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Slope deformation patterns in high mountain areas: insights from DInSAR analysis in NW Bhutan

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The small Himalayan country of Bhutan, landlocked between India and Tibet (between 88° and 92° east and 26° and 28° north) is characterised by rugged terrain and high topographic gradients, as well as by a variety of climatic conditions and is thus prone to different slope deformation phenomena. We present the results of our investigations of slope instabilities by means of remote sensing techniques.

The motivation to investigate slope instabilities here is twofold: on one side destructive mass movements such as landslides can have adverse direct and indirect effects on population and infrastructure; on the other hand, mass wasting phenomena play a key role in landscape evolution and, in turn, on rock slopes degradation. To the best of our knowledge, no comprehensive slope instability inventory exists for Bhutan as of yet. Moreover, the largely inaccessible terrain and the relatively unfavourable land cover for remote sensing analyses offer the perfect challenge for evaluating the trade-offs between advantages and disadvantages of the techniques used.

We first generated a landslide and rock glacier inventory based on the identification of characteristic geomorphological features on high resolution satellite images and digital terrain model. We then exploited Synthetic Aperture Radar Differential Interferometry (DInSAR) to identify formerly unknown landslides and to assess their activity, but also to detect slope deformation due to periglacial phenomena and reversible displacements related to annual variations in ground water levels. We generated a large number of interferograms for two ENVISAT ASAR and two ALOS PALSAR tracks and obtained displacement and velocity maps with the Small Baseline Subset (SBAS) approach for three of these. Mapping of potential slope deformation area was carried out visually on the basis of selected criteria.

Classifications of the detected deformation were made on the basis of the geomorphological features and, in the case of those detected with SBAS, also on the basis of the time series trends. Given the large amount of interferograms, we assigned a likelihood to each deformation feature, which can be used to analyse their distribution in relation to predisposing factors.

Validation of the applied methods was made partly on the field and, for selected cases, through further processing of ALOS PALSAR 2 and Sentinel 1 data.

The datasets produced in this work offer a valuable basis 1) for the analysis of landslide distribution in relation to predisposing factors such as geological and structural characteristics; 2) to unravel the evolution of the landscape in the region and the roles of fluvial incision and glacial erosion; 3) to generate regional (and local) landslide hazard maps that can be used to increase preparedness (e.g. earthquake triggered landslides), for general land use purposes or for the selection of specific sites for new infrastructure.