A robust debris-flow and GLOF risk management strategy for a data-scarce catchment in Santa Teresa, Peru

Holger Frey, Dr.[1]; Christian Huggel, Dr.[1]; Yves Bühler, Dr.[2]; Daniel Buis, MSc[1]; Maria Dulce Burga, MSc[3]; Walter Choquevilca, Ing.[4]; Felipe Fernandez, Ing.[4]; Claudia Giráldez, MSc[1]; Cesar Portocarrero, Ing.[5]; Luis Vicuña, MSc[1]

INTRODUCTION, STUDY SITE, AND BACKGROUND

The local center of Santa Teresa (Cusco Region, Peru, 7 km northwest of Machu Picchu, at 1550 m a.s.l.) 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, several settlements further upstream, a railway, several bridges, and a hydropower plant and resulted in a resettlement of the town. 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 present a risk analysis and a risk management strategy for debris-flows and glacier lake outbursts floods (GLOFs) in the Sacsara valley. The catchment is characterized by elevation differences of more than 4000 m, from glaciated peaks (Nevado Salcantay, 6254 m a.s.l.) down to densely vegetated and steep-sloped mountain forest. Data scarcity and limited understanding of both physical and social processes impede a full quantitative risk assessment. Therefore, a bottom-up approach is chosen in order to establish an integrated risk management strategy that is robust against uncertainties in the risk analysis.

RISK ASSESSMENT

Pre-event precipitation and temperature were investigated as potential triggers for the 1998 debris flow by analyzing meteorological station data and measurements from the Tropical Rainfall Measurement Mission (TRMM). Furthermore two earthquakes of M6.1 and M5.3 were registered four days and a few hours prior to the probable release of the mass movement, respectively. With RAMMS (RApid Mass Movement System), a physically based dynamic model, the Sacsara debris flow from 1998 was reconstructed 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 the simulation results, potential future debris-flows scenarios of different magnitudes, including outbursts of two glacier lakes are modeled for assessing the hazard on the catchment scale (Fig. 1). In the figure, RAMMS

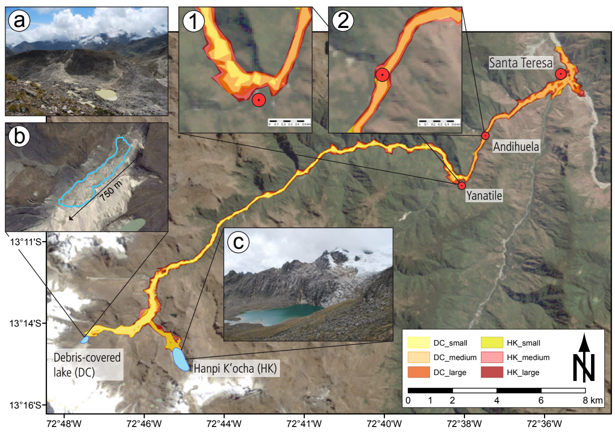

Figure 1. Modeling results of lake outburst scenarios from the potential future lake on the debris-coverd dead ice body (DC) and Lake Hanpi K'ocha (HK), spreading along the entire Sacsara cachment. (1) and (2) show zooms to the zones of the communal centers of Yanatile and Andihuela, respectively. (a) DC Lake in November 2012, (b) GoogleEarth image from June 2014, plus the possible extent of the fully developed potential future lake indicated in blue. (c) Lank Hanpi K'ocha (November 2012). Photos a and c from November 2012 (by C. Giráldez).

results of lake outburst scenarios from two lakes in the Sacsara catchment are shown. One lake is located on a debris-covered dead ice body (DC), the other one is the rock-dammed Lake Hanpi K'ocha (HK). Insets 1 and 2 show zooms to the zones of the communal centers of Yanatile and Andihuela, respectively. Inset a shows DC Lake in November 2012, b is a GoogleEarth image from June 2014, with an indication of the possible extent of the fully developed potential future lake (blue polygon). Inset c is a photo of Lank Hanpi K'ocha (November 2012).

For the four populated places along the Sacsara River, qualitative local hazard maps have been elaborated based on the RAMMS results, but including as well additional information from site visits and fieldwork and the analysis of high-resolution imagery form GoogleEarth. For these populated places, also vulnerability was assessed in situ and via interviews with the local inhabitants and authorities. Four types of vulnerability were taken into account: physical (materials for building), social (level of organization and participation), economic (access to economic activities) and institutional (institutional strength and capability). By crossing the resulting final vulnerability with the hazard map, a risk map was elaborated for each community.

RISK MANAGEMENT

The hazard and risk maps, some general information, and eventually a list of site-specific recommendations for intervention measures, are published in standardized risk sheets. For improving social and institutional preparedness, several activities together with the local inhabitants and local authorities are implemented, aiming at adapting everyday behavior according to the risk situation and at the same time at lowering vulnerability and exposure towards the identified hazards. To further reduce the risk for the local communities, an Early Warning System (EWS) has been designed. It is planned 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 modular design of the system is open to be enhanced by adding further sensors, cameras, meteorological stations, monitoring stations at glacier lakes, and related communication infrastructure.

CONCLUSIONS

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. Considerable uncertainties are related to model results due to the limited quality of the DEMs and the definitions of the outburst scenarios; however, these uncertainties can hardly be assessed quantitatively. On the other hand, social aspects and local traditions 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 implementation of the risk management strategy, the local and regional institutional framework must be considered as well.

This contribution is an example for the implementation of an integrated risk management strategy under the challenging conditions common for remote high-mountain regions in developing countries, characterized by data scarcity, high vulnerabilities of the local population, and weak governmental institutions.

KEYWORDS

Debris-flow risk; Robust risk management; Risk Sheets; EWS; Peru.

1 Department of Geography, University of Zurich, Winterthurerstrasse 190, 8057 Zurich, SWITZERLAND, holger.frey@geo.uzh.ch
2 WSL Institute for Snow and Avalanche Research SLF, Flueelastrasse 11, 7260 Davos, SWITZERLAND
3 Instituto de Ciencias de la Naturaleza, Territorio y Energías Renovables (INTE), Pontificia Universidad Católica del Perú, Lima, PERU
4 CARE Peru, Av. Oswaldo Baca J – 12, Urb. Magisterial, Cusco, PERU
5 Consultant, Huaraz, PERU