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Original Research Article

Effects of land use on catchment runoff and soil loss in the sub-humid Ethiopian highlands

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ABSTRACT

Land use and management affects runoff and soil loss from a catchment. The present study investigated the effects of land use on runoff and suspended sediment concentration and yield in the northwestern Ethiopia. We selected two small catchments: cultivated land and grassland dominated catchments within the 95 ha Debre Mawi catchment. Hydrometric and sediment concentration data were collected for five years (i.e., 2010–2014). Significant ($p < 0.05$) differences in daily, monthly and annual runoff, as well as suspended sediment concentrations were observed between cultivated land and grassland dominated catchments. The greater runoff, suspended sediment concentration and yield in the cultivated catchment could be attributed to repeated tillage and low soil organic matter. Repeated tillage in the cultivated land lead to soil disturbance and the low organic matter lead to aggregate instability, both of which consequently increase the detachment of soil particles and transport by generated runoff. Our results support that land management practices that involve lower soil disturbance and increase ground cover on degraded highland areas such as the Ethiopian highlands could help reduce runoff and soil loss.

1. Introduction

Soil erosion is a serious global threat to agricultural productivity, sustainable use of land and water resources and environmental quality (Lal, 1996). It reduces the Q2 resilience of local communities and causes rapid siltation of dams. In addition to soil erosion, loss of soil organic matter and nutrients and deforestation are also environmental problems that developing countries are facing (Pimentel, 2006; Teketay, 2001). Erosion and the subsequent land degradation are the most serious environmental problems in Africa and this is true in the Ethiopian highlands (Shiferaw and Holden, 1999). In the Ethiopian Q3 highlands, severe land degradation started since the 1960s,

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when people started clearing of forests for agriculture and cultivating marginal lands (Mitiku et al., 2006; Tato and Hurni, 1992; Constable and Belshaw, 1986).

Deforestation for the expansion of agricultural lands and cultivation of marginal lands are attributed to the increase in human population and the associated increase in demand for food and fuelwood (Nyssen et al., 2004; Hurni, 1988). For example, the rate of deforestation in the Ethiopian highlands amounted to 62,000 ha yr^{-1} (Berry, 2003), the average soil loss from all land uses is estimated at 35 Mg ha^{-1} yr^{-1} (Keyzer and Sonneveld, 2001), and nutrient depletion is estimated at 30 kg ha^{-1} of nitrogen and 15–20 kg ha^{-1} of phosphorus (Selassie and Belay, 2013). This has led to persistent environmental degradation in different parts of the country, loss of forest resources and agricultural biodiversity, and reductions in ecosystem services (Taye et al., 2013; Nunes et al., 2011; Morgan, 2009; Tamene and Vlek, 2008; Lemenih et al., 2005).

Studies conducted in the highlands of Ethiopia (e.g., Taye et al., 2013; Koch et al., 2012; Admassu and Haile, Q4 2011) and in other similar environments (Nunes et al., 2011; De Vente and Poesen, 2005; Stieglitz et al., 2003; Pardini et al., 2002; Poesen and Hooke, 1997) have investigated the impacts of land management practices and land use/cover change on the hydrology and soil loss. These studies found out that cultivated land generates more runoff, erosion, and land management practices such as vegetation cover reduces the magnitude of runoff and erosion, although overgrazed grasslands generate more runoff and erosion as compared with cropland (Blanco and Lal, 2010). Most of the above mentioned studies, however, based their investigation on either computer models or plot level data due to the difficulty of finding catchments with single land use/cover. Such studies might not be able to explain the variability in runoff and determinants of runoff and sediment yield between watersheds dominated by different land uses. Therefore, this study investigated the variations in catchment runoff and soil loss and the factors explaining the variations in runoff and soil loss within a watershed. Understanding the impacts of dominant land use and land management practices on runoff and soil erosion processes at a catchment scale is essential to: (a) design and implement effective erosion control measures, (b) improve and sustain agricultural productivity, and (c) maintain or enhance ecosystem services. This even becomes more important for the Ethiopian highlands, which covers less than half of the country's land area, but supports nearly 90% of the human and livestock population (Mohamed-Saleem, 1995).

2. Materials and methods

2.1. The study area

The Debre Mawi catchment is situated in the upper Blue Nile Basin, in the sub-humid Ethiopian highlands (Fig. 1). The catchment has an area of 95 ha. Altitude varies between 2220 m near the outlet and 2300 m in the southeast. The mean annual rainfall (for the period of 1986–2006) is 1240 mm, while the mean annual temperature is 24 °C (Tebebu et al., 2010). Most of the rainfall usually occurs between June and September.

The geology in the catchment consist of shallow, highly weathered and fractured basalt overlaid by dark brown compacted clay, followed by light brown wet and sticky clay and then by black clay and organic rich soil sequences (Abiy, 2009). The fractures are highly interconnected with limited clay infillings. Intrusive lava dykes are seen across the stream perpendicular to the flow direction of the stream and catchment areas near the stream interrupting the connection in fissures and giving rise to several springs during the main rainy season.

The dominant soil types of the catchment are Nitisols, Vertisols and Vertic-Nitisols. Nitisols, (locally called "*Dewel*"), Vertisols ("*Walka*") and Vertic-Nitosols ("*Selihana*") are found in the upper-, foot- and mid-slope positions of the catchment, respectively. Nitisols, which are derived from volcanic rocks are deep soils, well drained, permeable, reddish in color, clay dominated, and are fertile. Vertisols are soils with high content of shrinking/swelling clay minerals, self-mixing due to shrink-swell of clay minerals forms deep wide cracks during dry monsoon phase and swell during rainy phase. Vertic-Nitisols on the other hand are reddish-brown in color, well-drained and are permeable soils with high moisture retention, and cracks are formed when dry. This soil is well suited for '*tef*' production (Tilahun, 2012; Tebebu et al., 2010; Zegeye et al., 2010).

Main crops produced are cereals such as '*tef*' (*Eragrostis tef*), maize (*Zea mays*), finger millet (*Eleusine coracana*), barley (*Hordeum vulgare*) and wheat (*Triticum vulgare*). Legumes such as Haricot bean (*Phaseolus vulgaris*), Fava beans (*Vicia faba*), pea (*Pisum sativum*), and lentils (*Lens culinaris*) are grown in the catchment (Tilahun et al., 2013a,b; Zegeye et al., 2010).

Similar to other catchments in the Ethiopian highlands, deforestation for fuelwood, agricultural expansion and cultivation of marginal lands are common. Key changes over the past 50 years in land use and management that occurred in the Debre Mawi catchment include the reduction in natural forest, shrub lands and grazing land, and an increase in cultivated land (Fisseha et al., 2011). Such changes in land use resulted a reduction in soil organic matter and formation and development of gullies. In addition, gullies are formed in the periodically saturated foot slope positions to carry off additional direct runoff (both interflow and subsurface water) from agricultural lands (Tebebu et al., 2010).

2.2. Data collection

Within the 95 ha Debre Mawi catchment, two smaller catchments: a catchment dominated by grassland (having an area of 8.8 ha) and cultivated land (6.4 ha) were selected to investigate the impact of land use on runoff and soil loss. During the entire study period (2010–2014), hydrogeomorphic data consisting of precipitation, stream flow and suspended sediment concentration (SSC) were measured during the rainy season of each year (i.e., June to September).

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