The Impact of Large-scale Government-led Soil and Water Conservation on Runoff and Soil Loss in the Debre Mawi Watershed

Debre Mawi is an agricultural watershed in the upper Blue Nile Basin. The slope ranges from 1% to 30% and the altitude varies from 2,195 m near the outlet to 2,308 m in the southeast. The area receives a mean annual rainfall of 1,240 mm with most of it concentrated between June and September (Dagnew *et al.,* 2014). Smallholder farmers produce cereals such as teff, maize, finger millet, barley, and wheat, which dominate land use in the watershed, followed by grassland and sparse vegetation.

The watershed is characterized by very low vegetation cover, severe sheet, rill and inter-rill erosion, and an active gully formation. The rate of erosion in the region is far beyond the tolerable rate, reaching 36 tons/ha/year from upland erosion (Zegeye *et al.,* 2010) and 234 tons/ha/year from gully erosion (Zegeye *et al.,* 2014). Erosion in the watershed has resulted in a loss of crop productivity due to loss of soil nutrients and land that is severely damaged by gully erosion.

Of the 528 ha covering the watershed, instruments were installed in an area of 95 ha by the Amhara Agricultural Research Institute and Bahir Dar University for erosion and hydrology studies. Traditionally, contour furrows were mainly used by farmers as soil and water conservation (SWC) measures. In 2012, the government initiated a large-scale SWC campaign, where 67 ha of the 95-ha study area was covered with SWC measures. The case study presented here discusses the effects of the government-led, large-scale SWC work on runoff and soil loss in the Debre Mawi watershed, which was studied under the umbrella of the Partnership for Enhanced Engagement in Research (PEER) science program funded by the United States Agency for International Development.

The intervention

Under the large-scale government-led intervention in the watershed, both physical and biological SWC measures were implemented. The physical measures included erecting soil bunds, stone-faced soil bunds, and stone bunds with infiltration ditches as deep as 50 cm. The SWC measures were placed in the up-slope, mid-slope, and bottom-slope positions and mainly on cultivated fields. To support the physical SWC structures, tree and grass species such as Sesbania (*sesbania grandiflora*), vetiver grass (*Chrysopogon zizanioides*), elephant grass (*Pennisetum purpureum*), and pigeon pea (*Cajanus cajan*) were planted (Dagnew *et al.,* 2014).

Farmers in the area received 2-week training on the causes of natural resource degradation, its effects on crop and livestock productivity, and the need to undertake watershed management to reverse the situation. With the support of development agents (DAs) and the local government, farmers formed village watershed committees and developed bylaws. The SWC campaign was conducted during the dry period when there were fewer farming activities. What differentiates this program from previous donor-driven interventions in Ethiopia is the no-cash-payment-to-farmers policy adopted by the campaign. In the SWC campaign, it was mandatory for women, men, youth (including the landless), and the elderly to participate. Absentees were penalized with a fine of up to 80 Ethiopian birr ($4). Given that this intervention was a huge investment in the environment and farmers' time, it is particularly important to investigate its effects in terms of hydrology and soil loss.

Methodology

Rainfall was measured by installing automatic tipping-bucket rain gauges. Stream flow was computed at the gauging stations using manual depth measurement and velocity of flow. Suspended sediment concentration (SSC) was evaluated by taking water samples every 10 min, filtering and weighing, and then determining the weight of the sediment per liter. Perched groundwater table was assessed by installing piezometers, whereas infiltration rates were measured by using a single ring infiltro-meter. Four years of data (2010–2013) of the main rainy months (June to September) were collected for this study. Outside of these months, rainfall, runoff, and soil loss were minimal and too inconsequential to evaluate the effects of SWC practices. In addition, a continuous observation of conservation structures and the watershed using transect walks, photo monitoring, and informal discussions with farmers helped acquire information pertinent to the study.

Results

Precipitation and infiltration

The total rainy-season rainfall from 2010 to 2013 was 890 mm, 917 mm, 832 mm, and 858 mm, respectively. The maximum intensity of rainfall in the 4 years was 38 mm/h/yr. The median infiltration rate was 33 mm/h/yr, 24 mm/h/yr, and 31 mm/h/yr, in 2010, 2012, and 2013, respectively. A comparison of rainfall intensity and infiltration capacity shows that rainfall intensity exceeded the infiltration capacity of the soil less than 5% of the time. This indicates that the dominant runoff-generating mechanism is saturation excess (Tilahun *et al.,* 2014) where runoff is initiated when the soil becomes saturated.

Water table dynamics

The groundwater table was deep up-slope, got shallower in the mid-slope, and was close to the surface down-slope in August. The water table is deep in the up-slope because the contributing area is small and the slope is steep. Thus, a relatively small flux with a large driving force provides for fast drainage. The lower slope position has a large drainage area, a low slope, and is the convergent area of the lateral subsurface flow and overland flow. To carry off the imposed flux, the water table rises until it intersects the surface. Water-table dynamics are extremely important for the design of infiltration furrows because when the water table intersects the infiltration furrows, water will flow out of the soil instead of into the soil. In the lower parts of the watershed, the water table comes near the surface, the soil saturates, and this further leads to the saturation of soil bunds. In fields where the groundwater is slightly deeper, the bunds are stable and they carry the drainage water off the field. But in fields where the groundwater is near the surface, any excess saturated flow through the furrows will flow at the end of the furrow down the hill and initiate gullies.

Discharge before and after SWC

The total runoff volume was, respectively, 33%, 21%, 13%, and 12% of the rainy-season rainfall from 2010 to 2013. Though there is monthly and interannual rainfall variability in the watershed, runoff reduction was 46% after SWC implementation, indicating that the interventions have resulted in reduced surface runoff as rainwater was collected and as it infiltrated in the furrows of bunds. The comparison of discharge for the month of September showed that it increased after SWC implementation. This is related to the effect of rainwater that infiltrated the furrows during July and August. The water was stored in the watershed, flowed with deeper flow paths to the outlet, and appeared as interflow and base flow, indicating that the measures have positive impacts on increased base flow response.

Changes in suspended sediment concentration and load

Sediment loads in July were the largest. The monthly sediment loads after the SWC intervention were reduced by half in July and August. The annual trend was very distinct where the loads were reduced fourfold. The decrease in sediment loads is mainly caused by the decrease in runoff and, to a smaller degree, a decrease in sediment concentration as sediment is trapped in the ditches of bunds. The mean sediment concentrations decreased from 22 g/liter before SWC implementation to 14 g/liter, in the first year after the intervention (in 2012). The lower rainfall in 2012 partly contributed to the reduction in sediment concentration. But the concentration increased to almost the previous level (20 g/liter) in 2013.

The disturbed soil from tillage and bund construction, together with the low vegetation cover and rills, may have played a role in the elevated sediment concentrations at the beginning of the rainy season. Later, sediment concentrations decreased because of the increase in vegetation cover and fewer rills. A large amount of sediment was trapped in the infiltration furrows of bunds. In the first year after implementation, an average depth of 21 cm of silt was deposited in the ditches (Fig. 2). Despite the sediment collected in the infiltration furrows of soil bunds, the 2013 reduction in SSC was not as large as that of 2012. In the watershed, the sediment concentrations do not show large reductions because the loose soils of the collapsed banks in the gullies contribute a significant amount to the sediment concentration at the outlet (Zegeye *et al.,* 2014).

Conclusion

The terraces installed as part of the government-led large-scale SWC program produced some very clear changes in the watershed, such as lower runoff and lower sediment load. However, sediment concentrations were not reduced. Unless gullies are treated, sediment from the gullies would lead to an increase in the sediment at the outlet. When soil bunds are placed in saturated bottomlands, the bund loses its strength and may initiate new gullies.

The recommendations in light of the findings from this case study are as follows:

- Treat gullies to reduce sediment in streams: Currently, gully treatment is not part of the large-scale SWC work in the watershed. To reduce sediment concentration, control and treatment of gullies need to be prioritized as part of large-scale SWC programs.
- Consider local hydrology: In the existing large-scale SWC works, SWC structures are sometimes installed without taking into account local hydrologic conditions. Increased performance of government-led SWC works can be achieved by taking local hydrologic conditions, such as high groundwater tables that prevent infiltration of rainwater, into account. This not only reduces the effectiveness of the SWC practices this not only reduces but also causes sediment loss as well.
- Maintain bunds to sustain their impact: Bunds that were installed in the Debre Mawi watershed in the last 2 or 3 years were not maintained. Although great reduction in sediment load was observed for the 2 years after SWC implementation, sustaining the reduction might not be easy. Furrows were half-filled with sediment within the first year and, therefore, their trap efficiency would only last for another 2-year period. This would be similar to the graded Fanya Juu bunds (infiltration furrows just off the contour, with soils thrown uphill) installed in the Anjeni watershed in the 1980s, which were only effective over a 4-to-6-year period (Elkamil, 2014).

- Consider further research into innovative practices: Continuous work is needed to maintain the infiltration furrows and this could be expensive as the SWC practices are currently under way on a large scale. Thus, research into other inexpensive ways to increase infiltration such as planting deep-rooted plants on bunds or deep plow by breaking the hard pan could be an area of further research.

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