Runoff, soil loss, and soil properties as influenced by land use and management practices: Case study from the Upper Blue Nile basin, Ethiopia

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Abstract

Soil erosion by water is one of the most pressing environmental challenges in Ethiopia where small-scale agriculture is the main source of livelihood for about 87% of country's population. In the past few decades, huge financial and labor resources have been invested for the implementation of sustainable land management (SLM) practices in many regions of Ethiopia to mitigate soil erosion and related consequences. Relevant studies are, however, limited for the wetter and actively eroding regions like the Upper Blue Nile basin due partly to insufficient policy attention and difficulties inherent in collecting sufficient and reliable runoff, soil, and sediment data at wider spatial and temporal scales. This study was, therefore, conducted in three contrasting agro-ecologies (lowland, midland, and highland) of the Upper Blue Nile basin to quantify the influence of land use and management practices on runoff, soil loss (SL), and soil properties. The analysis of runoff and SL was based on the data collected during the rainy seasons of 2015 and 2016 using runoff plots (30 m $\times$ 6 m) from three land use types (cropland, grazing land, and degraded bushland) with four treatments (control, soil bund, Fanya juu, and soil bund reinforced with grass) for croplands, and three treatments (control, and exclosure with and without trenches) for non-croplands (grazing land, and degraded bushland). Topsoil (0–20 cm) samples were collected from the runoff plots in 2015 (at the beginning of the experiment) and 2018 (three years later) and analyzed for nine soil properties—texture, bulk density (BD), pH, electrical conductivity (EC), cation exchange capacity (CEC), total nitrogen (TN), soil organic carbon (SOC), available phosphorus (Pav), and available potassium (Kav). The results show that runoff, SL, and soil properties varied greatly across land use and SLM practices in all three agro-ecologies. The highest rates of both seasonal runoff (898 mm in 2016) and SL (39.67 t ha-1 in 2015) were observed from untreated grazing land in the midland agro-ecology, largely because of heavy grazing and intense rain events. Whereas, the lowest values of pH, CEC, SOC, and TN values were observed in croplands, probably owing to unsustainable cropping systems practiced over centuries. In all agro-ecologies and land use types, both runoff and SL were significantly lower ($P < 0.05$) in plots with SLM than without: SLM practices reduced runoff by 11% to 68%, and SL by 38% to 94% depending of land use and agro-ecology, and sensitive soil properties (BD, SOC, TN, Pav, and Kav) were markedly improved three years after the implementation of SLM practices. Soil bund reinforced with grass in croplands and exclosure with trenches in non-croplands were found to be the most effective SLM practices for reducing runoff and SL, and improving soil properties, indicating that combined structural and vegetative measures are the best way to control soil erosion and related consequences.

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1. Introduction

•Land degradation by soil erosion is among the critical problems worldwide; it is, however, most pressing in developing countries where soil erosion by water is accelerated by population pressure and improper land use practices (**Fig.1,** left).

•Huge financial and labor resources have been invested for the implementation of sustainable land management (SLM) practices in Ethiopia (**Fig.1,** right) to mitigate soil erosion; relevant studies are, however, limited particularly for the actively eroding regions.

•The objectives of this study were to (i) quantify runoff and soil loss (SL) under different land use and management practices; and (ii) explore the variation in key soil properties as influenced by land use and management practices.

Fig.1. Major causes of soil erosion and counter measures implemented in the highlands of Ethiopia. The black arrows indicate the slope direction.

2. Study area

- The study was conducted at three agro-ecologically different sites in the Upper Blue Nile Basin of Ethiopia (**Fig. 2**). These sites were selected in the view of representing different the biophysical features of the basin (**Table 1)**.

Table.1 Altitude and climatic features of the study sites.

Sites	Elevation (m.a.s.l)	Mean daily Temp.(ºC)	Mean annual rainfall (mm)
Guder	2489–2882	9.4–25.0	2454
Aba Gerima	1912–2126	11.8–27.5	1343
Dibatie	1487–1718	13.1–28.2	1022

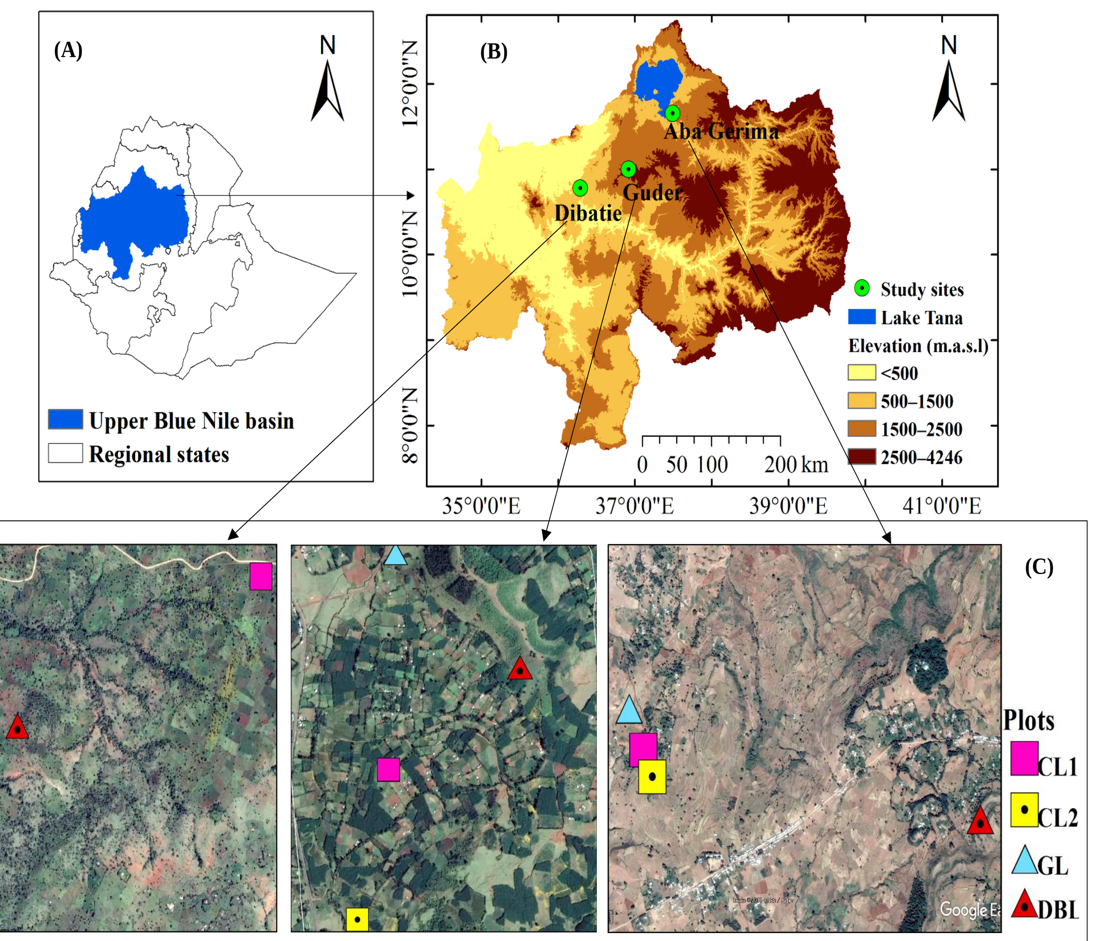

Fig. 2. Map of the study area: (A) Ethiopia, (B) Upper Blue Nile basin, and (C) sampling plots in different land use types at Dibatie (left), Guder (middle), and Aba Gerima (right) sites.

3. Methods

•Runoff and soil loss (SL) were measured using 42 bounded runoff plots (6 m x 30 m) in three land use types: cropland (CL), Grazing land (GL) and bushland (DBL). Five SLM practices were evaluated for two seasons (2015 & 2016): Soil bund (SB), *Fanya juu* (F), and soil bund reinforced with grass (SBG) for CL, and exclosure (E), and exclosure with trenches (E+T) for GL and BDL (**Fig. 3 and Table 2**).

•A total of 162 topsoil (0–20 cm) samples were analyzed for nine soil quality indicators – texture, bulk density (BD), pH, electrical conductivity (EC), cation exchange capacity (CEC), total nitrogen (TN), soil organic carbon (SOC), available phosphorus (Pav), and available potassium (Kav).

Table 2. Characteristics of runoff plots at the study sites, and some of the physical and chemical properties for initial soil samples* (range of values for a specific land use).

Land use	Slope (%)	Treatments	Bulk density (gm/cm³)	Silt +clay (%)	pH	CEC ($cmol_c$ kg^{-1})	SOC (%)	P_{av} (mg kg^{-1})
CL1	5	C, SB, F & SBG	1.09 –1.30	71–86	5.05 –5.83	28.40 –40.40	0.08 –2.65	0.34–11.10
CL2	15	C, SB, F & SBG	1.11–1.34	55–84	5.01–5.85	37.60–46.80	0.19–2.34	1.34–10.20
GL	15	C ,E, E+ T	1.03 –1.44	64–84	5.40 –5.88	35.60 –50.00	1.17 –2.38	1.69–6.87
DBL	35	C, E, E+ T	0.83 –1.40	52–76	5.58 –6.10	40.00 –58.00	2.03 –2.56	0.62–30.89

Fig. 3. Partial view of monitoring runoff plots on cropland (CL), grazing land (GL), and bushland (DBL), the treatments and other detailed characteristics are given in **Table 2**. The photo of GL was taken from Guder, while others were from Aba Gerima.

4. Results and discussion

4.1. Effects of land use and management practices on runoff and soil loss

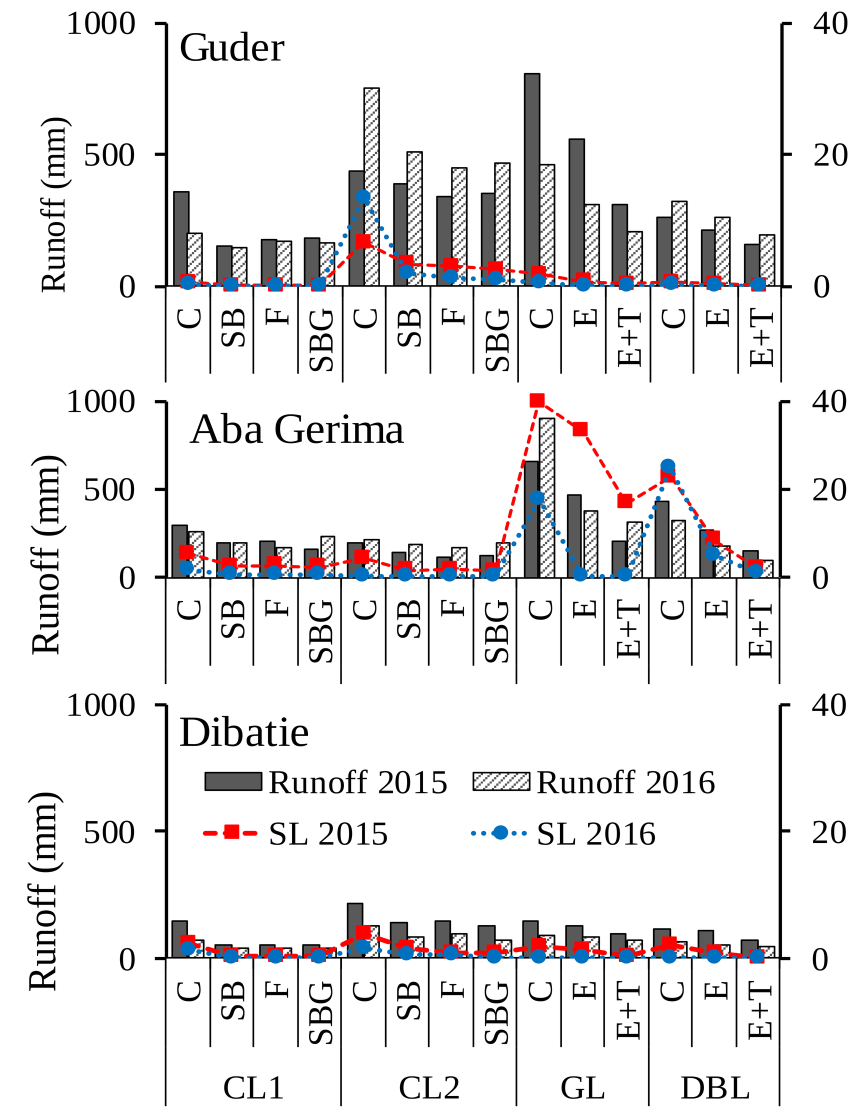

Fig. 4. Seasonal runoff and soil loss (SL) amounts under different land use and SLM practices.

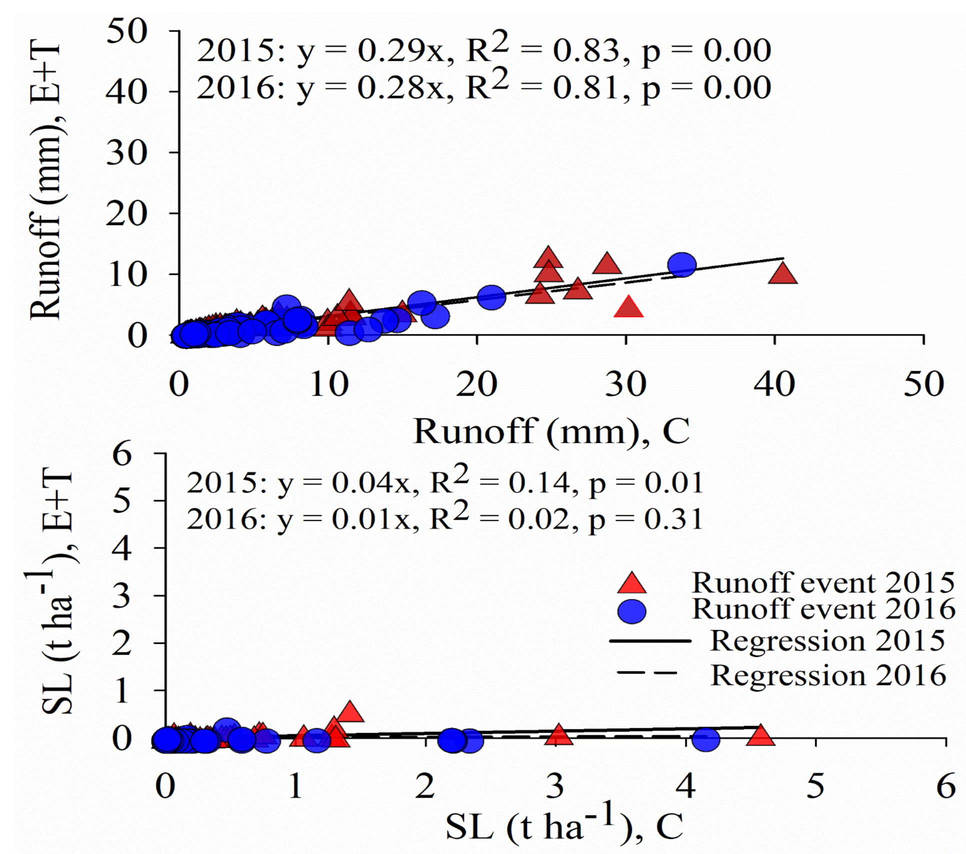

Fig. 5. Regression curves fitted to daily runoff and SL data for plots without (C) versus with SLM practices (SBG, and E+T) in grassland.

5. Conclusions

• Runoff, soil loss, and soil properties substantially varied across different agro-ecologies and land use types, suggesting that management interventions should be based on land use and location-specific information.

• The studied SLM practices significantly reduced runoff and soil loss, and improved soil quality properties.

•Soil bund reinforced with grass and exclousre were found to be the best SLM practices. However, further investigation is needed in consideration of ecological succession, and other possible effects such measures might have, for example, effects on biodiversity and productivity.

4.2. Effects of land use and management practices on soil properties

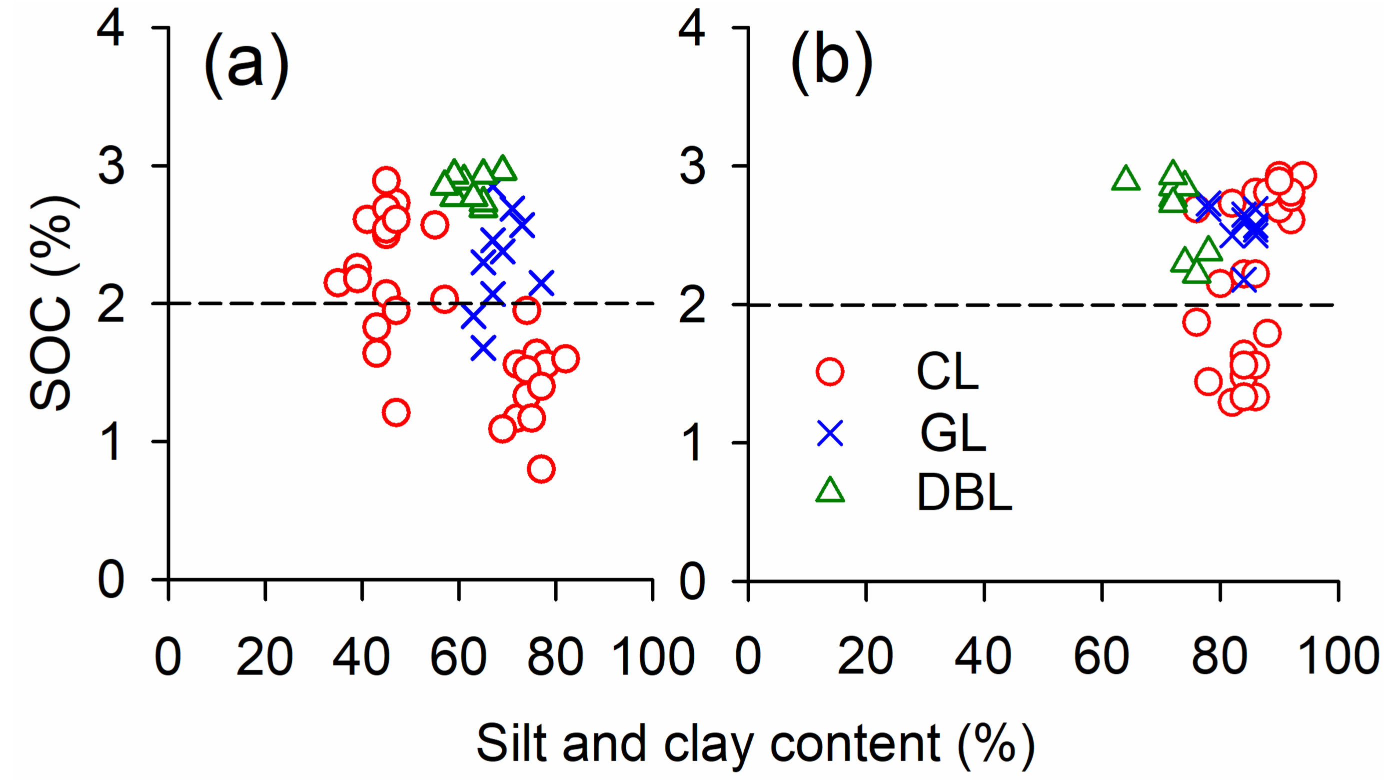

Fig. 6. Scatter plots of SOC and as a function of silt and clay (S+C) contents in different land uses at Aba Gerima (a) and Dibatie (b) sites. The dashed horizontal lines indicate the critical levels of SOC, according to Wasa et al. (2013), and Musinguzi et al. (2016).

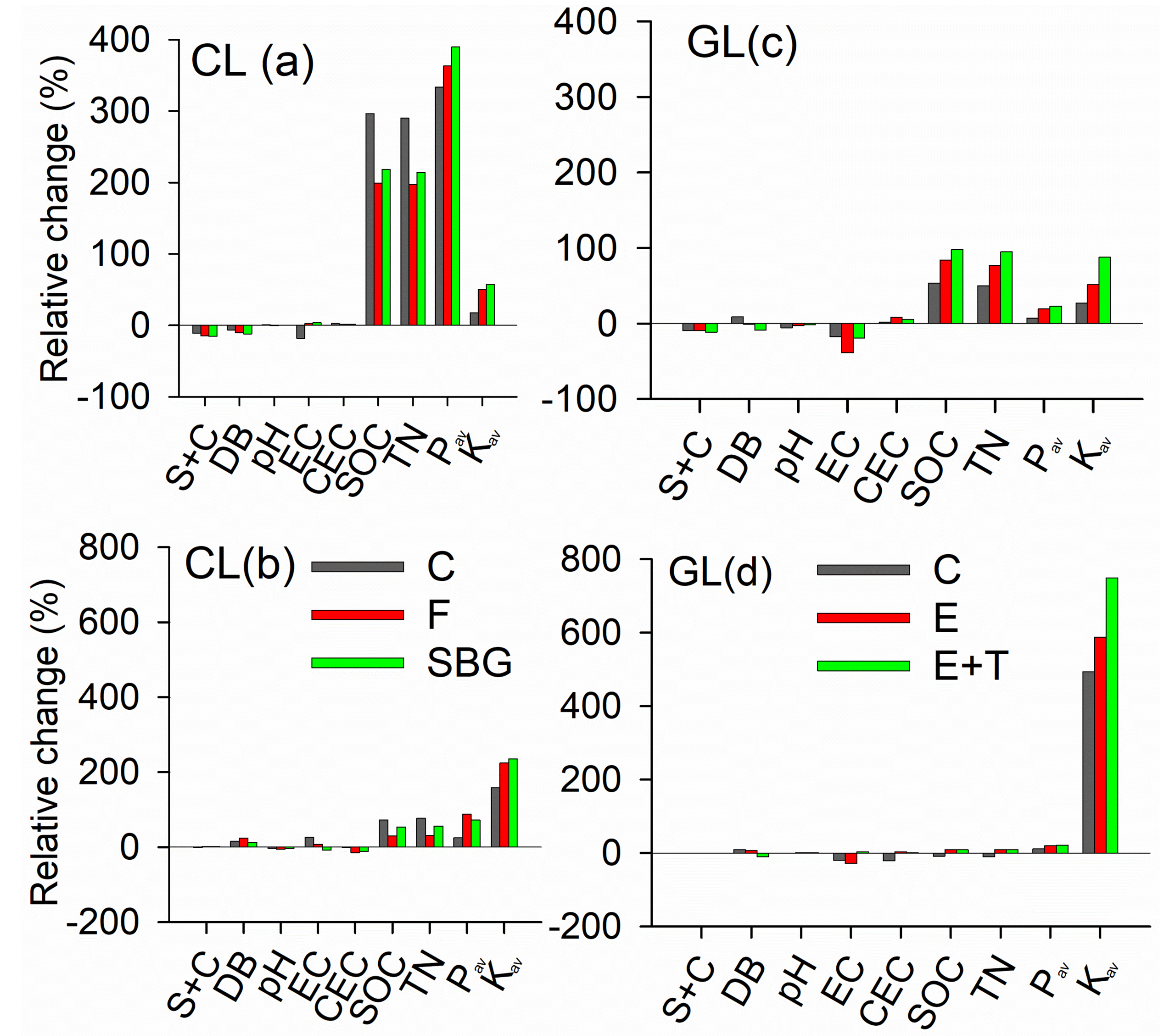

Fig. 7. Relative changes in soil properties three years after the implementation of different management practices in croplands and grazing lands at Aba Gerima (a & C) and Dibatie (b & d) sites. The relative change values were calculated in 2018 using the actual values obtained for samples of initial year (2015) as a baseline data (**Table 2**).

Acknowledgments

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