Modelling soil erosion response to sustainable landscape management scenarios in the Mo River Basin (Togo,West Africa)

Citation:

Diwediga, Badabate; Bao Le, Quang; Agodzo, Sampson K.; Tamene, Lulseged; Wala, Kperkouma. 2018. Modelling soil erosion response to sustainable landscape management scenarios in the Mo River Basin (Togo,West Africa) . Science of the Total Environment. 625: 1309-1320.

Publisher's DOI:

https://doi.org/10.1016/j.scitotenv.2017.12.228

Supporting Information to the manuscript:

Modelling soil erosion response to sustainable landscape management scenarios in the Mo River Basin (Togo, West Africa)

Graphical user interface of the LAMPT_Mo

Fig S1 presents the graphical use interface of LAMPT_Mo adapted from the original LAPMAT (Tamene et al., 2014). Labelled feature 1 composes of options for importing input variables spatially explicated through maps (individually displayed via Feature 2). The selection of adequate values for mean annual rainfall, slope steepness and length, and definition of threshold constants for potential location of gullies (Moore et al., 1991) are performed under Feature 1. Management options for enclosing gully lands, erosion hotspot areas, and steep lands, as well as terracing steep lands and gully areas and updating P factor are proposed under the same Feature 1. Feature 3 offers the ability to compute the spatially explicit potential (STCI) and actual (GSL) soil loss, sediment delivery ratio (SDR) and net soil loss (NSL) at the landscape level. While the imported and generated variables as well as the simulated soil loss are visualised for their spatial configuration (Feature 4), graphical options are offered to visualise the outputs according to slope classes (Feature 5), land use/cover types and protection status (Feature 6), and river buffer zones (Feature 7). Features 8 and 9 are provided for exporting the outputs in tabular forms for usage in other analytical environment (GIS, statistical software, etc.).

Different types of settings (key inputs) are relevant to design and implement LAMPT_Mo. Therefore, initial biophysical conditions (data on terrain and its derivatives, land use/cover, soil erodibility based on soil types, protection status of lands, buffer zones of river network, etc.) are prepared for the Mo River basin (see Fig S2).

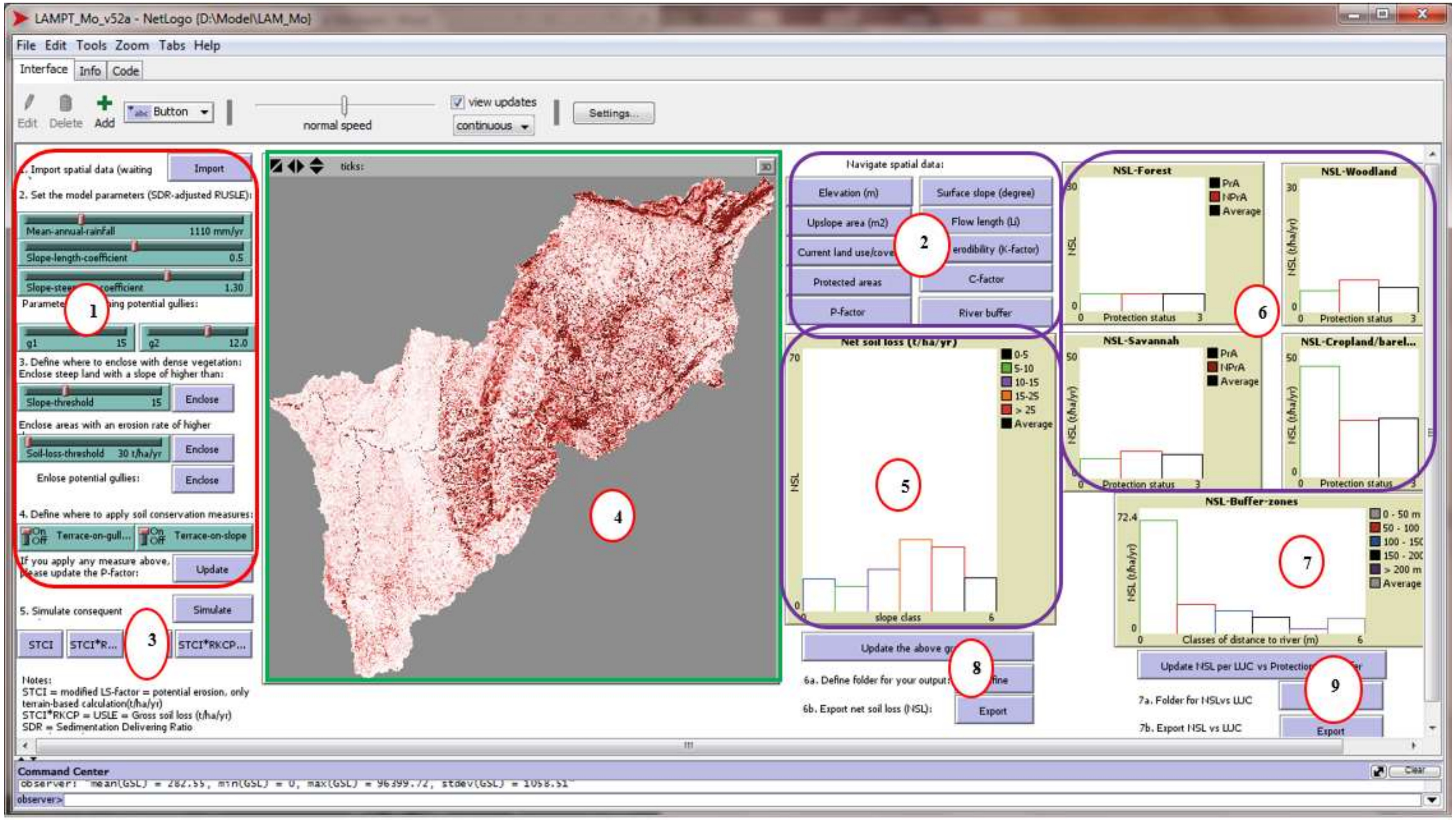

Fig S1. Graphical user interface of the LAMPT_Mo

Key inputs for LAMPT_Mo

The different key layers used to design and implement LAMPT_Mo are presented in Fig S2. They are provided at 30 m resolution. These data show only those that were imported into the model as maps. Other numerical inputs are presented in the main text of the paper.

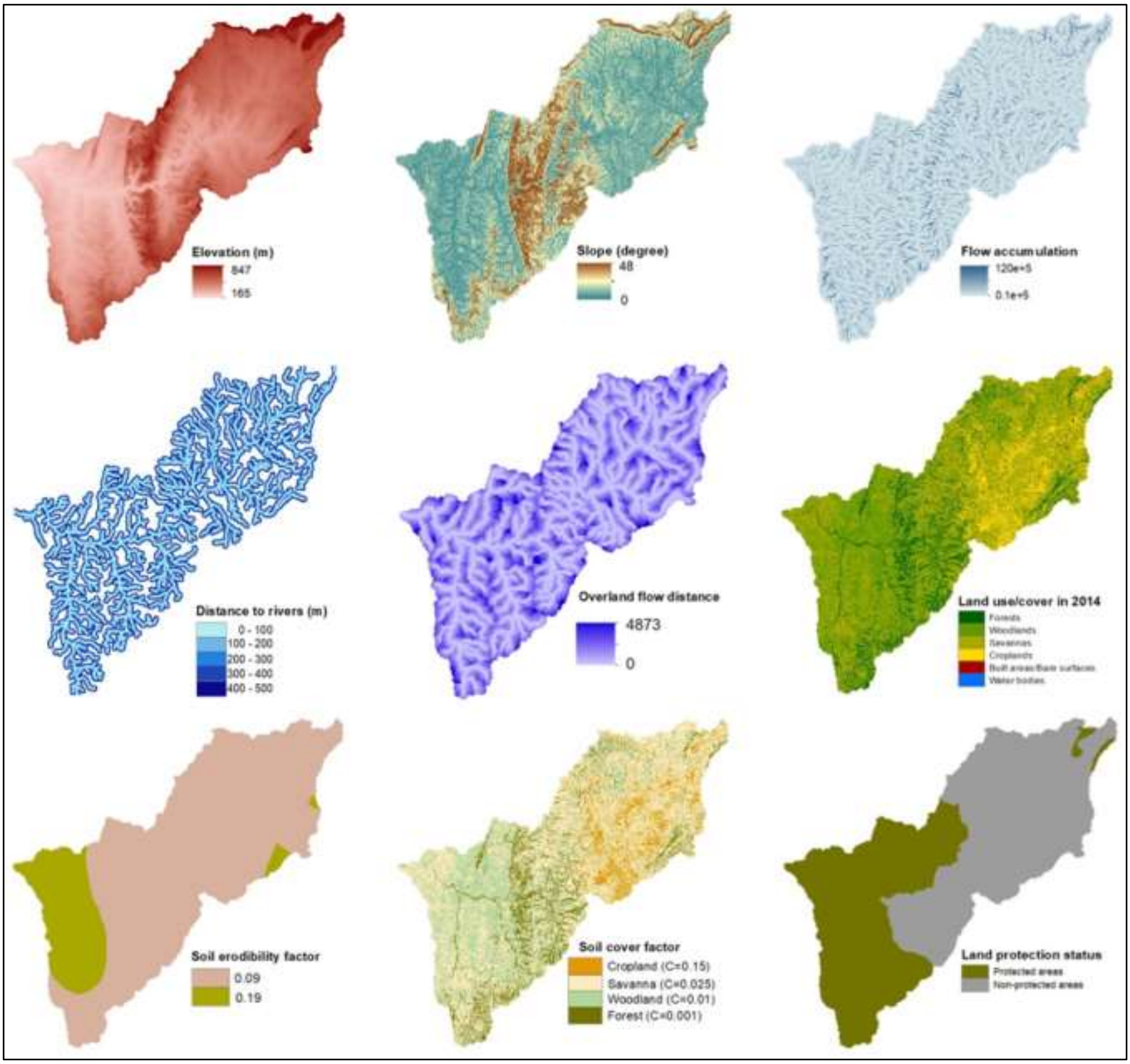

Fig S2. Input layers for LAMPT_Mo

Description of scenarios and simulation outputs

According to Economics of LD initiative, scenario analysis or planning is a 'structured process of exploring and evaluating alternative futures', whose ultimate aim is to illustrate the consequences of policy options, inform and improve decisions. In this context, two categorical scenarios were defined for simulating soil loss and propose alternatives for adapted land management: (i) simulation based on business as usual (BAU or S0) conditions, and (ii) simulation based on LUC management options (S1). For all scenarios, simulated soil loss is analysed to highlight the contribution of specific LUC types, slope-classes and river buffer zones to soil erosion. Most of the scenario designs result from LUC-reorganisation at the landscape level in order to identify viable options that significantly reduce soil loss (Tamene, 2005; Tamene et al., 2014). In all of the scenarios proposed in the LAMPT_Mo, default values of model variables are offered according to the conditions in the Mo river basin. Nevertheless, large ranges of values are provided for selecting appropriate design of conservation in specific sites and when facing uncertainties related to the selection of values (Tamene et al., 2014).

a) Scenario of business as usual for historical soil loss assessment

Simulation was performed for the status quo (BAU) i.e. annual soil loss/sediment yield rate and its spatial pattern for 2014 was calculated based on the landscape conditions representing the existing land conditions (Tamene, 2005; Tamene et al., 2014). The result of 2014 served as reference data for comparison of the simulated soil erosion/sediment yield of 1972, 1987 and 2000 in order to highlight not only the effects of LUCC but also the potential effects of changing rainfall. Since there is no historical reference for the Mo basin for quantitative validation of the simulated historical NSL, the reference simulation for 2014 was used to qualitatively validate the aforementioned data based on LUCC.

b) Management scenarios (S1): reducing soil loss at landscape level

Management options are built to express scenarios that focus on reorganising LUC types and adopting conservation practices across landscapes based on predefined criteria, such as conserving gullies and their buffer zones (S1G), managing intensive erosion areas or hotspots (S1H), reducing erosion from steep slopes (S1S), and planting strips along stream network in UPA (Strips).

- **Management options targeting gullies (S1G)**

Conservation measures to reduce erosion from gullies, especially in human-accessible landscapes, are recognised as preventive measure for reducing soil loss potential (Tamene et al., 2014; Tamene, 2005). For that purpose, scenario S1G focused on the conservation of gullies and buffer zones of 25 m alongside these gullies (Tamene et al., 2014). Though this study encompasses both natural (protected or not) areas and human dominated landscapes (agrosystems), management efforts through S1G aim at terracing the 25 m buffer zones by converting them into vegetated lands (woodlands), suggesting a status of these areas as protected against human impacts. Therefore, it is proposed as default values for *P* factor (0.5) and C factor (0.01). C factor meets the proposed value for woodlands based on the patterns of the study area where most of the streams and rivers, acting as gullies, are bordered by vegetation. The outputs from this scenario are compared to the benchmark (scenario S0) to highlight the efficiency of the proposed preventive measure.

- **Management options targeting the conservation of erosion hotspots (S1H)**

In this sub-scenario S1H, efforts are undertaken in reducing the erosion severity in the identified erosion hotspots based on acceptable soil loss in the area (Tamene et al., 2014). For the Mo basin with tropical climate, mountainous topography and medium annual rainfall, the tolerable soil loss is located on potential hotspots with soil loss higher than or equal to 15 t/ha/yr. The latter threshold was considered to evaluate and easily compare the NSL in the Mo basin with the tolerable limits of 12 – 15 t/ha/yr (Roose, 1996), used in West Africa environments (Le et al., 2012b). In addition, varying threshold for hotspots definition, this scenario evaluated the effects of management size on the NSL at landscape level, if efforts could target soil loss limits lower than (5 and 10 t/ha/yr) or higher than (20 and 25 t/ha/yr) the acceptable value of 15 t/ha/yr. The scenario principle is that erosion hotspots higher than the tolerable set value are assumed to be converted into either vegetated areas (S1HA). In addition, terraces or grasses could be used to conserve gullies along with the enclosure of the erosion-prone areas (S1HB). Proposed default values for P and C factors were 0.5 and 0.01, respectively. The results from this scenario are compared with the benchmark (S0) and other management options to judge their efficiency on the reduction of soil loss.

- **Management targeting exclusively areas with steep slopes (S1S)**

Due to the high roughness of the Mo landscapes, conservation measures focusing on steep slope management are oriented towards the reduction of surface runoff and hydrological processes, which often occur at relatively high rate on these slope positions, regardless of the surface cover. The rate of sediment yield and transport toward rivers/streams is acutely observed in these sensitive lands since slope influences the surface flow rates and sediment movement by increasing surface hydrological phenomena (e.g. Moore et al., 1991). Therefore, efforts targeting these erosion-prone areas are assumed to reduce the amount of net soil loss at the landscape level and reduce river siltation. Though the purpose of this option is not to cut down the steep slopes into gentle ones, it is assumed that preventive measures such as covering these slopes with dense vegetation will stabilise lands and reduce the occurrence of new gullies, and consequently abate the rate of surface runoff and transported sediments (Tamene, 2005). The proposed preventive measures in the current study focused on land with slope higher or equal to 15 ^{O} (considered as very steep). In this scenario (S1S), the considered steep lands (> 15 ^{O}) are converted into PA with restricted human interventions affecting their stability. Therefore, they are assumed to be covered by relative dense vegetation (e.g. woodlands), setting the C factor value to 0.01. Finally, the outputs from this scenario are compared with other scenario runs and the benchmark to assess the efficient impact of the proposed management option on soil loss/sediment yield at the landscape level.

- Planting strips along river network in unprotected areas

Like terraces and contour lines, strip cropping represents a support practice for soil erosion control. In contrast to structural technologies such as terracing, stonewalls and ridging, strip cropping is part of organic technologies that improve the soil characteristics to resist erosion while increasing biomass production and ground coverage (Donovan & Casey, 1998). A buffer strip of native plants can reduce the impact of surrounding land uses on the sediment yield downstream. This scenario could help in addressing issues of soil loss in undisturbed landscapes that affect biogeochemical cycles of carbon and nitrogen, and implications for climate change issues. In the LAMPT_Mo, it is suggested that the planting of highly diverse native plant species in order to match local soil types and especially increase the resistance to soil erosion (Berendse et al., 2015). Therefore, an alternation of strips and natural vegetation is proposed in the riparian lands up to 500 m alongside rivers (Table 7.3). Exclusively, this option is implemented in unprotected areas to highlight the influence of this support practice on agricultural land use system. In the first 100 m from the riverbanks, the option sets strips of natural vegetation (mainly as riparian forests with heavy-deepen root systems) and the C factor is 0.001. This option is implemented regardless of the stream importance and location in unprotected areas.

Table 7.3. Strip planting in the first 500 m along riversides

Buffer zones	Strip types	C factor and Ri
0 – 100 m	Natural vegetation (Riparian forests)	C=0.001; Ri = 0.35
100 – 200m and 300 – 500 m	Perennial croplands/orchards /Agroforests	C= 0.15; Ri = 2.13
200 – 300 m	Natural vegetation (woodland/savannah)	C= 0.01 ; Ri = 0.40

Group discussions and participatory mapping

Photo S1. Group meeting sketching erosion prone areas during a participatory mapping in Aleheride

Historical NSL according to LUC types in the Mo basin

The distribution of NSL according to the four major LUC types (forests, woodlands, savannahs and croplands) are presented in Fig S3.

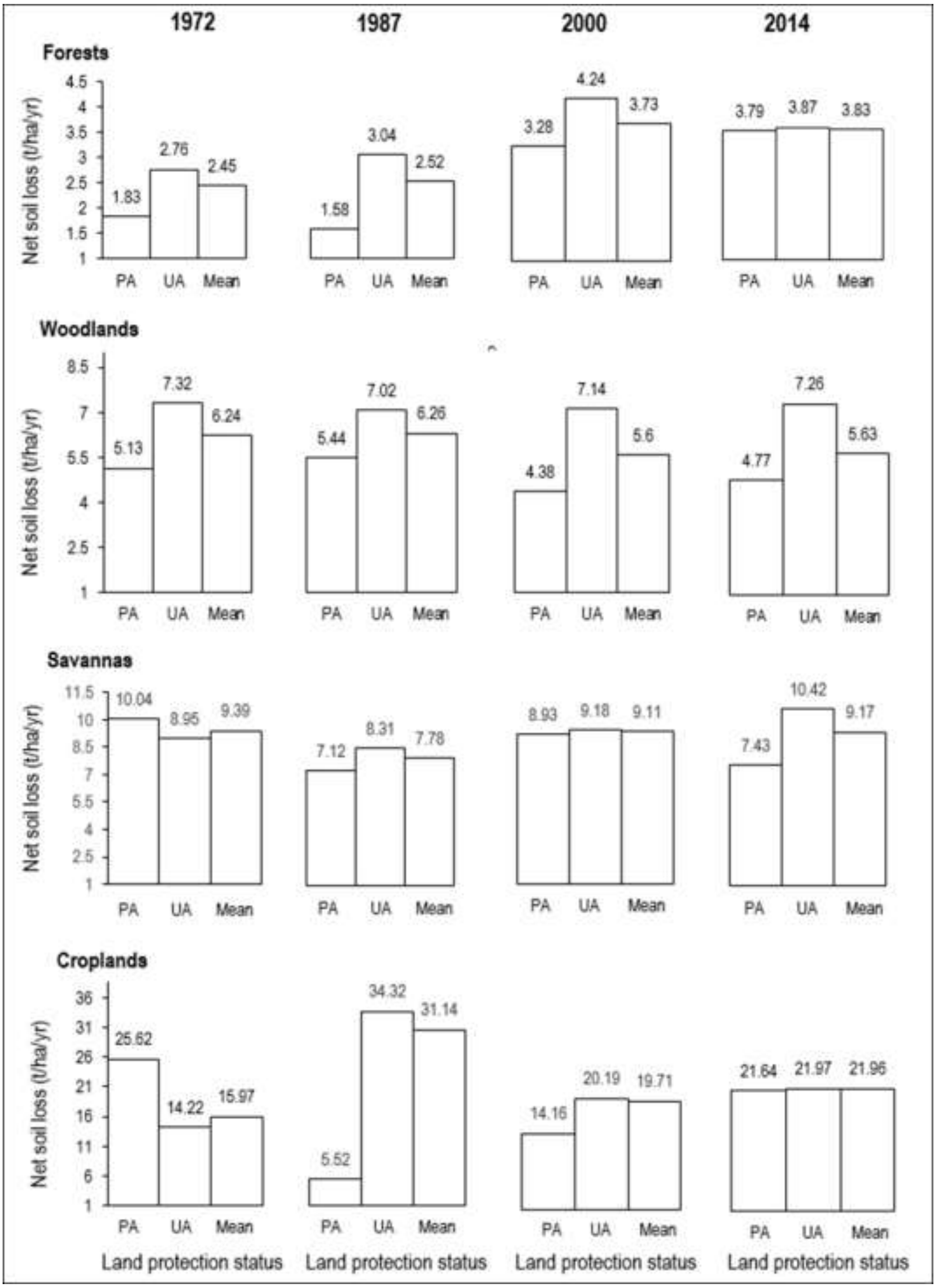

Fig S3. Historical NSL in different land use cover types per land protection status (PA = protected areas, UA = unprotected areas, Mean = average value)

Historical NSL in relation to distance to river in the Mo basin

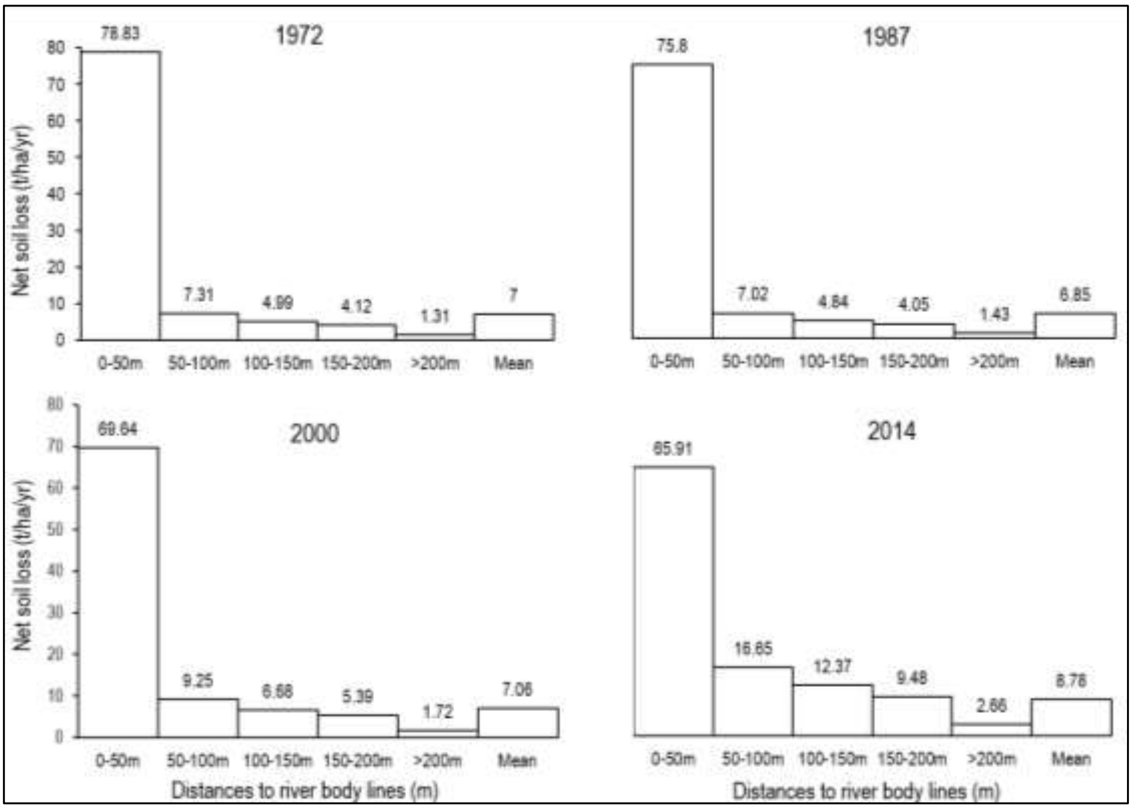

Fig S4. NSL over time according to distances to river/stream

Effects of land management on NSL in forest areas

Though S1G and S1S show a slight decrease of savannah-NSL in both PA and UPA, the effects are very low to encourage the adoption of such options towards the reduction of savannah-specific NSL reduction. In areas with poor surface cover dominated by croplands, Strip planting in UPA contribute to a significant reduction of NSL (from 22 to 9 t/ha/yr), indicating that this option is effective in reducing soil loss up to 59 % compared to the baseline. The NSL in UPA remains unchanged for croplands because the strip-planting option suggests that sole areas outside are managed since croplands in PA are illegal incursions that will not gain agreement for option implementation. Option S1S seems to be not efficient in reducing NSL since it is rare to observe croplands on steep lands. When land management aims at targeting gullies, NSL in PA significantly reduces by 50 % whereas in UPA, the change is not sensitive at landscape level. This is because gullies are densely developed in PA, which lies in more rough landscapes while in UPA, farmers concentrate on more fertile lands on flat terrains and inland valleys.

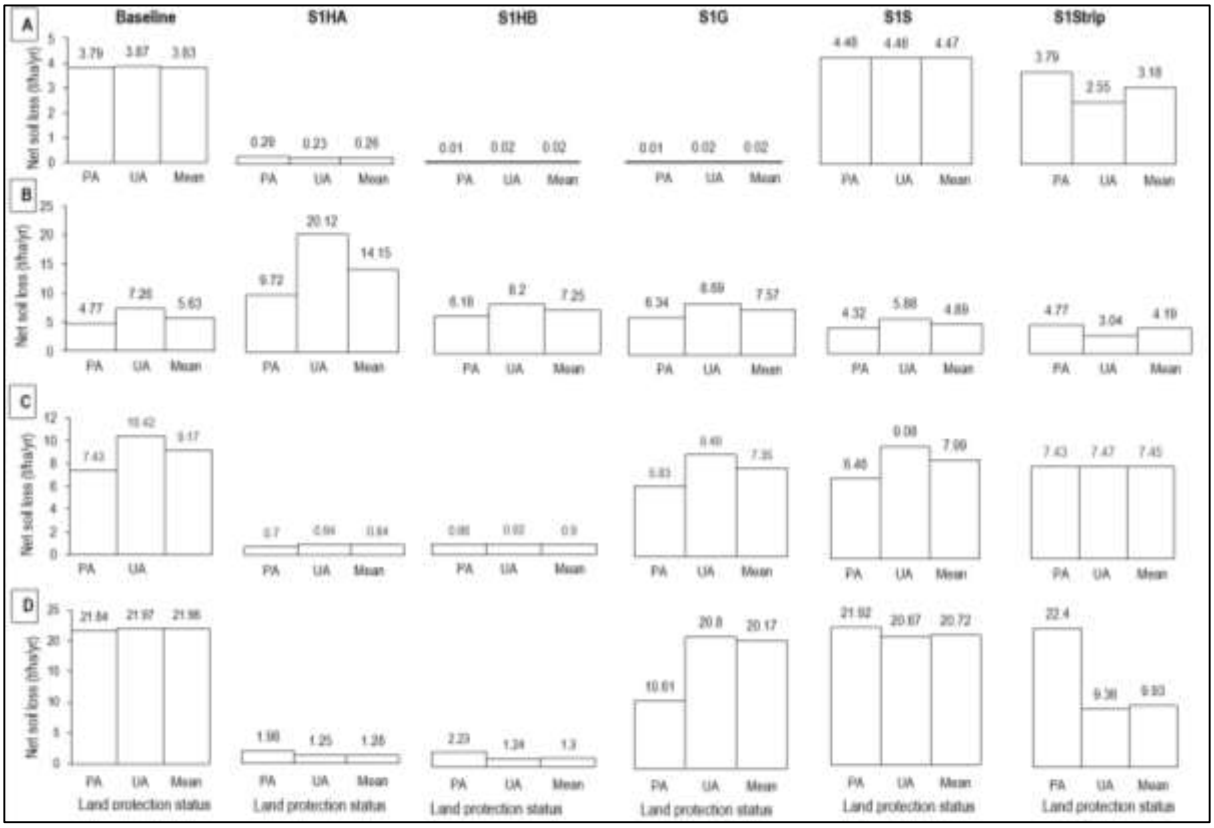

Fig S5. NSL (in t/ha/yr) in LUC according to protection status (PA = Protected Areas, UA = Unprotected Areas) and management options (Baseline, S1HA= scenario aiming at controlling erosion hotspots, S1HB = S1HA + terraces + grasses; S1G = Protection of gullies; S1S = Protection of steep slopes; S1Strip = Planting strips). A = Forests, B = Woodlands, C = Savannas; D = Croplands.

NSL sensitivity to management thresholds of NSL

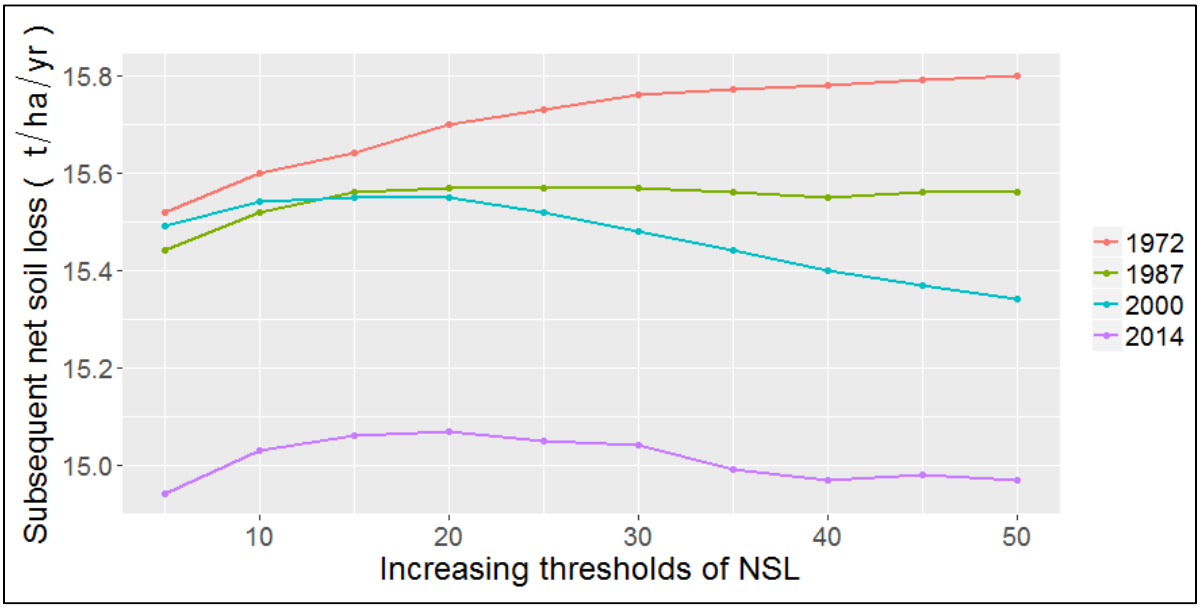

Fig S6. Consequent NSL in relation to soil loss thresholds for the four years

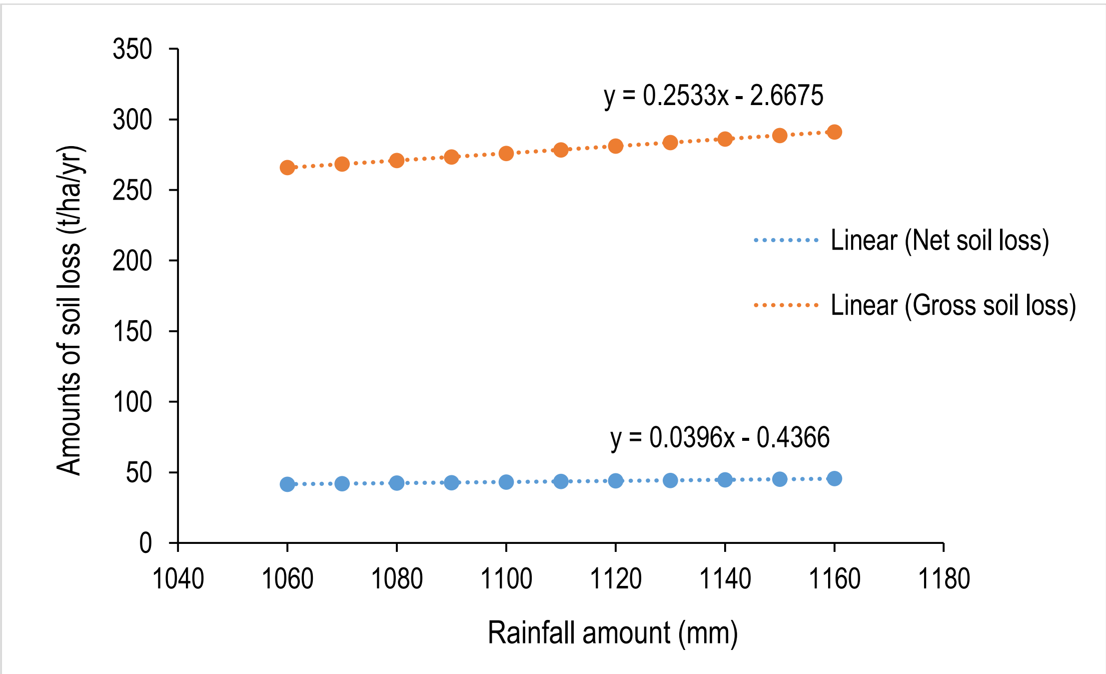

Figure S7. Linearity between rainfall and the simulated soil loss at the basin level

References

Berendse, F., van Ruijven, J., Jongejans, E., & Keesstra, S. (2015). Loss of Plant Species Diversity Reduces Soil Erosion Resistance. *Ecosystems 18(5): 881-888*. doi: 10.1007/s10021-015-9869-6

Donovan, G., & Casey, F. (1998). Soil fertility management in sub-Sahara Africa.. World Bank Technical Paper (Vol. 408).

Moore, I. D., Grayson, R. B., & Ladson, A. R. (1991). Digital terrain modelling: a review of hydrological, geomorphological and biological applications. *Hydrol Process,* 5, 3-30.

Tamene, L., Le, Q. B., & Vlek, P. L. G. (2014). A Landscape Planning and Management Tool for Land andWater Resources Management: An Example Application in Northern Ethiopia. *Water Resources Management, 28*. doi: 10.1007/s11269-013-0490-1

Tamene, L. (2005). *Reservoir siltation in Ethiopia: Causes, source areas, and management options*. PhD thesis, University of Bonn, Germany.