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High-mountain multihazard assessment in the Pamir (Tajikistan) with GRASS GIS

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The high-mountain areas of Central Asia are experiencing pronounced environmental changes, most likely caused by an increase in air temperature. These changes include both permafrost melting and the retreat of glaciers. Together with earthquakes, they disturb the dynamic equilibrium of the fragile high-mountain geomorphic systems, leading to the increased occurrence of rapid mass relocation processes, sometimes with a long travel distance and therefore threatening the population in the valleys.
Here we present a scheme for a regional-scale high-mountain multihazard assessment, implemented with the Open Source software package GRASS GIS. This scheme is applied to a test area in the Pamir (Tajikistan). It focuses on low-frequency, high-magnitude processes for which the preparedness and awareness among the population are limited:
(1) Lake outburst hazards: The sudden drainage of lakes can lead to major flows of debris, mud and water (in the case of glacial lakes, Glacial Lake Outburst Floods or GLOFs). 1642 lakes, out of them 652 glacial lakes, were identified from satellite imagery. The relevant characteristics of each lake (dam type, lake volume, lake development, topographic situation) were determined or estimated.
(2) Rock-ice-avalanche hazards: glaciers retreating over steep rock cliffs (hanging glaciers), loosing their abutment, may produce (rock-)ice avalanches, depending on their slope, thermal condition and possible triggering factors (e.g., earthquakes). Susceptible glaciers were identified from remotely sensed data.
(3) Rock slide hazards: portions of steep terrain that may be involved in large rock slides (or rock avalanches), most commonly triggered by earthquakes, were identified using a simple topography-based model.
First, the susceptibility of each type of event is determined, depending on an exactly defined scheme, and a score is assigned to each object (lakes, hanging glaciers) or raster cell (rock slides). This score is increased for areas with melting permafrost, which are particularly susceptible to mass relocation processes: a solar irradiation model is used to determine permafrost areas under the current conditions and under projected conditions in the future.
Second, empirical relationships are applied to compute the possible travel distances and impact areas of all types of processes. Inaccuracies of the relationships are accounted for by applying multiple random walks with the key parameters varied within the confidence interval. The results for all processes are overlaid, so that a multihazard impact susceptibility score is assigned to each raster cell.
The impact susceptibility score is then superimposed with a layer of settlements, farmland and infrastructures, in order to derive a raster cell-based risk indication map. The risk indication scores are summarized by village. The results shall represent an objective base for (1) the prioritization of areas requiring mitigation measures and (2) the identification of safe places.