Development of training materials on the use of Geo-information for Multi-Hazard Risk Assessment in a Mountainous Environment

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ABSTRACT: The analysis of multi-hazard risk requires the use of models that are very data demanding. Data is needed of the areas that might be affected and the characteristics of the hazard, but also of the elements at risk that might be impacted, and their vulnerability. In the framework of two European projects (FP6-PEOPLE-2006-ITN Marie curie Mountain risks and FP7 SafeLand) a training package has been developed on the use of spatial information for the assessment and management of mountain risks. This training package explains the procedures to collect, analyze and evaluate spatial information for risk assessment from natural hazards in a mountainous environment. It aims at researchers and practitioners that have to carry out risk assessments at a medium scale, and use the risk information in disaster risk reduction planning. The training package guides the participants through the entire process of risk assessment, on the basis of a case study of an area exposed to multiple hazards in Barcelonnette, France. In order to achieve maximum applicability the training package is made for use with Open Source software. Three-dimensional stereoscopic image interpretation using images downloaded from Google Earth is used to familiarize the participants with the hazard phenomena. These are then used in either a statistical or heuristic approach for modelling the initiation areas for landslides, debris flows, snow avalanches and rockfalls. The source areas are used for run-out modelling on a medium scale using a routing-spreading model and the results are converted into impact maps. Flood hazard assessment is done using a 1D-2D flood propagation model and flood impulse is calculated for different return periods. The source maps and run-out maps for mass movements and the flood maps are then used in a quantitative multi-hazard risk assessment, by calculating the exposed elements at risk, the temporal and spatial probability and the vulnerability of the elements at risk. Also emphasis is given to the evaluation of uncertainty in the risk assessment process. A qualitative method for multi-hazard risk assessment is also included, using Spatial Multi-Criteria Evaluation, in which a hazard index and a vulnerability index are generated. The final part of the training package deals with the use of risk information for disaster risk management, e.g. by incorporating the risk information in preparedness planning, cost-benefit analysis for the planning of remedial measures, and land use zoning.

1 INTRODUCTION

Mountain hazards, such as flooding, landslides, debris flows, rock falls and snow avalanches pose a risk to society and may lead to direct and indirect losses in many mountainous areas in Europe, and elsewhere. There have been many attempts to analyze the hazards and use the resulting maps in land use planning. A whole series of European research projects have been focussed on developing relevant methods and tools for mapping, monitoring and analyzing mountain hazards and risks. The Marie Curie Initial Training Network Mountain Risk (2006-2010), was aimed to develop an advanced understanding of how mountain hydro-geomorphological processes behave and to apply this knowledge to long-term cohabitation with such hazards (Mountain Risk, 2010). Within this project there has been also an important component focused on training a group of young scientists at PhD and Postdoc level. As part of the Mountain Risk project a series of training courses have been given. One of these courses dealt with the use of spatial information in multi-hazard risk assessment in a mountain environment. In 2009 another major research projects on mass movements, called SafeLand was funded by the EU. SafeLand will develop generic quantitative risk assessment and management tools and strategies for landslides at local, regional, European and societal scales and establish the baseline for the risk associated with mass movements in Europe (debris and mud flows, rock fall, slides and avalanches) to improve our ability to forecast landslide hazard and detect risk zones (SafeLand, 2010). Within both projects the dissemination of project results is carried out through the development of training materials and the organization of training courses (e.g. the international LARAM training school on "Landslide Risk Assessment and Mitigation" focusing on PhD researchers) (LARAM, 2010). As a contribution to the Mountain Risk and SafeLand projects a training package has been developed on the use of spatial information for the assessment and management of mountain risks.

The Faculty of Geo-Information Science and Earth Observation (ITC) of the University of Twente has been active in the development of training materials for hazard and risk assessment for several decades. In order to maximize the applicability of the training materials they have been written for use with Open Source software, as license costs for GIS software can be a severe limitation, especially in developing countries. Under the collaboration with the United Nations University (UNU-ITC School for Disaster Geo-Information Management) a distance education course was developed on the use of spatial information for multi-hazard risk assessment (ITC, 2009). This course was focused on urban areas in developing countries, and was centred around a case study, named RiskCity, exposed to multi-hazard such as earthquakes, landslides, floods and technological hazards.

Based on previous experience with landslide risk assessment at various scales (Van Westen et al., 2008) a training package was developed that focuses on possible tools for hazard and risk assessment given the availability of data, and taking into account the scale of analysis.

The exercises are written for the ILWIS software (Integrated Land and Water Information System), which is a GIS with integrated image processing capabilities. ILWIS is Open Source software that can be used freely by the course participants after the course thus enhancing the applicability. The software is easy to learn, contains extensive help functions, the installation files are relatively small and installation is very simple. The major advantage of the ILWIS software is its very powerful raster data analysis module, with functions that allow the user to integrate many maps using a map calculator, and automate these using scripts.

Figure 1 gives the framework of the training package with an indication of the various components (A to G). The first component (A) deals with the input data required for a multi-hazard risk assessment, focusing on the data needed to generate susceptibility maps for initiation and runout, triggering factors, multi-temporal inventories and elements at risk. The second session (B) focuses on hazard assessment, and is divided into three components: one dealing with the modelling of potential initiation areas, which are then used as source areas in the modelling of potential runout areas. The third component deals with the magnitude frequency analysis, and explains the various methods that can be used, e.g. the use of event-based inventory maps and rainfall thresholds. The third section (C) focuses on vulnerability assessment and indicates the various types of vulnerability and approaches that can be used. In the exercise the focus is on the use of expert opinion in defining vulnerability classes, and the application of available vulnerability curves.

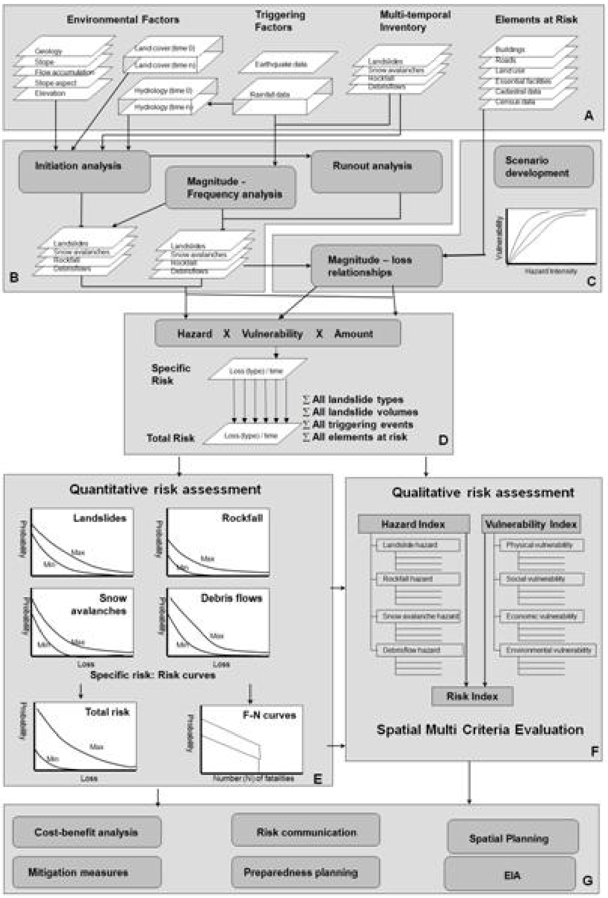


Figure 1. Flowchart of the procedure used in the training package. A: Input data; B: Hazard assessment, consisting of initation analysis, runout analysis and magnitude-frequency analysis; C: Vulnerability analysis; D: Risk analysis integrating the components spatially; E: Quantitative risk analysis using risk curves; F: Qualitative risk assessment using Spatial Multi-Criteria Evaluation; G: Risk reduction options.

Section D, E and F deal with risk assessment, which is done both using quantitative (E) and qualitative methods (F). The last session (G) deals with the use of risk information in various stages of Disaster Risk Management.

2. STUDY AREA AND INPUT DATA

1.1 Study ares

The training package is developed for the Barcelonette area in the French Alps (Fig.2) , This area has been extensively studied in a number of previous EU projects (Flageollet et al., 1999; Maquaire et al., 2003; Remaitre et al., 2005; Thierry, 2007).

Figure 2. Location of the Barcelonette study area.

A large part of the study area is underlain by black marls, partly covered with morainic materials. The area is exposed to a number of hydrometeorological hazards: flooding, debris flows, landslides, rockfall, and snow avalanches (Fig. 3). For the development of the training package we made use of the very extensive GIS database that has been collected over the years and which is also partly online (CNRS ,2010). The Barcelonette area is also one of the study areas in the Mountain Risk and SafeLand projects. An overview of the data that was used in the training package is given in Table 1.

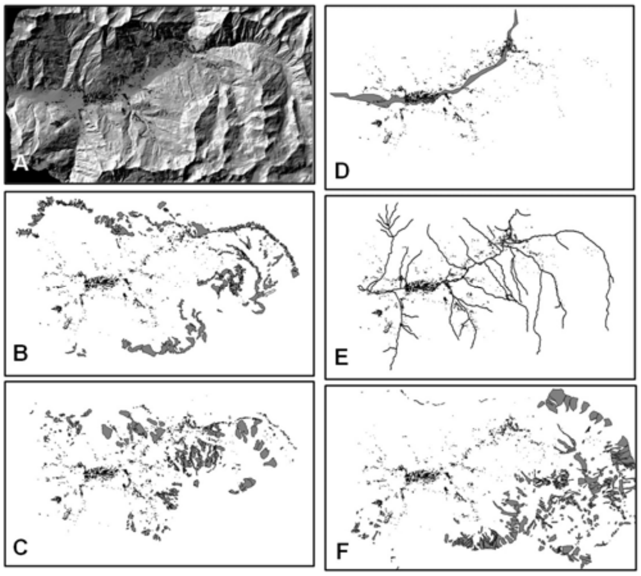


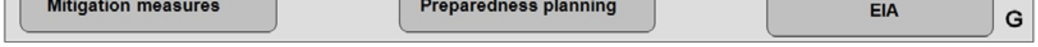
Figure 3. Hillshading image (A) and inventories for rockfall (B), landslides (C), floods (D), debris flows (E) and snow avalanches (F)

The information indicated in Table 1 was collected by many organizations. It is beyond the scope of this paper to mention all of them.

Even though this area has an extensive amount of data, there are also a number of clear limitations in the available data, especially related to locations and occurrence dates of the various hazardous phenomena. Extensive research has been done on obtaining historical information for the occurrence of landslides and floods, for a period going back to 1928 (Flageollet et al., 1999). However, there are relatively few data on event-based landslide inventories and the exact linkage of runout areas with occurrence dates and source areas. This situation is used to illustrate the uncertainty in estimating the temporal and spatial probability of the hazard events.

Table 1. Overview of input data used in the training package.

Data	Characteristics
Image data	
Satellite image	Downloaded from Google Earth
3-D image	Anaglyph image made by combining Google Earth image and DEM
Topographic data	
Contour lines	Digitized from topographic map
DEM	Interpolated from contour lines
Slope angle	Slope steepness made from DEM
Slope aspect	Slope direction made from DEM
Hillshading	Artificial illuminated made from DEM
Openness	Visualization of DEM
Plan curvature	Concavity-convexity made from DEM
Flow accumulation	Contributing area made from DEM
Elements at risk data	
Communes	Adm. units with population data
Building footprints	Individual buildings & characteristics
Cadastral map	Individual land parcels with ownership
Roads / powerlines	Linear structures
Bridges	Point file with bridge characteristics
Environmental factors	
Lithology	Lithological units
Materials	Unconsolidated materials
Soils	Soil types and average depths
Landuse 2007	Land use map of 2007
Landuse 1980	Land use map of 1980
Triggering factors	
Rainfall data	Daily rainfall for 2 stations
Discharge data	Discharge data for 1 station
Hazard inventory data	
Flood heights	Modeled for 4 return periods
Streams	Drainage network
Flood events	Historical flood events
Avalanche field	Catalog of avalanches mapped in field
Avalanche photo	Catalog mapped from airphotos
Landslide inventory	Mapped from photos and field
Landslide dates	Table with known landslide dates
Heuristic hazard	Hazard map: direct mapped by experts
Statistical hazard	Hazard map through statistical analysis
Debris flow dates	Table with known events
Debris flow zones	Map of catchments with DF frequency
Rockfall area	Inventory of rockfall areas



3. HAZARD ASSESSMENT

The training package starts with an exercise in which the software is introduced, using a number of demo files, and in which the input data is introduced, as indicated in Table 1. The students are also shown how to generate a three-dimensional view using the anaglyph method, by combining the high resolution image (with 1.5 m resolution, which was downloaded from Google Earth) together with a Digital Elevation Model obtained by contour interpolation. The students then follow a session on image interpretation, during which they have to evaluate the completeness of the various inventories (especially the ones for landslides). They also use image interpretation to analyze the patterns of the various processes and relate those with the available environmental factors listed in Table 1.

3.1 Source area characterization.

This information is then used in analyzing initiation areas of events. As most of the elements at risk are located in the flood plain, on alluvial fans, and on lower slopes, the largest hazard is due to runout of hazardous processes, rather than to initiation. Therefore the risk assessment focuses on the analysis of runout risk specifically. For the runout analysis source maps are required indicating areas where processes might occur. These can be modelled with heuristic, statistical or physically based models (Van Westen et al., 2008). In the current version of the course emphasis is given to the use of heuristic methods, given the limited time available. Students are asked to combine the most relevant factors maps (landuse, slope and lithology) and generate joint-frequency tables, in which they can directly indicate the expected susceptibility class (high, moderate, low or not susceptible). In order to go from susceptibility to hazard maps an assumption is introduced as indicated in Table 2, that during a major triggering event mass movements might initiate in the high, moderate and low susceptible areas, and that a minor triggering events will only trigger landslides in the high susceptible zones.

Table 2. Assumption used in analyzing the susceptibility maps.

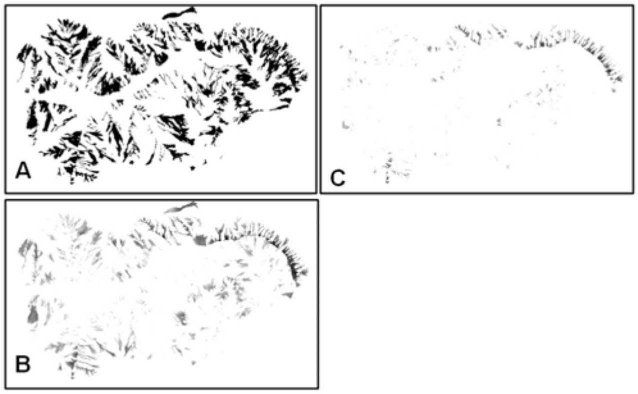
	Triggering event		
Susceptibility class	Major event	Moderate event	Minor event
High	1	1	1
Moderate	1	1	0
Low	1	0	0
Not	0	0	0

This results in a series of 12 binary maps, indicating the presence or absence of source areas for major, moderate and minor triggering events for all mass movement types. Students normally work in a group concentrating on one type and sharing the results with the others.

3.2 Runout modelling

The source areas are used for run-out modelling on a medium (1:25000) scale using the routing-spreading model DFGRIDPROB, developed in MatLab, by the University of Lausanne, Switzerland (Horton et al., 2008). The model takes the results of the source identification and calculates the spreading zone for each source. The choice of spreading algorithms is made by the user. In this runout model, the source mass is unknown. The runout distance calculation is based on a unit energy balance, a constant loss function and a maximum threshold (Horton et al. 2008). The results of this analysis are therefore more an indication rather than an accurate prediction of runout distance and energy. Nevertheless they do give a fairly good indication as shown by Blahut (2009). The calculation of the probable maximum runout is based on the definition of an average slope angle between the starting and end point, considering a constant friction loss. In the training package the students have to select for each of the triggering events (major, moderate and minor) and each type of process such an average slope angle. The resulting maps of Kinetic Energy are converted into impact pressure maps using average values for bulk densities. Figure 4 shows some example of the results of the runout assessment.

Figure 4. Example off the output of the runout assessment for debrisflows for major (A), Moderate (B) and Minor (C) events.



The maps display the kinetic energy, and can also show the extend of the runout areas.

It is evident from figure 4 that the determination of the source areas, and the selection of the average runout angles may lead to an overestimation of the areas potentially affected. In the training package, students are asked to do this process iteratively and compare the results with the inventories, until a reasonable result is obtained.

4. QUANTITATIVE RISK ASSESSMENT

The results from the runout analysis are used in the next part of the training package to show a procedure to do a quantitative risk assessment using risk curves as indicated in Fig. 1. The analysis is based on the equation:

$$R = Pt * Ps * V * A \tag{1}$$

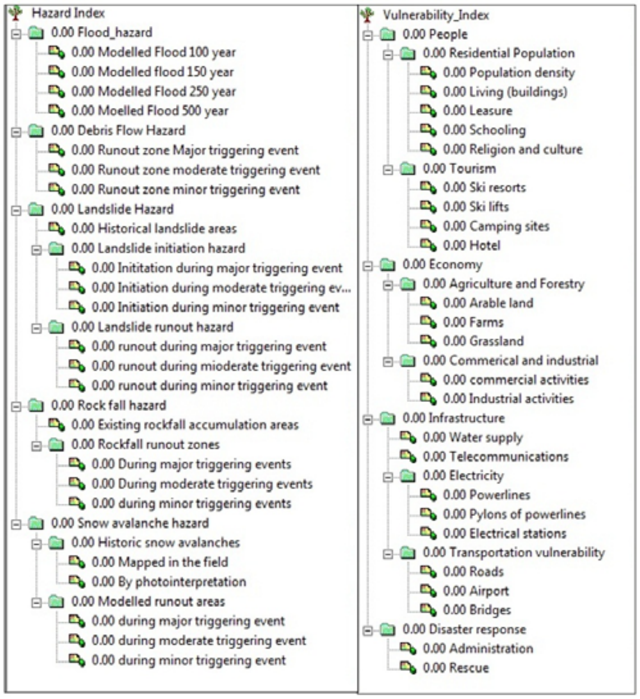
The component A is the Amount of Elements at Risk exposed to the hazard. This is calculated in GIS by overlaying the runout maps with the elements at risk maps (e.g. building footprints). V is the vulnerability, which in the current version of the training package is simplified to 1, given the difficulty in obtaining vulnerability curves for the various processes studied, and time limitations of the course. The component Pt is the temporal probability of major, moderate and minor triggering events, which is estimated based on the available multi-temporal inventory. The component of spatial probability (Ps) is introduced as only a part of the modelled hazard zones (e.g. debris flow runout zones) are expected to experience actual events given a triggering event with a given return period. The better the model narrows down to the future sites of events, the higher the Ps will be. Low accuracies in modelling will therefore result in lower risks, contrary to what would be expected. This is illustrated in Table 3, where the expected losses become much less if the spatial probability is included, as the modelled area for major runout might be 100 times larger than the actual area affected.

Table 3. Example of a quantitative risk assessment for debris flow as used in the training package. L1 shows losses without incorporating the spatial probability. L2 includes the spatial probability as well.

		Major	Moderate	Minor
Pt	Temporal Probability.	0.01	0.02	0.1
Ps	Spatial Probability	0.01	0.007	0.006
A	Building exposed	496	171	1
V	Vulnerability	1	1	1
L1	Losses (V*A)	496	171	1
L2	Losses (V*A*Ps)	4.96	1.197	0.006

5. QUALITATIVE RISK ASSESSMENT

Qualitative risk assessment is illustrated through a Spatial Multi-Criteria Evaluation, in which a risk index is generated, by combining a hazard index and a vulnerability index. The indices are composed of major groups (e.g. people, economy, infrastructure etc) for which a number of indicators are used that can be spatially represented. Each of the indicators is standardized between 0 and 1. Weights are generated by comparing the contribution of each indicator to the overall goal in relation to the others. An example of possible criteria trees for a hazard index and a vulnerability index are given in Figure 5.



- Hazard Index
  - 0.00 Flood_hazard
    - 0.00 Modelled Flood 100 year
    - 0.00 Modelled flood 150 year
    - 0.00 Modelled Flood 250 year
    - 0.00 Moelled Flood 500 year
  - 0.00 Debris Flow Hazard
    - 0.00 Runout zone Major triggering event
    - 0.00 Runout zone moderate triggering event
    - 0.00 Runout zone minor triggering event
  - 0.00 Landslide Hazard
    - 0.00 Historical landslide areas
    - 0.00 Landslide initiation hazard
      - 0.00 Inititation during major triggering event
      - 0.00 Initiation during moderate triggering ev...
      - 0.00 Initiation during minor triggering event
    - 0.00 Landslide runout hazard
      - 0.00 runout during major triggering event
      - 0.00 runout during mioderate triggering event
      - 0.00 runout during minor triggering event
  - 0.00 Rock fall hazard
    - 0.00 Existing rockfall accumulation areas
    - 0.00 Rockfall runout zones
      - 0.00 During major triggering events
      - 0.00 During moderate triggering events
      - 0.00 during minor triggering events
  - 0.00 Snow avalanche hazard
    - 0.00 Historic snow avalanches
      - 0.00 Mapped in the field
      - 0.00 By photointerpretation
    - 0.00 Modelled runout areas
      - 0.00 during major triggering event
      - 0.00 during moderate triggering event
      - 0.00 during minor triggering event

- Vulnerability_Index
  - 0.00 People
    - 0.00 Residential Population
      - 0.00 Population density
      - 0.00 Living (buildings)
      - 0.00 Leasure
      - 0.00 Schooling
      - 0.00 Religion and culture
    - 0.00 Tourism
      - 0.00 Ski resorts
      - 0.00 Ski lifts
      - 0.00 Camping sites
      - 0.00 Hotel
  - 0.00 Economy
    - 0.00 Agriculture and Forestry
      - 0.00 Arable land
      - 0.00 Farms
      - 0.00 Grassland
    - 0.00 Commerical and industrial
      - 0.00 commercial activities
      - 0.00 Industrial activities
  - 0.00 Infrastructure
    - 0.00 Water supply
    - 0.00 Telecommunications
    - 0.00 Electricity
      - 0.00 Powerlines
      - 0.00 Pylons of powerlines
      - 0.00 Electrical stations
    - 0.00 Transportation vulnerability
      - 0.00 Roads
      - 0.00 Airport
      - 0.00 Bridges
  - 0.00 Disaster response
    - 0.00 Administration
    - 0.00 Rescue

Figure 5. Example of criteria trees for a hazard index (left) and a vulnerability index (right), with indication of subgoals and indicators.

6. USE OF RISK INFORMATION

The last component of the training package deals with the use of risk information for disaster risk management. Below an example is given of the type of exercise that is used in this section of the course. In Figure 5 three hazard maps for a valley in a mountainous area are given, with 3 types of hazards: floods, debrisflows and snow avalanches. In the exercise it is proposed that the municipality in which the area is located considers to make a holiday park for winter tourism, with 100 chalets in the area. They have to select the best location. Students are first asked to calculate the risk in the areas A, B, and C and express it in the percentage of chalets that could be destroyed annually, with and without considering the uncertainties). Table 4 shows the result of this particular exercise. The students are then asked in which of the three possible selected areas the population at risk would be the highest, considering that the chalets have an average occupation of 5 persons each and are used for skiing holidays only. The students should then select the best location for the development. The students are then asked which risk reduction measures they would suggest and for which hazard to get the optimal result in risk reduction. Finally the students are asked to reflect on the uncertainty in the procedure and indicate which components have the highest uncertainty.

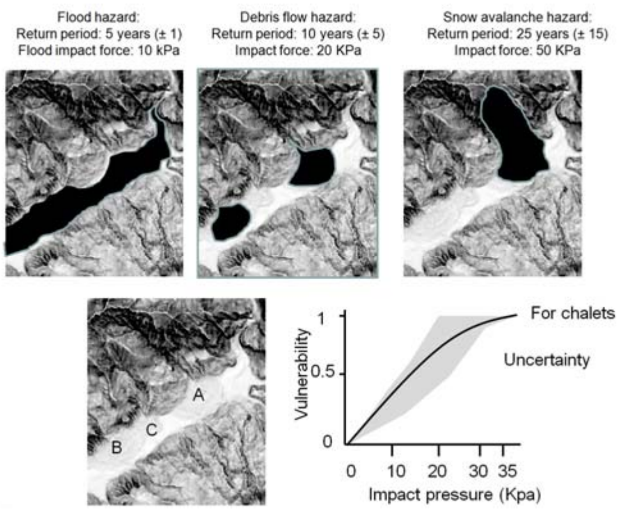


Figure 5: Example of an exercise on the use of risk information for spatial planning. See text for explanation.

Table 4. Example of a simple risk calculation for the problem outlined in Figure 5.

Site	Type	H	V	A	Rs	
A	Flood	0.2	0.3	100	6	18
	Debris flow	0.1	0.8	100	8	
	Avalanche	0.04	1	100	4	
B	Flood	0.2	0.3	100	6	14
	Debris flow	0.1	0.8	100	8	
	Avalanche	0.04	0	100	0	
C	Flood	0.2	0.3	100	6	6
	Debris flow	0.1	0	100	0	
	Avalanche	0.04	0	100	0	

7. CONCLUDING REMARKS

The training package focuses on the methods and spatial data for the various components required for a multi-hazard risk assessment at a medium scale.

All relevant hazards have to be taken into account, in a comparable, comprehensive manner. There are many challenges arising with this step from single- to multi- hazard risk (Kappes et al., 2009). The processes are very different, and so are the models.

For flood hazard mapping for instance a 1D-2D flood model is used, resulting in flood impact maps for different return periods. The generation of such flood maps is more straightforward than those for the mass movements. Flood modelling requires reasonable data for discharges, DTM, and surface roughness. Flood intensity-magnitude relationships can be obtained from discharge records. Flood vulnerability curves are available and can be applied rather easily.

In the training package we illustrate that for mass movement hazards this is much more difficult. Source areas can be modelled using different approaches but the uncertainty is high. Magnitude-frequency analysis is often difficult, due to lacking multi-temporal landslide inventories. Runout modelling is complicated, because there are many uncertainties: initiation locations, initiation volumes, and parameters to use. Temporal probability has a high uncertainty, as there is often not a clear link between triggering meteorological events and landslide density. Spatial probability has a high uncertainty, due to the problems outlined in the source area and runout area delineation. The uncertainties in all of the components of the risk analysis should be incorporated, leading to minimum, average and maximum risk curves for the different hazardous processes. These could also be transferred in a loss exceedance curve, given the probability that the annual probability exceeds a certain value. The training package will be further developed incorporating also methods for larger scales.

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