Quantitative landslide risk analysis: Between local field monitoring and spatial modelling

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ABSTRACT: Since decades, risk analysis is a very common approach in technological and engineering risk procedures. The application of these concepts to natural processes started two decades ago, and received increasing attention in the last years. Risk analysis ranges hereby from local analysis to spatial assessments. Landslide risk analysis is an increasingly popular tool to determine potential effects of landslide occurrences. The difficulty was – and still is – to determine local risk of single slopes and to link these results to spatial analysis. These spatial assessments are indeed of high importance for any party interested in spatial information. Although such spatial risk information is mostly associated with high uncertainty, this uncertainty is often not quantified. This presentation will review some basic concepts of risk assessments at various scales and will identify some of the most crucial issues based on various examples from Germany and Iceland.

KEYWORDS : Landslide, monitoring, modelling, hazard, risk.

1. General instructions

Risk studies determine the adverse effects of an activity or process to society. One of the origins of detailed studies relate to technological, engineering, biological and medical operations. Herein, it is commonly aimed to quantify the adverse effects of a new product, a construction, or a treatment. Such quantification addresses the likelihood of a potential result. Two main directions arise. One considers only the likelihood of an impact and does not explicitly include the quantification of the effects. The other reflect the whole chain of imposing event and probable results. In recent years, risk studies mostly cover the latter approach. Resulting effects of a given event are commonly split in the two groups of quantifiable and un-quantifiable consequences. The quantifiable consequences relate the risk to a monetary values, such as any currency related to a given impact. If the spatial extent is known, it is expressed as value/unit area, e.g. €/m^2. Un-quantifiable consequences are any type of impacts which cannot expressed as a monetary value, e.g. religious believes, psychological effects. A crucial issue always was and is life of humans. Indeed, the monetary value of life can also been quantified, as it is a common procedure in economy or insurance industry. However, there is an ethical issue involved, because a pure economic assessment consequently leads to higher value for people from industrialized countries in contrast to low-developed countries. And this is highly questionable. To overcome this issue, life is expressed in a separate unit with probability of loss of life and different grades of injury.
When dealing with natural processes, same principles of hazard and risk were introduced by UNDRO (1982) and Varnes (1984), and most recently addressed in Alexander (2000) or Dikau and Weichselgartner (2005), to name a few publications only. In landslide research, hazard and risk studies have been carried out in a variety of specific case studies. Landslides refer here to the definitions given by Cruden and Varnes (1996) and Dikau *et al.* (1996). Recently, the landslide risk procedure has been summarized by GEO (1998), AGS (2002),

Lee and Jones (2004) and Glade *et al.* (2005). This study refers to landslide and hazard/risk terminology introduced by these authors.

2. Principles of landslide risk

2.1. Definitions and terminology

A landslide event is a natural process operating in nature without disturbing the society. It turns into a hazard when society is directly or indirectly potentially affected and is thus defined as the probability of a potentially damaging event occurring within a given period of time, a predefined area and for a specific magnitude. The hazard changes into risk when consequences are also addressed. Hence, risk is a function from hazard and consequences, while the consequences are generally divided into elements at risk (including its maximum damage potential) and their vulnerability. In this formula, vulnerability is tricky. It is commonly expressed as the percentage of a total damage and consequently related to both the forces of impact and the strength of the affected element. Vulnerability values range between 0% (no damage) to 100% (total destruction), or expressed dimensionless between 0 to 1 respectively. One has to be aware, however, that vulnerability can also relate to the coping strategies of the affected society, to the different capacities of different groups within a society (e.g. children, middle aged, elderly) or to the vulnerability of a political system towards landslide processes, to name a few further issues only (Alexander 2000).

2.2. Landslide risk assessment

All these different types of studies are structured in three main components within the general concept of landslide risk assessment. *Landslide risk analysis* relates the detailed behaviour of the processes and their frequency and magnitude characteristics to the potential consequences. In *landslide risk evaluation*, studies investigate the involved parties, communication between them and their perception of the risk. *Landslide risk management* finally decides through either expert decisions or participatory processes on what are the acceptable and tolerable risk levels and what sort of management strategies (e.g. mitigation structures, land-use planning, educational procedures) have to be taken (Glade *et al.* 2005). These procedures have to be linked to the risk cycle, as described e.g. by Alexander (2002).

2.3. Local analysis versus spatial analysis

Research on landslide risk always faces two problems. First, the landslide is a definite object occurring at a given locality. Thus, traditional monitoring techniques can be implemented to study this specific landslide to the greatest extent. Second, the demand on spatial information arises continuously. Table 1 summarizes different approaches for respective scales and gives a recommendation for the usage of the different methods. It has to be emphasized, that this recommendation might change with the rapidly evolving technology.

Tab. 1. Recommended scales for different spatial landslide analysis (Glade and Crozier 2005, extended from Soeters and van Westen 1996)

Scale	Qualitative methods		Quantitative methods	
	Inventory	Heuristic analysis	Statistical analysis	Process-based and numerical analysis
<1:10,000	Yes	Yes	Yes	Yes
1:10,000-1:100,000	Yes	Yes	Yes	Probable
1:100,000 – 1:500,000	Yes	Yes	Probable	No
>1:750,000	Yes	Yes	Probable	No

In addition to the general challenge of spatial analysis of landslides, it is even a greater challenge to determine risk at these various scales. Often, these information are not hold in similar units, e.g. regionalized property values are based on postal codes or on borders of a community. Furthermore, mobilized elements at risk such as cars and people increase the difficulty to determine risk. A general solution is to calculate different scenarios, e.g. day versus night, public holiday versus normal working day, etc. In the following, two examples give a brief glance on options to calculate landslide risk on a spatial scale.

3. Examples of spatial landslide risk studies

3.1. Generalized landslide risk in Rheinhessen

For an area in Rheinhessen a regional landslide susceptibility map corresponding to a 50years return-period rainfall event was calculated (Glade 2001). This information was combined with elements at risk derived from land-use plans available at scale 1:25,000) and economic values adopted from a study on flood damage. Vulnerability was assumed to be 1, thus an element at risk affected by a landslide is totally destroyed. The resulting regional landslide risk map is shown in Fig. 1a. Despite the generalized input data, the area of major concern for the society can clearly been attributed to settlements, thus the area with largest potential for future problems is identified.

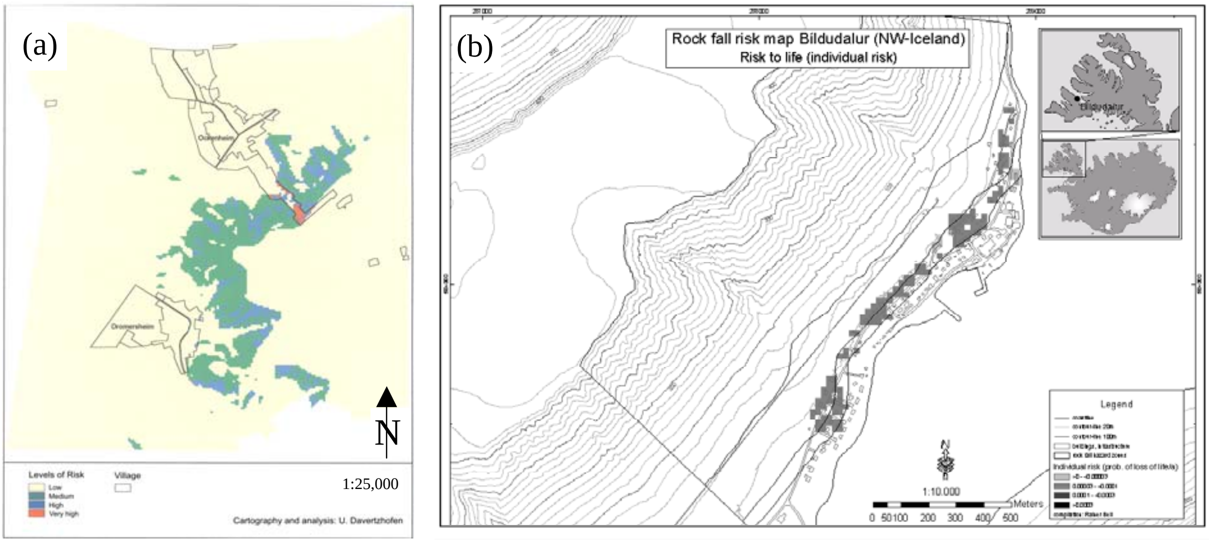

Fig. 1. (a) Generalized landslide risk in northwest Rheinhessen, Germany (Glade *et al.* in prep.) and (b) detailed rock fall risk to life in Iceland (Bell and Glade 2004).

3.2. Detailed rock fall risk in Iceland

In Bíldudalur in Northwest Iceland, detailed data on run-out zones calculated using a 2-dim. process–based model were combined with economic data on elements at risk and social data on population. In contrast to Fig. 1a, the resulting map in Fig. 1b displays the risk of individuals being hit by a rock fall (refer to Bell and Glade 2004 for full details). In addition to economic risk, risk to life adds information for the society and thus, provides a further important information necessary to take appropriate decisions for management strategies.

4. Conclusions and perspectives

The theoretical introduction demonstrates the importance of a general agreement on terminology and methodological concepts to address landslide risk. In addition to local risk analysis also spatial analysis are indispensable for stakeholders and decision makers. When working in the field of risk, it is most important not to focus on one specific element of the total risk chain only (e.g. calculation of energy released by debris flows), but rather to include also societal aspects through the elements at risk. In any calculation, the uncertainty must explicitly expressed and provided for the decision makers. Additionally, communication links within the decision making progress and decision responsibilities in landslide management are most important and need to be clarified before a future event impacts a unprepared society. Various frameworks exist, but indeed need to be further refined. Relevant issues are:

- Better process understanding including process mechanisms, but also frequency and magnitude aspects.
- Modelling of scenarios to determine potential effects of both environmental change but also social changes (e.g. sub-urbanisation).
- Further enhancing the classification of elements at risk and their economic dimensions.
- Determining vulnerability values for different landslide types and respective magnitudes.
- Calculation of the extremely large associated errors and uncertainties in the risk analysis.
- Linking local, site specific risk analysis to spatial assessments at various scales.
- Introducing scientific results to responsible parties to support sustainable decisions.

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