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# Impact of landslides on soil characteristics: Implications for estimating their age

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ABSTRACT

The slopes of Mount Elgon, a complex volcano at the border between Uganda and Kenya, are frequently affected by landslides with disastrous effects on the livelihood of its population. Since local people greatly depend on the land for crop production, this paper examines if and how fast physico-chemical characteristics in landslide scars recover. A chronosequence of 18 landslides covering a period of 103 years was sampled in order to explore differences between topsoil inside and outside landslide scars. For each landslide, two topsoil samples were taken within the landslide and two in nearby undisturbed soils to compare their physico-chemical characteristics. Samples inside the landslides were located at the transition zone between the depletion and accumulation zone, which is situated at the contact line between the plan concave and plan convex section of the landslide. No differences were found for available phosphorus, $Ca^{2+}$, $Mg^{2+}$ content or for the fine earth texture. Recent landslides had however lower content of soil organic carbon (OC) and $K^{+}$, and higher content of rock fragments and $Na^{+}$ than the adjacent soils. Soil OC content increased significantly with age and reached levels of the corresponding undisturbed soils after ca. 60 years. Older landslides had even higher OC contents than soils adjacent to the landslide. Hence landslide scars act as local carbon sink. We suggest that the occurrence of rock fragments in the topsoil is a useful indicator for mapping past landslides. Moreover, the difference in soil OC content between landslide scars and adjacent soil could be used for estimating the age of landslides in data-poor regions.

## 1. Introduction

Landslides affect humans in many ways leading to socio-economic disarray, casualties and environmental damage. Landslides induce significant soil loss, sediment deposition and result in the mixing of soil material. Previous studies showed that topsoil characteristics are altered in the process of soil movement. Most authors report lower contents of nitrogen and soil organic carbon of soils located inside landslides compared to nearby undisturbed soils (e.g. Dalling and Tanner, 1995; Guariguata, 1990; Manjusha, 1990; Reddy and Singh, 1993; Zarin and Johnson, 1995a). In terms of soil texture, Zarin and Johnson (1995a) found lower clay content in landslides in a montane forest in Puerto Rico. As far as soil nutrients are concerned, results are less clear. Most authors reported lower content of available phosphorus (P), and exchangeable $Ca^{2+}$, $Mg^{2+}$ and $K^{+}$ (e.g. Guariguata, 1990; Manjusha, 1990; Reddy and Singh, 1993). However, several researchers have challenged these findings. Shrumpf et al. (2001) argued that landslides can bring deeper, less weathered and therefore more nutrient-rich material to the surface, which leads to a possible improvement of soil fertility. Similarly, Adams and Sidle (1987), found higher pH and higher exchangeable $Ca^{2+}$ concentrations in three recent landslides in Southeast Alaska. Also Manjusha (1990) observed a higher pH in landslides in Kumaun Himalaya despite lower nutrient concentrations. Recently, Cheng et al. (2016) observed higher rock fragment content and pH, but lower concentrations of organic carbon due to landslide deposition in Central Taiwan.

Temporal trends in characteristics of soils located in landslide scars have been reported for organic carbon (OC), nitrogen (N), available P, exchangeable basic cations and soil texture, with an increase in soil fertility over time (Lundgren, 1978; Manjusha, 1990; Reddy and Singh, 1993; Zarin and Johnson, 1995a, 1995b). However, soil fertility restoration typically takes a few decades, as reported for the Uluguru mountains in Tanzania by Lundgren (1978), who found lower OC and clay content inside landslides compared to undisturbed soils 7 years after the occurrence of the landslide. Similarly, Zarin and Johnson (1995a, 1995b) found no full restoration of the OC and $Ca^{2+}$, $Mg^{2+}$ and

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$K^+$ contents in the topsoil over a period exceeding 55 years. Other studies did not find a significant spatial or temporal trend in values of soil properties. The large spatial heterogeneity of parent material within a landslide may be an important obstacle for capturing significant trends (Walker and Shiels, 2013).

Most research reporting on the impact of landslides on soil fertility characteristics has been conducted in Central America. In contrast, whereas the East African highlands are prone to landslides and have been the object of several studies (e.g. Broothaerts et al., 2012; Davies, 1996; Jacobs et al., 2016; Kitutu et al., 2009; Knapen et al., 2006; Mugagga et al., 2012; Ngecu and Mathu, 1999; Van Den Eeckhaut et al., 2009), few studies have analysed their impact on soil fertility characteristics (Lundgren, 1978).

As on Mount Elgon landslides frequently occur in cropland the objective of this study was to assess their impact on the physico-chemical characteristics of the topsoil. In particular, we attempted to determine how long it would take for soil characteristics inside landslides to recover from the disturbance by landsliding to the level of nearby undisturbed soils. Based on previous studies, we focussed on the effect of landsliding on the content and recovery rate of topsoil organic carbon (OC), exchangeable $Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$, soil texture and rock fragments.

## 2. Materials and methods

### 2.1. Study area

The study area is in Bududa district (0°5′45″ - 1°7′22″N, 34°16′18″ – 34°32′67″E; Uganda), one of the eight districts covering the south-western part of Mount Elgon (Fig. 1). Based on a reconnaissance field survey in March 2014, Bududa district was found to have the largest number of landslides from all eight districts in the Mount Elgon region and was therefore chosen for this study. Mount Elgon (4321 m a.s.l.) is an extinct complex volcano at the border between Uganda and Kenya and was mainly built up during the Pliocene (Davies, 1952). The Elgon succession consists of the Basement complex, followed by Pre-Elgon volcanic activity with alkaline intrusions, the building of a shield volcano (Mount Elgon) followed by erosion and deposition processes (Davies, 1956). Mt. Elgon is a central volcano with its summit at 4321 m (Ollier and Pain, 2000). Based on SRTM data (Shuttle Radar Topography Mission (SRTM) void filled 1 arc-second global elevation data (~30 m) available at https://earthexplorer.usgs.gov/; accessed 14 March 2017), we determined that from north to south the volcanic cone is ca. 70 km across and 50 km from west to east. In Uganda its base is at ca. 1200 m while in east Kenya it is at ca. 1800 m a.s.l. It is an alkaline stratovolcano built of a succession of agglomerate deposits, principally nephelinite and olivine basalt lava separated by ash layers (Ollier and Pain, 2000; Westerhof et al., 2014). The volcanic cone has a radial drainage but despite being of Miocene age, instead of having planezes the flanks consist essentially of a series of steps or structural terraces (Ollier and Pain, 2000). Bududa district is dominated by granites from the Pre-Cambrium complex together with an alkaline intrusion from Pre-Elgon volcanic activity (GTK Consortium, 2012). Only some small parts at the northern and eastern side of this district are covered by volcanic materials. The harmonized soil map of Africa (Dewitte et al., 2013) indicates that the dominant Reference Soil Groups are Nitisols, Acrisols, Ferralsols and Luvisols.

Annual rainfall ranges from 1500 to 2200 mm with a seasonally

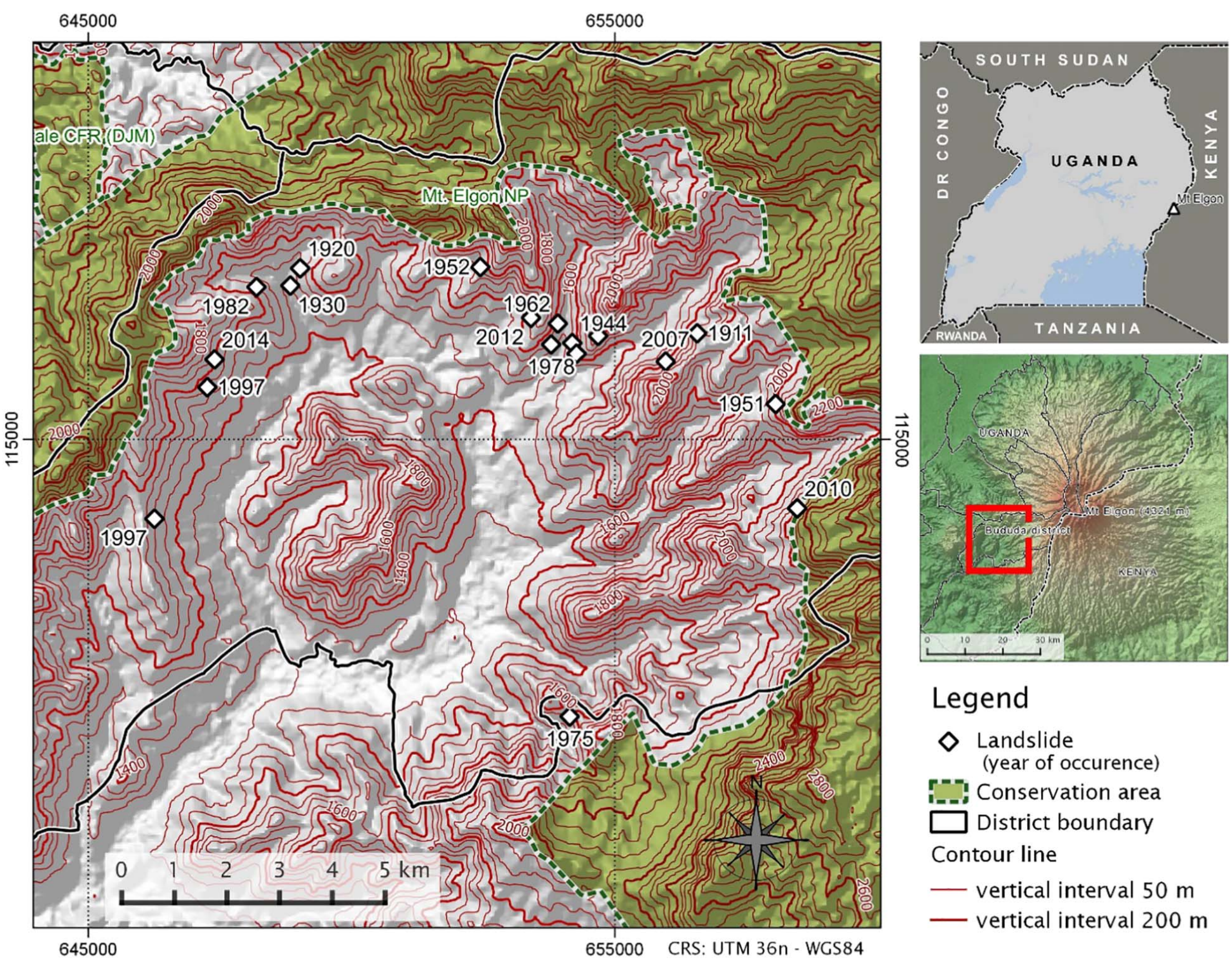


**Fig. 1.** Location of the dated and sampled landslides in Bududa district on Mt. Elgon, Uganda (topography based on SRTM data downloaded from USGS https://earthexplorer.usgs.gov/).