Advances in Natural and Technological Hazards Research

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Mountain Risks: From Prediction to Management and Governance

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Preface

This book offers a cross-disciplinary coverage for the rapidly growing field of integrated approaches in risk assessment in mountain areas. It considers all the aspects related to hazard and risk assessment, risk management and governance, all illustrated with a wide range of case studies. The book associates (1) technical chapters on the state-of-the-art methods for the understanding of mountain processes and quantitative hazard and risk forecasts and (2) case study chapters detailing the integration of natural, engineering and human sciences within multi-scale methodologies for risk management and prevention planning.

Long-term cohabitation of the social, economic and environmental systems in mountain areas necessitates (1) to reflect the 'chain of safety' (e.g. pro-action, prevention, preparation, response and follow-up) and (2) to cover the chain of the 'living with risk' process, from quantitative risk assessment to coping strategies including socio-economic and political decision-making. The observed increase in disastrous events over the last decades, associated with an often low perception of most natural risks by the local communities, along with the lack of efficient, socially accepted and environmentally sound remedial measures are amongst the drivers behind the increasing effects of mountain risks.

Landslides and rockfalls on mountain slopes, debris flows within torrential streams and flooding on river valleys, driven by climatic and anthropogenic factors as well as land mismanagement, all cost the economy dearly, especially in mountain areas. Even today, development is still taking place in many hazardous zones, and even more development is taking place in future hazard zones where planning and predictive assessment are at odds. Growing attention has to be paid also to the impact of climatic and non-climatic changes that will result in changing hazard risk patterns over Europe. The development of viable livelihoods on the long-term also endorses the task of governing the risk assessment process at all levels of spatial planning, and for several spatial and temporal scales.

The assessments of natural hazards and risks are generally carried out by natural scientists from fields such as engineering geology, geomorphology, geophysics, hydrology, soil science and geography; however, while the physical problems associated with risk assessment need continual science and engineering attention (e.g. development of monitoring techniques, alert systems and protection measures), some of the ongoing questions need to be addressed by other disciplines including social and economic science, cognition science, civil and public law, planning and politics.

Most text books deal with some aspects related to hazard and risk assessments (Turner and Schuster 1996; Lee and Jones 2004; Glade et al. 2005; Landslide Committee – National Research Council 2008; Sassa and Canuti 2008). This book focuses on comparative multi-disciplinary case studies and gives a complete picture of all the aspects related to hazards and risks.

The book provides valuable insights, guidance and advice to research scientists, engineers, people in charge of local and regional risk management, planners and policy makers and all those who share a common interest of effective risk reduction to show them the importance of an integrated approach of all aspects of risks in mountainous areas. It is envisaged that the presented cross-disciplinary approach may extend their vision, add to their understanding and possibly, facilitate their work.

The first part of the book is focusing on new techniques for assessing mass movement and flood hazards. It describes the state-of-the-art techniques for the morphological characterization and the monitoring of displacements. Computational advances are described to understand the physical processes, the interactions within the systems and to quantify the hazard.

In the introduction, *Greiving et al.* (Chap. 1) discuss key issues related to aspects of hazards and risks of natural processes in mountain areas and set up the framework of risk governance, which aims to integrate these elements. *Lu et al.* (Chap. 2) introduce several innovative remote-sensing techniques to monitor and analyse the kinematics of slow moving to moderately moving landslides. These are illustrated in three case studies in Italy and France. *Kniess et al.* (Chap. 3) highlight the interest of combining different techniques obtained from numerous developments in remote-sensing, near-surface geophysics, field instrumentation and data processing. In a number of case studies, they show significant advances in characterizing the landslide morphology and internal structure. *Ferrari et al.* (Chap. 4) give an overview of the recent developments of numerical models to describe the complex behaviour of slow and rapid mass movements which form the basis for hazard and risk assessment and the development of reliable Early-Warning Systems (EWS). Special attention is given to the complex hydrological system of landslides, which controls their dynamic behaviour. Case studies are presented to illustrate the performance of the numerical models detailed in this chapter.

The second part of the book is focusing on methodologies to assess the impact of the natural hazards on the society in terms of risks. It presents methods and tools for a quantitative risk assessment of dangerous rapid mass movements using run-out models and the characterization of the vulnerability of the elements at risk.

Luna et al. (Chap. 5) evaluate several dynamic process-based models able to simulate the propagation of rapid mass flows and forecast the hazard (e.g. delineation of the zones where the elements-at-risk will suffer an impact of a certain level of intensity) and the risk through the application of fragility and vulnerability curves and the generation of risk curves based on economic losses. *Mavrouli et al.* (Chap. 6) give a review on the current methodologies that are used for the assessment of rockfall susceptibility, hazard and risk. The authors present advances involving the consideration of the magnitude of the events and the intensity of the phenomena at selected locations as well as the incorporation of a quantitative vulnerability into the risk equation. *van Westen et al.* (Chap. 7) discuss the analysis of multi-hazards, especially in terms of their interaction, in mountainous environments at a medium scale (1:25,000). They give an overview of the problem of multi-hazard risk assessment illustrated through a case study for the Barcelonnette area (French Alps). *Sterlacchini et al.* (Chap. 8) discuss how vulnerability assessment plays a crucial role in 'translating' the estimated hazard level into an estimated level of risk. They stated that it is impossible to address risk assessment without assessing vulnerability first, and it appears unquestionable that a multi-disciplinary approach is requested in vulnerability assessment studies. *Garcia et al.* (Chap. 9) present a quantitative survey to evaluate the response capacity of the population in the mountainous environment of the Italian Central Alps, in order to assess the levels of preparedness and the perceived risk. The outcome of the enquiry showed that, in this case study, a gap between the occurred disasters and the possible lessons to be learnt still exist and that an effective method to share and disseminate knowledge is missing.

The third part of the book is focusing on the response of the Society towards the problems of hazard and risk. It highlights the role of spatial planning, Early-Warning Systems and evacuation plans for risk management. It establishes practical thresholds for acceptable and tolerable risks and emphasizes the validity of education and communication towards the Society.

Greiving and Angignard (Chap. 10) discuss options for mitigating risk by spatial planning and highlight the effectiveness of such measures by analysing the example of the municipality of Barcelonette (French Alps). *Mavrouli et al.* (Chap. 11) distinguish two different strategies for corrective and protective measures for the mitigation of landslide risk, namely stabilization/interception measures and control measures. A variety of mitigation measures are presented for three different landslide types: rockfalls, debris flows and shallow to deep seated slope movements. *Angignard et al.* (Chap. 12) discuss the interconnection of factors that determine risk perception through a series of social variables and by concentrating on the relevance of legal frameworks and insurance possibilities. The theoretical implications of risk culture on risk assessment and management in practice are explained by the example of the case study of the region of Valtellina (Italian Central Alps). *Garcia et al.* (Chap. 13) analyse different types of Early-Warning Systems with the aim to connect scientific advances in hazard/risk assessment with local management strategies and practical demands of stakeholders/end-users. An Integrated People-Centred Early Warning System (IEWS) is presented, which is mainly based on prevention as a key element for disaster risk reduction. *Peters-Guarin and Greiving* (Chap. 14) give an analysis about risk acceptability and tolerance, which greatly depend on the existing social, economic, political, cultural, technical and environmental conditions of the society at a given moment in time.

Frigerio et al. (Chap. 15) propose interactive tools by means of a WebGIS service architecture to inform stakeholders about the different stages of risk management, especially the preparation phase and emergency management. Different cases are set up using a common open source environment: multi-hazard risk assessment, risk management with interoperability on spatial data and metadata, collection of information on historical natural events and visualisation of outcomes of multi-hazard risk analyses.

The book chapters are the results of the collaborative work of 19 young researchers of the MOUNTAIN RISKS Project (www.mountain-risks.eu/) carried out during 4 years, from January 2007 to January 2011. This collaborative work was supported by the 6th Framework Program of the European Commission through a Marie Curie Research & Training Network. The focus of the project is on research and training in all aspects of mountains hazards and risks assessment and management. The project has involved 14 partners throughout Europe, each hosting a Post-Doc (ER) and a PhD (ESR) position. The partners have organized a series of intensive courses and workshops to train young scientists in all aspects of natural, social and engineering sciences dealing with mountain risks.

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Contents

Chapter 1
Introduction: The components of Risk Governance

Stefan Greiving, Cees van Westen, Jordi Corominas, Thomas Glade, Jean-Philippe Malet, and Theo van Asch

Abstract This introductory chapter discusses key issues related to aspects of hazards and risks of natural processes in Mountain area's and discusses the framework of risk governance, which aims to integrate these elements.

Hazard assessment intends to make an estimate of the spatial and temporal occurrence and magnitude of dangerous natural processes. The chapter describes different methods to assess hazard in a qualitative and quantitative way including all kind of data driven statistically approaches and the use of coupled hydro mechanical deterministic models.

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Since statistical approaches, will meet difficulties in future predictions in case of changes of the environmental factors, like land use and climate, special attention is given to the use of physical deterministic models which makes it possible in theory to do predictions about hazard without historical data sets.

An overview is given of the different approaches to come to a final risk assessment. For a risk assessment information on temporal, spatial and intensity probabilities of the endangering processes is required as well as an identification of the vulnerability of the society for the impact of these processes. Vulnerability assessment, which forms a key element in these procedures still knows a lot of difficulties.

Current research on natural risks is fragmented and isolated with natural sciences and engineering disciplines on the one hand and societal sciences on the other hand. The complex, socio-political nature of risk calls for an integrated approach. A discussion is presented about the concept of risk governance, which tries to combine all the physical, technical, socio-economic and political aspects to take the right decisions for a safe and sustainable society.

Abbreviations

IUGS	International Union of Geological Sciences
GIS	Geographical Information Systems
ALARP	As Low As Reasonably Practicable
EIA	Environmental Impact Assessments
EWS	Early Warning Systems
DEM's	Digital Elevation Models
LIDAR	LIght Detection And Ranging
F-N curves	Frequency vs. Number of fatality' graphs
UN	United Nations
UN-ISDR	United Nations International Strategy for Disaster Reduction
EC	European Commission
IRGC	International Risk Governance Council
RG	Risk Governance
RA	Risk Assessment
RM	Risk Management
RC	Risk Communication
MORLE	Multiple Occurrence Regional Landslide Events

1.1 Hazard Assessment

Hazard and risk assessment are prerequisites for a safe and sustainable development of the society in mountainous areas. *Hazard* assessment for example of landslides aims at an estimate of the spatial and temporal occurrence and magnitude of these natural processes (IUGS Working Group on Landslides 1997).

Decisions in the area of so called "traditional" hazards like landslides are normally based on expert expertise, often combined with results from modelling analysis. Hereby, the calculation of the spatio-temporal probabilities of the natural hazards on the basis of recent field monitoring but also related to available historical information is crucial.

Different methods are used to assess landslide hazard in a qualitative and quantitative way (Soeters and Van Westen 1996; Carrara et al. 1999; Guzzetti et al. 1999; Dai et al. 2002). All kind of data driven statistically approaches are used now at days to relate the occurrence of landslides which their causal factors. In recent years there is a growing interest for the use of coupled hydro mechanical models, which can describe quantitatively the frequency and dynamic of landslides.

For the assessment of hazard by the heuristic or statistical approach temporal information is needed in terms of magnitude and frequency of dated historic landslide events that can be related with sufficient long historical records of the most important triggering events: rainfall and earthquakes (Zezere et al. 2004; Corominas and Moya 2008). However, analysed data are only available for a specific period – and are thus not representative for longer periods. This problem is enhanced when using historical data. These add indeed the value of information in particular for frequency and magnitude analysis of the investigated processes. It has to be admitted that historical data are always incomplete information covering in particular the large scale events, but not the events with smaller magnitudes.

Historic information can be completed by landslide interpretation from aerial photographs and satellite imagery. This needs however great skills in field and photo interpretation and even then different experts may deliver different results (Carrara et al. 1992; Van Westen et al. 1999).

Statistical approaches, which are based on correlations between past landslide occurrences and the causative landscape factors will meet difficulties in future predictions in case of changes of the environmental factors, like land use and climate. The observed climate changes related effects on temperature and precipitation will lead to new uncertainties, because past events might be not representative anymore. Similarly, other changes in the catchments (e.g. deforestation, melting of glaciers, surface sealing through settlement development, surface modification by infrastructure, etc.) will also lead to high uncertainties. Here, the perspective changes from probabilities to just possibilities. With public decision-making not having any precise information at hand, restrictions for private property rights are probably not anymore legally justifiable. Hereby, justification of actions and consensus about thresholds for acceptable risks and response actions becomes more important.

1.1.1 Susceptibility Assessment

The spatial component of the hazard assessment is called the susceptibility assessment. A susceptibility map shows the subdivision of the terrain in zones that have a different likelihood that landslides or other mountain hazards may occur. The likelihood may be indicated either qualitatively (as high, moderate low, and not susceptible) or quantitatively (e.g. as the density in number per square kilometers, area affected per square kilometer, Safety Factor, height or velocity of run-out). Landslide susceptibility maps should indicate both the zones where landslides may occur as well as the run out zones. Therefore the landslide susceptibility methods are divided into two components. The first susceptibility component is the most frequently used, and deals with the modelling of potential initiation areas (susceptibility to failure). The resulting maps will then form the input as source areas in the modelling of potential run-out areas (run-out susceptibility).

Many statistical techniques have been developed and applied successfully to landslide susceptibility assessment and mapping in the last 10 years using bivariate or multivariate approaches, probabilistic approaches (like Bayesian inferences or logistic regression) and artificial neural networks approaches Such techniques are capable to predict the spatial distribution of landslides adequately with a relatively small number of conditioning variables.

Overviews and classification of methods for landslide initiation susceptibility assessment can be found in Soeters and Van Westen (1996), Carrara et al. (1999), Guzzetti et al. (1999), Aleotti and Chowdury (1999), Cascini et al. (2005), Chacon et al. (2006), Fell et al. (2008), Cascini (2008), Dai and Lee (2003).

Landslide susceptibility assessment can be considered as the initial step towards a quantitative landslide hazard and *risk* assessment. But it can also be an end product in itself, or can be used in qualitative risk assessment if there is insufficient information available on past landslide occurrences in order to assess the spatial, temporal and magnitude probability of landslides.

Methods for assessing landslide run-out may be classified as empirical and analytical/rational (Hungr et al. 2005). For susceptibility zoning purposes both methods are widely used given their capability of being integrated in GIS platforms. However, they vary a lot depending on the type of process modelled, the size of the study area (modelling individual events or modelling over an entire area), availability of past occurrences for model validation, and parameterization.

For flood susceptibility assessments, also the two components mentioned for landslides can be differentiated: the initiation component dealing with the runoff modelling in the upper catchment (hydrologic modelling), and the spreading component, dealing with the estimation of the spatial distribution, height and flow velocity in the downstream section (hydraulic modelling).

In near-flat terrain with complex and also in urban environments and in areas with a dominant presence of man-made structures, flood models are required that calculate flow in both X- and Y-direction (2-D models). Such models, like SOBEK (Stelling et al. 1998; Hesselink et al. 2003), Telemac 2D (Hervouet and Van Haren 1996) and MIKE21 can also be applied in the case of diverging flow at a dike breach. They require high quality Digital Elevation Models (DEM's), which ideally are generated using LIDAR data (Alkema and Middelkoop 2005). The flood modelling is usually carried out at a municipal to provincial scale, at a selected stretch of the river. These models provide information on how fast the water will flow and how it propagates through the area. It is very suitable to assess the effects of the surface topography, like embanked roads and different land cover types on the flood behavior (Stelling et al. 1998).

1.1.2 From Susceptibility to Hazard

Hazard assessment requires information on temporal, spatial and intensity probabilities. The analysis of these probabilities is very different for landslide and flood hazard assessment. In the case of flood hazard assessment, flood inundation scenarios are generated for flood discharges that are related to a specific return period, which can be analyzed using magnitude/frequency analysis of historical discharge data. The resulting flood scenarios already indicate the areas that are likely to be flooded (hence the spatial probability of flooding in these areas is 1), and the intensity of flooding (in terms of water depth, flow velocity or impact pressure).

In the case of landslide hazard assessment the conversion of susceptibility maps into quantitative hazard maps is much more complicated, especially at medium scales of analysis. Conversion of landslide susceptibility maps into landslide hazard maps often requires a separate estimation of the spatial, temporal and magnitude probabilities of landslides (Guzzetti et al. 1999; Fell et al. 2008; Van Asch et al. 2007; Corominas and Moya 2008; van Westen et al. 2008), which may not be correct as these three components are interdependent.

- The spatial probability required for hazard assessment is not the same as the landslide susceptibility. A susceptibility map outlines the zones with a relatively likelihood of landslides. However, only a fraction of the high hazard zones outlined in these maps may actually experience landslides during different scenarios of triggering events. In most of the methods that convert susceptibility to hazards, triggering events and the landslide pattern they cause, play a major role. Hence it is important to obtain event-based landslide inventories or MORLE (Crozier 2005) for which one can determine the temporal probability of the trigger, the spatial probability of landslides occurring within the various susceptibility classes, and the intensity probability. In this approach, which is mostly carried out at medium scales, the susceptibility map is basically only used to subdivide the terrain in zones with equal level of susceptibility.
- Intensity probability is the probability of the local effects of the landslides. Intensity expresses the localized impact of a landslide event, measured in different ways, such as height of debris (e.g. for debris flows), velocity (e.g. of debris flows, or large landslides), horizontal or vertical displacement (e.g. of large landslides), or impact pressure (e.g. for debris flows, rockfalls). Whereas the magnitude of a landslide, which can be represented best by the volume of the displaced mass, is a characteristic of the entire landslide mass, the intensity is locally variable, depending on the type of landslide, the location with respect to the initiation point, and whether an element at risk is on the moving landslide,