Development stages of hazardous mountain lakes and simulation of their outbursts (Central Caucasus, Russia; Sichuan mountain region, China).

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The importance of mountain lakes studies is related to the increasing threat of natural disasters, associated with lake outbursts and debris flows formation, because of population growth on exposed areas. The outburst hazard has not been sufficiently researched, there is a lack of data because of the lakes inaccessibility and remote sensing data is usually not detailed enough. The main scientific topics include assessment of outburst possibility and further simulation of possible outbursts scenarios.

There are two types of mountain lakes: glacial (cirque, cirque-moraine, barrier-moraine, glacial-barrier, etc.) lakes and barrier (landslide, rockfall, debris flow, etc.) lakes. The first type was studied in the Central Caucasus (Russia), and the second type – in the Sichuan mountain region (China). The group of scientists, including authors, has been monitoring glacial lakes in the Mnt. Elbrus area for more than ten years. The unique data were collected, including detailed hydrological characteristics of more than ten lakes (water level dynamics, temperature, morphometrical characteristics, water balance components, etc.). Outbursts of at least three glacial lakes were observed. Hydrological characteristics of landslide Tangjiashan Lake were collected with Chinese colleagues during field studies in 2010 and 2011 years. Analysis of the collected data was used to understand the outburst mechanisms, formation factors, dam breaking factors, development stages of mountain lakes. Statistical methods of analysis in this case can be applied with some limitations because of the lack of sufficient monitoring objects, and therefore the results has been verified by experts.

All types of possible outbursts mechanisms were divided by the authors into five groups: geomorphologic (caused by changes in lake dams), seismic, or geodynamic (caused by seiches, waves from rockfalls, landslides), glacial (caused by breaks in impounding glaciers, ice floating and melting), water-balance (caused by changes in lakes water balance) and anthropogenic. Three development stages of mountain lakes were identified: 1) constant changes of lake hollows and rapid volume growth; 2) stable state, moderate changes; 3) outburst or overflow because of some external factors or gradual shallowing and disappearing.

According to the type of outbursts mechanisms and stage of development, the authors assessed the risk of outburst and chose methods, models and scenarios for simulation.
Analysis of the data (weighted estimation, graphoanalytical methods, etc.) showed that glacial lakes outburst possibility is influenced by (in order of importance): 1) water volume, 2) position of lake related to parent glacier, 3) characteristics of dam, 4) conditions of lake banks, 5) high water heat reserve and presence of ice lenses in dam. Barrier lakes outburst possibility is influenced by: 1) lake depth, 2) shape of lake hollow and coastline, 3) characteristics of dam, 4) conditions of lake banks. The most essential external factors are landslides, rockfalls, meteorological and seismic conditions.

The most dangerous lakes in research areas were allocated, for them outbursts scenarios have been developed, depending on studied characteristics. These scenarios were simulated using the River and FLO-2D models. At the final stage, zoning of mountain valleys depending on the level of risk was conducted, which is the basis for further risk mitigation.