EGU2020-10597
https://doi.org/10.5194/egusphere-egu2020-10597
EGU General Assembly 2020


# Monsoon-driven landslide dynamics in Nepal – the complex mass movement system in the Muktinath Valley

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The Nepalese Himalaya is affected by a major rift valley, the Thakkhola half graben (THG). Along this fault-bounded basin, the Kali Gandaki (KG) flows from the Tibetan plateau southwards to the Dhaulagiri and Annapurna massifs, where it forms the deepest gorge on earth. The THG has been filled with up to 1 km thick Plio- and Pleistocene sediments, underlain by clay shales of the Jurassic Spiti Formation that are strongly water swellable and prone to landslides. These pre-conditions led to a series of large and complex landslides, particularly along the eastern flank of the THG, with strong effects on infrastructure and the local population. One of these landslide systems (c. 15 km²) is located in the semi-arid Muktinath Valley, a tributary basin of the KG (c. 92.5 km²). Water as most important driver of the system is provided by precipitation mainly during the summer monsoon (annual rainfall: ~ 350 mm), snowmelt and irrigation.

Against this background, we aim i) to better understand regional-scale landslide systems (spatial pattern, drivers/controls), ii) to establish a long-term monitoring of local-scale landsliding in the Muktinath Valley, and iii) to share our findings with local communities to support the development of mitigation strategies.

Reconstruction of landslide dynamics over the past 30 years is based on local information (interviews), field observations (damaged buildings and walls), geomorphological mapping and multi-temporal (ortho-) photo analyses (WorldView, Pleiades). Since 2018, annual UAV surveying is applied.

Results include a geomorphological map of the area focusing on landslide related processes and landforms, indicators of recent landslide activity, hydrologic characteristics and irrigation infrastructure, as well as the distribution of Spiti shale outcrops. Surrounding the presently most active landslide, we observed an average displacement of c. 20 cm/a since 1988 with an increasing trend towards present (30 - 50 cm/a since 2011). In the center of the most active landslide significantly higher displacements of up to 15 m have been detected since 2011, which corresponds to an average of about 2 m/a. The landslide monitoring based on UAV surveying, structure-from-motion processing and different approaches of high-resolution topographic

change and error modelling (DEM resolution: 2.6 - 4.3 cm) shows massive change between April 2018 and March 2019 (gain: 33395 ± 5489 $m^3$; loss: 50276 ± 10781 $m^3$), accompanied by a total sediment export of 16881 ± 12098 $m^3$ to the Jhong River. Detailed orthophotos (resolution: 1.29 - 2.15 cm) provide valuable supplementary information not only on recent landslide propagation and dynamics but also with regard to future threatened areas (opening cracks). Boosted landslide activity in 2018 is associated to the strong monsoon that heavily impacted in the larger region as well (debris flows, flash floods, multiple bank collapses): In August 2018 Muktinath recorded the highest monthly rainfall since 1978 (172 mm, DHM Nepal).

The research is located at the interface between humans and the environment. The "symbiosis" of the local population and the landslide system is unique - and enables to deconstruct various interacting landslide processes driven and modified by climate (change) and human impact.