High-mountain geohazards in the Pamir (Tajikistan) induced by climate change

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The high-mountain areas of Central Asia have experienced pronounced environmental dynamics during the past decades, most likely caused by climate change. These dynamics include both permafrost retreat and the retreat of glaciers. Whilst the degree and the spatio-temporal patterns of permafrost retreat remain largely unknown due to the lack of detailed studies, glacier changes can be mapped from satellite imagery. The trends of glacial retreat in Central Asia are clear in general, but unbalanced and complex in detail (Mergili et al. 2012). Glacier and permafrost changes disturb the dynamic equilibrium of the high-mountain geomorphic systems, leading to the increased occurrence of rapid mass relocation processes (Huggel 2004). Such can constitute hazards for the population in the valleys. In contrast to small-scale "local" geohazards occurring at high frequencies, which are well-known to the communities, so-called "remote" geohazards with the source high up in the mountains and long travel distances down to the populated areas occur at low frequencies. Therefore the communities are not adequately prepared and events may lead to disasters.

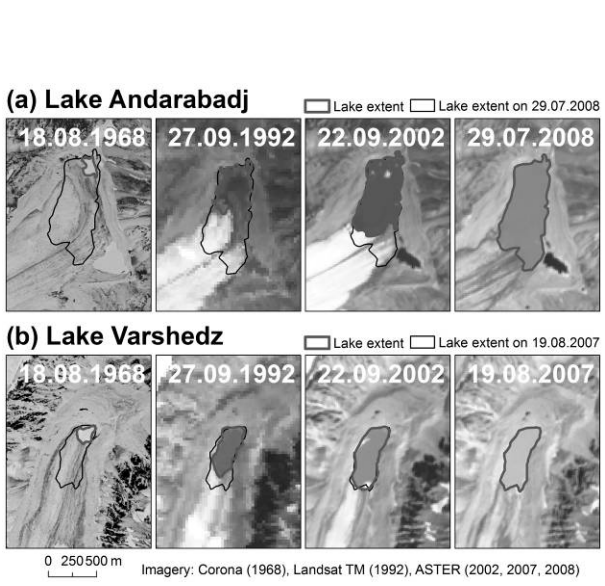
The research presented concentrates on the analysis of evolving glacial and periglacial hazards in the Pamir of Tajikistan. A multi-scale approach is used, the regional-scale investigations largely build on medium-scale satellite imagery (ASTER, Landsat) and DEMs (ASTER GDEM, SRTM V4), the local-scale investigations are supported by WorldView-1 imagery and the derived DEMs.

Based on extensive multi-temporal mapping, the spatio-temporal development of potentially hazardous lakes in the forefields of the retreating glaciers is explored. Many of the several hundred glacial lakes in the area have newly developed or grown substantially since the late 1960s (declassified Corona images are used to identify glacial lakes in this period; Fig. 1). Most of them are located between 4200 and 4900 m a.s.l., and it is observed that the emergence and growth of glacial lakes has been shifting towards more elevated catchments in the last decade. Depending on the condition of the dam, possible mass movements into the lake and lake size and evolution, glacial lakes are more or less susceptible to sudden drainage which can lead to major flows of debris, mud and water (Glacial Lake Outburst Floods or GLOFs). At least two significant events of this type have occurred in the Pamir since 2002, one of which was catastrophic.

Furthermore, glaciers retreating over steep rock cliffs possibly producing rock/ice avalanches are identified. Particular attention is paid to areas susceptible to melting permafrost. A solar radiation model is used to determine permafrost areas under the current conditions and under projected conditions in the future. Particularly in the western Pamir, glacierized areas with steep slopes will become susceptible to melting permafrost and therefore mass movements during the next decades.

A multi-hazard regional-scale analysis framework for high-mountain geohazards, based on the Open Source Geographic Information System GRASS GIS, is developed and used. The susceptibility of glacial lakes to produce GLOFs is determined, based on an exactly defined scheme taking into account the characteristics of the lake and the dam, but also of the catchment of the lake (e.g. possible landslides into the lake; Fig. 2; Mergili et al. 2011). The susceptibility to rock/ice avalanches is determined in an analogous way. In a further step, the impact areas of possible lake outburst floods and rock/ice avalanches are delineated. For this purpose, various empirical-statistical model approaches are combined in order to come up with robust estimates (see Fig. 2; Mergili et al. 2011). The validity of the regional-scale model

framework is evaluated for selected areas where high-resolution satellite imagery (mainly WorldView-1) and DEMs are available: (1) The regional-scale models are run with the high resolution datasets in order to figure out the influence of raster resolution; (2) local-scale models for the motion of mass movements are used; (3) observed events are used as reference. Based on the findings from the evaluation, the parameters of the regional-scale models are adapted and the uncertainty of the results is determined.



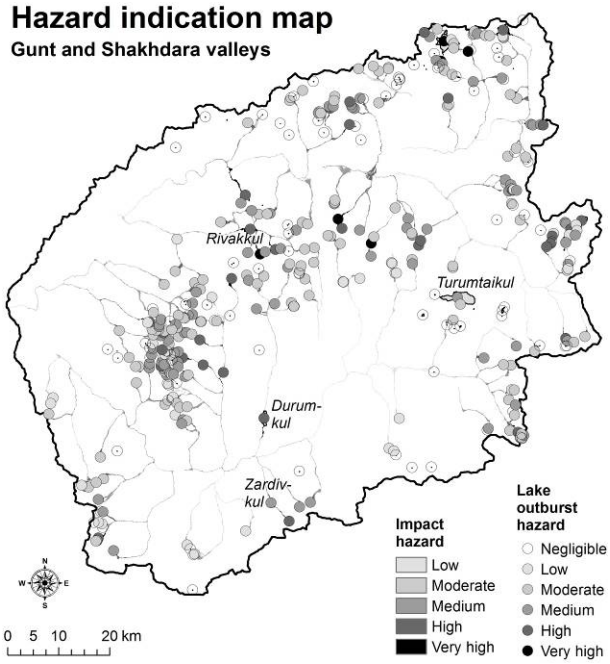


Figure 1 (left). Two growing glacial lakes in the Pamir
Figure 2 (right). Hazard indication map for lake outburst floods in the southwestern Pamir (lake outburst susceptibility and possible impact areas; glacial and non-glacial lakes are included)

The further development of the model framework will aim at the inclusion of datasets of populated zones and of local geohazards. The major task will be (1) to prioritize areas for mitigation measures and (2) to facilitate the identification of safe places. One major challenge of these tasks will be to appropriately account for the spatial inaccuracies immanent to regional-scale models.

References

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