Hydrological modeling of sustainable land management interventions in the Mizewa watershed of the Blue Nile Basin

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This analysis utilizes recent hydrological and meteorological data collected from the Mizewa watershed in Fogera woreda in order to better understand the physical impact of sustainable land and watershed management (SLWM) investments. The effectiveness of the simulated conservation practices (terraces, bunds, and residue management) are evaluated using the Soil and Water Assessment Tool (SWAT) model taking into account investment decisions on different terrain types. Simulations compare the limited investments that currently exist with increases in terracing and residue management activities within the watershed. The results suggest mixed impacts on surface run-off and erosion depending on terrain and management practices. However, the type and amount of investment (and therefore costs) in SLWM have different implications with respect to labor input and utilization of agricultural land, and the consequent socio-economic effects on households.

Continuous investments in SLWM in the Blue Nile Basin suggest a need for improved water management in order to boost agricultural output in the highlands of Ethiopia. Ethiopia’s unique biophysical variability provides the underlying conditions for abundant freshwater resources. However, deforestation, fragile soils, undulating terrain, and heavy seasonal rains make the highlands of Ethiopia vulnerable to soil erosion and gully formation in the rainy season. During the dry season in the Upper Blue Nile basin, water scarcity and low water tables cause previously perennial streams to be intermittent, affecting agricultural yields.

Study area and focus

The Mizewa watershed in Fogera woreda in the South Gondar zone of Amhara region in north-central Ethiopia is the focus study area. We examine the impact of runoff and sediment capture of a variety of SLWM investments on different slope types (steep, midlands and flatland). We simulate a variety of SLWM investments over a 20-year investment period (2009-2030) in order to measure the impact of these investments on agricultural production.

Figure 1 – Mizewa watershed, elevation and streambed

The Mizewa watershed is approximately 27 km² in area, with altitude ranging from 1,850 to 2,370 m above sea level. Approximately 65 percent of households live on a slope that is between 5 and 20 degrees, while 22 percent live on steep slopes (> 20 degrees). The remaining 13 percent of households live on relatively flat land with less than a 5 degree slope. Farmers in the midland area (5-20 degree slope) of the watershed use a variety of soil conservation practices, including terracing, rainwater harvesting structures, afforestation, and area enclosures to slow runoff during the wet season. However, during data collection in 2010, farmers identified water shortages during the dry season as a major challenge, pointing to the recent seasonal drying of one of the tributary rivers (Ginde Newr) during the dry season as evidence of this trend. Conversely, farmers in the flat area of the watershed identified flooding as a major problem during the main kiremt rains with frequent waterlogging of maize.

Modeling simulations to assess SLWM investments

We model different SLWM investments including terracing, soil and stone bund construction, and residue management. The Soil and Water Assessment Tool (SWAT) is used to simulate the impact of SLWM investments on water balance and erosion. In this analysis, the simulations created are:

1) Terracing on steep hillsides (slopes greater than 20 degrees)
2) Terracing on mid-range and steep hillsides (slopes greater than 5 degrees)
3) A mix of terracing and bunds on varying slope gradients
4) Residue management on all agricultural fields
5) A mix of terraces and residue management on steep and mid-range terrain where a majority of agricultural activity takes place

We compare these simulations to a calibrated base simulation that reproduces the current conditions in the watershed.

Results

Simulations of the selected SLWM investments suggest that improvements in infiltration and decreases in surface runoff and erosion are achievable in the Mizewa watershed. These decreases depend on the magnitude of the investment. The effectiveness of each simulation also depends on the share of land available and the topographical characteristics of the watershed. Given that 65 percent of the Mizewa watershed terrain has a slope between 5 and 20 degrees, the most effective SLWM investments on
overall water balance measurements occur when investing on mid-range slopes. Constructing terraces in areas with slopes greater than 5 degrees reduced average daily surface flow from 0.40 to 0.32 mm (20 percent). Similarly, a combination of residue management in flat and middle slope areas and terracing on steep slopes reduced surface runoff from 0.40 to 0.32 mm. The effects of extreme rainfall events on runoff response (maximum flow) also decreased with improved watershed management, although peak flows remain relatively high in all investment simulations.

Table 1 – Percentage change in average annual simulated discharge and sedimentation of SLWM practices (2009-2030) relative to baseline conditions

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Surface flow</th>
<th>Groundwater flow</th>
<th>Stream flow</th>
<th>Sediment yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Baseline scenario</td>
<td>44.6 mm</td>
<td>65.6 mm</td>
<td>313 mm</td>
<td>1.0 mt/ha</td>
</tr>
<tr>
<td>2) Terrace steep slopes</td>
<td>-13.8</td>
<td>4.5</td>
<td>-7.7</td>
<td>-35.4</td>
</tr>
<tr>
<td>3) Terrace middle &amp; steep slopes</td>
<td>-42.6</td>
<td>80.4</td>
<td>-10.0</td>
<td>-90.3</td>
</tr>
<tr>
<td>4) Terraces middle &amp; steep slopes, soil bunds on slopes of 1 to 5 degrees</td>
<td>-47.2</td>
<td>83.2</td>
<td>-10.0</td>
<td>-92.2</td>
</tr>
<tr>
<td>5) Terraces middle &amp; steep slopes, residue management slopes up to 5 degrees</td>
<td>-45.8</td>
<td>82.3</td>
<td>-10.0</td>
<td>-88.7</td>
</tr>
<tr>
<td>6) Terraces steep slopes, residue management slopes up to 20 degrees</td>
<td>-29.1</td>
<td>12.2</td>
<td>-7.8</td>
<td>-45.5</td>
</tr>
</tbody>
</table>

Source: Authors’ calculations

The simulations suggest that a landscape-wide approach of terrace and bund construction has the greatest effect in terms of decreasing surface runoff and sediment yield. A comprehensive landscape investment of terraces on middle and steep slopes and soil bunds on slopes of 0-5 degrees over the simulation period (2009-2030) would decrease surface flow by approximately 47 percent, increase groundwater flow by 83 percent, and decrease sediment yield (erosion) by 92 percent (Table 1, Simulation 4).

Moreover, constructing only terraces in areas with greater than 5 percent slopes has a similar effect (Simulation 3). Residue management also has an effect on surface flow and erosion in the Mizewa watershed decreasing sediment yield by almost 46 percent if paired with terraces on steep land (Simulation 6).

The simulations suggest that decreased average monthly runoff during the rainy season is the primary driver to reduce erosion (Figure 2) and surface flow (Figure 3). Residue management on flat and middle slopes with terraces on steep slopes had less of an effect on surface runoff and sediment.

Caveats and further study

A model performs well only with reliable, accurate data input. Some weaknesses in this kind of analysis should be noted:

- Non-linear relationships between hydrologic input and response

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