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Sustaining the benefits of soil and water conservation in the highlands of Ethiopia

SUMMARY

Soil and water conservation (SWC) measures introduced by the Ethiopian government in 2010, under the Growth and Transformation Program (GTP), have positively impacted watersheds in northern Ethiopia. Five years of field studies (2010-2014) in the Debre-Mawi watershed in northwestern Ethiopia found that different SWC measure need to be considered in different agro-ecological zones. Government planners and NGOs should consider different SWC measures based on a variety factors. This brief provides recommendations on how to improve the design and implementation of SWC measures to sustain their positive impacts into the future.

SEDIMENT DEPOSITED IN DITCHES JUST ONE YEAR AFTER CONSTRUCTION.

CONTEXT OF SOIL AND WATER CONSERVATION IN ETHIOPIA

In 2010, the Ethiopian government launched a land restoration program that aimed to double agricultural productivity through improving the management of natural resources and agricultural lands.[1] Following the launch of the program, the regional bureaus of agriculture, district agricultural offices, and other local adminstrative bodies mobilized farmers to help with the construction of SWC measures. Since 2010, more than 15 million people have contributed free labor equivalent of US$750 million each year. Physical and biological SWC measures have been introduced in more than 3,000 watersheds managed by local communities.[2]

CHARACTERISTICS OF THE STUDY WATERSHED

The results of this study are based on data collected from the entire 95 ha Debre-Mawi watershed (Figure 1). The main watershed has four sub-watersheds, ranging in size from 8 to 12 ha, each of which is equipped with a weir. Five gauging stations for stream and sediment flow measurements were installed at the five weirs; the main watershed was monitored at weir 5 (i.e., at the main outlet).

In early 2012, farmers implemented various physical and biological SWC measures on most of the agricultural land in the watershed, as facilitated by the large-scale, government-mobilized SWC campaign. The physical SWC measures included soil bunds with infiltration ditches, established to a depth of 50 cm; stone-

RECOMMENDATIONS

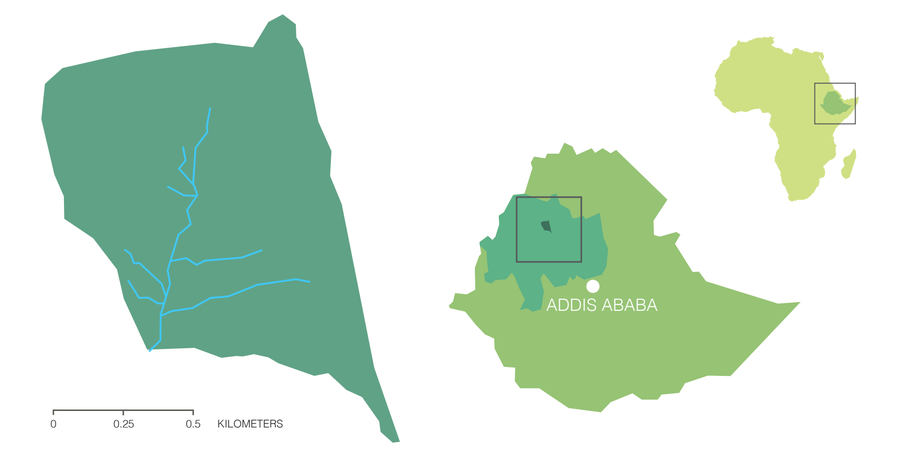
1. **Soil and water conservation (SWC) measures should be designed to accommodate peak rainfall events and be able to adequately collect runoff and trap sediments during such times.**
2. **A sound understanding of groundwater dynamics in a watershed is necessary to be able to design and implement SWC measures that can successfully reduce runoff and sediment yield.**
3. **Variability in soil types and landscapes (e.g., upper slopes vs. lower slopes) affect the efficiency of different SWC measures and should be considered when designing and placing such measures.**
4. **Gully treatment and stabilization should complement integrated SWC measures in a watershed to reduce annual sediment loads and soil losses as well as to prevent siltation of reservoirs.**
5. **Constructed SWC measures should be maintained every two to three years to sustain their function in runoff and sediment reduction.**

[1] MOFED (2010). Growth and Transformation Plan of Ethiopia (GTP), 2010/2011-2014/15 of the Federal Democratic Republic of Ethiopia (FDRE).
[2] MOA (2013). Annual report of the Ministry of Agriculture for 2013/2014 (unpublished).

faced soil bunds; and stone bunds, and they were constructed on almost all upper, mid and bottom slopes. To stabilize the bunds, different types of tree and grass species were planted on their banks.

The Debre-Mawi watershed is also plagued by severe gully erosion.[3] Sub-watersheds 1 and 3 have no gullies. Sub-watershed 2 has one small gully (slightly stabilized), whereas the power of the stream in sub-watershed 4 erodes stream banks. In the main watershed (outlet), one large active gully and more than 14 small were observed. Despite the most severe erosion being caused by gully formation, the SWC campaign did not implement gully treatment measures in the Debre-Mawi watershed.

FIGURE 1: THE STUDY AREA; THE DEBRE-MAWI WATERSHED.



RESULTS AND IMPLICATIONS FOR SWC MEASURE DESIGN AND MAINTENANCE

1) SWC measures help reduce storm water runoff and sediment yield

This study shows that the implementation of SWC measures in the Debre-Mawi watershed resulted in considerable reductions in storm water runoff and sediment yields: The reductions in runoff ranged from 26 to 71%, while the reductions in sediment yield ranged from 45 to 81% (Table 1).

While runoff was reduced, the reduction was not equal across all five sub-watersheds. This could be attributed to differences among sub-watersheds, including their different sizes, differences in density of constructed SWC measures, contribution of runoff from impermeable roads, existence of gullies, differences in land use, and whether (perched) groundwater was near the surface.

The positive effects of SWC measures are underscored by only a slight variation in total rainfall between 2010 and 2014, (total annual rainfall in 2010 was 889.9 mm; 916.8 mm in 2011; 831.8 mm in 2012; 858.3 in 2013; and 887 mm in 2014), despite which runoff was reduced considerably during that period.

2) Peak rainfall events contribute significantly to runoff and sediment yields and must be considered in SWC measure designs

In the sub-humid highlands of Ethiopia, in this case the Debre-Mawi watershed, high intensity storms are common. For example, during the entire study period, the maximum intensity of rainfall recorded was 38 mm hr^{-1}, whereas the maximum daily precipitation was 152 mm, indicating heavy rainfall during short periods. Such storms produce large amounts of runoff and peak sediment loads, especially in areas where the watershed is saturated and has little storage.

Regarding infiltration of rainwater, our results demonstrate that the steady state infiltration rates ranged from 6 to 360 mm hr^{-1}. The median infiltration rate in 2010 was 33 mm hr^{-1}; 24 mm hr^{-1} in 2012; and 31 mm hr^{-1} in 2013. Comparison of the rainfall intensity and infiltration rate shows that rainfall exceeded median infiltration rates in fewer than 10% of cases, adding to the evidence that few, but heavy storms are causing runoff. Runoff occurs in areas where the soil is saturated, such as near the regional groundwater in the valley bottom or on hillsides where groundwater is perched below the surface.

Regarding sediment yields, our study indicates that ten–minute rain storms cause sediment load events that account for up to 22% (11 t ha^{-1}) of the annual sediment yields.[4] The contribution of the largest and second largest daily sediment

TABLE 1: EFFECTS OF SWC MEASURES IN REDUCING RUNOFF AND SEDIMENT YIELD

	AVERAGE RUNOFF (MM)			AVERAGE SEDIMENT YIELD (T HA-1)		
	BEFORE SWC	AFTER SWC	% REDUCTION	BEFORE SWC	AFTER SWC	% REDUCTION
Weir 1	95	71	26	3.3	1.8	45
Weir 2	242	155	36	16.1	6.3	61
Weir 3	110	74	32	6.6	2.6	61
Weir 4	160	101	37	16.0	3.9	76
Weir 5	272	78	71	62.1	11.6	81

Note: before SWC measures refers to the mean values for the years 2010 and 2011. After SWC measures refers to the mean values for the years 2012-2014.

[3] Tebebu et al. (2010), Hydrology and Earth System Sciences Discussions, 7, 5235–5265; Zegeye et al. (2014), Proceedings of the International Conference on the Advancements of Science and Technology in East Africa (ICAST), Bahir Dar University, Bahir Dar, Ethiopia; Tebebu et al. (2015), Front. Earth Sci. 3:49. doi: 10.3389/feart.2015.00049.

[4] Dessalegn et al. (2015a), Tropical lakes in a changing environment: Water, land, biology, climate and humans, presented at TropiLakes 2015 conference, September 2015, Bahir Dar, Ethiopia.

loads to the annual sediment yield ranged from 30 to 75% (i.e., up to 56 $t\ ha^{-1}\ day^{-1}$) and from 45 to 86% (up to 65 $t\ ha^{-1}\ day^{-1}$), respectively. These findings show that peak rainfall events cause considerable runoff and contribute significantly to annual sediment loads. Therefore, SWC measures should be designed to accommodate peak rainfall events and be able to adequately collect runoff and trap sediments during such times.

3) SWC measures have led to increased infiltration and groundwater recharge

The SWC measures implemented in the Debre-Mawi watershed have been effective in improving groundwater infiltration and raising the groundwater level. Our analysis revealed that the groundwater table could rise up to 0.5 m from the surface following the implementation of SWC measures (Figure 2).

The increase in groundwater level indicates that these measures have been effective in collecting rainwater and surface runoff, recharging groundwater and increasing the availability of water for crops. The higher groundwater level in the watershed could also support the development of springs at the bottoms of hills (at the foot slope positions),[5] thus improving the availability and access to water for agriculture and domestic uses in the long run.

4) Groundwater dynamics, soils and differences in landscape influence the effectiveness of different SWC measures

Understanding groundwater dynamics is critical for designing and implementing SWC measures that are successful in harvesting water and reducing runoff in the Debre-Mawi watershed.

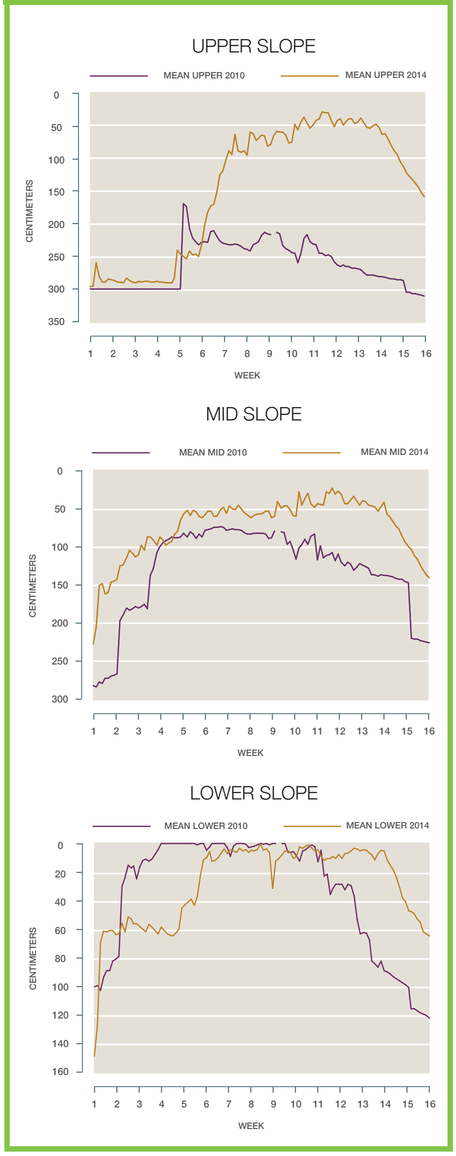
Because the level of the groundwater table varies between different positions in the landscape, i.e., on upper, mid and lower slopes, different SWC measures are suitable in different areas. At the bottom of slopes (at the foot slope position), the groundwater level begins to rise immediately after the onset of the rains and remains almost at surface level for most of the rainy season – both before and after the implementation of SWC measures (Figure 2). This could be due to the gentle slope, large drainage area and converging of sub-surface water and overland flows in these positions.

But, constructing soil bunds in such saturated areas, where the perched groundwater table is at or near the surface, makes the soil bunds unstable, collapse and wash away. Constructed bunds even initiated gullies on several occasions in the Debre-Mawi watershed. Graded bunds and waterways, however, could be effective in reducing runoff, suspend sediment concentration and sediment yield in the foot slope positions.

At locations on upper slopes, however, the groundwater table is lower, which could be attributed to a small contributing area, steep slopes and good drainage. Here, trenches and infiltration furrows could be more effective in reducing runoff.

Similarly, variations in soil and landscape also influence how effective different SWC measures are in collecting runoff. For example, the upper slopes in the Debre-Mawi watershed are well drained (dominated by Nitosol), and here trenches and soil bunds were effective in collecting runoff.[6] However, in lower lying areas, which saturate periodically (and are dominated by Vertisols), vegetated waterways and drainage ditches can be more effective in conserving soil and draining excess water than level bunds and trenches. In sum, design and implementation of SWC measures in a watershed must take groundwater dynamics, soil types and landscape differences into account to be successful.

FIGURE 2: GROUNDWATER DYNAMICS BEFORE AND AFTER THE IMPLEMENTATION OF SWC MEASURES IN THE DEBRE-MAWI WATERSHED (DESSALEGN ET AL., 2015).



5) Gully erosion must be addressed in conjunction with SWC to reduce the total sediment yield

Our study demonstrated that the presence or absence of gullies influence how peak sediment loads contribute to annual sediment yield, which in turn affects how effective SWC measures are in reducing peak sediment loads. In sub-watersheds with no gullies, the sediment loads were reduced by two-fold following the implementation of SWC measures. However, in sub-watersheds with gullies, the difference was not considerable. Also, we found

[5] Nyssen et al. (2010), Impact of soil and water conservation measures on catchment hydrological response—a case in north Ethiopia, Hydrological Processes, 24, 1880–1895.

[6] Dessalegn et al. (2015b). Effectiveness and sustainability of large-scale soil and water conservation interventions in the sub-humid Ethiopian highlands; Evidence from Debre-Mawi watershed, paper presented at the 10th Alexander von Humboldt International Conference, November 2015, Addis Ababa, Ethiopia.

that large gullies contributed up to 90% of the catchment sediment loads. Thus, gully treatment and stabilization is essential to reduce annual sediment load, lessen soil losses and prevent siltation of reservoirs in the downstream areas, and should complement integrated SWC measures.

6) SWC structures must be maintained every two to three years to sustain benefits

A close look at runoff and sediment yield from the sub-watersheds revealed that the effectiveness of SWC measures in reducing runoff and sediment yield reduces over time (Figure 3). This decline could be caused by constructed bunds being filled by sediments within two to three years after construction. Therefore, maintaining the constructed SWC measures every two to three years is essential to sustain their effectiveness in reducing runoff, SSC and sediment yield. The ongoing maintenance of existing SWC measures could be carried out by the government-led SWC campaign.

Acknowledgements

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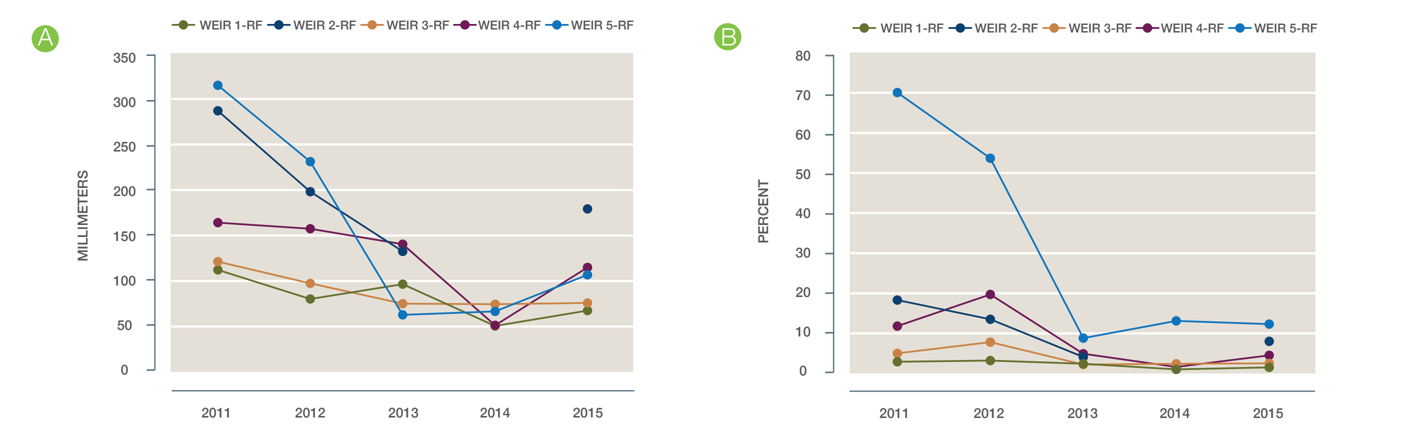
FIGURE 3: EFFECTIVENESS OF SWC MEASURES TO REDUCING RUNOFF (A) AND SEDIMENT YIELD (B) AS AFFECTED BY YEARS AFTER IMPLEMENTATION.



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