Modelling stream flow and Sediment using SWAT in Gumara-Maksegnit watershed

Reducing Land Degradation and Farmers' Vulnerability to Climate Change in the Highland Dry Areas of North-Western Ethiopia

TECHNICAL REPORT OF EXPERIMENTAL ACTIVITIES

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Implemented by

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About the Project

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The International Center for Agricultural Research in the Dry Areas (ICARDA) is the global agricultural research Center working with countries in the world's dry and marginal areas, supporting them for sustainable agriculture development to help increase their productivity, raise incomes for smallholder farmer families, improve rural nutrition and strengthen national food security. With partners in more than 40 countries, ICARDA produces science based-solutions that include new crop varieties (barley, wheat, durum wheat, lentil, faba bean, kabuli chickpea, pasture and forage legumes); improved practices for farming and natural resources management; and socio-economic and policy options to enable and empower countries to improve their food security. ICARDA works closely with national agricultural research programs and other partners worldwide in Central Asia, South Asia, West Asia, North Africa, and Sub-Saharan Africa.

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Synthesis

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Summary report

The coincidence of intensive rainfall events at the beginning of the rainy season and the unprotected soil conditions after exhaustive dry spells expose the Ethiopian Highlands to severe soil erosion. Massive efforts are being made in soil conservation strategies by the government of Ethiopia. However, the effectiveness of this soil and water conservation on the dynamics of the nutrient, stream flow and sediment loading is not sufficiently studied. Soil and water conservation measures (SWC) have been applied to counteract land degradation in the endangered areas, but SWC efficiency may vary related to the heterogeneity of the landscape. In this research simulation modelling was conducted to assess the spatially distributed impact of SWC structures at different scales (main watershed: sub-watersheds). Runoff/erosion plot experiments were also conducted to obtain further data to support modelling, in addition to the hydrological data measured at watershed outlets described in section 1.1 of this report. The plot studies were the subject of research for several junior researchers and MSc students from BOKU University. Their theses are published and available for consultation, the results are not summarized here for reasons of space. The results obtained through SWAT modelling at the scale of the main watershed (Gumara-Maksegnit) are currently in publication (article under revision) and are only briefly summarized in Part I of this report section. At the sub-watershed scale the study is still ongoing and is the subject of a PhD research that will continue until the end of 2017.

Part I: Main watershed (Gumara-Maksegnit)

The Soil and Water Assessment Tool (SWAT) model was used to model hydrology and sediment dynamics of the Gumara Maksegnit watershed (53.7 km2).

Spatially distributed stone bund impacts were simulated in the model through modification of the surface runoff ratio and adjustment of a practice factor simulating the trapped amounts of water and sediment at the SWC structure and watershed level.

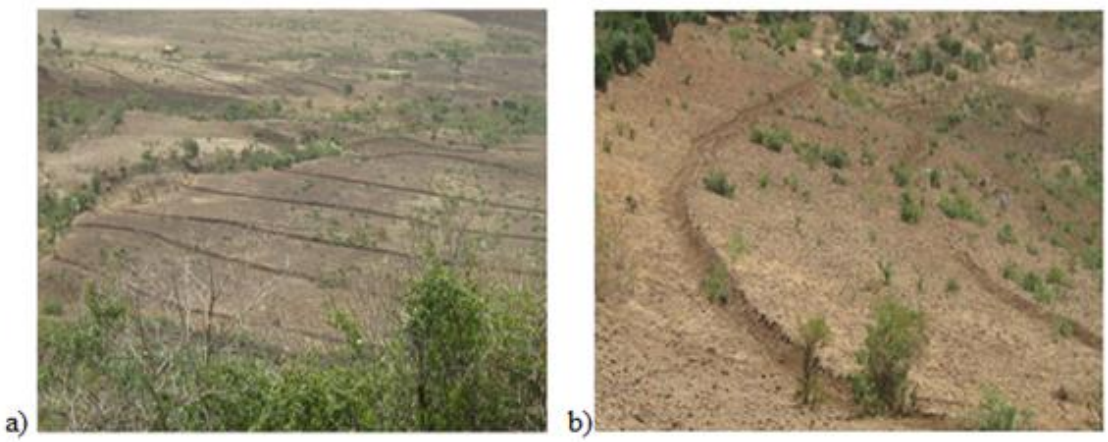

Figure 1. Stone bund treated fields (a) and small channel above the stone bund (b)

The resulting Nash-Sutcliffe efficiency (NSE) for daily stream flow simulation was 0.56 for the calibration and 0.48 for the validation period, suggesting satisfactory model performance.

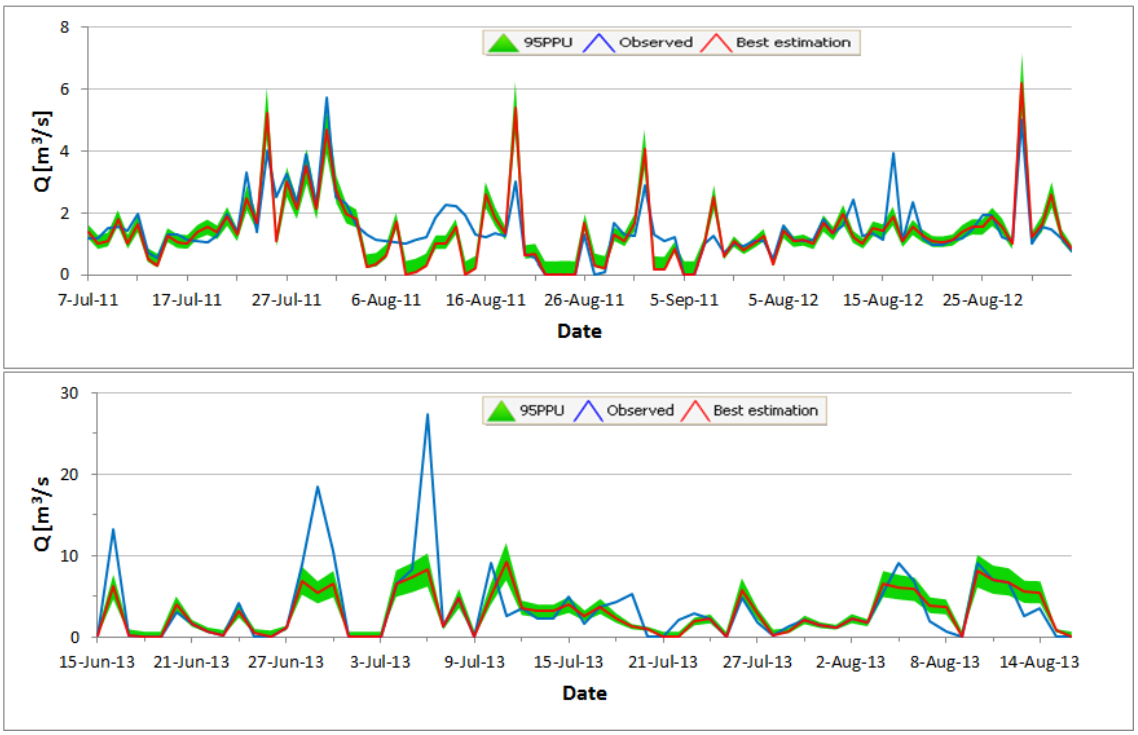

Figure 2. Observed and simulated daily stream flow hydrograph at the outlet of Gumara-Maksegnit watershed, calibration (top) and validation (bottom)

In contrast, the daily sediment simulation resulted in unsatisfactory model performance, with the NSE value of 0.07 for the calibration and –1.76 for the validation period and this could be as a result of high intensity and short duration rainfall events in the watershed. Based on the calibrated SWAT model, the long-term average annual runoff at the main outlet was predicted to be 352 mm, while approximately one third of annual rainfall amount (373mm) becomes evapotranspiration. Meanwhile, insufficient sediment yield prediction may result to some extent from daily based data processing, whereas the driving runoff events and thus sediment loads occur on sub-daily time scales, probably linked with abrupt gully breaks and development. The calibrated model indicated 21.08 Mg ha-1 average annual sediment yield, which is far beyond potential soil regeneration rate. Despite the given limits of model calibration, SWAT may support the scaling up and out of experimentally proven SWC interventions to encourage sustainable agriculture in the Ethiopian Highlands.

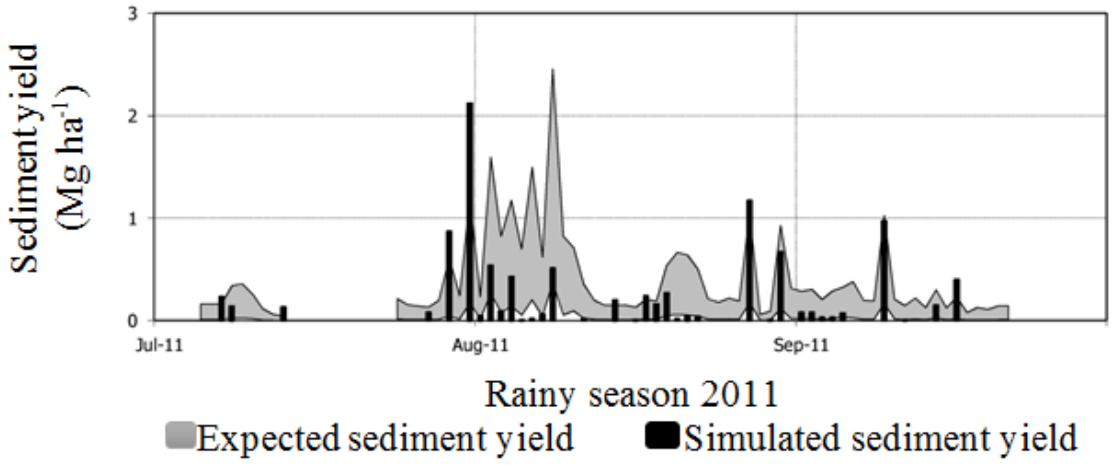

Figure 3. Example of sediment yield records (expected/simulated) for one full rainy season (2001).

Rethinking of land management strategies and intensification of SWC interventions may be needed to achieve sustainable agriculture. The Ethiopian Highlands are a fragile eco-region worthy of protection and physically-based modeling may be one method to guide scaling up of efficient measures to counteract ongoing land degradation. Eventually, advanced SWC impact assessment may be needed to consider the interaction between various SWC structures and heterogenic landscape conditions to support proper decision making in the future.

Part II: SWAT model for the two adjacent sub-watersheds (ongoing)

SWAT model is being applied to estimate the sediment yield and runoff in two adjacent sub watersheds in Gumara-maksegnit (Abakaloye and Ayaye), one treated with SWC structures, the other not treated. The effects of SWC measures (stone bunds) in the treated sub-watershed (Ayaye) in comparison to the untreated sub-watershed (Abakaloye) were evaluated.

The two sub-catchments are located in the southern, lower part of Gumara-Maksegnit watershed (Figure 4). They are neighboring each other with a distance of about 1 km between the outlets. Aba-Kaloye and Ayaye sub-watershed embrace an area of 31 and 24 ha respectively while their altitude reaches from about 1998 m.a.s.l. to about 2150 m.a.s.l. They are also characterized by a mountainous topography with steep slopes, where about 80 % of the area have an inclination >10 %.

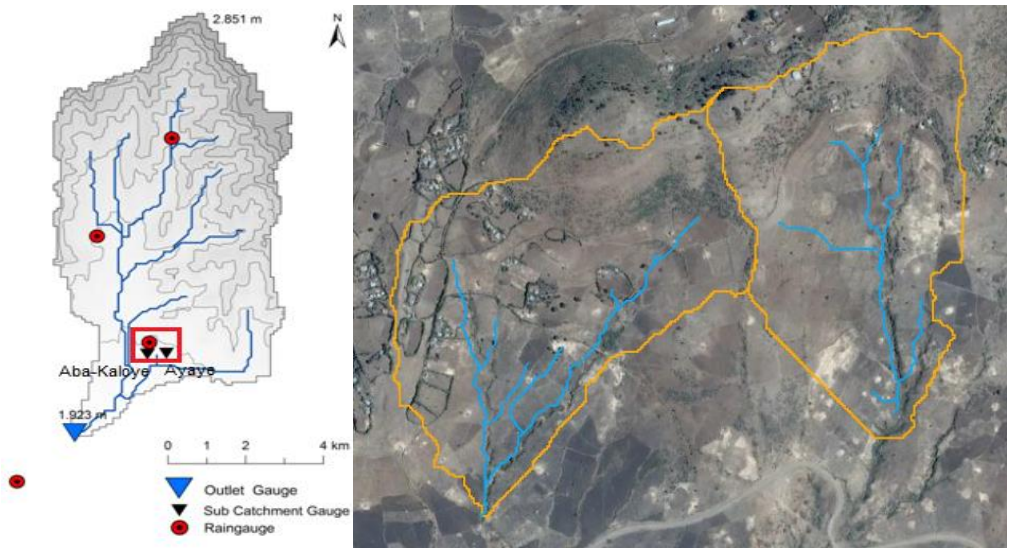

Figure 4 Map of the study area (Gumara-Maksegnit watershed) with Abakaloye (left) and Ayaye (right) sub watersheds.

To prepare the study, highly detailed (5 m resolution) digital elevation models (DEM) of the sub-watersheds were generated by using data collected with theodolites from field survey. A detailed soil map was made based on soil samples taken in a 100 m by 100 m square grid across the sub-watersheds. The land-use data were digitized using Google earth images.

All data available from the hydrological monitoring system are being used to calibrate and verify a distributed simulation model.

Expected output

Both sub watershed show severe soil erosion problems, which show itself in the development of deep gullies. According to Bosshart (1997), the potential short-term benefits of stone bunds are the reduction of slope length and the creation of small retention basins for runoff and sediment. These effects appear immediately after the construction of the stone bunds and result in reduced soil loss. The major medium and long-term effect is the reduction in slope steepness by progressive formation of terraces through the filling up of the retention spaces with sediment.

The stone bunds form a barrier that slows down water runoff, allowing rainwater to seep into the soil and spread more evenly over the land. This slowing down of water runoff helps with building-up a layer of fine soil and manure particles, rich in nutrients. The layers have an impact on slope, flow direction and flow accumulation changes. Stone bunds on cultivated land reduce slope length and slope gradient but increase the number of boundaries of the cultivated plots, which aggravates tillage erosion.

The SWAT model will be used to simulate these effects. The simulation results will be compared with the observed values. After model verification different land use and climate change scenario will be simulated to evaluate present and future sustainable land use/management systems and to work out recommendations. The findings should then be used for the up-scaling of SWC impacts, to gain a deeper insight into SWC interactions at sub-watershed level related to hydrological and land degradation issues.

REFERENCES

Addis, H.K., Strohmeier, S., Klik, A.,. Modeling streamflow and sediment using SWAT in Ethiopian highlands. International Journal of Agricultural and Biological Engineering. Under revision.