Landslide frequency in the Kivu Rift: impact of landscape evolution and deforestation

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Both landscape rejuvenation through tectonic uplift and human-induced deforestation are known to increase landslide (LS) activity. Yet, the interaction between deforestation and landscape evolution has hitherto not been explicitly considered. Here, we investigate how shallow LS frequency is impacted by deforestation and landscape rejuvenation through knickpoint retreat in the Kivu Rift (East African Rift) while accounting for rock strength and slope steepness. In the past 12 Ma, the Kivu Rift has been characterized by tectonic uplift which gave rise to knickpoints in the river profiles enforcing topographic steepening. On a much shorter timescale, the rapidly growing population in the Rift has gradually expanded its cultivated and urban land leading to widespread deforestation.

We compiled an inventory of almost 8000 shallow LSs using Google Earth imagery. To quantify LS frequency, we developed a new method that accounts for the temporal and spatial inconsistency of satellite imagery coverage. To characterize long-term landscape evolution, we identified (i) 672 non-stationary knickpoints in the Rift and (ii) quantified the impact of lithology on slope threshold angles (TA). We identified two homogenous lithological groups: one group of younger/weaker lithologies (<540 Ma, TA=19.0 +/- 2.0°) and one group of older/stronger ones (>540 Ma, TA=27.9 +/- 0.3°). Further analysis focused on the latter group since it covers 85% of the study area and contained more than 95% of the observed LSs.

The overall shallow LS frequency in the rejuvenated landscapes inside the rift is 0.039 LS/km²/yr versus 0.010 LS/km²/yr in the relict landscapes outside the rift. Generally, LS frequency on recently deforested slopes increased by 200 to 800% in comparison to forested land. There is no notable difference in LS frequency on equally steep non-forested slopes (i.e. slopes deforested at least several decades ago) inside and outside of the rift. However, forest slopes of similar steepness are 2-3 times more sensitive to landsliding within the rift. We propose two mechanisms that might explain the higher frequency of landsliding on similar topographies within the rift: (i) the active undercutting by rivers may lead to slope destabilization without significantly increasing the average slope gradient as extracted from the SRTM DEM and (ii) tectonic uplift may induce rock and regolith fracturing, leading to weaker, more LS-prone slopes. The fact that we did not observe
differences in LS frequency on hillslopes that were deforested long ago suggests that on such slopes a new equilibrium is established whereby these aforementioned mechanisms are no longer important.

In conclusion, one of the key factors why the rejuvenated landscape inside the rift is more sensitive to landsliding is the higher prevalence of threshold slopes due to active incision. However, the impact of rejuvenation cannot be understood by considering only its effects on overall topography. Deforestation dramatically increases LS frequency in both relict and rejuvenated landscapes, in the first decades after forest cover removal.