



Assessment and management of debris-flow risk in a tropical high-mountain catchment in Santa Teresa, Peru

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The local center of Santa Teresa (Cusco Region, Peru, 7 km northwest of the ruins of Machu Picchu) has been affected by several large debris-flow events in the recent past. In January and February 1998, three events of extreme magnitudes with estimated total volumes of several tens of millions cubic meters each, caused the destruction of most parts of the municipality and resulted in a resettlement of the town on higher grounds. Additionally, several settlements further upstream, as well as valuable infrastructure such as bridges, a railway, and a hydropower plant, were destroyed.

Some events were related to large-scale slope instabilities and landslide processes in glacial sediments that transformed into highly mobile debris flows. However, the exact trigger mechanisms are still not entirely clear, and the potential role of glacial lakes for past and future mass flows remains to be analyzed. Here we applied RAMMS (RAPid Mass Movement System), a physically based dynamic model, to reconstruct one of the 1998 events in the Sacsara catchment using the ASTER Global Digital Elevation Model (ASTER GDEM) with 30 m spatial resolution and a photogrammetric DEM compiled from ALOS PRISM data with 6 m spatial resolution. A sensitivity analysis for various model parameters such as friction and starting conditions was performed, along with an assessment of potential trigger factors. Based on these results, further potential debris-flows for this catchment were modeled, including outburst scenarios of several glacial lakes. In combination with a vulnerability analysis, these hazard scenarios were then incorporated in a qualitative risk analysis.

To further reduce the risk for the local communities, technical risk sheets were elaborated for each of the 17 local settlements in the catchment. Furthermore an Early Warning System (EWS) has been designed. The modular structure of the EWS aims at a first step to install an inexpensive but efficient system to detect debris-flow type mass movements and temporal damming of the river with trigger cables, geophones, and water level measurements. Independent energy supply, real-time data transfer to the data center in the municipality of Santa Teresa and remote access to the system via internet allows constant monitoring from within and outside the catchment. On a later stage the system is open to be enhanced by adding further sensors, cameras, meteorological stations, monitoring stations at glacier lakes, and related communication infrastructure.

Risk management in such a context is a complex task: on one hand the data and information scarcity as well as the environmental conditions challenge scientific and technical aspects of debris-flow modeling and the design of the EWS. On the other hand, social aspects must be taken into account to make actions coherent with local risk perceptions and to achieve a good preparedness of the population. For a successful realization of the EWS and the entire risk management scheme, the local and regional institutional framework must also be considered. This contribution thus illustrates the implementation of an integrated risk management strategy under the challenging conditions common for remote high-mountain regions.