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.

S. Greiving
Institute of Spatial Planning, TU Dortmund University, August-Schmidt-Straße 10,
D-44227 Dortmund, Germany

C. van Westen
Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente,
Hengelosestraat 99, 7514 AE Enschede, The Netherlands

J. Corominas
Department of Geotechnical Engineering and Geosciences, Technical University of Catalonia,
BarcelonaTech, Jordi Girona 1-3, D-2 Building, 08034 Barcelona, Spain

T. Glade
Department of Geography and Regional Research, Geomorphic Systems and Risk
Research Unit, University of Vienna, Vienna, Austria

J.-P. Malet
Institut de Physique du Globe de Strasbourg, CNRS UMR 7516, Université de Strasbourg/EOST,
5 rue René Descartes, F-67084 Strasbourg Cedex, France

BEG, Bureau d'Etudes Géologiques SA, Rue de la Printse 4, CH-1994 Aproz, Switzerland

T. van Asch (✉)
Faculty of Geosciences, Department of Physical Geography, Utrecht University,
Heidelberglaan 2, 3584 CS, The Netherlands
e-mail: aschtheo@gmail.com

T. van Asch et al. (eds.), *Mountain Risks: From Prediction to Management and Governance*, Advances in Natural and Technological Hazards Research 34,
DOI 10.1007/978-94-007-6769-0_1,

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,

in front of it, or directly above it. The quantitative estimation of the probability of occurrence of landslides of a given size is a key issue for any landslide hazard analysis (Malamud et al. 2004; Fell et al. 2008). Magnitude probabilities of landslides can be estimated after performing the magnitude-frequency analysis of landslide inventory data. For estimating landslide magnitudes, the area of landslide (m^2) can be considered as a proxy (Guzzetti et al. 2005b) to the volume, which is often difficult to collect from inventories. The frequency-size analysis of landslide area can be carried out by calculating the probability density function of landslide area using the maximum likelihood estimation method assuming two standard distribution functions: Inverse-Gamma distribution function (Malamud et al. 2004), and Double-Pareto distribution function (Stark and Hovius 2001).

- Temporal probability can be established using different methods. A relation between triggering events (rainfall or earthquakes) and landslide occurrences is needed in order to be able to assess the temporal probability (Corominas and Moya 2008). Temporal probability assessment of landslides is either done using rainfall threshold estimation, through the use of multi-temporal data sets in statistical modeling, or through dynamic modeling. Rainfall threshold estimation is mostly done using antecedent rainfall analysis, for which the availability of a sufficient number of landslide occurrence dates is essential. If distribution maps are available of landslides that have been generated during the same triggering event, a useful approach is to derive susceptibility maps using statistical or heuristic methods, and link the resulting classes to the temporal probability of the triggering events. The most optimal method for estimating both temporal and spatial probability is dynamic modeling, where changes in hydrological conditions are modeled using daily (or larger) time steps based on rainfall data (Van Asch et al. 2007). However, these require reliable input maps, focusing on soil types and soil thickness. The methods for hazard analysis should be carried out for different landslide types and volumes, as these are required for the estimated losses.

1.1.3 Physical Modelling and Monitoring as a Basis for Hazard and Risk Assessment

The use of physical deterministic models plays an essential role in quantitative landslide hazard and risk assessment because these estimate in a quantitative way failure and motion, calculate run-out distances, velocities, impacts and material spreading. The use of physical deterministic models makes it possible in theory to do predictions without historical data sets. However the modeling tools require rather detailed spatial information about the input parameters, sometimes very difficult to obtain, like for example soil thickness. Therefore this deterministic approach is only feasible in more site specific situations or at the catchment scale in rather homogeneous areas with simple landslides (Dietrich et al. 2001; Chen and Lee 2003; Van Beek and Van Asch 2003).

Coupled hydrological slope stability and run-out models can be used to determine the temporal frequency of land sliding. Coupled hydrological catchment models and hydraulic propagation models forms the basis for flood frequency assessment. An estimate of the temporal occurrence of landslides triggered by earthquakes is more problematic. There are many types of hydrological triggering mechanisms dependent on the state of the system, which defines the thresholds for first-time failure and landslide reactivation. Therefore it is a necessity to understand the hydrological triggering mechanisms. Most systems are related to infiltrating water, decrease in suction and increase in groundwater pressures (van Asch and Sukmantalya 1993; Terlien et al. 1995; Fredlund et al. 1996; Sun et al. 1998; Brooks et al. 2004) Also, surface runoff following high-intensity rainfall in steep catchments can infiltrate into accumulated debris and trigger debris flows (Blijenberg 1998; Berti and Simoni 2005; Tang et al. 2011). Difficulties in modelling properly the hydrological triggering system are related to the complexity of real landslides, the difficulty to monitor groundwater levels or soil moisture contents in unstable terrain, and the difficulty to understand the water pathways within the landslide bodies (Brunsden 1999). Especially, the complex morphology of landslides and the presence of fissure systems may result into complex and inter-connected hydrological subsystems (van Asch et al. 1996; Malet et al. 2005).

In hydrological models a coupling between unsaturated and saturated flow and the influence of the vegetation on water losses by evapotranspiration is essential to forecast changes in failure frequency induced by climate and land use changes (Bonnard and Noverraz 2001; Bogaard and van Asch 2002; van Beek 2002).

With respect to the hazard assessment of slow moving landslides, the essence of modelling must be focused on an accurate reproduction of the deceleration and acceleration of landslide bodies and in particularly, a reliable forecast of the potential transformation towards catastrophic, extremely rapid surges. Post-failure movement of landslides is controlled by a complex and dynamic interaction between mechanical and fluid properties and states which results in a spatio-temporal variation in the effective strength and apparent rheological properties of the material (Vulliet 1997, 2000; Picarelli et al. 1995; Leroueil et al. 1996; Pastor et al. 2010).

Due to these complex interactions, the parameterization of hydrological and geomechanical factors by field and laboratory tests is not sufficient to describe the post-failure movement patterns of landslides (Vulliet 2000) and not all the processes can be included in detail in the simulation (van Asch et al. 2006).

The modelling of fast landslides with large run out distances (rock falls, debris flows, rock avalanches) is important because of their intensive impacts and the higher spatial probability to hit elements at risk. The deterministic modelling of these rapid mass movements for a reliable hazard zonation is problematic because of the great variety in and complexity of the triggering processes, the amount of sediment release per event, the related mechanical run out characteristics, the mechanics of entrainment along the run-out track and the spreading in the deposition zone (Quan Luna et al. 2012). The modelling becomes uncertain because direct field measurements of key variables such as pore-pressure and viscosity are impossible. Rheological properties (yield stress, viscosity) determined from laboratory small-scale samples may not be representative at the slope scale. The parameterisation for a given rheological model is therefore most times determined by back-analyses of observed events (Malet et al. 2004; Hungr et al. 2005; Quan Luna et al. 2012). For a reliable hazard zonation of these flow-like features in the deposition areas, one has to know the detailed DTM's of the dynamic and changing topography of the built-up debris fans to predict adequately the spreading (Hungr et al. 2005; Van Asch et al. 2007).

One of the challenges is to extend our methodologies to get better predictions about the temporal occurrences and magnitudes of landslides making use of statistical and deterministic methods or a combination of this. When there is a lack of temporal information it is promising to couple spatial probability of landslides (susceptibility) acquired by statistical techniques with temporal probabilities obtained by stochastic hydrological slope instability modelling using rainfall with different return periods as input (Thiery 2007).

The last decade shows a rapid development in all kind of geodetic, geo-information and remote sensing techniques to detect, and monitor landslides and to deliver more precise topographical information and other environmental causative factors (Van Westen et al. 2005). An important task for the future is to further explore develop and evaluate these new techniques because they seem very promising to improve our ability for early warning and for hazard and risk assessment.

1.1.4 Multi-technique On-Site and Remote Monitoring as a Basis for Hazard and Risk Assessment

To develop comprehensive hazard assessment procedures, it is important to incorporate time series, 3-D patterns and deformation analyses in the model-building exercise; it is also essential that the physically-based models be improved so that a greater spatial and temporal description can be included. This goal requires first that rapid-varying factors (rainfall, freeze-thaw, meltwater, ground acceleration) and slow-varying factors (tectonic movements, weathering and associated property changes, erosion, deposition, changing confinement and unloading) are properly specified at adequate spatial and temporal resolutions. The influence of these elementary factors for the different landslide types can be identified through new investigation and monitoring techniques, and detailed analyses of event databases.

The last decade shows a rapid development in all kind of geodetic, geo-information and remote sensing techniques to detect, and monitor landslides and to deliver more precise topographical information and other environmental causative factors (Fig. 1.1). Displacement monitoring of unstable slopes is a crucial tool for the prevention of hazards. It is often the only solution for the survey and the early-warning of large landslides that cannot be stabilized or that may accelerate suddenly. The choice of an adequate monitoring system depends on the landslide type and size, the range of observed velocity, the required frequency of acquisition, the desired accuracy and the financial constraints.

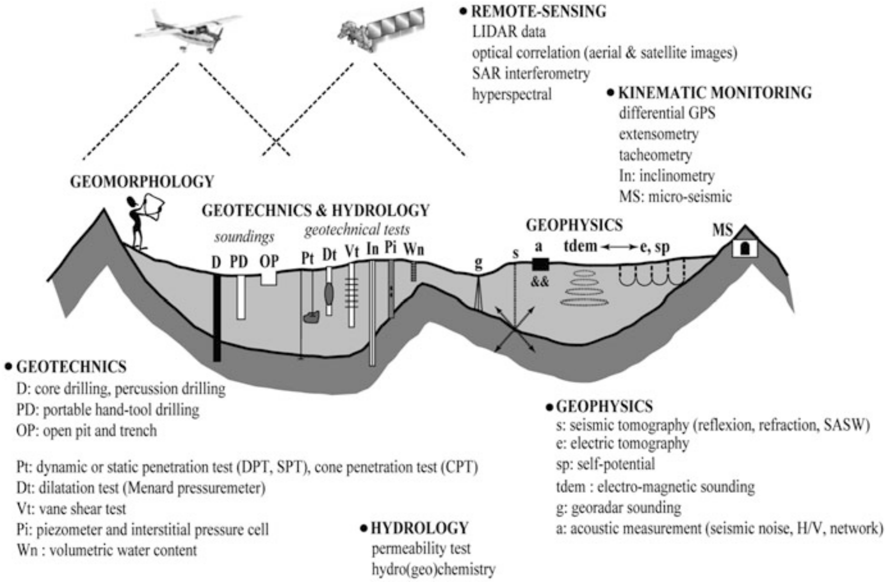


Fig. 1.1 Multi-technique strategy of investigation and monitoring of an active slope movement

Displacement monitoring techniques applied on landslides can be broadly subdivided in two main groups: geodetic and remote-sensing techniques.

Geodetic surveying consist in detecting geometrical changes in the landslide topography by measuring geometric parameters such as angles, distances or differences in elevation (e.g. levelling, tacheometry; Naterop and Yeatman 1995; Jaboyedoff et al. 2004). These techniques necessitate the installation of targets in and outside the landslide and in measuring their position at different times. They have the advantage to be very accurate (0.2–2.0 cm) with a high potential of automation. Furthermore, many authors demonstrated the efficiency of a permanent (Malet et al. 2002) and non-permanent (Squarzoni et al. 2005) differential Global Positioning System (dGPS) for landslide monitoring with a centimetric accuracy during any daytime and weather conditions. However, because landslides can show highly variable displacement rates in time and space according to the local slope conditions (bedrock geometry, distribution of pore water pressures), the major drawbacks of the geodetic techniques are (1) to provide only discrete point measurements of the displacement and (2) the costs of installation and maintenance of the survey network. They are usually only justified in the case of a real risk for the population.

Remote-sensing techniques are interesting tools to obtain spatially-distributed information on the kinematics (Delacourt et al. 2007) and can be operational from spaceborne, airborne and ground-based platforms. Remote-sensing techniques give the possibility to discriminate stable and unstable areas and to map sectors within the landslide with different kinematics from a regional to a local scale. They are also useful tools for a process-based analysis of the deformation field affecting the slope (Casson et al. 2005; Teza et al. 2008; Oppikofer et al. 2008). In the last decades, the development of ground-based platforms for landslide monitoring at the local scale provided many advantages over spaceborne and airborne platforms despite a shorter spatial coverage (Corsini et al. 2006). The geometry and frequency of acquisitions are more flexible and adaptable to any type of local environment. In addition permanent installations of ground-based platforms allow continuous monitoring (Casagli et al. 2004). Three main categories of ground-based remote sensing techniques are used in landslide monitoring: Ground-Based Synthetic Aperture Radar Interferometry (GB-InSAR), Terrestrial Laser Scanning (TLS) and Terrestrial Optical Photogrammetry (TOP). Detailed reviews of the application of GB-InSAR and TLS to landslides can be found in Corsini et al. (2006), Tarchi et al. (2003), Jaboyedoff et al. (2010), Teza et al. (2007, 2008) and Monserrat and Crosetto (2008). A state-of-the art of the application of TOP to landslide and related geomorphological processes is given in Travelletti et al. (2012).

An important task for the future is to further explore develop and evaluate these new techniques because they seem very promising to improve our ability for early warning and for hazard and risk assessment.

1.2 Risk Assessment

Risk assessment focuses on the consequences of the impact of these processes on society in terms of loss (IUGS Working Group on Landslides 1997). In order to come to a risk evaluation we need to identify the vulnerability of the society for the impact of these flooding and landslide processes and to assess the losses.

1.2.1 The Problem of Vulnerability

There are different types of vulnerabilities and associated losses which are related to physical, economic social and environmental aspects. For analyzing the physical vulnerability various types of approaches can be used, that can be either quantitative (Uzielli et al. 2008) or qualitative (Glade 2003), and based on heuristic, empirical or analytical methods. In the case of flooding, vulnerability curves are available that link the flood intensity (water height, velocity or impact pressure) to the degree of damage for different elements at risk. In the case of landslides vulnerability assessment is much more complicated. First of all because there are many types of landslides, and different measures of intensity (e.g. impact pressure for rock-fall, height for debris flows etc.). Secondly, the spatial variation of the intensity is much more difficult to estimate for landslides than for flooding, as the run-out of mass movements depends on many factors, which are very difficult to predict on a medium scale (e.g. expected initiation volume). There are also much less historical damage data available for landslides than for flooding that allow the construction of vulnerability curves (Fuchs et al. 2007). Therefore the focus in landslide vulnerability assessment at a medium scale is mostly on the use of expert opinion in defining vulnerability classes, and the application of simplified vulnerability curves or vulnerability matrices. In many situation, when there is not enough information to specify the expected intensity levels of the hazard, or when there is not enough information available to determine vulnerability classes, vulnerability is simply given a value of 1 (completely destroyed). Other types of vulnerability (e.g. social, environmental, and economic) are mostly analyzed using a Spatial Multi-Criteria Evaluation, as part of a qualitative risk assessment.

Damages on physical elements at risks like buildings and infrastructures can be translated relatively easy in direct losses in terms of money. More problematic are the assessments of direct and indirect economic and environmental losses due to the complexity of economic and environmental systems. The most difficult is to define indicators which can express direct and indirect social damages and losses related to for example fatalities, injuries, psychological impact and loss of social cohesion (Glade 2003; Guzzetti et al. 2005a).

1.2.2 From Hazard to Risk

For a direct risk assessment of physical objects the hazard and vulnerability components have to be integrated with an exposure component. This exposure component is based on an analysis of the number of elements at risk that are spatially overlapping with a certain hazard scenario. In the case of flooding, the individual flood extend maps for different return periods can be spatially combined in GIS with the footprints of the elements at risk (e.g. buildings) to calculate the number of buildings affected during that specific scenario. In the case of landslides the hazard map, which has basically the same spatial units as the susceptibility map, is spatially combined with the elements at risk. Here the spatial probability that within a certain hazard class a landslide will occur needs to be included in the analysis, leading to a much higher degree of uncertainty then in the case of flood risk assessment.

To come to a quantitative risk assessment the losses or consequences are calculated by multiplying the vulnerability and the amount of exposed elements at risk for each hazard scenario with a given temporal probability The results is a list of specific risk scenarios, each one with its annual probability of occurrence and associated losses. The specific risk is calculated for many different situations, related to hazard type, return period and type of element at risk. Given the large uncertainty involved in many of the components of the hazard and vulnerability assessment, it is best to indicate the losses as minimum, average and maximum values for a given temporal probability.

The specific risks are integrated using a so-called risk curve in which for each specific risk scenario the losses are plotted against the probabilities, and expressing also the uncertainty as minimum and maximum loss curves. The total risk can then be calculated as the integration of all specific risks, or the area under the curve. The risk curves can be made for different basic units, e.g. administrative units such as individual slopes, road sections, census tracts, settlements, or municipalities.

A similar approach can be used also for the analysis of population risk (societal risk), although the analysis depends on the spatial and temporal distribution of population and the application of specific population vulnerability curves, either for people in buildings, or in open spaces. The results are expressed as f-n curves (Salvati et al. 2010).

1.2.3 A Summary Related to Aspects of Risk Assessment

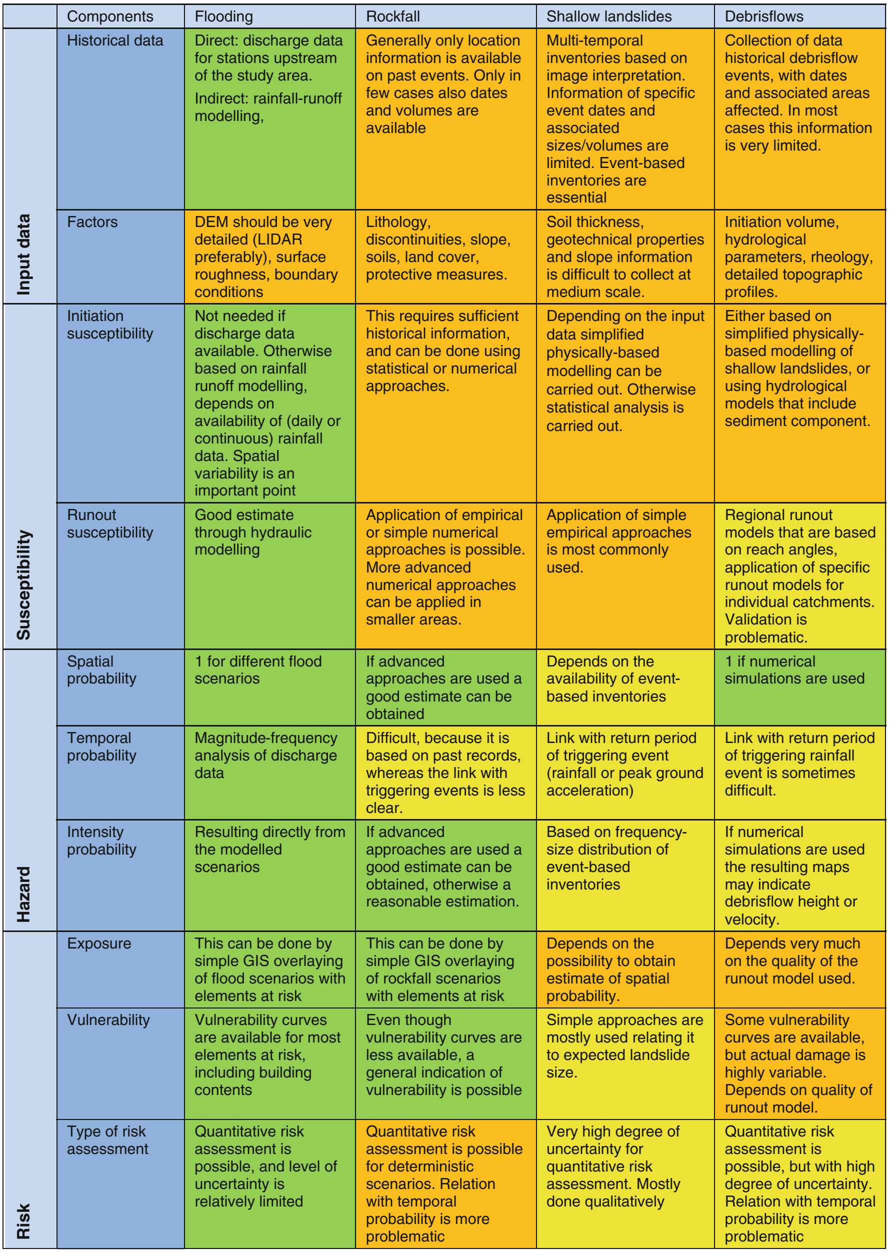
Table 1.1 gives a summary of the main aspects related to risk assessment at a medium scale for flooding and different types of mass movements discussed in the earlier part of this section. It is clear from the description of the problems associated with each of the components of quantitative risk assessment, that a hazard and risk assessment often includes a large degree of uncertainty. If the uncertainties in the input factors cannot be evaluated, or if there are simply not enough data to estimate the hazard and vulnerability components, the best option is then to carry out a qualitative risk assessment instead. This could be done in several ways. For instance a set of worst-case scenarios could be used to address the maximum possible losses, without including information on temporal probabilities or vulnerabilities (See for instance the example from the Barcelonnette area in this chapter). Another option is to carry out a qualitative risk assessment using a Spatial Multi-Criteria Evaluation, in which a hazard and a vulnerability index is made using a set of indicators and expert derived weight values.

The results from the risk assessment are subsequently used for evaluating the best disaster risk reduction measures. Some of these measures require quantitative risk assessments, whereas for other qualitative risk assessment can be sufficient. For cost-benefit analysis of physical mitigation measures, quantitative values of annualized risk are required which should be based on the analysis of many different scenarios with respect to their return periods (probabilistic approach). For the development of early warning systems and the design of disaster preparedness programmes, quantitative risk could be calculated for specific hazard scenarios (deterministic approach). For spatial planning and Environmental Impact Assessments, also qualitative risk information could be used.

1.3 Risk Management

Risk management is the systematic application of policies, procedures and practices to the tasks of identifying, analyzing, assessing, monitoring and mitigating risk. It takes the output of the risk assessment and weighs up risk mitigation options

Table 1.1 Main aspects related to risk assessment at medium scale for flooding and different types of mass movements



	Components	Flooding	Rockfall	Shallow landslides	Debrisflows
Input data	Historical data	Direct: discharge data for stations upstream of the study area. Indirect: rainfall-runoff modelling,	Generally only location information is available on past events. Only in few cases also dates and volumes are available	Multi-temporal inventories based on image interpretation. Information of specific event dates and associated sizes/volumes are limited. Event-based inventories are essential	Collection of data historical debrisflow events, with dates and associated areas affected. In most cases this information is very limited.
	Factors	DEM should be very detailed (LIDAR preferably), surface roughness, boundary conditions	Lithology, discontinuities, slope, soils, land cover, protective measures.	Soil thickness, geotechnical properties and slope information is difficult to collect at medium scale.	Initiation volume, hydrological parameters, rheology, detailed topographic profiles.
Susceptibility	Initiation susceptibility	Not needed if discharge data available. Otherwise based on rainfall runoff modelling, depends on availability of (daily or continuous) rainfall data. Spatial variability is an important point	This requires sufficient historical information, and can be done using statistical or numerical approaches.	Depending on the input data simplified physically-based modelling can be carried out. Otherwise statistical analysis is carried out.	Either based on simplified physically-based modelling of shallow landslides, or using hydrological models that include sediment component.
	Runout susceptibility	Good estimate through hydraulic modelling	Application of empirical or simple numerical approaches is possible. More advanced numerical approaches can be applied in smaller areas.	Application of simple empirical approaches is most commonly used.	Regional runout models that are based on reach angles, application of specific runout models for individual catchments. Validation is problematic.
Hazard	Spatial probability	1 for different flood scenarios	If advanced approaches are used a good estimate can be obtained	Depends on the availability of event-based inventories	1 if numerical simulations are used
	Temporal probability	Magnitude-frequency analysis of discharge data	Difficult, because it is based on past records, whereas the link with triggering events is less clear.	Link with return period of triggering event (rainfall or peak ground acceleration)	Link with return period of triggering rainfall event is sometimes difficult.
	Intensity probability	Resulting directly from the modelled scenarios	If advanced approaches are used a good estimate can be obtained, otherwise a reasonable estimation.	Based on frequency-size distribution of event-based inventories	If numerical simulations are used the resulting maps may indicate debrisflow height or velocity.
Risk	Exposure	This can be done by simple GIS overlaying of flood scenarios with elements at risk	This can be done by simple GIS overlaying of rockfall scenarios with elements at risk	Depends on the possibility to obtain estimate of spatial probability.	Depends very much on the quality of the runout model used.
	Vulnerability	Vulnerability curves are available for most elements at risk, including building contents	Even though vulnerability curves are less available, a general indication of vulnerability is possible	Simple approaches are mostly used relating it to expected landslide size.	Some vulnerability curves are available, but actual damage is highly variable. Depends on quality of runout model.
	Type of risk assessment	Quantitative risk assessment is possible, and level of uncertainty is relatively limited	Quantitative risk assessment is possible for deterministic scenarios. Relation with temporal probability is more problematic	Very high degree of uncertainty for quantitative risk assessment. Mostly done qualitatively	Quantitative risk assessment is possible, but with high degree of uncertainty. Relation with temporal probability is more problematic

Colours indicate the degree of uncertainty: *yellow* = high, *orange* = moderate, *green* = relatively low

Table 1.2 Landslide risk mitigation strategies

Strategy	Action	Goal
Risk acceptance	Do nothing	
Hazard avoidance	Reduce exposure	Locate people and structures in safe places
Hazard reduction	Slope maintenance	Control of landslide preparatory factors
	Reduce landslide occurrence: landslide stabilization	Reduce driving forces Increase resisting forces
	Reduce landslide severity	Reduce landslide magnitude and/or intensity
Minimizing consequences	Evacuation	Saving lives and reduce damages
	Reduce vulnerability	Increase resilience of exposed element
	Protection	Avoid damages

Modified from Corominas (2013)

(Fell et al. 2005). Different strategies may be considered to face landslide risk (Corominas 2013): accepting the risk, avoiding hazardous locations, reducing the hazard level, and minimizing the consequences (Table 1.2).

These strategies have different goals and actions, and may be implemented through specific measures, which may be either active or passive (Mavrouli et al. 2012 – this book). Active measures aim at modifying the occurrence or the progression of the landslides and involve earthworks, the construction of concrete structures (structural measures) or the implementation of surface protective works including eco-engineering techniques (non-structural measures). Passive measures do not interfere with the landslide process. They are conceived to either avoid or reduce the adverse consequences of the landslides as in the case of the land use planning or the early warning systems.

1.3.1 Risk Acceptance

Risk acceptability is the predisposition to accept the risk. This occurs when the incremental risk from a hazard to an individual is not significant compared to others risks to which a person is exposed in everyday life. Under the risk acceptability premises, any action for further reducing the risk is usually found as not justifiable. However, risk acceptance may sometimes be forced by the lack of economic resources to reduce landslide hazard or to construct protection works. Risk may then be managed within the ALARP (As Low As Reasonably Practicable) principle and it is considered tolerable only if its reduction is impracticable or if its cost is grossly in disproportion to the improvement gained (Bowles 2004).

Risk acceptance strategy also includes transferring the costs through insurance, compensation, or emergency relief actions. Slow-moving landslides and creep mechanisms may justify taking the option of repair and replacement of the affected structures without adopting specific stabilization or protective measures.

1.3.2 Hazard Avoidance

Hazard avoidance is fundamentally achieved by adopting land use planning measures that aim at reducing the exposure to the hazardous events. This strategy is by far the most efficient and economic option to manage risk. It is also important to consider that some landslides cannot just be controlled by implementing stability or protective measures. This is particularly true for very rapid and high intensity phenomena, such as large debris flows or rock avalanches. Avoidance of hazard requires, first of all, the appropriate identification and mapping of all existing and potential landslides and their potential paths, which is the goal of the landslide susceptibility and hazard maps. The detail and intensity of the analysis will depend on the available resources and, at its turn, it will condition the spatial resolution and reliability of the landslide hazard map and subsequent zoning.

1.3.3 Hazard Reduction

Hazard reduction strategies aim at improving the safety of the elements at risk in areas threatened by landslides. The goal of these strategies may consist (i) to reduce the probability of occurrence of the failure or the reactivation of an existing landslide by means of stabilization works or (ii) to construct structures with the purpose to intercept or constrain the landslide progression, reducing its magnitude, velocity, and run-out. The stabilization of the slopes or the existing landslides may be achieved by either reducing driving forces or by increasing resisting forces. Some recent books present an up to date review of the current practice of landslide stabilization (e.g., Turner and Schuster 1996; Cornforth 2005; Highland and Bobrowsky 2008). Reducing driving forces is mainly achieved by the removal of the unstable mass or by slope regrading. The increase of resisting forces in the slopes may require the use of external loads such as retaining structures or anchoring systems. Drainage is one of the most effective actions in stabilizing slopes by increasing shear strength of soils and reducing cleft water pressures in rock joints. Alternatively, the hazard level may be reduced once the landslide has occurred. To this end, the measures have to be implemented along the potential landslide path. They may have different goals such as diverting the trajectory away from the exposed elements, directly protecting the exposed elements or decreasing the landslide intensity by reducing the magnitude, the velocity or both.

The implementation of these type of active measures require careful engineering design, which must be technically feasible, affordable, environmentally sound, and accepted socially, making sure that they will not divert the problem elsewhere. Numerical models are usually used to facilitate the decision of the location of the structures (e.g. barriers, dissipaters) and for their dimensioning. Despite the recent developments a lot of uncertainties still remain, which concern the rheological parameters of the moving mass and in the assessment of the potential movable volume in order not to overcome the storage capacity of the retention works.

Maintenance and protection of the slope is also part of the hazard reduction strategy. The former aims to control the evolution of preparatory factors such as rock weathering, toe erosion or water infiltration that dispose the slope prone to failure. Measures to restrict the development of instability preparatory factors include slope protection and adoption of best practices (Chatwin et al. 1994; GEO 2003).

1.3.4 Consequence Reduction

Risk may be mitigated by minimizing the damages by avoiding the harmful effects of the hazardous process. Measures for reducing the consequences of the landslides range from the reinforcement of the exposed elements, the implementation of adaptive designs, the active protection, and the evacuation systems. These measures may involve a combination of non-structural and structural measures. Vulnerability of the exposed elements may be reduced by structural reinforcement or with adaptive designs (e.g. large bridge spans, flexible pipes). They must be considered a very last option only as few structures are able to resist high intensity impacts such as those produced by debris flow or rock-fall events. Most frequently, consequence reduction is achieved by the construction of protective works which include structural elements such as galleries, wall, tunnels or earth-works.

Alert systems are a risk mitigation option for places where urban population and infrastructures have expanded into landslide-prone areas. Their goal is to alert the public in order to reduce their exposure to the landslides and to mobilize the emergency teams within government departments. The alert system requires an effective early warning system (EWS) for landslides, as well as operational administrative units and educated population. EWS are commonly based on correlation with triggers (i.e., cumulative rainfall) or on monitoring schemes that use predefined rates of displacement or changes in groundwater levels to launch the alert (Guzzetti et al. 2008). Some landslide triggers such as earthquakes are, however, difficult to predict.

1.3.5 Implementation of Risk Mitigation Measures

The most efficient strategy to manage landslide risk is avoiding hazardous zones by means of an appropriate land-use planning policies. This requires the consideration of the potential hazardous locations, which is the goal of the landslide susceptibility and hazard maps. Despite the impressive development of the landslide mapping methods and the support of the GIS platforms and integrated physically based models, the definition of hazardous zones is still a challenge. The main uncertainties come from our inability to estimate the landslide volume beforehand and the probability of occurrence, particularly considering the climate and the land-use changes. Consequently, landslide maps must be validated and updated whenever possible.

The slope stabilization and protection measures are best recommended in situations where population or infrastructures are subjected to an imminent landslide threat (Mavrouli et al. 2012 – this book). In any case, to stabilize a landslide requires the appropriate understanding of the failure geometry and of the mechanism. Landslide stabilization is a permanent activity that does not stop after the completion of the works and continues with the maintenance of the structural elements and with the monitoring of the whole system.

Operational early warning systems exist only for a few areas and most of those systems are prototypes. Furthermore, inadequate monitoring networks, insufficient personnel and, sometimes, insufficient warning criteria hamper the ability of the existing systems to issue effective warnings (Baum and Godt 2009). Because of this, when considering any type of risk mitigation technique it is important not to generate a false sense of security, particularly in urbanized areas and to inform and educate population properly.

1.4 Risk Governance as an Overall Framework

1.4.1 Introduction

In mountain regions, natural hazards and risks are of major importance. Due to the limited space in the valley floors and the slopes, it is often unavoidable to use exposed areas for susceptible socio-economic activities. Therefore it seemed to be consequent, to focus on this in detail in mountain regions.

Commonly, the link between modelling, consequent prediction of natural processes and risks to management and governance of these is rather weak. This is true for places all over the world, however, more dominant in mountain regions. Consequently, it is important not to stop with the modelling and the production of results, often presented in form of maps. Instead, it has to be carefully evaluated what is really needed. This setting is in particular determined by the local, regional and national legislation. Therefore, it is consequent to include the involved stakeholders' right from the start and get guidance from the relevant institutions throughout the whole procedure of process analysis incl. modelling and presentation of relevant results in required forms in order to allow a sustainable development of the region. Herein, risk governance as a guiding principle is of major importance.

The reduction of disaster risk from multiple hazard sources is an explicitly pronounced aim in several international agendas, for example in the Agenda 21 (from the UN Conference on Environment and Development, 1992), the Johannesburg Plan (adopted at the 2002 World Summit on Sustainable Development) or the Hyogo Framework for Action 2005–2015: Building Resilience of Nations and Communities to Disasters (UN-ISDR 2005). Strategies and actions to "control, reduce and transfer risks" on basis of risk assessments and analyses can be subsumed under the term risk management (UN-ISDR 2009). Linking the relevant actors and policies throughout the disaster management cycle, but also creating an inventory of information on disasters are propagated as key objectives by the 2009 EC Communication "A Community approach on the prevention of natural and man-made disasters" (European Commission 2007). Here, it becomes clear that available knowledge on disasters is currently limited and suffers from a lack of comparability.

However, this current limitation of research on natural risks, which is fragmented and isolated (i. e. with natural sciences and engineering disciplines on the one hand and societal sciences on the other hand) the importance and difficulty of maintaining trust among all stakeholders, and the complex, socio-political nature of risk call for an amplified approach. The concept of risk governance tries to fill exactly this gap.

The objective of this book is to give an overview of the whole concept of risk governance and its application in the field of natural risks, shed some light at each single component, explaining its significance and inherent challenges. Due to the complexity and multi-disciplinarity, this approach is a first step to identify the main challenges and bridge the existing gaps between natural and social sciences in disaster risk research. Herein, risk governance strategies are of major importance.

1.4.2 A Theoretical Discussion of Risk Governance

'Risk governance' aims to enhance the disaster resilience of a society (or a region) and includes "the totality of actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analysed and communicated and management decisions are taken" (IRGC 2005). Risk governance is therefore related to the institutional dimension of resilience, which "is determined by the degree to which the social system is capable of organising itself and the ability to increase its capacity for learning and adaptation, including the capacity to recover from a disaster" (UN-ISDR 2002).

The IRGC definition points at the elements of risk governance (RG): risk assessment (RA, divided into a pre-assessment and a risk appraisal) and risk management (RM on basis of a tolerability and acceptability judgement which is informed by the assessment of risk). The whole procedure has to be embedded in a risk communication (RC) process among scientists, politicians and the public (public and private stakeholders). The whole risk governance framework is explained by the following Fig. 1.2:

This figure clearly indicates that the framework is divided into two spheres, an assessment sphere which is about generation of knowledge and a management sphere where decisions are taken. The latter is of a normative character and thus influenced by cultural beliefs and political preferences. However, even the assessment sphere is influenced by normative factors, because whoever controls the definition of risk and controls risk policy. Thus a concern assessment should

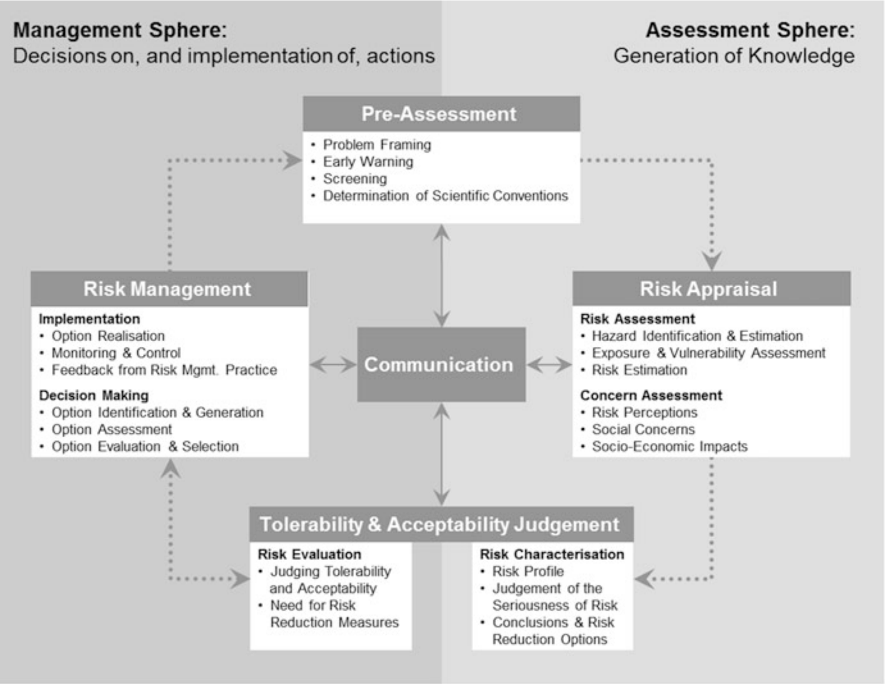


Fig. 1.2 Risk governance framework (Source: Adapted from IRGC 2005)

be part of the risk appraisal. It has to be stressed, however, that there is no clear divide between the two spheres. Although they might also be represented in different institutions (e.g. Geological Surveys – spatial planning unit), their relation and communication has to cross these borders.

Aiming at the development of integrative models and concepts that link the different phases of risk governance mentioned before, attention has to be paid to the given variations in characteristics of the several risk types, both on the collective level and the individual risk perception. There are many factors known to affect an individual’s perception of risk, namely familiarity with a risk, control over the risk or its consequences, proximity in space, proximity in time, scale of the risk or general fear of the unknown (the so called “dread factor”). Apart from these factors, individual risk perception is also shaped by how the community or a certain socio-cultural milieu generally deals with a special type of risk or risky situations. Risk perception enters the risk management equation through differing estimations on, for example, how probable in space and time an event may be, and how much money is to be spent on preparedness according to the level of acceptable risk which is a characteristic of each single cultural setting and differs largely from one region to the other. These factors might contribute in each single case in a different manner to the perception and estimation of risk. In addition, they are strongly interlinked with more collective socio-political factors and form a particular culture of risk. The variation in different cultural (regional, national) contexts is a perspective studied within the cultural risk paradigm.

Risk governance has become increasingly politicised and contentious. The main reasons are controversies concerning risks that are not supported by adequate scientific analysis methods (Armaş and Avram 2009). Rather, risk controversies are disputes about who will define risk in view of existing ambiguity. In many cases policy discourse is not about who is correct about assessment of danger, but whose assumptions about political, social and economic conditions, as well as natural or technological forces win in the risk assessment debate. Thus, the hazard as a potentially damaging physical event is real, but risk is socially constructed.

Scientific literacy and public education are important but not the only aspect necessaries to avoid conflicts about risk. Emotional response by stakeholders to issues of risk is truly influenced by distrust in public risk assessment as well as in risk management. Due to this fact, those who manage and communicate risks to the public need to understand the emotional responses towards risk and the way risk is perceived by the at-risk population. It is a matter of the definition of risk how risk policy is carried out. Moreover, defining risk is an expression of power. Slovic (1999) thereby argues that whoever controls the definition of risk controls risk policy. Within the communication strategies in all approaches, trust can be seen as a central term in this respect (Löfstedt 2005).

Distrust makes institutional settings vulnerable as it lowers the efficiency and effectiveness of management actions. The whole disaster cycle from mitigation, preparedness, response to recovery is embedded in an institutional system. Thus, institutional vulnerability can in principle be understood as the lack of ability to involve all relevant stakeholders and effectively co-ordinate them right from the beginning of the decision-making process. It refers to both organisational and functional forms as well as guiding legal and cultural rules. Consequently, a stakeholder-focused process is needed meaning consulting and involving administrative stakeholders as well as the general potentially affected community. In this regard, research on risk governance has to be understood as co-operative research: a form of research process which involves both researchers and non-researchers in close co-operative engagement. However, any communication has to be tailor-made to the educational background as well as social and cultural beliefs of individuals and groups and adjusted to the given legal-administrative framework of a study site.

The concept of risk governance has been created and adapted in the area of new emerging mostly man-made risks such as nanotechnology. Nonetheless, it is of particular relevance for mountain risks either. Actually the successful management of mountain risks is limited due to the fact that the interactions between individual sectors, disciplines, locations, levels of decision-making and cultures are not known or not considered (IRGC 2005; Greiving et al. 2006). Inadequate public available information about risks in terms of societal and natural dimensions, inapprehensible procedural steps as well as insufficient involvement of the public in the risk related decision-making process lead to severe criticism and distrust towards respecting relevant decisions in regard to a specific risk.

The risk governance approach has recently been regarded as important by the new Territorial Agenda of the EC, launched in 2007 in Leipzig, Germany by the Member States Ministers for Spatial Planning as part of the priority 5 “Promoting Trans-European Risk Management” (European Commission 2007).

1.4.3 Relevance for Europe

Within the global change debate, the field of climate change in general, but particularly as a triggering factor for many natural hazards, is of special importance for Europe with its existing settlement structures, cultural landscapes and infrastructures which have been developed over centuries. Mitigation actions, carried out i.e. by spatial planning (discussed more in detail in part 3), are under these circumstances less effective than in countries which are still growing rapidly in terms of population and the built environment. Here, disaster prone areas can be kept free from further development whereas most of these areas are in Europe already built-up. However, this calls for authorities to improve public risk awareness and to look for means to mitigate this problem. Moreover, measures based on mandatory decisions of public administration, as well as measures which are in the responsibility of private owners need to be understood and regarded as suitable by their addresses for their implement ability. This is clearly visible when looking at evacuation orders or building protection measures to be taken by private households. Having these facts in mind, the “active involvement”, of the population at risk, propagated e.g. by the European Communities Flood Management Directive (European Communities 2007), has to be seen as crucial for the success of the Directive’s main objective: the reduction of flood risks.

Within the European Community it has also been recognized, that a risk approach has also to be applied to other natural hazards such as coastal hazards or soil erosion and landslide hazards (e.g. Soil Thematic Strategy 2006). The risk governance approach has recently been regarded as important by the new Territorial Agenda of the EC, launched in 2007 in Leipzig, Germany by the Member States Ministers for Spatial Planning as part of the priority 5 “Promoting Trans-European Risk Management” (European Commission 2007).

The previously addressed issues found the basis for this book. Thus the content includes the traditional assessments of hazards and risks indeed, but it offers information and concepts beyond the purely engineering and natural science solutions.

1.5 Conclusions

Hazard and risk assessment are prerequisites for a safe and sustainable development of the society in mountainous areas. Hazard assessment aims at an estimate of the spatial and temporal occurrence and magnitude of damaging natural processes. Risk assessment focuses on the consequences of the impact of these processes on society in terms of loss.

The observed climate changes related effects on temperature and precipitation will lead to new uncertainties in the assessment of hazard, because past events might be not representative anymore to predict future hazards. Similarly, other changes in the catchments related to land use change will also lead to high uncertainties in the prediction of these processes.

The use of physical deterministic models plays an essential role in quantitative hazard and risk assessment because these estimate in a quantitative way the frequency, spatial extent and impact of these processes without the necessary access to historical data sets.

A major step forward in the assessment of landslide hazard is the further development of all kind of geodetic, geo-information and remote sensing techniques to detect and monitor landslides and to deliver more precise topographical information and other environmental causative factors.

Vulnerability assessment is a crucial step towards a risk assessment. Vulnerability assessment for the different element at risk are especially difficult in case of landslide hazard. Other types of vulnerability assessments (e.g. social, environmental, and economic) are also problematic due to the complexity of economic and environmental systems.

It turned out that a quantitative risk assessment often includes a large degree of uncertainty. If the uncertainties in the input factors cannot be evaluated, or if there are simply not enough data to estimate the hazard and vulnerability components, the best option is then to carry out a qualitative risk assessment instead.

It is not appropriate to focus solely on products of hazard and risk assessment, without a careful evaluation what society really needs. Therefore, it is important to include the involved stakeholders' right from the start and get guidance from the relevant institutions throughout the whole procedure of risk assessment and presentation of relevant results in order to allow a sustainable development of the region. Herein, risk governance as a guiding principle is of major importance.

Risk governance is an important framework which integrates all the aspects related to risk assessment, tolerability and acceptability judgment of risk and risk management. It aims to study how relevant risk information is collected, analysed and communicated and management decisions are taken.

References

Aleotti P, Chowdury R (1999) Landslide hazard assessment: summary review and new perspectives. Bull Eng Geol Environ 58(1):21–44

Alkema D, Middelkoop H (2005) The influence of floodplain compartmentalization on flood risk within the Rhine – Meuse delta. Nat Hazard 36(1–2):125–145

Armaş J, Avram E (2009) Perception of flood risk in Danube Delta, Romania. Nat Hazard 50(2):269–287

Baum RL, Godt JW (2009) Early warning of rainfall-induced shallow landslides and debris flows in the USA. Landslides 7:259–272

Berti M, Simoni A (2005) Experimental evidences and numerical modelling of debris flow initiated by channel runoff. Landslides 2(3):171–182

Blijenberg H (1998) Rolling stones? Triggering and frequency of hill slope debris flows in the Bachelard valley, southern French Alps. Netherlands Geographical Studies 246, Utrecht

Bogaard TA, Van Asch TWJ (2002) The role of the soil moisture balance in the unsaturated zone on movement and stability of the Beline landslide, France. Earth Surf Processes Landf 27:1177–1188

Bonnard C, Noverraz F (2001) Influence of climate change on large scale landslides: assessment of long-term movements and trends. In: Landslides: causes, impacts and counter measures. Verlag Glückhauf, Essen/Davos

Bowles DS (2004) ALARP evaluation: using cost effectiveness and disproportionality to justify risk reduction. ANCOLD Bull 127:89–106

Brooks SM, Glade T, Crozier MJ, Anderson MG (2004) Towards establishing climatic thresholds for slope instability: use of a physically-based combined soil hydrology-slope stability model. Pure Appl Geophys 161(4):881–905

Brunsden D (1999) Some geomorphological considerations for the future development of landslide models. Geomorphology 30:13–24

Carrara A, Cardinali M, Guzzetti F (1992) Uncertainty in assessing landslide hazard and risk. ITC J 192(2):172–183

Carrara A, Guzzetti F, Cardinali M, Reichenbach P (1999) Use of GIS technology in the prediction and monitoring of landslide hazard. Nat Hazard 20(2–3):117–135

Casagli N, Farina P, Leva D, Tarchi D (2004) Application of ground-based radar interferometry to monitor an active rock slide and implications on the emergency management. In: Evans SG, Scarascia-Mugnozza G Strom A, Hermanns RL (eds) Landslides from massive rock slope failure. Proceedings of the NATO Advanced Research Workshop on Massive Rock Slope Failure – New Models for Hazard Assessment, Springer, Celano/Berlin, 16–21 June 2004

Cascini L (2008) Applicability of landslide susceptibility and hazard zoning at different scales. Eng Geol 102(3–4):164–177

Cascini L, Bonnard C, Corominas J, Jibson R, Montero-Olarte J (2005) Landslide hazard and risk zoning for urban planning and development. In: Hungr O, Fell R, Couture R, Eberthardt E (eds) Landslide risk management. Taylor & Francis, London

Casson B, Delacourt C, Allemand P (2005) Contribution of multi-temporal sensing images to characterize landslide slip surface – application to the La Clapière Landslide (France). Nat Hazard Earth Syst Sci 5:425–437

Chacon J, Irigaray C, Fernandez T, El Hamdouni R (2006) Engineering geology maps: landslides and geographical information systems. Bull Eng Geol Environ 65:341–411

Chatwin SC, Howes DE, Schwab JW, Swanston DN (1994) A guide for management of landslide-prone terrain in the Pacific North-West. Research Branch, Ministry of Forests, Victoria

Chen H, Lee CF (2003) A dynamic model for rainfall-induced landslides on natural slopes. Geomorphology 51(4):269–288

Cornforth DH (2005) Landslides in practice: investigation, analysis and remedial/preventative options in soils. Wiley, Hoboken

Corominas J, (2013) Avoidance and protection measures. In: Shroder J (Editor in Chief), Marston RA, Stoffel M (eds) Treatise on geomorphology, vol 7, Mountain and hillslope geomorphology. Academic Press, San Diego, pp 259–272

Corominas J, Moya C (2008) A review of assessing landslide frequency for hazard zoning purposes. Eng Geol 102:193–213

Corsini A, Farina P, Antonell G, Barbieri M, Casagli N, Coren F, Guerri L, Ronchetti F, Sterzai P, Tarchi D (2006) Space-borne and ground-based SAR interferometry as tools for landslide hazard management in civil protection. Int J Remote Sens 27(12):2351–2369

Crozier MJ (2005) Multiple occurrence regional landslide events in New Zealand: hazard management issues. Landslides 2:247–256

Dai FC, Lee CF (2003) A spatial temporal probabilistic modelling of storm induced shallow landsliding using aerial photographs and logistic regression. Earth Surf Processes Landf 28(5):527–545

Dai FC, Lee CF, Ngai YY (2002) Landslide risk assessment and management: an overview. Eng Geol 64(1):65–87

Delacourt C, Allemand P, Berthier E, Raucoules D, Casson B, Grandjean P, Pambrun C, Varel E (2007) Remote-sensing techniques for analysing landslide kinematics: a review. Bull Soc Géol Fr. 178(2):89–100

Dietrich WE, Bellugi D, Real de Asua R (2001) Validation of the shallow landslide model, SHALSTAB, for forest management. In: Wigmosta MS, Burges SJ (eds) Land use and watersheds: human influence on hydrology and geomorphology in urban and forest areas, vol 2, Water science and application. American Geophysical Union, Washington, DC, pp 195–227

European Communities (2007) Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. European Communities, Brussels

European Commission (2007) Territorial Agenda of the European Union. European Commission, Brussels

Fell R, Ho KKS, Lacasse S, Leroi E (2005) A framework for landslide risk assessment and management. In: Hungr O, Fell R, Couture R, Eberhardt E (eds) International conference on landslide risk assessment and management, Vancouver

Fell R, Corominas J, Bonnard C, Cascini L, Leroi E, Savage WZ (2008) Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. Eng Geol 102:85–98

Fredlund DG, Xing A, Fredlund MD, Barbours SL (1996) The relationship of the unsaturated shear strength to the soil-water characteristic curve. Can Geotech J 33(3):440–448

Fuchs S, Heiss K, Hóbl J (2007) Towards an empirical vulnerability function for use in debris flow risk assessment. Nat Hazard Earth Syst Sci 7:495–506

GEO – Geotechnical Engineering Office (2003) Layman’s guide to slope maintenance. The government of Hong Kong. Geotechnical Engineering Office, Hong Kong

Glade T (2003) Vulnerability assessment in landslide risk analysis. Beitrage Erdsystemforschung 134(2):123–146

Greiving S, Fleischhauer M, Wanczura S (2006) Management of natural hazards in Europe: the role of spatial planning in selected EU member states. J Environ Plann Manag 49(5):739–757

Guzzetti F, Carrara A, Cardinali M, Reichenbach P (1999) Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. Geomorphology 31(1–4):181–216

Guzzetti F, Reichenbach P, Cardinali M, Galli M, Ardizzone F (2005a) Probabilistic landslide hazard assessment at the basin scale. Geomorphology 72:272–299

Guzzetti F, Peruccacci S, Rossi M, Stark CP (2008) Rainfall thresholds for the initiation of landslides in central and southern Europe. Meteorol Atmos Phys 98(3–4):239–267

Guzzetti F, Salvati P, Stark CP (2005b) Evaluation of risk to the population posed by natural hazards in Italy. In: Hungr O, Fell R, Couture R, Eberhardt E (eds) Landslide risk management. Taylor & Francis, London

Hervouet JM, Van Haren L (1996) Recent advances in numerical methods for fluid flows. In: Anderson MG, Walling DE, Bates PD (eds) Floodplain processes. Wiley, Chichester

Hesselink AW, Stelling GS, Kwadijk JCJ, Middelkoop H (2003) Inundation of a Dutch river polder, sensitivity analysis of a physically based inundation model using historic data. Water Resour Res 39(9):1234

Highland L, Bobrowsky P (2008) The landslide handbook: a guide to understanding landslides. United States Geological Survey Circular 1325. U.S. Geological Survey, Reston

Hungr O, Corominas J, Eberhardt E (2005) Estimating landslide motion mechanisms, travel distance and velocity. In: Hungr O, Fell R, Couture R, Eberhardt E (eds) Landslide risk management. Taylor & Francis, London

IRGC – International Risk Governance Council (2005) White paper on risk governance: towards an integrative approach. IRGC, Geneva

IUGS Working Group on Landslides, Committee on Risk Assessment (1997) Quantitative risk assessment for slopes and landslides-the state of the art. In: Cruden D, Fell R (eds) Landslide risk assessment. Balkema, Rotterdam

Jaboyedoff M, Ornstein P, Rouiller J-D (2004) Design of a geodetic database and associated tools for monitoring rock-slope movements: the example of the top of Randa rockfall scar. Nat Hazard Earth Syst Sci 4:187–196

Jaboyedoff M, Oppikofer T, Abellan A, Derron M-H, Loye A, Metzger R, Pedrazzini A (2010) Use of LiDAR in landslide investigations: a review. Nat Hazard 2010:1–24. doi:10.1007/s11069-010-9634-2

Leroueil S, Locat J, Vaunat TJ, Picarelli L, Lee H, Fuare R (1996) Geotechnical characterization of slope movements. In: Seneset K (ed) Proceedings of the 7th international symposium on landslides. Balkema, Trondheim/Rotterdam

Löfstedt R (2005) Risk management in post-trust societies. Palgrave Macmillan, Houndmills/Basingstoke/Hampshire/New York

Malamud BD, Turcotte DL, Guzzetti F, Reichenbach P (2004) Landslide inventories and their statistical properties. Earth Surf Processes Landf 29:687–711

Malet JP, Maquaire O, Calais E (2002) The use of global positioning system techniques for the continuous monitoring of landslides. Geomorphology 43(1–2):33–54

Malet JP, Maquaire O, Locat J, Remaître A (2004) Assessing debris flow hazard associated to slow-moving landslides: methodology and numerical analyses. Landslides 1:83–90

Malet JP, Van Asch TWJ, Van Beek LPH, Maquaire O (2005) Forecasting the behaviour of complex landslides with a spatially distributed hydrological model. Nat Hazard Earth Syst Sci 5:71–85

Mavrouli O-C, Corsini A, Corominas J (2012) Chapter 11: Disaster mitigation by corrective and protection measures. In: Van Asch TV, Corominas J, Greiving S, Malet J-P, Sterlacchini S (eds) Mountain risks: from prediction to management and governance. Springer, London, pp 303–326

Monserrat A, Crosetto M (2008) Deformation measurement using Terrestrial Laser Scanning data and least squares 3D surface matching. ISPRS J Photogramm Remote Sens 63:142–154

Naterop D, Yeatman R (1995) Automatic measuring system for permanent monitoring: Solexperts Geomonitor. In: Proceedings of the 4th international symposium on field measurements in geomechanics (FMGM-1995), Bergamo, 18–23 April 1995

Oppikofer T, Jaboyedoff M, Kreusen H-R (2008) Collapse at the eastern Eiger flank in the Swiss Alps. Nat Geosci 1(8):531–535

Pastor M, Manzanal D, Fernǘndez Merodo JA, Mira P, Blanc T, Drempetic V, Pastor MJ, Haddad B, Sanchez M (2010) From solids to fluidized soils diffuse failure mechanisms in geostructures with applications to fast catastrophic landslides. Granul Matter 132:211–228

Picarelli L, Russo C, Urcioli G (1995) Modelling earth flow movement based on experiences. In: Proceedings of the 11th European conference on soil mechanics and foundation engineering. Balkema, Copenhagen/Rotterdam

Quan Luna B, Remaître A, Van Asch TWJ, Malet J-P, Van Westen CJ (2012) Analysis of debris flow behavior with a one dimensional run-out model incorporating entrainment. Eng Geol 128:63–75

Salvati P, Bianchi C, Rossi M, Guzzetti F (2010) Societal landslide and flood risk in Italy. Nat Hazard Earth Syst Sci 10:465–483

Slovic P (1999) Trust, emotion, sex, politics, and science: surveying the risk-assessment battlefield. Risk Anal 19(4):689–701

Soeters R, Van Westen CJ (1996) Slope instability recognition, analysis and zonation. In: Turner AK, Schuster RL (eds) Landslides, investigation and mitigation, Transportation Research Board, National Research Council, Special report 247. National Academy Press, Washington, pp 129–177

Soil Thematic Strategy (2006) Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. Brussels

Squarzoni C, Delacourt C, Allemand P (2005) Differential single-frequency GPS monitoring of the La Valette landslide (French Alps). Eng Geol 79(3–4):215–229

Stark CP, Hovius N (2001) The characterisation of landslide size distributions. Geophys Res Lett 28:1091–1094

Stelling GS, Kernkamp HWJ, Laguzzi MM (1998) Delft Flooding System, a powerful tool for inundation assessment based upon a positive flow simulation. In: Babovic VM, Larsen LC (eds) Hydro-informatics. Balkema, Rotterdam

Sun HW, Wong HN, Ho KKS (1998) Analysis of infiltration in unsaturated ground. In: Slope engineering in Hong-Kong. Balkema, Rotterdam

Tang C, Renger N, van Asch TWJ, Yang YH, Wang GF (2011) Triggering conditions and depositional characteristics of a disastrous debris flow event in Zhouqu city, Gansu Province, Northwestern China. Nat Hazard Earth Syst Sci 11:1–10. doi:10.5194/nhess-11-1-2011

Tarchi D, Casagli N, Fanti R, Leva DD, Luzi G, Pasuto A, Pieraccini M, Silvano S (2003) Landslide monitoring by using ground-based SAR interferometry: an example of application to the Tessina landslide in Italy. Eng Geol 68(1-2):15–30

Terlien MTJ, Van Westen CJ, Van Asch TWJ (1995) Deterministic modelling in GIS: landslide hazard assessment. In: Carrara A, Guzetti F (eds) Geographical information systems in assessing natural hazards. Kluwer, Rotterdam, pp 57–77

Teza G, Galgaro A, Zaltron N, Genevois R (2007) Terrestrial laser scanner to detect landslide displacement fields: a new approach. Int J Remote Sens 28(16):3425–3446

Teza G, Pesci A, Genevois R, Galgaro A (2008) Characterization of landslide ground surface kinematics from terrestrial laser scanning and strain field computation. Geomorphology 97(3–4):424–437

Thiery Y (2007) Susceptibilité du Bassin de Barcelonnette (Alpes du Sud, France) aux 'mouvements de versant': cartographie morphodynamique, analyse spatiale et modélisation probabiliste. PhD thesis, University of Caen, Caen

Travelletti J, Delacourt C, Allemand P, Malet J-P, Schmittbuhl J, Toussaint R, Bastard M (2012) Correlation of multi-temporal ground-based optical images for landslide monitoring: application, potential and limitations. ISPRS J Photogramm Remote Sens 70:39–55

Turner AK, Schuster RL (1996) Landslides, investigation and mitigation. Transportation Research Board, National Research Council, Special Report 247, National Academy Press, Washington, DC

United Nations-International Strategy for Disaster Reduction (UN-ISDR) (2002) Natural disasters and sustainable development: Understanding the links between development, environment and natural Background Paper No. 5. Geneva. http://www.johannesburgsummit.org/html/documents/backgrounddocs/unisdr%20report.pdf

United Nations-International Strategy for Disaster Reduction (UN-ISDR) (2005) Hyogo Framework for Action 2005-1015: Building the Resilience of Nations and Communities to Disasters, Tech. Report, World Conference on Disaster Reduction. Geneva

United Nations-International Strategy for Disaster Reduction (UN-ISDR) (2009) Terminology on Disaster Risk Reduction. Geneva. http://www.unisdr.org/eng/terminology/terminology-2009-eng.html

Uzielli M, Nadim F, Lacasse S, Kaynia AM (2008) A conceptual framework for quantitative estimation of physical vulnerability to landslides. Eng Geol 102:251–256

Van Asch TWJ, Sukmantalya IN (1993) The modelling of soil slip erosion in the upper Komering area, South Sumatra-Province, Indonesia. Geogr Fisica Dinam Quat 16:81–86

Van Asch TWJ, Hendriks MR, Hessel R, Rappange FE (1996) Hydrological triggering conditions of landslides in varvedclaysin the French Alps. Eng Geol 42:239–251

Van Asch TWJ, Van Beek LH, Bogaard T (2006) Problems in predicting the rate of slow moving landslides. Eng Geol 88:59–69

Van Asch TWJ, Malet JP, VanBeek LPH, Amitrano D (2007) Techniques, issues and advances in numerical modelling of landslide hazard. Bull Soc Geol Fr 178(2):65–88

Van Beek LPH (2002) Assessment of the influence of changes in climate and land use on landslide activity in a Mediterranean environment. Geographical Studies 294, Utrecht

Van Beek LPH, Van Asch TWJ (2003) Regional assessment of the effects of land-use change on landslide hazard by means of physically based modelling. Nat Hazard 31:289–304

Van Westen CJ, Seijmonsbergen AC, Mantovani F (1999) Comparing landslide hazard maps. Nat Hazard 20(2–3):137–158

Van Westen CJ, Van Asch TWJ, Soeters R (2005) Landslide hazard and risk zonation—why is it still so difficult? Bull Eng Geol Environ 65(2):167–184. doi:10.1007/s10064-005-0023-0

Van Westen CJ, Castellanos Abella EA, Sekhar LK (2008) Spatial data for landslide susceptibility, hazards and vulnerability assessment: an overview. Eng Geol 102(3–4):112–131

Vulliet L (1997) Three families of models to predict slowly moving landslides. In: Klubertanz G, Laloui L, Vulliet L (eds) Computer methods and advances in geomechanics. Balkema, Rotterdam

Vulliet L (2000) Natural slopes in slow movement. In: Zaman M, Gioda G, Booker J (eds) Modeling in geomechanics. Wiley, Chichester, pp 653–676

Zezere JL, Rodrigues ML, Reis E, Garcia R, Oliveira S, Vieira G, Ferreira AB (2004) Spatial and temporal data management for the probabilistic landslide hazard assessment considering landslide typology. In: Lacerda WA et al (eds) Landslides, evaluation and stabilization. Proceedings of the 9th international symposium on landslides, Rio de Janeiro