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# Landslide dynamics and debris export in the central Himalaya, as documented by a multi-methods approach

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It is generally considered that the steep slopes of active mountain ranges are essentially eroded by landslides, and that they are conditioned by the critical angle of stability of the bedrock which would lead to uniformity of hill slopes. Such simplified vision is equivalent as giving to the river network a dominant role during denudation, and to assume that mountain landscapes will react to a changing climate through only the response of rivers in terms of down-cutting variations. Nevertheless, such long term view eludes the issue of the landslide pre-conditioning factors and triggering mechanisms, as well as the modes of sediment export from the hillslope down to the major rivers.
The spectacular topography of the Central Himalayas in Nepal offers the opportunity to explore these issues using various recent observations and measurements based on satellite imagery, time-lapse cameras, rainfall records, hydrology and sediment load measurements, cosmogenic nuclides or geochemistry of river sediments. We particularly focused our study on a small watershed (the Khudi watershed) along the wet and warm southern flank of the High Himalaya, where a zone of active and continuous landsliding has been active for 50 years. In this active area, the highly fractured and weathered bedrock, probably resulting from a probable DSGSD that partly collapsed the whole hillslope, is affected by retrogressive erosion along the crown of the landslide scar. Annual crown collapse and scar expansion were traced using satellite images (Gallo et Lavé, 2014). Time-lapse survey over a period of 6 years permitted to document within the internal landslide area the slow movement of the debris issued from the collapsed crown. Finally, daily sediment load measurements, operated 10km further downstream provide a view on sediment export by the river. These complementary observations and records help to draw several conclusions. As expected, the crown collapses, debris movements or peaks in sediment export are generally associated with major precipitation or hydrologic events. However the landslide and hillslope dynamics are not related to rainfall in a simple manner: the debris movement within the landslide primarily depends on cumulated precipitation (and water table elevation), whereas sediment export is rather related to rainfall intensity; at the whole landslide scale, we also observe a clear uncoupling between landslide activity and the flux of exported sediments, with a time lag close to one year.
Our study therefore indicates that Himalayan hillslopes respond in a complex manner to both average rainfall and storminess. The Khudi example also illustrates the dominant role of the pre-conditioned fractured bedrock in the locus of the landslide activities. Such role of the bedrock fracturing implies both complexities and time lag (>several kyrs) in hillslope response to the presumed rivers down-cutting lead. Both phenomena have large implications on landslide hazard mitigation in Nepal, as well as on the hillslope and landscape response to climatic (including storminess) variations, and tectonic forcing.