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EVALUATION OF HAZARDS AND ITS MAIN COMPONENTS IN HIGH MOUNTAIN REGIONS[1]

Hazards relating to glaciers and permafrost occur in most mountain regions of the world and are a threat to lives, livelihoods, and sustainable development within some of the world's most vulnerable communities. In view of rapid global warming and related changes in the sensitive mountain cryosphere, landscapes are evolving and new threats are emerging. Recognizing the need for a structured and global approach of hazard assessment, the Joint Standing Group on Glacier and Permafrost Hazards in High Mountains (GAPHAZ) has drawn up a technical guidance document with the general aim of providing a concise compilation of the state of knowledge and best practices relating to glacier and permafrost hazard assessment. This work has received significant support from the Swiss Agency for Development and Cooperation (SDC) through the Glaciares+ Project in Peru. This executive brief highlights the systematic focus and fundamental components for hazard assessment according to the methodology of the new guidance document.

According to international definitions, ***hazard*** is identified as the potential occurrence of a phenomenon or physical process (natural or human induced), which could cause harm to humans and negative impacts in the territory at social, economic and/or environmental levels. Technically, hazard is assessed as a function of the probability of occurrence of an event and its expected intensity in the place in question.

HAZARD = F (PROBABILITY, INTENSITY)

The process of hazard assessment has two main components, namely: 1) susceptibility and stability assessment; and 2) impact assessment. Figure 1 presents the various elements and stages of each component and phase, which will then be explained.

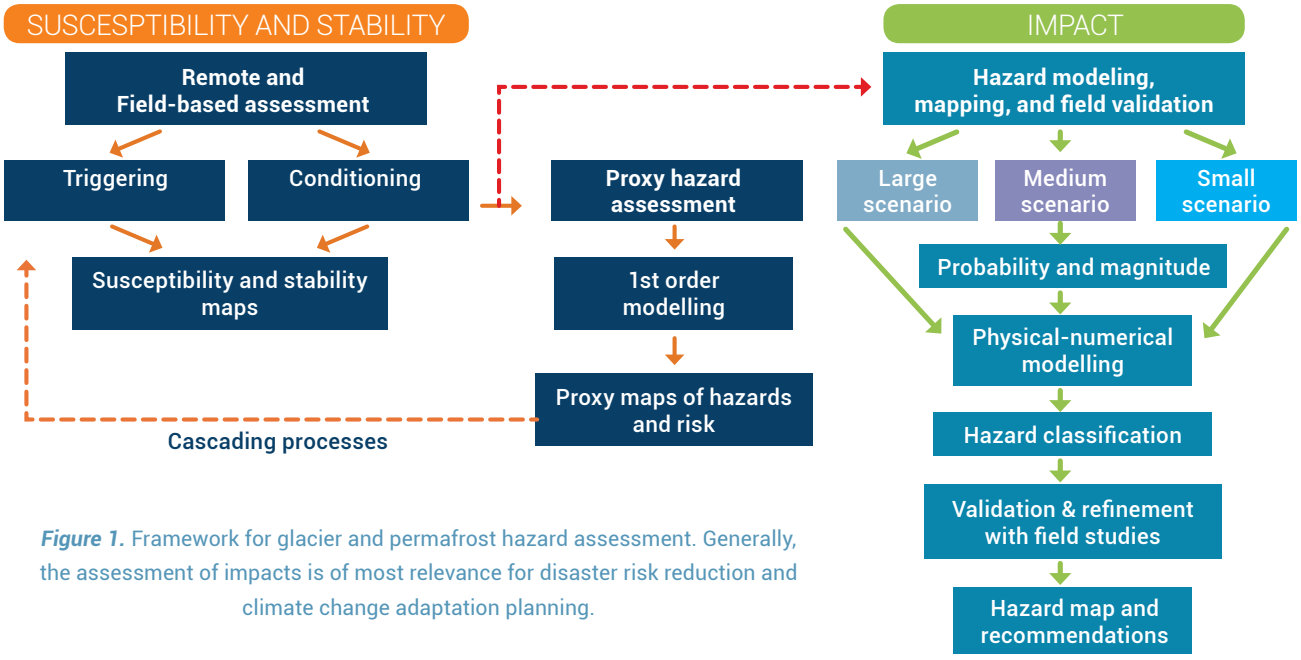

Figure 1. Framework for glacier and permafrost hazard assessment. Generally, the assessment of impacts is of most relevance for disaster risk reduction and climate change adaptation planning.

[1] This executive brief has been drawn up based on the *Assessment of Glacier and Permafrost Hazards in Mountain Regions-Technical Guidance Document*, executed by S. K. Allen, H. Frey, C. Huggel and other researchers of the GAPHAZ Working Group.

PHASE 1. SUSCEPTIBILITY AND STABILITY ASSESSMENT

Identify where hazards probably begin

Susceptibility is a relative measure of the likelihood (or probability) that a hazard will occur or initiate from a given site, based on intrinsic properties and dynamic characteristics of that site. It is in inverse relation to stability; that is, the greater the susceptibility, the lesser the stability of the territory and vice versa.

Susceptibility assessment is based on ***conditioning factors*** that encompass static and inherent characteristics of the site, but also those dynamic factors that gradually increase the susceptibility of a site over time (e.g. average air temperature). ***Triggering factors*** are reserved for those processes that directly initiate movement or transform a site from a stable to unstable state. (e.g. earthquakes). The significance of certain factors on susceptibility will vary from one case to another and expert judgment will be needed to establish whether or not more emphasis (weighting) should be applied to some factors in the local assessment.

Susceptibility and stability assessment provides a basis for identifying and prioritizing where subsequent impact studies will be focused (e.g. focusing on highly susceptible or unstable slopes) Similarly, information gathered during this stage will also feed directly into the scenario development and hazard modeling within the impact assessment phase. Susceptibility assessment at basin or larger scales can be based on remotely derived information. Geographic Information Systems (GIS) can thus be used to overlay various susceptibility factors and enable pixel-based semi-qualitative classifications to be implemented. Where the recognition of critical areas is possible and feasible, site-specific data can be used to drive quantitative analyses, such as slope stability or slope kinematic models. This must be used in conjunction with access to the field, in situ geophysical research and/or very high resolution remote sensing.

PHASE 2. IMPACT ASSESSMENT

Identify the potential threat of the hazard for downstream regions and provide scientific grounds for decision making and planning

Impact is defined as the potential physical threat produced by a hazard event. The information gathered in phase 1 together with the use of simple models and empirical approximations make it possible to develop maps of potential hazard. This first step, known as "proxy hazard assessment", includes approaches that provide a first indication of the extension and possibility of natural hazards, though their intensities are not physically modelled. These approaches combine empirical estimates of possible magnitudes of events (e.g. avalanche volume or flood volume and peak discharge) and runout distances, with simple hydrological models or flow routing algorithms. They should be used as a first order indicator of potential hazards and as a basis for prioritizing further local investigations and hazard mapping. For cascading processes, first-order modelling can also feed back into the susceptibility assessment, identifying, e.g., where lakes are located within the potential runout path of an ice or rock avalanche.

Where critical situations have been identified, it is recommended that hazard modelling and mapping of be carried out; this is an important support in obtaining a hazard map. Hazard mapping typically draws upon historical records to establish frequency (probability) – magnitude (intensity) relationships. This information can be used subsequently for scenario development and hazard modelling. For hazards originating in high mountain environments, the ability to establish reliable frequency – magnitude relationships is limited by three factors:

- Hazards originate often in remote, inaccessible locations, meaning even large events may have passed unnoticed and dates are poorly constrained for the historical record. The dynamic cryosphere is changing rapidly and in some cases conditions are beyond any historical precedence, meaning frequency–magnitude relationships are of decreasing significance.

- Many events may occur only once, and hence, frequency–magnitude relationships may not apply at all.

Given these limitations, a semi-qualitative approach to scenario development is recommended. In the context of glacier and permafrost hazards assessment, the scenario describes a possible hazard event based on the magnitude and probability of occurrence.

The objective of scenario development is to establish feasible scenarios of different magnitudes to model the hazard, where initial potential mass or volume is estimated for different cases (generally for a small, medium or large event) and the best possible estimate of probability of occurrence of the event is assigned.

In view of possible extreme events that have a low probability but a sufficiently high potential magnitude not to be excluded from the assessment, a single "worst case" scenario can be proposed. This could be appropriate, for example, for a large volume lake that is deemed to have a very low probability of outburst.

According to the hazard modelling results, the potential land area affected by the worst-case event could be marked as area of residual danger.

The expert may establish possible scenarios based on the following primary sources of information:

- Information compiled during the basin to site susceptibility /stability assessment
- Inferences based on local historical inventories and field evidence from past events.
- Inferences based on evidence and process understanding of international cases.

The time horizon for which the scenario is valid should also be stated. If the intention is to have a scenario that is valid for prolonged periods of time (several decades), future climate changes must be sufficiently taken into account. Thus, the hazard scenarios may be independent of or may be linked to climate scenarios, depending on the time horizon for which the hazard assessment is considered valid. However, in view of rapidly changing environmental conditions, scenario development should incorporate information and current understanding of changes and transformations of glacial and periglacial landscapes, and resulting implications for hazard events magnitude and probability.

The high availability of physical-numerical models provides the basis for physically based mapping of event intensities for each hazard scenario. The selection of the model (or models) to be used should fit local requirements, resources and data availability.

Swiss standards distinguish low, medium and high intensities based on possible damages the event could cause to people and infrastructure. However, these suppositions do not actually consider whether or not people and infrastructure are exposed to the simulated event, as would be considered under a risk assessment. Quantitative criteria according to physical units of the processes (e.g. flow velocities, kinetic energy) can be used for a better definition of classes of intensity, using one or more of the results (products) of the simulated model.

- **High intensity:** People and animals face threat of injuries inside buildings. Heavy damages to buildings or even their destruction would be possible.
- **Medium intensity:** People and animals face the threat of injuries outside buildings. Lighter damages to buildings.
- **Low intensity:** People and animals face the threat of injuries outside buildings. Lighter damages to buildings
- People and animals would be slightly threatened, even outside (except in the case of stone and block avalanches, which could harm or kill people and animals). Superficial damages to infrastructure could be expected.

To link the scenario modelling intensities with a corresponding hazard level, a matrix-based approach to hazard classification is favored (see figura 2). For each scenario, the 3-by- 3 matrix links the modelled flood or mass movement intensities with the assigned probability level for that scenario. A danger or hazard level is thus established. Multiple scenarios (e.g. small, medium and large scenarios) can be overlaid and fine-tuned through field mapping in order to arrive at a hazard map.

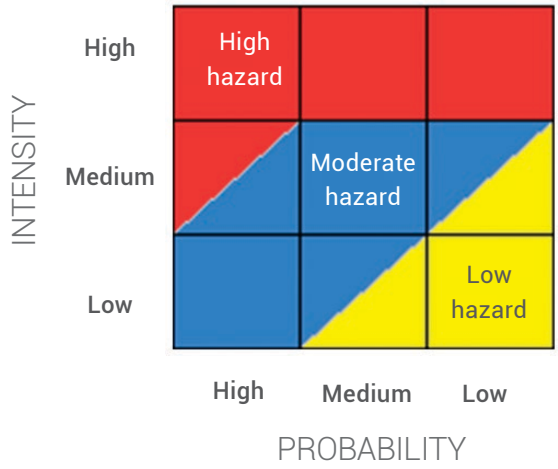

Figure 2. Matrix-based method that links probability of occurrence assessment (with the scenario-based intensity modelling). A hazard classification is achieved this way.

CONCLUSIONS AND RECOMMENDATIONS

- The **guide** drawn up by GAPHAZ provides guidance **for experts on assessing natural hazards in high mountain areas**. The annexed tables with the factors that should be analyzed for each process are new and detailed tools. The document reflects the latest scientific knowledge and makes it possible to obtain a comprehensive assessment of hazardous processes and their possible interactions. The document **cannot, however, replace the local knowledge and experience of the professional responsible for the assessment** and may be subject to adaptations according to conditions on the ground.

- This **brief** focuses on showing the main components to be taken into account in glacier and permafrost hazards assessment, as set out in the original guide. Thus, it **only provides the information required for one of the risk components: hazards**.

- **Proxy hazard assessment is useful in many ways**: 1) as an intermediate stage to identify potential risk points, which future studies, field research, risk modelling and mapping can focus on; 2) as an alternative to process modelling and hazards mapping, where data quality and resolution prevent a more sophisticated approach; 3) as an identifier of potential cascade processes and chain reaction events; and 4) as early anticipation of future threats.

- **The aim or final product of phase 2** of hazard assessment is to draw up a **hazard map**. The map presents the main hazards (in this case glaciers and permafrost) present in a city or community, and the level to which they are affected by areas, taking into account the previously variables and factors analyzed. The hazard map is an indispensable **tool in an Early Warning System (e.g. danger of flooding) and is an important instrument in territorial planning**.

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