Fanya juu reduced runoff by 33.2% in Anjeni watershed and Adimassu, et al. [22] found that soil bunds reduced the average annual runoff by 28% in Galessa watershed. Moreover, Asnake and Elias [29] observed that stone-faced soil bund reduces runoff and helps keep nutrients on the field and essential for soil moisture retentions through reducing runoff velocity by conserving and storing water and infiltration. This implies that the implementation of PSWC at the watershed scale had a positive impact on controlling runoff through increasing infiltration capacity, and improved other hydrological processes such as percolation, moisture storage in a different part of Ethiopia. This argument is in line with a study made by Jemberu, et al. [61] showed that farmland treated with soil bund increased porosity and infiltration by 14.2%, and 41% respectively compared to those of untreated farms in Koga catchment, Highlands of Ethiopia.

Conserving soil moisture is important in controlling various atmospheric, ecological, hydrological, and pedological processes, particularly in water-limited environments [55]. In addition, onsite moisture storage favors the survival of trees and rehabilitation of degraded land which results through proper implementation of SWC [62]. Particularly, integrated physical soil and water conservation measures with an in-situ water harvesting structure are more effective in tree seedling survival and rehabilitation potential of degraded land [15,62-65] (example Figure 2). Habtamu [66] revealed that the highest mean (27.1%) value of moisture storage was noted in a watershed conserved with soil bunds, Fanya juu, trench and stone bunds, and the lowest mean (12.0%) value under the non-conserved watershed in Dimma Watershed, Central Ethiopia. This indicated that the implementation of PSWC enhanced soil moisture storage through increasing soil

Table 1: Impact of PSWC measures on soil moisture storage in the highlands of Ethiopia.

Type of PSWC	Study site	Age (year)	Moisture Storage (%)		Effectiveness (%)	Reference
			with	without	Moisture Storage	
Graded stone bund	Adaa Berga district West Shewa Zone	6	19.6%	17.6%	11.36%	Abay, et al. [28]
Soil bund with trench	Anjeni watershed	5	34.73%	29.30%	18.5%	Mengistu, et al. [69]
Stone bund	Degua Temben district Northern Ethopia	-	10%	8.6%	16.2%	Welemariam, et al. [68]
Stone faced- soil bund	Guba-Lafto Woreda	3	34.95%	24.48%	42.8%	Asnake and Elias [29]
Soil bund	Arsi Negelle District	4	0.417	0.38	9.8%	Husen, et al. [107]
Stone bund	Gumara-Maksegnit watershed	5	24.49%	22.88%	7%	Alemayehu, et al. [30]

Table 2: Impact of PSWC measures on soil loss and runoff in the highlands of Ethiopia.

Type of PSWC	Study site	Soil Loss (t $ha^{-1}yr^{-1}$)		Runoff (m^3/ha)		Effectiveness (%)		Reference
		with	without	with	without	Soil Loss	Runoff	
Graded Soil bund	Galessa watershed	187	259	240	460	28	47	Adimassu, et al. [22]
Graded fanya juu	Anjeni watershed	35.6	110.	3246.4	4866	67.6	33.2	Mengistu, et al. [60]
Soil bund	Debre Mewi watershed	46	71.3	2498	3017	35.5	17.2	Tadele, et al. [23]
Trench	May Leiba watershed	4	39	0.13	0.43	89.7	69.7	Taye, et al. [108]
Stone-faced soil bund	Welkait district Tigray	8	79	1358	6557	89.8	79.2	Abrha, et al. [24]
Stone bund	Gumara watershed	0.74	3.07	305	641	60-80	33-55	Klik, et al. [109]
Stone terraces	Harfetay watershed	23	119	264	401	80	34.2	Selassie, and Belay [74]
Fanyajuu bund	Guder	-	259	240	460	-	47	Sultan, et al. [110]

Figure 2: Integrated stone bund with insitu water harvesting structure in Gumara-Maksegnit watershed; stone bunds (top), micro-basins (bottom left) and trenches (bottom right) [65].

aggregation and improved other hydrological processes in the watershed. Abay, et al. [28] also observed that highest soil moisture content (19.6%) in farm plots with graded stone bund compared with non-conserved farm plots (17.6%), Likely, successful implementation of stone bund increase soil water content along the hillslope by interrupting hillslope hydrology and increasing time of infiltration and also increases saturated hydraulic conductivity while decreasing bulk density [67].

Furthermore, Asnake and Elias [29] observed that stone-faced soil bund increased moisture storage by 30.6% in Guba-Lafto Woreda; Welemariam, et al. [68] found stone bund increased soil moisture retention by 16.2% in Degua Temben district Northern Ethopia and Mengistu, et al. [69] noted that soil bund with trench enhanced by 18.5% in Anjeni watershed compared to non-conserved land. Moreover, Fenta, et al. [70] observed trench combined with stone-faced soil bund enhanced soil moisture storage and could rehabilitate degraded land for sustainable land management. This indicated that implementing PSWC is enhancing moisture storage via enhancing infiltration rate and improve aggregation of soil structure and water holding capacity. Soil moisture storage of the soil is important parameters which determine the plant growth and productivity; it also influences the decomposition rate of soil substrates.

Furthermore, the effectiveness of PSWC measures in reduction of runoff and enhancing moisture storage can be enhanced due to proper quality and design implementation. Some studies have been conducted on the assessment of dimension and quality of implemented PSWC measures in line with recommended specification by soil and water conservation guideline [18] and its impact on soil moisture storage, runoff as well as soil loss [20,21,61,71,72]. A study made by Jemberu, et al. [61] elaborated that bund structure design should be adapted to local biophysical settings at the catchment level , of which the higher top width (> 85 cm) and height (> 75 cm) relatively better-enhanced soil porosity and moisture storage (Figure 3). Engdayehu, et al. [71] observed some wider terrace spacing has reduced the effectiveness of bunds. This indicated that using recommended dimension of SWC layout are affordable for sustainable soil erosion reduction. Kassawmar, et al. [21] also investigated the efficiency of PSWC measures at landscape scale implemented by free community labor mobilization in 16 systematically selected watersheds in Amhara and Tigray regions, the majority of the watershed were poor in quality and spacing while Gebriel watershed was found at lower P (Management factor) value associated with good quality, proper spacing and wider coverage of structure in the watershed implies effective in controlling interrill and rill erosion.

Soil loss and sediment accumulation

Soil erosion in the form of water erosion is the main threat and concern in the highlands of Ethiopia, particularly in the Upper Blue Nile (UBN) basin [3,4,56]. Various studies in the highlands of Ethiopia have been reported that physical soil and water conservation measures reduced soil loss due to trapping sediment behind the structures and forming bench terrace (Table 2). But the reduction of soil loss or accumulation of sediment achieved under quality layout, design of PSWC measures [21,72], and strong institutional mechanisms in construction and regular maintenance [73]. For example, the impact of PSWC measures on soil loss made by Gebremichael, et al. [13] reported that the stone bund on croplands in northern Ethiopia reduced the annual soil loss by 68% (from 57 to 18 tha^{-1}yr^{-1}). Abrha, et al. [24] also observed the lowest average soil loss (8 t/ha/yr) value in stone-faced soil bund compared with an untreated cultivated field (79 tha^{-1}yr^{-1}) in Welkait district Tigray Ethiopia. Likely, Selassie and Belay [74] observed the lowest soil loss (23 tha^{-1}yr^{-1}) in conserved cultivated land while highest soil loss (119 tha^{-1}yr^{-1}) in non-conserved land. And also Adimassu, et al. [22] reported that soil bunds reduced the average annual soil loss by 47%. This showed that the implementation of stone bund and stone faced soil bund on cultivated land highly reduced the amount of soil loss through creating surface roughness, convey the erosive surface flow and minimize the removal of top fertile soil out of the catchment and enhance the accumulation of sediment behind it.

Furthermore, Mekonnen, et al. [75] observed the role of physical SWC measures on sediment accumulation in the Minizr catchment, northwest Ethiopia and revealed that 144 km soil bunds and Fanya juu ridges enhanced the sediment trap with a non-significant difference at three topographic positions and minimize sediment releasing into Koga reservoir (Table 3) averagely by 55 kgm^{-1}y^{-1}. Likely, a dissertation work made by Debie [17] reported that both actual surface damage and volume of eroded soil from rill erosion were low in the conserved field than in non-conserved fields. The lower volume of eroded soil at downslope in the conserved terrace is due to the rill channel is filled by sediment behind the terrace. Tiki, et al. [73] also indicated that averagely 45.74 tha^{-1}yr^{-1} sediment was accumulated on soil bunds in Goba District in Bale Zone South East Ethiopia. In addition, the sediment deposition behind hillside terraces was 116.7 tha^{-1}y^{-1} with less than 7 years old in Maego Watershed, North Ethiopia [20]. Nyssen, et al. [76] also reported that the sediment accumulation rate on the stone bund is 57 tha^{-1}yr^{-1} in Tigray Highland. The different results could have occurred due to differences in agroecology and biophysical features. If

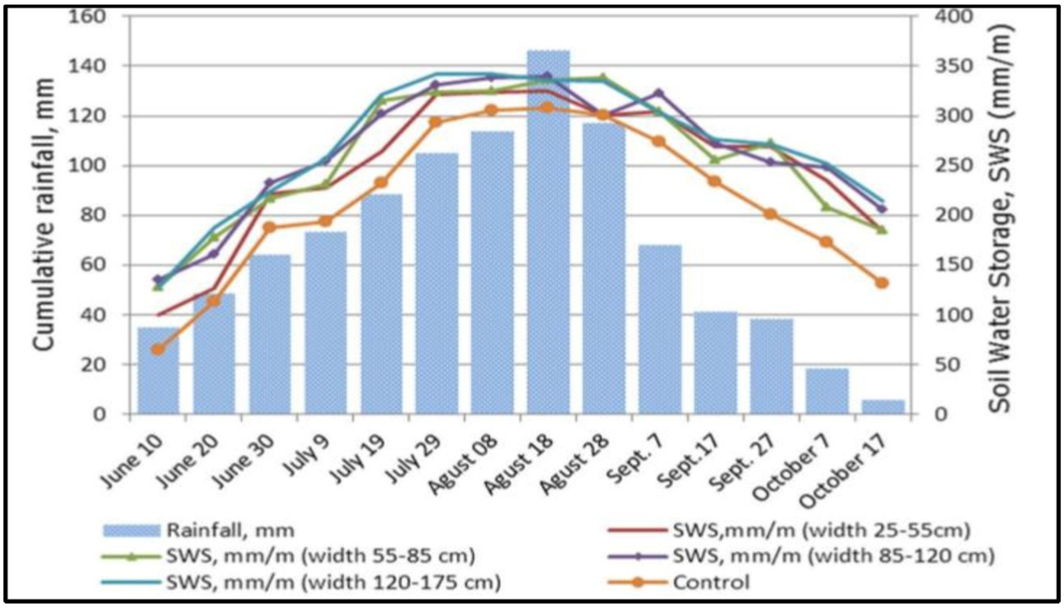

Figure 3: The variation of soil water storage in relation to rainfall and widths of bunds in Koga catchment for the rainy season of 2015 [61].

Table 3: Catchment sedimentation within a sample of fanya juu and soil bund structures in the Minizr catchment.

PSWC measures[a]	Position in watershed[b]	Sediment depth(m)[c]	Total sedimentation ($m^3 30\ m^{-1}$) [d]	Rate of sedimentation[e]	
				$m^3m^{-1}y^{-1}$	$kgm^{-1}y^{-1}$
Fanya juu	Upper	0.11	1.92	0.064[a]	65.28[a]
Fanya juu	Middle	0.09	1.68	0.056[a]	57.12[a]
Fanya juu	Lower	0.10	1.74	0.058[a]	59.16[a]
Soil bunds	Upper	0.08	1.20	0.040[a]	40.80[a]
Soil bunds	Middle	0.10	1.50	0.050[a]	51.00[a]
Soil bunds	Lower	0.11	1.65	0.055[a]	56.10[a]
Average		0.09	1.60	0.053	55.00

Source (Mekonen, et al. 2017)[79]

[a]Average sedimentation width is 0·6 m (fanya juu); 0·5m (soil bund) and ditch length is 30 m; [b]Position in the catchment; Upper (> 7%), Middle (5-7%) and Lower (< 5%) slopes; [c]Two years average deposited sediment depth; [d]Two years average sediment deposited behind 30 m structures; [e]Two years average rate of sedimentation. A Significance test of mean difference among treatments at p < 0·05, which shows a non-significant difference.

there is high and erratic rainfall and the topography is with a high slope category, more sediment deposition could be recorded.

As a result, for the effectiveness of PSWC on the reduction of soil loss and accumulation of sediment at an acceptable level, it needs to be complemented with considerable practicing of agronomic (composting, legume-cereals crop rotation, leave crop residue) and biological (tree plantation, shrub, agroforestry, area closure, grass) measures and also leaving rock fragments like stoniness cover on cultivated land were effective in soil erosion control. For instance, in semiarid areas of Northern Tigray Ethopia, the rock fragments like stoniness cover are often considered by farmers as surface mulches that are beneficial for reducing soil erosion [77]. Haregeweyn, et al. [15] reported that integrated watershed management reduced sheet and rill soil loss rates by about 89% with a mean soil loss rate of 9.8 $tha^{-1}yr^{-1}$.

Change in slope length/degree of landscape

One of the functions of constructing PSWC measures is reducing the slope gradient of the landscape features. Construction of physical SWC measures usually involve earth movements and are often located along the contour and in marginal rainfall areas where rainfall needs to be conserved on-site. The deposition of soil materials and debris on the upper position of PSWC measures (usually the accumulation zone) causes the height of the bunds to increase year after year, thereby reducing the inter-terrace slope gradient between two successive structures [75]. A recent study conducted by Guadie, et al. [27] reported that lower average inter-terrace slope gradients were found in treated land with stone bund (7.1%) and stone-faced soil bund (8%) while the highest average inter terraced slope was found in untreated fields (19.5%). Dimtsu, et al. [20] also observed that the highest slope gradient reduction was recorded on the stone bund followed by stone bund with trenches in Maego Watershed, and reduced slope degree by 29.2% and 25% respectively (Table 4). This is due to high sediment deposition behind stone and stone-faced trench forming series of bench terrace along with the inter terrace slope position.

Likely, Gebremichael, et al. [13] observed that sediment accumulated on stone bunds changed the inter slope gradient from 14.1% to 11.2%. Amdemariam, et al. [26] also observed that a soil bund had the lowest inter-terrace slope (12%) while in the control treatment the inter slope was characterized as high (21%). The change in the slope of the landscape is mainly due to high sediment ridge through trapped sediment behind it and gradually converted into bench terraces. This is in line with Nyssen, et al. [76] revealed that after implementation of stone bund physical soil and water conservation measure, averagely decreased slope gradient by 1% every 3 years. This implies that the age of constructed PSWC structures could be related to their difference in the accumulation of sediment and consequently change the inter terrace slope of the landscape. Hence, older measures through proper maintenance and stabilization could reduce more of the gradient via high accumulation of sediment and forming bench in the watershed.

Improving soil quality

Besides reducing runoff, soil loss interslope gradient and improving moisture storage, PSWC also causes some desirable improvements in soil physicochemical properties. Studies reported that soil properties like bulk density, soil organic matter content (SOM), total nitrogen, phosphorus, and cation exchange capacity determine their suitability to cultivation, soil water, and air supplying capacity to plants and generally determine plant growth component [27,31,78-80]. Various studies reported that the implementation of PSWC showed a significant improvement in soil properties compared with non-conserved land (Table 5). For instance, Guadie, et al. [27] showed that stone-faced soil bund improved bulk density, SOM, total nitrogen, and CEC by 10%, 53%, 88%, and 79% respectively compared to non-treated land in Lole Watershed. Alemayehu and Fisseha [81] also indicated that soil bund combined with pigeon pea were improved bulk density, SOM, TN, and CEC by 24%, 25%, 22%, and 10% respectively compared to a non-conserved landscape in Debre-Yakob Watershed in northwestern Ethiopia. Similarly, Kebede, et al. [82] observed level soil bund and stone bund improved SOC, TN, AP, K+, PH and CEC in Bokole watershed. Yonas, et al.

Table 4: Slope change after construction of PSWC measures in highlands of Ethiopia.

PSWC Structure	Study site	Age (Year)	plot	Before (%)	After (%)	Slope change (%)	Refrencess
Stone bund	Maego Watershed	7	50	15.54	11	29.2%	Dimtsu, et al. [20]
Stone bund+ Trench	Maego Watershed	7	50	20	15	25%	
Stone bunds	Dogu'a Tembien district	> 3	202	14.1	11.2	20.6%	Gebremichael, et al. [13]
Soil bund	Banja Shikudad District,	9	4	21	12	42.8%	Amdemariam, et al. [26]
Stone-faced soil bund	Lole Watershed	10	3	19.5	8	58.9%	Guadie, et al. [27]
Soil bund	Lole Watershed	10	3	19.5	7.16	63.2%	

Table 5: Effect of PSWC measures on selected soil properties in highlands of Ethiopia.

SWC Intervention	Study site	Land Position	Bd (g/cm³)		SOM (%)		TN (%)		CEC (cmol/kg)		Soil property improvement due to SWC (%)				Reference
			With SWC	Without	With SWC	Without	With SWC	Without	With SWC	Without	Bd	OM	TN	CEC	
SFSB	Wege Alba watershed	Upper	-	-	13.90	11.09	0.048	0.03	25.84	22.87	-	25	41	13	Asnake and Elias [29]
SFSB	Lole watershed	Middle	0.97	1.08	4.21	2.75	0.32	0.17	38.53	21.47	10	53	88	79	Guadie, et al. [27]
Graded stone bund	Adaa Berga district	-	1.13	1.21	3.42	2.87	0.24	0.17	38.24	30.07	7	19	41	27	Abay, et al. [28]
Fanya juu	Goromti Watershed	-	1.09	1.16	3.3	3.74	0.17	0.24	31.69	32.95	6	12	29.2	4	Hailu, et al. [111]
SFSB	Gondar Zuriya Woreda	Middle	1.1	1.33	4.1	3.2	0.23	0.15	-	-	17.3	28	53	-	Hailu [32]
Stone bund	Weday Watershed		-	-	2.4	1.8	0.12	0.09	12.27	11.93		33	33	3	Teressa [112]
Soil Bund + pigeon pea	Debre-Yakob Watershed	Lower	1.35	1.77	3.01	2.40	0.11	0.09	30.17	27.31	24	25	22	10	Alemayehu and Fisseha [81]
Soil bund and Manure	Zikre watershed	-	1.14	1.3	5.88	2.63	0.3	0.13	31.01	25.02	12	123	130	24	Selassie, et al. [78]

Note that SFSB = Stone- Faced Soil Bund.

[83] also reported that soil and water conservation structures improved soil PH, K+, AP, SOC, TN, and CEC in Wonago district, Southern Ethiopia compared to adjacent without SWC treatment. This is true that the implementation of PSWC had a positive impact on soil properties improvement because of higher soil moisture storage; accumulation of sediments and residues behind SWC. As shown in Table 5, integrated SWC measures are more effective in improving soil properties like soil organic matter and total nitrogen due to its enhanced plant biomass production and high residues return onsite. For instance, Selassie, et al. [78] reported that soil bund integrated with animal manure practice increasing SOM and TN by 123 and 130% respectively compared to nonconserved land in Zikre watershed North-Western Ethiopia. Similarly, Guadie, et al. [27] observed that stone-faced soil bund increase SOM, TN, and CEC by 53, 88 and 79 respectively. This indicated that increasing soil organic matter enhances the CEC of soil. According to Daniel, et al. [84] soils with a high amount of organic matter and clay content have higher CEC because of their high high negatively charged soil surface.

Improving crop production

Implementations of PSWC measures and crop productivity are highly complementary, because conservation of soil, water, and natural vegetation increase the soil fertility and water availability which leads to higher crop productivity [40]. This indicated that proper design and layout of PSWC according to the biophysical attributes of the watershed could bring improvement in crop productivity as well as livelihood improvement. For instance, integrated soil bund, fanyajuu, and trench in situ water harvesting structures were able to reduce sediment loss, TN, AP, and SOC losses by 46.8%, 57.97%, 65.86%, and 61.3%, respectively in the Gumara-Maksegnit watershed [65]. Thereby, improved soil is naturally conducive to a better plant growth and productivity. Similarly, Adimassu, et al. [22] reported soil bund reduced soil loss, SOC, TN, and AP by 48, 51, 48, and 54% respectively in Galessa micro-watershed. This implies that implementations of PSWC are effective in top fertile sediment accumulation and sediment-associated nutrients, which contributes to crop productivity improvement.

Several studies carried on the various PSWC measures on crop production, indicated that sediments accumulated behind PSWC resulted in improving crop growth component (Table 6). For example, Guadie, et al. [27] showed that stone-faced soil bund and soil bund improved grain yield of barely by 56%, 48% respectively compared to non-conserved land in Lole Watershed. Amare, et al. [33] also showed that fanyajuu terrace increased wheat grain yield and biomass yield in Anjeni Watershed by 64% and 19% respectively. Likely, Enyew and Akalu [34] observed fanyajuu terrace increased maize grain and biomass yield by 151 and 85% in Anjeni Watershed. This implies that stone-faced soil bund, stone bund, and fanyajuu terrace improving crop productivity through enhancing moisture storage, improving soil properties, and reduction of top fertile soil loss.

Despite implementations of integrated SWC measures are not well-practiced in our country, some studies showed that it is highly effective in increasing crop production due to relatively better moisture storage, reduction of runoff and soil loss, and high accumulation of organic materials. For example, Abera, et al. [85] indicated that a stone bund with biological measure contributed to crop production by 170% compared to the lone implementation of stone bund and fanyajuu SWC structure in Ethiopia. Similarly, Alemayehu and Fisseha [81] also indicated that soil bund combined with pigeon pea were improved grain yield of maize by 52% compared to the non-conserved landscape in Debre-Yakob Watershed in northwestern Ethiopia. This is because SWC has a lot of functions in the ecosystem such as protect from raindrop impact, improve soil aggregation, increasing the infiltration capacity of the soil and reduce runoff and trap sediment soil transport by erosion agents and resulting in high crop productivity.

Constraints to Bring the Expected Impact of Implemented SWC Measures

The approach of SWC implementation

In Ethiopia, even though numerous studies conducted on the impact of individual SWC measures on soil erosion control,

Table 6: Effects of PSWC on grain yield and straw biomass in Ethopia.

SWC	Study site	Crop Type	GY (q ha^{-1})		SY (q ha^{-1})		Effectiveness (%)		Reference
			With PSWC	Without PSWC	With PSWC	Without PSWC	GY	SY	
SFSB	Lole watershed	Barley	25.55	16.38	68.33	42.5	56	61	Guadie, et al. [27]
Soil bund	Lole watershed	Barley	23.88	16.11	47.50	35	48	36	
Fanyajuu	Anjeni Watershed	Wheat	10.77	6.56	52.08	43.91	64	19	Amare, et al. [33]
Fanyajuu	Anjeni watershed	Maize	26.95	10.72	171.25	92.92	151	85	Enyew and Akalu [34]
Stone bund	Gumara-Maksegnit watershed	Sorghum	20.59	18.81	-	-	9.5	-	Alemayehu, et al. [30]
Soil Bund + pigeon pea	Debre-Yakob Watershed	Maize	44.84	29.46	-	-	52	--	Alemayehu and Fisseha [85]
ISWC	Maego watershed,	Wheat	82.31	33.76			143	-	Damitsu, et al. [90]

i.e. ISWC = Integrated Soil and Water Conservation Measures; SFSB = Stone Faced Soil Bund ; GY= Grain Yield and SY= Straw Yield.

soil properties, and crop productivity, little information is available regarding the effects of integrated watershed management (IWM) on the reduction of continued soil erosion and livelihood improvement [15]. The low adoption of sustainable land management practices are the main constraint for the unsuccessful of implemented SWC in the reduction of continued soil degradation and unable to bring the expected result in livelihood improvement [86]. Currently, sustainable land management is a valuable new approach for sustainable soil, water, and other natural resource management as well as for the improvement of livelihoods in Ethiopia [64,86]. Besides, Desta [2] indicated that lack of consideration of knowledge and experience of farmers in the SWC extension system and lacks of including farmers' preferences in implementation of SWC are other constraints to the success of SWC in the reduction of continued soil erosion. Furthermore, lack of integration of different disciplines and sectors are the main challenges/ constraints for the failure of implemented SWC and unable to bring expected improvement in livelihood of households [41]. Besides, the top-down approach of SWC intervention was the main governmental policy constraints in the past and might have sustained later. Kebede, et al. [87] were identified as the top-down approach in SWC intervention is the main constraint for the sustainability of implemented technologies. This indicated that planning and implementing SWC measures through a top-down approach without the agreement and willingness of landowners, farmer's ideas, and experience affect the continuous use of SWC measures. Thereby, prerequisite analysis of farmer's attitude towards SWC practices and follow bottom-up approach and include farmers in any decision making process is significant for sustainable management of implemented SWC measures [88]. Hence the problem of continued erosion and lack of a significant livelihood benefit in SWC management approach could be alleviated through practicing a new sustainable land management approach like participatory community-based IWM and integrating local knowledge and experience in the implementation of SWC.

Inappropriate/poor quality of the SWC technologies

The inappropriateness of implementing SWC are the main constraints to bring expected change in erosion control and livelihood improvement via land management practices in Ethiopia [21,71,72,89]. For example, Tadele, et al. [62] observed that lone implementation of pits and half-moon SWC technologies in degraded hillside areas are effective only for the short rainy season while after long season the structures are filled with sediment and effectiveness of SWC decline quickly in Gerduba Watershed. Whereas, the effectiveness of stone bund remained fairly constant during three consecutive rainy seasons. The combination of stone bund and trench were more effective in reducing runoff and soil loss for hydrological response improvement and soil productivity. Obviously in a watershed characterized by shallow in soil depth and steep topography, limited vegetation, the compatible SWC technologies have been hillside terrace incorporated with water harvesting structure bring expected output Debie [17] also observed that implementation of traditional drainage ditches on the bottom part of soil bunds initiated for rill formation on cultivated fields in Berberi catchments. Hence, the implementation of appropriate and recommended SWC in standard layout and design [18] is important to the sustainability of SWC intervention for soil erosion control [90,91].

Likiely, Desta, et al. [92] reported that the low efficiency of stone terraces in the upper landscape position resulted in about 10 to 46% biomass yield reduction compared to the bottom position in Angereb watershed. This implies that steep slope land positions are highly susceptible to erosion hence integrated SWC measures are a valuable option rather lonely implementation of PSWC measures. As a result, proper quality and compatible SWC to the biophysical characteristics of the watershed is necessary to bring the expected result in the implementation of SWC.

Community acceptance and commitment

In addition to the approach and inappropriateness of the SWC practices, changing mindset of farmers and convincing them to adopt the appropriate SWC technology are still the main constraints to successes in soil erosion control and livelihood improvement [40]. Similarly, Adugna, et al. [93] observed that lack of participation of the community at all stages in SWC intervention brought less sense of ownership to soil and water conservation structures constructed in the area that imposed negative impacts on its sustainability. For instance, Bewket [94] reported that the implementation of SWC without the interest of local farmer's leads to the destruction of SWC rather retained and reconstruct. This is due to a lack of short-term benefits from the technology and difficulty to plow and other limitations. This idea is supported by Debie, et al. [17] reported that farmer implementing SWC technologies on cultivated land has no significant change in livelihood improvement compared to farmers not adopting the technology adjacent to their farmland. This indicated that adopter farmers hesitate to sustain the SWC due to lack of benefit on it. On the other hand, lack of awareness of landowners and low perception to soil erosion may destruct and remove conservation structures from their land, due to they consider conservation works as barriers for farming and wish to get additional land from the destruction of constructed physical conservation structure [88,95]. Gedefaw, et al. [96] also identified that the inactive involvement of farmers in the conservation activities hinders the sustainable adoption of SWC measures in Simien Mountain National Park, Highlands of Ethiopia. Thereby, improving farmer's attitude and perception regarding the conservation of soil, water, and other natural resources as a whole found to be principal for a sustainable environment and livelihood improvement.

Institutional factors

Unstable institutional frameworks and a weak link between research and extension are major policy constraints that discourage farmers from making any sort of investment in the land and to use it in a more suitable way [88]. Lack and rare extension services and training by the developmental agent are a very important constraint for the success of any SWC intervention [97]. This because landowners with the frequent visit of the farmer training center and demonstration sites are more voluntary to maintain soil conservation works because it gives chance to learn technical skills and principles of natural resource management [88,98]. Similarly, Yitayal and Adam [99] reported that households with access to information have a better understanding of land degradation problems and adopt and sustain soil conservation practices. Extension services make farmers aware of the importance of controlling soil erosion by using soil conservation technologies and easily adapt them through maintaining it. Several studies indicated that access to extension service was found to have a significant positive effect on the adoption and sustainability of SWC practices in different parts of the country: Northwest Ethiopian highlands [100,101]; Wereillu district, northern Ethiopia [102]; Gibe basin, southwest Ethiopia [103] and Lemo district, southern Ethiopia [104]. Hence, capacity building on SWC intervention, awareness creation, and information delivery through various media is crucial for smallholders to the use and misuse of conservation of natural resources.

Physical factors

In Ethiopia, small landholding size is the main problem to adopt and to use sustainably the SWC technologies. This implies that farmers having large farm sizes were able to adopt the PSWC measures on cultivated land than farmers having small farm size [102]. Studies in a different part of Ethiopia indicated that landholding size was found to have a positive effect on farmers' perception to invest in SWC technologies [101,104,105]. Besides, physical SWC measures are challenged by frequent maintenance requirements, which are high labor demanding, loss of land to conservation, and unfit to the farming system [40,106]. On the other hand, various studies indicated that farmland distance from the homestead was found to have a negative and significant effect on farmers' perception to invest in SWC technologies in different parts of the country [102-104]. For instance, Wordofa, et al. [97] observed that distance of the plot from the household dwelling showed a significant and negative relationship with improved soil bund and check dam conservation strategies in Haramaya District, Eastern Ethiopia. The implication is that farmland situated far from residence suffers from the destruction of conservation structures and exposed to erosion due to lack of follow up. Hence though smallholder farmers have limited cultivated land size, integrated SWC intervention like agroforestry practices could mitigate the cost and land exposed for intervention.

Conclusion and the Way Forward

PSWC measures like soil bund, stone bund, and stone-faced soil bund, fanyajuu terrace, and integrated with in situ water harvesting structure and biological measures are more effective in improving hydrological response and reduction of continued soil erosion as compared to non-treated land. However, low adoption and extent of sustainable land management practice, lack of integration of different disciplines, the inappropriateness of SWC measure, and community acceptance, and commitment, institutional and physical factors are the most influential constraints in the past and xontinue to influence the sustainability to future SWC intervention. Thus, a better understanding of constraints that influence the success of implemented SWC is important for sustainable agriculture in the highlands of Ethiopia. Thereby, considering the essence of these factors might contribute to designing appropriate strategies to attain sustainable natural resource conservation and livelihood improvement in Ethiopia. Thus, the following solutions were affordable for the reduction of continued soil erosion and livelihood improvement: (1) Implementing PSWC measures under proper quality, design and layout for erosion controlling performance, (2) Combination of PSWC measures with in situ water harvesting structure (trench, half-moon, eyebrow basin and others), (3) Integrated approach of physical and biological measures for stabilization of physical soil and water conservation.

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