Complex system behaviour of natural hazards in mountain regions

1. Introduction

Geomorphic processes are shaping the earth's surface. Processes contributing to earth surface dynamics can have an impact on lives, settlements and infrastructure, and can thus become "natural hazards". The most commonly observed natural hazards processes include rockfalls, avalanches, debris flows, landslides and floods, and they are most common in mountain regions where about 12 % of the world population live (Stäubli et al. 2018).

For this reason, natural hazards assessment is a key factor for a sustainable settlement of mountainous regions. Natural hazards processes are affected by topography, geology, meteorological conditions and – at higher elevations – by periglacial environment. This multitude of controlling factors leads to the widespread occurrence of these processes and to complex system behaviour. This complexity becomes particularly obvious in threshold processes, feedback loops and/or cascading effects, therefore rendering natural hazards assessments quite challenging.

Climate change will likely affect the frequency and magnitude of natural hazards processes (Beniston et al. 2018). Increasing air temperatures and the related retreat of glaciers and degradation of permafrost, will – in combination with higher intensity in heavy precipitation – ultimately lead to more instability and to a disequilibrium in the geomorphic system (Huggel et al. 2010). The likely consequence is an increase of the hazard potential in such a way that natural hazards assessments will become even more challenging. This is especially true when it comes to assessing the long-term development. To handle this complexity, an assessment based on the system approach is often recommended.

System approaches and system dynamics have a long tradition in geomorphology. In the early seventies of the last century, Chorley & Kennedy (1971) presented a system approach for physical geography and Kirkby (1971) developed hillslope process-response models. At the Binghamton symposium in geomorphology in 1992, geomorphic systems and modelling approaches were discussed (Phillips & Renwick 1992) – nonlinearity and nonequilibrium became important topics. Keiler (2011) stated that geomorphic literature, the terms complexity and complex systems have increased exponentially and Thomas et al. (2018) related geomorphic systems to resilience.

2. Approach

The focus of the work is on the development of a dynamic simulation model for process cascades in mountainous catchments. Based on this model, the long-term behaviour of typical catchment configuration will be analysed. In doing so, climate change will be taken into account. This work therefore aims to show which concepts of system dynamics are suitable to represent the complex behaviour of natural hazards processes.

The main fluxes within the system of interest are water and sediment. These fluxes are controlled by the availability of sediments and water. The sediment yield depends on weathering processes and, in higher areas, on permafrost degradation in rockwalls. In addition, sediment accumulations may exist from earlier climate phases (e.g. moraines, debris cones). For the transport to the torrential or river channel, fall processes, landslides and slope erosion are the main processes. For the transport within the torrents or rivers, channel geometry and runoff are the main factors. The availability of water depends on precipitation, temperature (snowmelt, evapotranspiration) and glacier melt.

For these processes, dynamic system models will be defined, based on literature. In the literature there exist many quantitative descriptions about the processes which are needed for the model construction (e.g. Jomelli et al. 2009, Luethi et al. 2015, Peres & Cancelliere 2018). The formulas from these publications are used here to define the relations between the system elements. In this context, timescale and units must be considered. In a further step, these single process models are integrated in a higher-level model.

After calibration and validation, the model is run for different scenarios and configurations. This is the basis for an extended sensitivity analysis. In this, the long-term behaviour is examined; the stability of the system is tested and possible threshold, feedback and bifurcation processes are analysed. The work ends with the compilation of system dynamics concepts that can be helpful in the analysis of process cascades and – in a further step – in the assessment of natural hazard processes.

3. Progress

The work presented here is in an early stage. Up to now, the conceptual framework for the higher-level model has been developed. Actually, the literature for the quantitative process descriptions is analysed systematically. From this, the best suited models are selected to build the system models for the diverse processes. Some models are already under development or could be adapted from other studies. In addition, real-world examples are evaluated that can be used as typical configurations. It is not yet clear whether only examples from Switzerland or also examples from other countries or continents should be used.

In the next steps, the models for the different processes will be defined, calibrated and validated. A further task will be to deepen the knowledge about stability and sensitivity analysis in the context of system dynamics. This is important for the evaluation of the results from the simulations.

4. Bibliography

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