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Development and testing of spatial multi-criteria evaluation for selected case sites

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SUMMARY

The aim of this document is to demonstrate the applicability of Spatial Multi Critera Evaluation (SMCE) for the qualitative assessment of the landslide hazard, vulnerability and risk. The methodology will contribute to participatory stakeholder-led processes for choosing prevention and mitigation measures that are appropriate from a technical, economic, environmental and social perspective and to agree on risk reduction targets. This deliverable exemplifies a methodology that aims at supporting decision makers who are faced with making evaluations of projects or policies based on criteria that cannot all be expressed with a common numeraire, for example, money, and for which stakeholders evaluate the criteria differently. Since stakeholders will evaluate the various hazard and vulnerability criteria differently, it will support multi-stakeholder decision processes in identifying a generic set of relevant criteria and techniques for weighting these criteria. The communication and participatory processes will be exemplary for other high-risk countries in Europe.

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FOREWORD

The goal of this document is to demonstrate the use of Spatial Multi-Criteria Evaluation (SMCE) as a qualitative tool for the assessment and zoning of landslide- and flood hazard and risk for a case-study site in Italy (Nocera Inferiore).

The activities of the SMCE Working Group include:

- Selection of an appropriate case study site;
- Participate in stakeholder meetings on multi-hazard risk reduction options;
- Collect, analyze and process the relevant and available data;
- Develop a SMCE to exemplify its applicability in a multi-stakeholder risk assessment process with conflicting viewpoints and less tangible concerns;
- Produce a compromise multi-hazard risk map.

1 INTRODUCTION

This deliverable introduces a relatively new concept for and approach to the assessment of landslide risk: Spatial Multi-Criteria Evaluation – or SMCE. One of the few examples of a previous application for landslide risk is a study by Castellanos (2008) who applied it for assessing landslide risk in Cuba at a national scale. His main argument for applying SMCE was that this was the only method that could be applied at this scale because the data was missing to use any other method. In this example we will argue that there are also other reasons why SMCE may be a useful complementary method to the quantitative methods as described in SafeLand deliverable 2.4 (Corominas and Mavrouli, 2011).

Currently there is widespread agreement that risk can be assessed via the generic formula postulated by Varnes in 1984:

Risk = **Hazard** x **Vulnerability** x **Elements at risk**

where:

Risk means the expected number of lives lost, person injured, damage to property, or disruption of economic activity due to a particular natural phenomenon;

Hazard is the probability of occurrence of an event of a certain magnitude in a given area within a specific period of time;

Vulnerability is the degree of loss suffered by a given element or set of elements exposed to a hazard of given magnitude;

Elements at risk means the population, properties, economic activities, including public services, etc., at risk in a given area.

This deliverable is about a new way to apply this formula using SMCE. In the following sections we discuss briefly what SMCE can add to existing risk assessment methods, especially in the assessment of hazard and vulnerability.

1.1 HAZARD

In hazard assement one can identify three problems:

1) How to establish the relationship between the spatial and temporal probabilities and the hazard’s magnitude? This is dealt with in detail in deliverable 2.4 (Corominas and Mavrouli, 2011).
2) In what units should one quantify the magnitude? For floods one can look at the flood depth, but maybe the velocity is equally important, or the duration, or the warning time, or the speed of rising of the water level. For landslides one can look at volume, but also velocity, runout distance and kinetic energy released may be appropriate

parameters to quantify the magnitude. All these different parameters have different spatial characteristics and have different implications for the vulnerability.

3) How to deal with multiple hazards? A rain event can cause flash-flooding or a debris flow or a landslide – or all three at the same time. Conceptually we separate these hazards but in reality they overlap because they share the same root causes. There may also be chain effects: landslides that cause floods, or vice versa. Combining all these hazards into a single multi-hazard map is not a trivial task due to differences in assessment methods and the parameters used to quantify the hazards.

Quantitative hazard assessment methods focus on problem 1. In this deliverable we hope to demonstrate the additional value of SMCE in addressing problems 2 and 3.

In general one can say that geo-hazards are complex spatial-dynamic processes and to assess their impact on the exposed elements in the affected area, multiple parameters must be considered. Process-based deterministic hazard models can generate series of parameter maps that describe the dynamic behaviour of the hazardous process. The idea of using multiple parameters to evaluate the impact is not new, as can be seen by numerous publications on this topic. In the case of flow-like hazards (floods, hyper concentrated flows, mudflows, …) most use two or three parameters, for instance Gendreau (1998) combines inundation depth, duration and maximum acceptable return period, Témez (1992) and Penning-Rowsell and Tunstall (1996) combine flow velocity and inundation depth, and Borrows (1999) combines flow velocity, inundation depth and warning time.

1.2 VULNERABILITY

Vulnerability is the most complicated component of risk assessment because the concept of vulnerability has a wide range of interpretations. Multiple definitions and different conceptual frameworks of vulnerability exist. Vulnerability refers to the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. It relates to the intrinsic fragility of exposed elements, systems or communities that favours loss when affected by hazard events. It includes also the lack of resilience that influences the capacity to anticipate, cope with, resist, respond to, and recover from the impact of a physical event (www.move-fp7.eu/)

The vulnerability of communities and households can be analyzed in a holistic qualitative manner using a large number of criteria that characterize the physical, social, economic and environmental vulnerability. Physical vulnerability is evaluated as the interaction between the intensity of the hazard and the type of element-at-risk, making use of so-called vulnerability curves and/or fragility curves (Corominas and Mavrouli, 2011). Social vulnerability refers to the inability of people, organizations, and societies to withstand adverse impacts from the hazards to which they are exposed. Economic and environmental vulnerability can be interpreted as the degree to which economic and environmental systems suffer from a hazardous event. Vulnerability is multi-dimensional, dynamic (it changes over time), scale-dependent (it can be expressed at different scales from individuals to countries), and site-specific (each location might need its own approach).

In this deliverable we hope to demonstrate that SMCE is a useful tool for a holistic qualitative analysis of vulnerability that incorporates all dimensions of vulnerability.

1.3 MULTI-PARAMETER RISK ASSESSMENT

No procedure exists yet that incorporates all relevant multi-hazard multi-parameter maps that can be generated by quantitative hazard assessment methods, such as flow velocity and depth, kinetic energy, warning time and duration of the event. The difficulty to do this in a quantitative way is that it is hard or perhaps impossible to develop such a procedure because historic information on the spatial distribution of the impact is often unavailable which inhibits establishing relationships between the hazard characteristics and its consequences. However, implicitly each parameter does hold information on its consequences: the higher the depths, velocity and duration, the more it will contribute to the hazard – and thus to the risk. The same logic can also be applied to the assessment of vulnerability. Even though it may be impossible to quantify the degree of loss for indivual elements at risk, one can evaluate their robustness – i.e. their ability to withstand, deal with and recover from a hazardous event. In the case of people one can look at paramaters such as age, health, income, education level, social connectiveness etc. In the case of buildings it may be construction materials, state of repair, etc.

With SMCE, this implicit information can be used to assess the risk in a qualitative manner. This approach differs from quantitative risk assessment methods because it does not rely on established vulnerability relationships between magnitude of the hazard and the impact on the elements exposed, nor does it apply a so-called ”look-up table” approach. In this approach a matrix (or set of matrices) is used to categorize the hazard as a function on a predefined and limited set of hazard indicators. SMCE allows the use of expert knowledge from hydrologists, engineers, disaster managers, economists, relief workers, local and regional authorities, farmers, etc. In addition it allows the inclusion of “soft” information like perception and preferences. This deliverable will show that spatial multi-criteria evaluation (SMCE) offers opportunities to formalise the procedure for multi-parameter risk assessment using this expert knowledge.

2 SPATIAL MULTI CRITERIA EVALUATION (SMCE)

In this deliverable we have made use of the Spatial Multi-Criteria Evaluation module in the ILWIS Geographical Information System (GIS). This SMCE application assists and guides users in doing multi-criteria evaluation in a spatial manner. The input is a set of maps that are the spatial representation of the criteria. They are grouped, standardised and weighted in a 'criteria tree.' The output is one or more 'composite index map(s),' which indicates the realisation of the model implemented. The theoretical background for the multi-criteria evaluation is based on the analytical hierarchical process (AHP).

In this chapter we will provide some background to SMCE and to its application. In the next chapters we will present the example of Nocera.

2.1 PROBLEM STRUCTURING IN SMCE

Multi-criteria evaluation is increasingly used in spatial decision problems (Malczewski, 2006). Spatial multi criteria evaluation can be thought of as a process that combines and transforms geographical data (input) into a resultant decision (output) – see Figure 8.1 (Malczewski, 1999). This process includes, apart from geographical data, also the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules. The result is an aggregation of multi-dimensional information into a single parameter output: the decision.

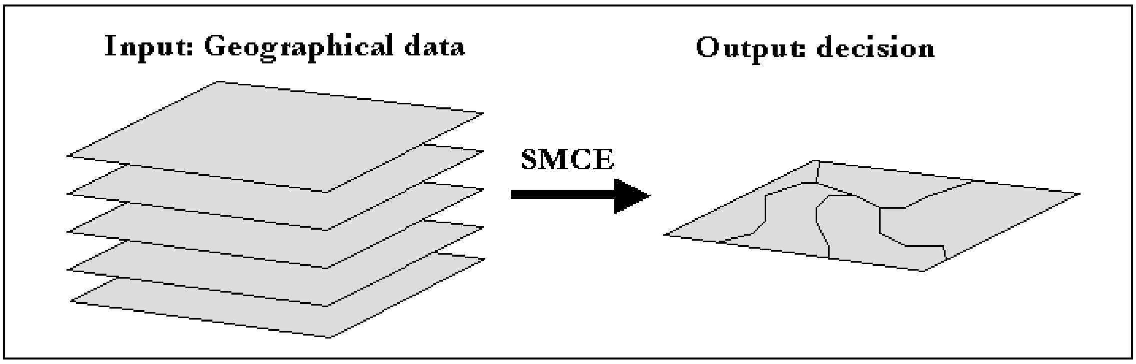


Figure 1 Spatial multi criteria evaluation (after Malczewski, 1999)

The strength of these support systems is that they make the users (decision makers) structure their problem (Scott Morton, 1971; Densham, 1991) and thus clearly outline their information requirements. Initially decision support systems were developed for complex business decisions, but in the last 20 years they have become applied to spatial problems as well, see e.g. Carver (1991), Chen et al. (2001), Sharifi et al. (2002), Pfeffer (2003) and Zucca (2005).

Before starting with an SMCE it is important to clearly define the goal, or set of goals of the decision maker or group of decision makers. Goals are the desired end states of the decision-making activities. In the case of risk assessment the short-term goal may be to identify areas of high risk. The long-term goal may be to develop strategies and policies to decrease risk in a given area or to avoid that risk increases as a consequence of certain activities. In defining the goals for a multi-parameter risk assessment two dichotomies can be distinguished: 1) specific purpose risk maps versus general purpose risk maps, and 2) evaluation of the present situation versus evaluation of a future situation (after a change has occurred). These two dichotomies are shown in Table 1.1.

Table 1.1 Goals for multi-parameter landslide-risk assessment.

	Specific purpose	**General purpose**
Present situation	Specific landslide-risk definition	General landslide-risk definition
Future situation	Specific landslide-risk impact assessment of proposed actions	General landslide-risk impact assessment of proposed actions

The distinction of specific purpose risk maps and general purpose risk maps means/refers to…. (I am missing the explanation of this dimension of the table. How do you intend this? Does it have to do with Catellanos? But that is too far away for in the text for the reader to make the connection here)

The distinction of present versus future situation is linked to the requirements of the multi-parameter risk assessment. Does it serve to inform the stakeholders on the present situation, or is it required to study the consequences of a proposed action that could alter the risk situation? In any case, agreement is required within the team (specific purpose) or within the coalition (general purpose) on the goals, the problem structure and the importance of the evaluation criteria. A study focussed on the present situation serves to inform the stakeholders, decision makers and authorities about possible critical locations. In case a future situation needs to be evaluated – for instance as part of an Environmental Impact Assessment (EIA), the study of the present risk situation serves as a reference or baseline study to identify areas where the risk will increase or decrease.

2.2 SMCE FOR DECISION-MAKING

Rational decision-making requires a careful analysis of the problem. A frequently applied approach is to decompose the problem into smaller, understandable parts that express relevant concerns. These smaller parts are the evaluation criteria (Malczewski, 1999; Pfeffer, 2003), standards by which a proper decision can be made. Saaty (1980) discusses this process, also called analytical hierarchy process (AHP), in further detail. The evaluation criteria can be further decomposed into objectives and attributes (Saaty, 1980; Malczewski, 1999; Pfeffer, 2003). An objective conveys a desired state that an individual or group would like to achieve, while an attribute is used to characterise an objective. Attributes can be quantified by parameters (some authors use the term indicator, e.g. Lorentz, 1999) – see also Figure 1.1. The interpretation of an indicator as to whether it's value is good with respect to its objective is a criterion (Ullman, 2006;Beinat, 1997)

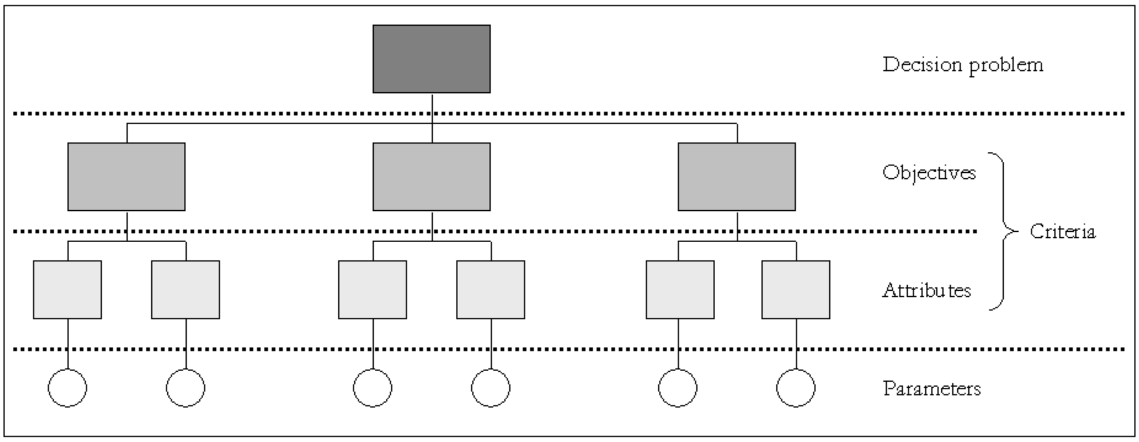


Figure 2 Decomposition of a decision problem into objectives, attributes and parameters. In principal there is no restriction to the number of hierarchical levels of objectives and attributes.

In this respect it is important to make another distinction and that is between discrete and continuous methods. Discrete methods tackle choice problems in which alternatives are selected from a discrete (and limited) set of alternatives, whereas continuous methods are more suitable for design problems (Beinat, 1997). The latter type of evaluation is referred to as multi-objective decision-making (e.g. Hwang and Masud, 1979; Malczewski, 1999) (Malczewski, 2006).

In this deliverable the decision problem is the definition of risk, where alteternatives are the different spatial locations, in this case pixels in a map of discretized landscape. It seeks to find a good definition of risk that provides the best possible information required for the decision-making – either for a specific purpose or for a general purpose. To select from an (in potential) infinite set of solutions, the stakeholders can use the procedure of SMCE to reach agreement on the objectives of the risk map, the set of attributes, indicators and criteria and the processing of this information. If agreement exists at all stages of the SMCE-procedure, they must also agree on the outcome: the risk map. In this way SMCE adds to the decision-making process in the sense that it identifies agreements and disagreements between the stakeholders, that it brings understanding, supports learning-by-doing and that it reveals areas where thinking is necessary (Beinat, 1997). Alternatively, different stakeholders could each want to make their own evaluation and locations of significant disagreement could be identified. Furthermore, SMCE supports the solution of a decision problem by analysing its robustness with respect to uncertainty (Geneletti, 2002)(Ullman, 2006).

2.3 STEPS IN SMCE

In the transformation process of the parameter maps into an output map four consecutive steps have to be taken: 1) identification of the parameter maps as costs or benefits; 2) standardisation of or value judgment about the parameter maps; 3) establishment of the importance of each individual criterion with respect to the decision problem; and 4) establishment of the aggregation procedure. An additional sensitivity analysis can be included to test the robustness of the outcome.

1 Cost and benefit parameters

The distinction between costs and benefit criteria is critical because with benefit criteria a high parameter value will have a positive effect on the achievement of the objective, whereas with cost criteria a high value is disadvantageous. In the case of flood risk, high inundation depth values are advantageous for risk – The higher the inundation depth values, the higher the risk values. In other words, the higher the inundation depth, the "better" the risk with respect to the objective of establishing risk; thus depth is a benefit criterion. Warning time is the opposite: the higher the warning time value, the lower the risk value, which makes it a cost criterion, again with respect to the objective of establishing risk.

Whether or not positive effects can balance disadvantageous effects depends on the choice for compensatory or non-compensatory techniques. In compensatory techniques poor performances on one criterion can be compensated by good performances on another, of course within specific limits (Beinat, 1997) – for instance the high-risk effects of high depths may be compensated by a long warning time. In non-compensatory techniques this counterbalancing is not possible. This can be the case if certain thresholds or limits are surpassed that are considered as absolute, regardless of the performance of the other criteria. Identification and definition of such limits must be included in the SMCE procedure, either by agreement of all stakeholders, or because of outside forces, like legislation and directives, or expert standards.

2 Standardisation

Each indicator has its own scale of measurement. Depth is often expressed as a length, measured in meters, velocity is measured as meters per second, or kilometre per hour; duration in hours, days or weeks, etc. It is clear that it makes no sense to simply add-up or multiply the values from the parameter maps. Apart from the fact that this would result in physically meaningless numbers, it would also make the result a function of the scale of measurement (depth in millimetre or in meter, duration in hours or weeks – the result would be very different). To overcome this problem a standardisation is required.

Moreover, each indictor can be interpreted in more detail as to whether a value is good or not. As we have seen a general interpretation such as higher values are better, i.e. benefits or lower values are better, i.e. costs. More sophisticated interpretation is possible, for instance a certain maximum or minimum optimum value may exists, or one or more threshold value.

This step – the value assessment (Geneletti, 2002) - transforms the parameter values of each parameter map into scores on an equal, dimensionless scale – often between 0 and 1 and at the same time provides the opportunity to interpret and value the parameter scores. This operation is performed by generating a value function, i.e. a mathematical relationship that represents human judgements, knowledge and goals. The value function explicitly links the factual information in the parameter maps to the corresponding parameter scores. The value function can be linear, meaning that equal increments of the parameter value result in equal increments in the parameter scores, but can also be non-linear or discontinuous. See also figure 3.

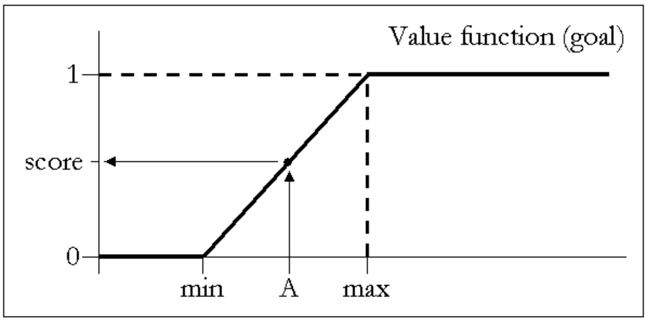


Figure 3 Example of a value function (type "goal"): on the horizontal axis are all possible values of a certain parameter map. Values below the lower threshold (min) get a corresponding score of 0, values above the higher threshold (max) get a corresponding score.

During the establishment of the appropriate form of the function model, the value assessment, the assessors face a dilemma (Beinat, 1997): on the one hand, the assessment aims at a numerical specification of the value function model, implying high precision and good knowledge of the transformation process; in practice, on the other hand, the assessors often find it difficult to provide reliable numerical judgements and prefer qualitative and tentative responses. Beinat (1997) treats this value assessment procedure in-depth and shows that this duality is at the basis of the many attempts that have been made to provide adequate solutions. Defining the value functions is one of the major discussion topics in the multi-criteria evaluation procedure. The assessor is most likely to be a group of people (experts, stakeholders). They either form a team or a coalition and together they have to reach agreement on the value functions for each parameter included in the assessment. This should avoid possible bias from individual members, but raises new problems like composition of the expert group (number and backgrounds of the experts) and the interaction within the group (see e.g. Ferell, 1985; Van Steen, 1991 – in Beinat, 1997).

3 Prioritisation

During the prioritisation, the preferences of the stakeholders with respect to the evaluation of the criteria are incorporated in the decision model. This is typically done by assigning weights to the criteria. The weights reflect the importance of each criterion relatively to the other criteria under consideration (Malczewski, 1999). The assignment of the weights is the second crucial step that, like the value assessment, is likely to be a group process in which the group members will have to reach agreement. To facilitate this discussion several techniques have been developed to assist the process of normalised weight assignment. Normalised in this context means that the sum of the weights equals 1. Among these are the following (Malczewski, 1999):

- Ranking methods in which the assessor ranks the criteria in order of preference. The numerical weights are then assigned as function of the rank;
- Rating methods in which the assessor assigns weights on a predetermined scale to each criterion using a predefined procedure. The numerical weights are then assigned by normalisation (dividing each weight by the sum of all weights);
- Pair-wise comparison method in which the assessor compares each possible pair of criteria and rates one relative to the other on a scale from “equal importance” to “extremely more important”. Comparison of all possible pairs results in a so-called ratio-matrix. The numerical weights are determined by normalizing the eigenvector associated with the maximum eigenvalue of the ratio matrix (Saaty, 1980).

There are advantanges and disadvantages of using one prioritization method or another. For instance ranks are relatively easy to provide but leave imprecision since the degree of priority difference between the criteria that are ranked is lost. Rating methods do not have that disadvantage but do suggest precision of priority that a decision maker might not be able to sustain if asked for the same prioritization exercise days or weeks later. Both ranking and rating methods assume decision makers can give a quantitative assessment of priority, but maybe a qualitative pair-wise comparison suits better, but is much more time consuming and difficult if a decision maker has no clear priority model in mind.

4 Aggregation

The outcome – or decision – depends on both the value functions (standardisation) and the weight-factors for each criterion (prioritisation) but also on how these are combined in a decision model. This is called the aggregation step (Geneletti, 2002). The most widely used aggregation method is the weighted linear combination, also called simple additive weighting or scoring method. This method is based on the concept of weighted average (Malczewski, 1999). In its simplest form a decision could be defined as:

$$F(x) = \Sigma_n(W_k\ (f_k(x))) \qquad 1$$

Where:

$F(x)$ = the outcome (the decision) as a result of the sum of n weighted criteria.

W_k = the normalised non-negative weight of the kth criterion.

$f_k(x)$ = the value function of the kth indicator (x).

Because the results of the value functions are on a scale from 0 to 1 and because the sum of the normalised weights equals 1, the resulting map F(x) – sometimes called ‘the decision’ or ‘composite index map’ is a dimensionless scalar map with scores between 0 to 1. Scores close to 0 identify areas where the criteria are absolutely disadvantageous and scores close to 1 indicate areas that meet the criteria perfectly. Figure 4 gives a summary of the procedure.

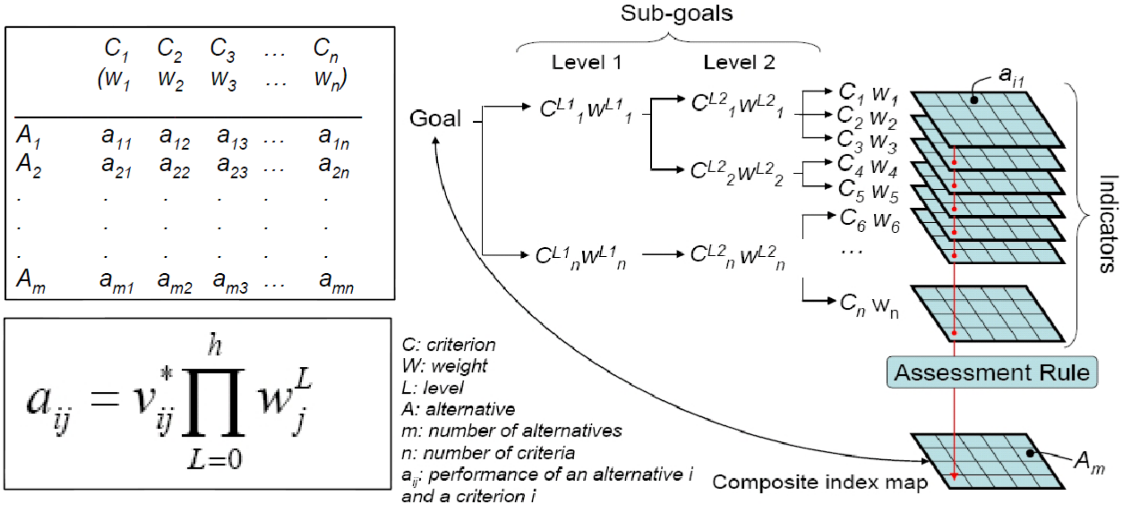


Figure 4 Schematic procedure for spatial multi-criteria evaluation based on the analytical hierarchical process

This method assumes that the criteria provide independent evidence and that there is no uncertainty in the decision situation. The first assumption means that there is no correlation between any two criteria. The second assumption, which we give more attention in the next section, means that all relevant information about the decision situation is known and that there is a known deterministic connection between every decision and the corresponding outcome (Malczewski, 1999). In practice these two assumptions are hard or impossible to test. To deal with uncertainty for instance a sensitivity analysis can be performed to quatify the effects of uncertainty on the shape of the outcome (Herwijnen, 1999) or Bayesian calculation methods of belief maps could be used (Ullman, 2006).

5 Sensitivity analysis

Until now we have implicitly assumed that all information required for decision-making is available to the decision makers: no errors in the indicator maps, no uncertainty in the assignment of weights and value functions and choice of decision model. Although methods exist to include uncertainty directly into the decision-making process, the most often applied approach is to incorporate them into the decision-making process indirectly, using a so-called sensitivity analysis. Sensitivity analysis is concerned with the way in which errors in a set of input data affect the error in the final outcome. In other words, it serves to test the robustness of the decision with respect to uncertainties in the parameter maps, weights, value functions and decision rules. Errors in the parameter maps can be classified into positional and attribute errors (e.g. Burrough and McDonnell, 1998). The first type of errors deals with uncertainty regarding the location, i.e. errors in the X-, Y- and Z-coordinate. The second type of errors deals with uncertainty regarding the measurement value or with misclassification of objects. Since most maps in hazard and risk assessment are based on modelling results, the latter type of errors also includes uncertainty generated during the modelling phase (due to inaccuracy in model input, boundary conditions, initial conditions and by approximations in the modelling procedure). There are ways to assess the map errors, for instance using root-mean-square error, or with a confusion matrix (Burrough and McDonnel, 1998).

Errors introduced in SMCE during the standardisation, prioritisation and aggregation are also called preference uncertainty (Malczewski, 1999). Decision makers are not able to provide precise judgements due to limited or imprecise information and knowledge. These types of errors do not always result from mistakes, although mistakes create errors of course, but are rather the result of a margin between the best judgement and alternative estimates. Within a group process, the range of possible weights and value functions can be estimated (with some level of confidence). During the sensitivity analysis this range-estimate can be used to test the robustness of the outcome. For instance the minimum and maximum limits of the range can be used instead of the best estimate, leaving all other factors constant. Another possibility is to specify a distribution model for each uncertainty range (normal, triangular, block, …) and to run a so-called Monte-Carlo simulation. In a Monte Carlo simulation a high number of runs are executed, where during each run parameter values are taken from the distribution models. The result is not a single outcome, but an outcome with an error distribution.

3 SMCE FOR NOCERA INFERIORE

3.1 INTRODUCTION TO THE CASE STUDY AREA

SafeLand deliverables 2.11, 5.3 and 5.7 describe the general situation in Nocera Inferiore (Campania region, southern Italy) in greater detail; here a short introduction and general problem statement will be given, followed by an overview of the hazard analyses that have been carried out and its results.

Problem statement

Historically, the Campania region is severely affected by landslides (Cascini et al., 2008). One of the worst tragedies occurred in 1998 when 160 people died due to a series of flowslides (Cascini, 2004). This landmark event raised the awairness of the people living in the area and when in 2005 a first-time landslide on open slope was triggered in Monte Albino hillslopes (within the municipal territory of Nocera Inferiore), approximately 12 kilometers away from Pizzo d'Alvano massif (affected by the event of 1998); this landslide killed three persons and destroyed some property, action plans were demanded by the population. However there was no concensus on what kind of action should be taken. This study is part of a process to develop feasible risk mitigation strategies that are supported by the local stakeholders.

Results of previous hazard and vulberability analyses

This SMCE study builds upon work carried out by numereous reseachers that is summarized by Corominas and Mavrouli (2012) in deliverable 2.11 of this SafeLand project. The data that is used in this analysis comes from these studies.

3.2 THE SMCE BASE DATA

Intensive studies carried out by the University of Salerno (Corominas and Mavrouli, 2012; Narasimhan and Faber, 2012; Scolobig and Bayer, 2012) have identified – for the case study at hand – four hazardous processes, namely: 1) flooding phenomena, 2) hyperconcentrated flows, 3) flowslides and 4) landslides on open slopes. In these studies these hazards were analysed using various advanced methods to obtain their spatial and temporal characteristics. In addition to this, data were collected to describe the exposed elements thanks to information provided by Local Authorities and through detailed surveying of the area at risk. The next two sections present the results of these studies that were used in this SMCE analysis.

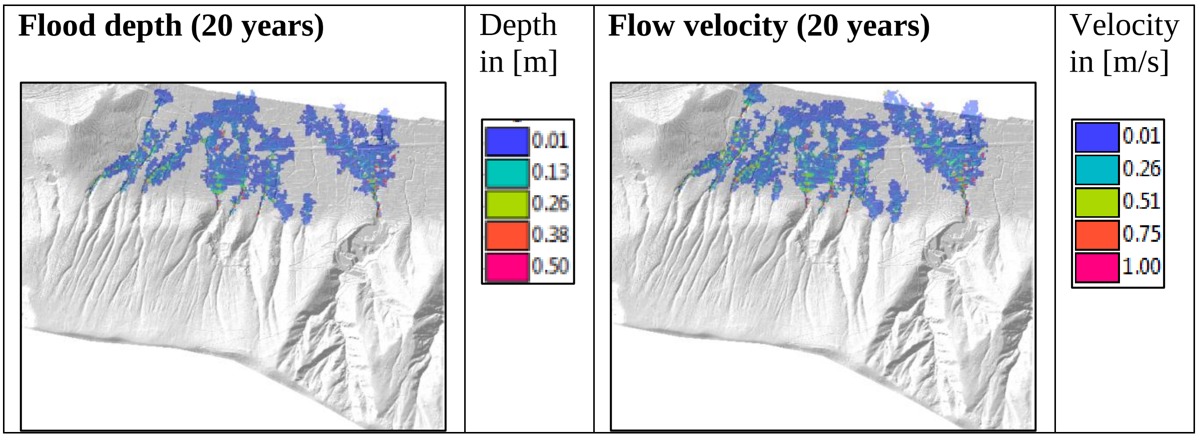
3.2.1 Hazard base maps

The propagation stage of flooding phenomena, hyperconcentrated flows and flowslides was modeled – by the University of Salerno – via the use of the FLO-2D numerical code (O'Brien et al., 1993) on a high quality DTM – of squared cells of 5 m x 5 m – obtained via the data achieved by a LIDAR survey. In particular, the flow patterns were evaluated for each basin by considering different return periods (T) of the triggering rainfall for the different phenomena (i.e., 20 and 100 years for flooding; 200 years for both hyperconcentrated flows and flowslides). It is worth to observe that, for the hyperconcentrated flows, three different couples of the considered rheological parameters (i.e., the shear strength at the base of the propagating flow and the dynamic viscosity) were considered for the analysis purposes. Details on the input data can be recovered in Corominas and Mavrouli (2012).

As far as landslides on open slopes are concerned, the stability conditions were assessed – in terms of safety factors along sliding surfaces, taking into account the soil stratigraphy - by using a combined groundwater and slope-stability model (Geo-Slope, 2004a, b). On the other hand, the run-out distance was evaluated by adopting a heuristic criterion, taking into account the shape of the ancient alluvial fans. The average return period of these phenomena equals to 20 years.

The obtained results are synthetised in the maps shown in Figures 5-11.

1 Flood maps

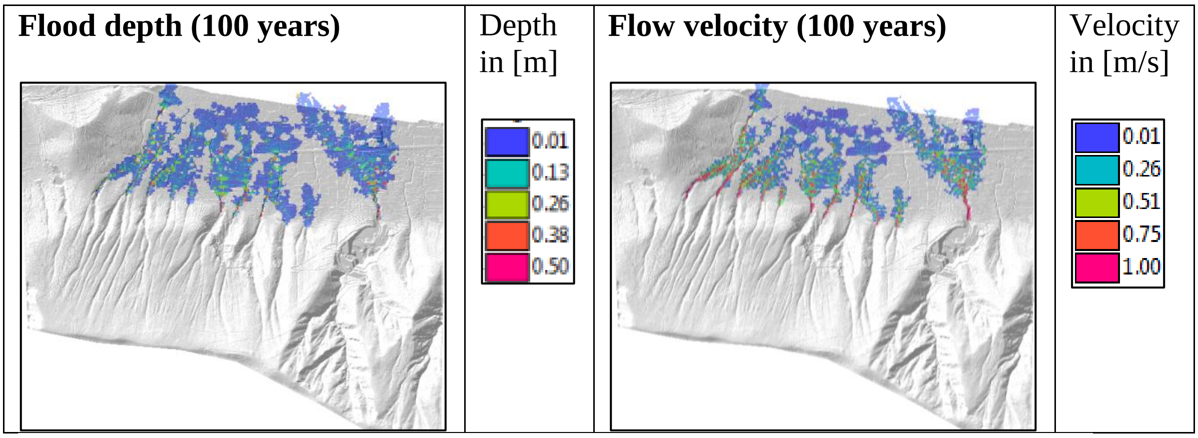

Flood depth (20 years)

Depth in [m]

Flow velocity (20 years)

Velocity in [m/s]

Figure 5 Flood depth maps (in meters) of the 20 year flood (left) and the 100 year year flood event (right). Map names in criteria trees: Flow_depth_020y and flow_depth_100y.


Flood depth (100 years)

Depth in [m]

Flow velocity (100 years)

Velocity in [m/s]

Figure 6 Flow velocity maps (in m/s) for the 20 year flood (left) and the 100 year flood event (right). Map names in criteria trees: Flow_velocity_020y and flow_velocity_100y.

2 Hyperconcentrated flow maps

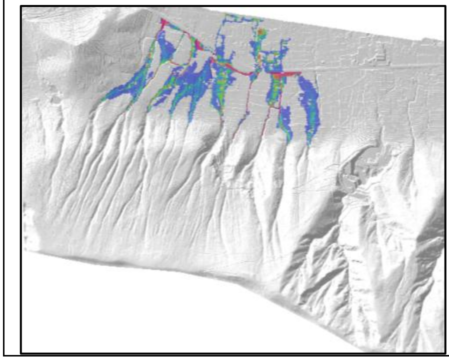
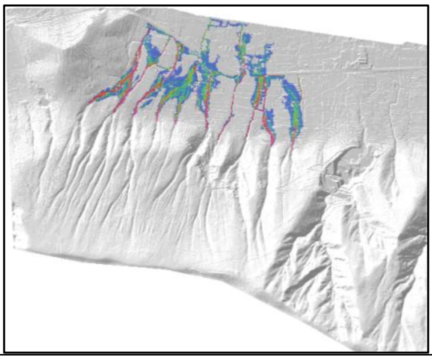
HCF-type 1 depth (200 years)	Depth in [m]	**HCF-type 1 velocity (200 years)**	Velocity in [m/s]
	🟦 0.01 🟦 0.26 🟩 0.51 🟧 0.75 🟥 1.00		🟦 0.01 🟦 0.26 🟩 0.51 🟧 0.75 🟥 1.00

Figure 7 Hyper Concentrated Flow - type 1 (least visceous). Map names in criteria trees: HCF_sc1_depth_smce and HCF_sc1_velocity_smce.

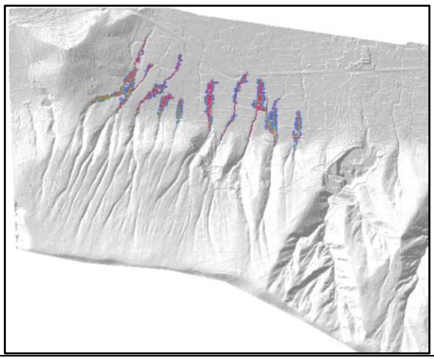
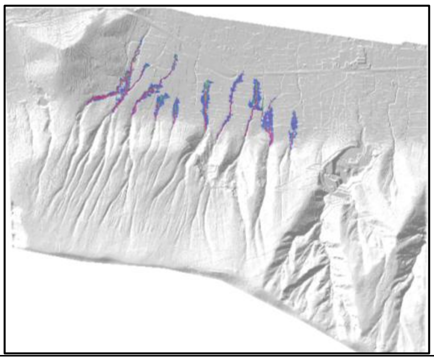
HCF-type 2 depth (200 years)	Depth in [m]	**HCF-type 2 velocity (200 years)**	Velocity in [m/s]
	🟦 0.01 🟦 0.26 🟩 0.51 🟧 0.75 🟥 1.00		🟦 0.01 🟦 0.26 🟩 0.51 🟧 0.75 🟥 1.00

Figure 8 Hyper Concentrated Flow - type 2 (medium visceous). Map names in criteria trees: HCF_sc2_depth_smce and HCF_sc2_velocity_smce.

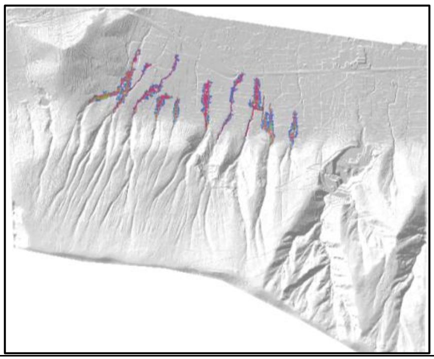
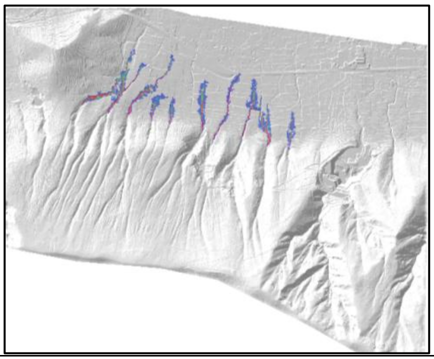
HCF-type 3 depth (200 years)	Depth in [m]	**HCF-type 3 velocity (200 years)**	Velocity in [m/s]
	🟦 0.01 🟦 0.26 🟩 0.51 🟧 0.75 🟥 1.00		🟦 0.01 🟦 0.26 🟩 0.51 🟧 0.75 🟥 1.00

Figure 9 Hyper Concentrated Flow - type 3 (most visceous). Map names in criteria trees: HCF_sc3_depth_smce and HCF_sc3_velocity_smce.

3 Flowslide maps

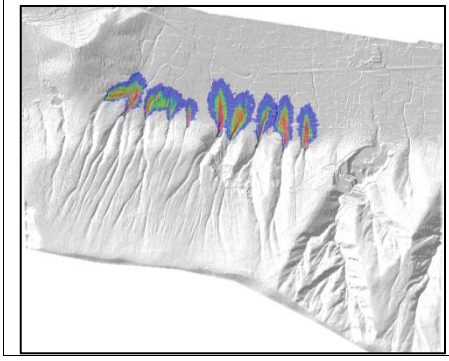
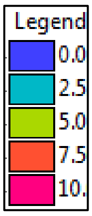
Flowslide velocity (200 years)	Velocity in [m/s]
	

Figure 10 Flowslides. Map name in criteria trees: mudflow_velocity_smce.

4 Landslide on open slopes maps

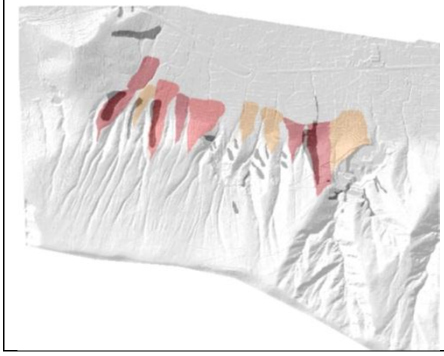
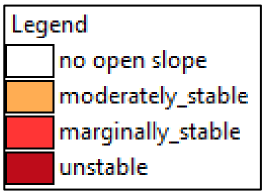
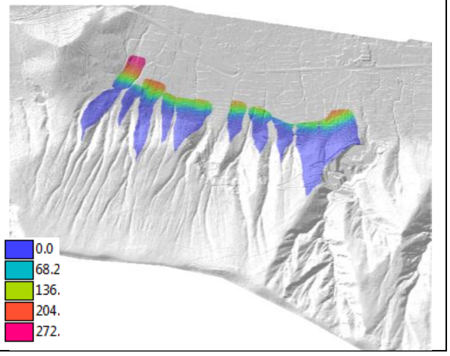
Landslides (20 years)	Stability	Landslide runout distance (m)
		

Figure 11 Left: Stability of the slopes with indication of potential runout. Historic landslides are indicated in black. Map names in criteria trees: open_slope_stability and landslide. Right: Potential maximum runout distance (in meters) of landslides originating from the slopes. Map name in the criteria trees: Landslide_distance.

3.2.2 Vulnerabilty base maps

The vulnerability information was derived from three source maps: 1) The landuse map, 2) the infrastructure map; and 3) the building footprint map. This last map contained additional attribute information for each building. This additional information comprised, a.o. number of inhabitants, number of floor, building material and type of occupancy. The building map was also used to calculate the distance to buildings map. In this section the four main maps are presented – in Figures 12 – 15.

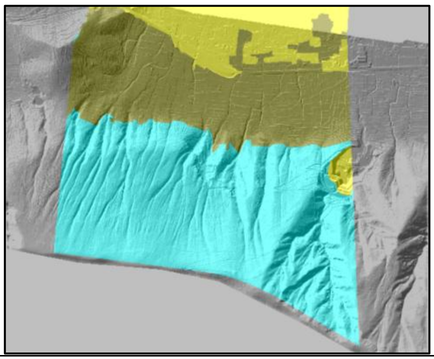
Landuse	Landuse types	
	Legend 🟨 91: Ambiente urbanizzato e superfici artificiali 🟦 51: Boschi di latifoglie 🟫 22: Frutteti e frutti minori ▨ 999: unknown	

Figure 12 General landuse map of the area; 91= Urban area; 51= forest; 22 = orchards and small fruits.

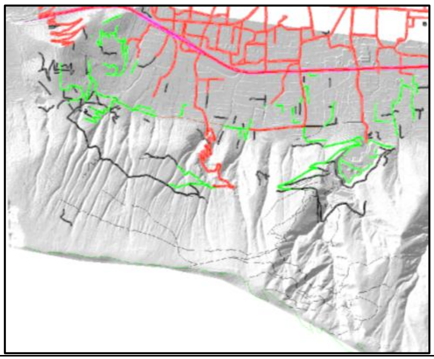
Roads	Road types	
	Legend □ no road ■ Footpath 🟩 Unpaved road 🟧 paved road 🟪 main road	

Figure 13 Road type map of the area

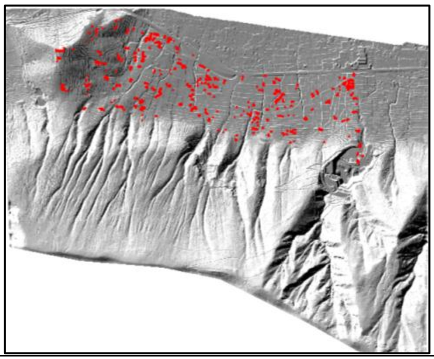
Buildings	Attribute info	
	- number of floors - building material (wood, brick, reinforced condcrete) - area (size in m^2) - use (residential, warehouse, restaurant) - number of inhabitants	

Figure 14 Building map; of each building attribute information was available

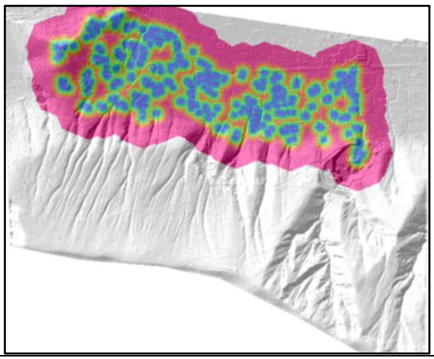
Distance to buildings 	Distance in [m] Legend 🟦 0.0 m 🟦 25.0 m 🟩 50.0 m 🟥 75.0 m 🟥 100.0 m	

Figure 15 Distance to buildings (in meters)

3.3 DEFINITION OF THE GOAL

The aim of this example is to define a risk map based on maps that describe on one hand the dynamics (depth and velocity) of three flow processes (flooding phenomena, hyper-concentrated flow and flowslides) and slope stability analysis for landslides on open slopes; and on the other hand a set of maps containing information with respect to the environmental-, physical- and social vulnerability.

4 SMCE FOR RISK ASSESSMENT IN NOCERA

4.1 SPATIAL MULTI CRITERIA EVALUATION FOR RISK ASSESSMENT

In chapter 2 it was explained that the input layers need to be standardised from their original values to the value range of 0–1. It is important to notice that the indicators have different measurement scales (nominal, ordinal, interval and ratio) and that their cartographic representations are also different (natural and administrative polygons and pixel based raster maps). Taking into account these elements, different standardization methods provided in the SMCE module of ILWIS were applied to the indicators. The standardisation process is different if the indicator is a 'value' map with numerical and measurable values (interval and ratio scales) or a 'class' map with categories or classes (nominal and ordinal scales). For standardizing value maps, a set of equations can be used to convert the actual map values to a range between 0 and 1. The next step is to decide for each indicator whether it is favourable or unfavourable in relation to the intermediate or overall objective. For example, for the intermediate objective of vulnerability, all indicator maps of which higher values show an increase in the overall vulnerability were considered as favourable. This may appear counter intuitive, but our overall goal is to assess risk (not the absence of rik) and of course higher vulnerability leads to (is favourable for) risk, and so do the indicator maps that indicate vulnerability. After selecting the appropriate indicators, defining their standardisation and the hierarchical structure weights were assigned to each criterion and intermediate result. For weighting, three main methods were used: direct method, pairwise comparison and rank order methods.

4.2 RISK ASSESSMENT USING SMCE

The input for the application is a number of raster maps of a certain area (so-called 'criteria' or 'effects'). The output is one or more maps of the same area, the so-called 'composite index' maps that indicate the extent to which criteria are met or not in different areas. For more information see for instance Sharifi and Retsios (2003) and the ILWIS website: http://www.itc.nl/ilwis/.

SMCE starts with contructing a so-called criteria tree (Fig 17) . The construction of the tree is a step-wise procedure that guides the users through the SMCE process: definition and structuring of objectives and criteria, selection of indicator maps to be used, the standardization of indicator maps assuming criteria definitions, prioritization and finally aggregation. In the tree output maps are defined that contain the (partial) results of the analysis, with one map that contains the results of the whole analysis. In this example two approaches were followed. In the first approach, the generic multi-hazard risk assessment, all hazard related criteria were grouped in a hazard criteria tree and all vulnerability related criteria were grouped in a vulnerability criteria tree. The final hazard- and vulnerability maps were then combined into a risk map. The second approach was to define vulnerability as a function of the hazard and to create four hazard-specific risk maps first. These four maps were then combined into a multi-hazard risk map. The two approaches are illustrated in Figure 16.

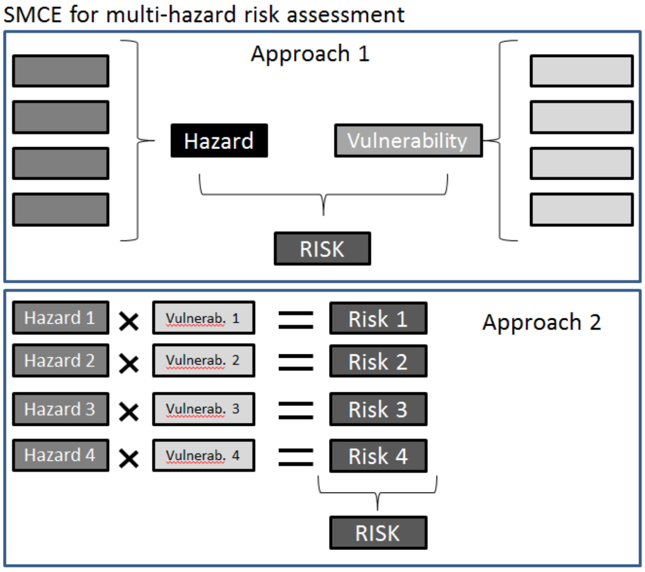
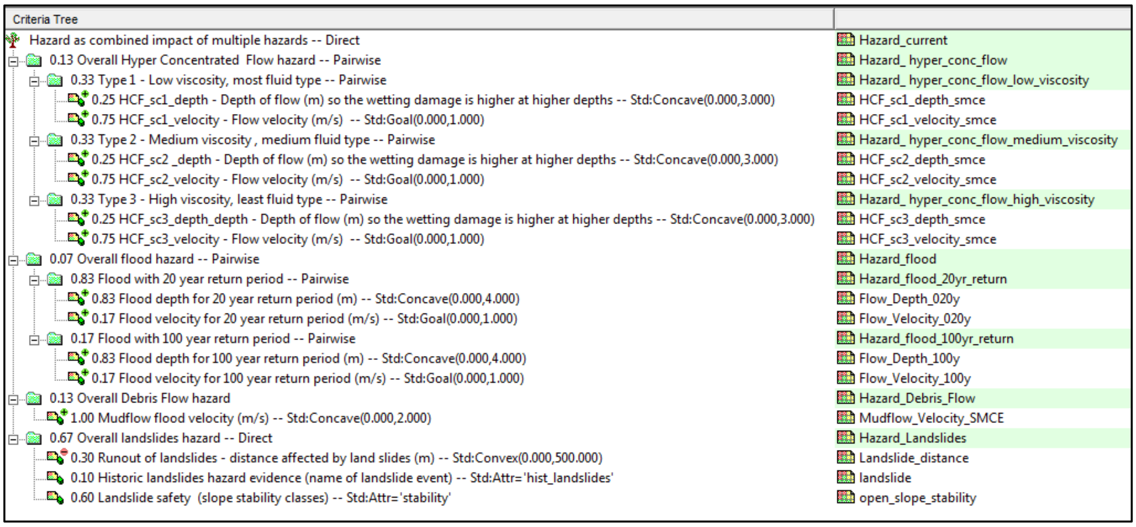


Figure 16 Two approaches to SMCE for multi-hazard risk assessment

4.3 APPROACH 1: GENERIC MULTI-HAZARD RISK ASSESSMENT

4.3.1 Design of the criteria tree for multi-hazard assessment

Figure 17 shows the criteria tree that was used for the generic multi-hazard assessment. At the top row, the goal is defined as "hazard as combined impact of multiple hazards" and the resulting output is the map "hazard_current" – defined at the corresponding row in the right-hand column. In the structure below the top line the four hazardous processes are listed: Overall Hyperconcentrated Flow hazard, Overall Flood hazard, Overall MudFlow hazard and Overall Landslide hazard. Each hazard is further divided into subcategories (indicated with a folder-icon) such as different types of hyper-concentrated flow (depending on its shear strength and viscosity), return period for flooding phenomena and characterization for landslides on open slopes. At the lowest level the criteria are defined (indicated with a map icon), such as depth and velocity maps. In the right-hand column the corresponding data source (map) is defined. These are the maps that were presented in chapter 3.



Criteria Tree	
Hazard as combined impact of multiple hazards -- Direct	Hazard_current
0.13 Overall Hyper Concentrated Flow hazard -- Pairwise	Hazard_ hyper_conc_flow
0.33 Type 1 - Low viscosity, most fluid type -- Pairwise	Hazard_ hyper_conc_flow_low_viscosity
0.25 HCF_sc1_depth - Depth of flow (m) so the wetting damage is higher at higher depths -- Std:Concave(0.000,3.000)	HCF_sc1_depth_smce
0.75 HCF_sc1_velocity - Flow velocity (m/s) -- Std:Goal(0.000,1.000)	HCF_sc1_velocity_smce
0.33 Type 2 - Medium viscosity , medium fluid type -- Pairwise	Hazard_ hyper_conc_flow_medium_viscosity
0.25 HCF_sc2 _depth - Depth of flow (m) so the wetting damage is higher at higher depths -- Std:Concave(0.000,3.000)	HCF_sc2_depth_smce
0.75 HCF_sc2_velocity - Flow velocity (m/s) -- Std:Goal(0.000,1.000)	HCF_sc2_velocity_smce
0.33 Type 3 - High viscosity, least fluid type -- Pairwise	Hazard_ hyper_conc_flow_high_viscosity
0.25 HCF_sc3_depth_depth - Depth of flow (m) so the wetting damage is higher at higher depths -- Std:Concave(0.000,3.000)	HCF_sc3_depth_smce
0.75 HCF_sc3_velocity - Flow velocity (m/s) -- Std:Goal(0.000,1.000)	HCF_sc3_velocity_smce
0.07 Overall flood hazard -- Pairwise	Hazard_flood
0.83 Flood with 20 year return period -- Pairwise	Hazard_flood_20yr_return
0.83 Flood depth for 20 year return period (m) -- Std:Concave(0.000,4.000)	Flow_Depth_020y
0.17 Flood velocity for 20 year return period (m/s) -- Std:Goal(0.000,1.000)	Flow_Velocity_020y
0.17 Flood with 100 year return period -- Pairwise	Hazard_flood_100yr_return
0.83 Flood depth for 100 year return period (m) -- Std:Concave(0.000,4.000)	Flow_Depth_100y
0.17 Flood velocity for 100 year return period (m/s) -- Std:Goal(0.000,1.000)	Flow_Velocity_100y
0.13 Overall Debris Flow hazard	Hazard_Debris_Flow
1.00 Mudflow flood velocity (m/s) -- Std:Concave(0.000,2.000)	Mudflow_Velocity_SMCE
0.67 Overall landslides hazard -- Direct	Hazard_Landslides
0.30 Runout of landslides - distance affected by land slides (m) -- Std:Convex(0.000,500.000)	Landslide_distance
0.10 Historic landslides hazard evidence (name of landslide event) -- Std:Attr='hist_landslides'	landslide
0.60 Landslide safety (slope stability classes) -- Std:Attr='stability'	open_slope_stability

Figure 17 Criteria tree for hazard; The righ-hand column shows the input indicator maps (not-shaded) and the output 'composite index' maps or results (shaded). The final outcome – the composite index map or decision – is in this case the map "hazard_current", as defined at the top of the right-hand column.

Relative weight for the four hazards

The numbers in front of the group or the criterion are the weights that have been assigned to the criteria to indicate their relative importance with respect to the final result. Criteria that contribute more to the "hazard as combined impact of multiple hazards" have received a higher weight than those that contribute less. In particular, landslides on open slopes - characterized by the lowest return period - received a five times higher weight (0.67 vs 0.13) than the other hazards (hyperconcentrated flows and flowslides). On the other hand, a secondary argument was used to reduce weight for flooding phenomena; this hazard was widely perceived by the stakeholders as a nuisance rather than as a hazard and therefore received a weight of 0.07.

Relative weights for Hyperconcentrated flow

Because there was no information that indicated that one of the three types of hyperconcentrated flows (HCF) would have a higher annual probability of occurrence, all three received the same weight (0.33). Each flow type was characterized by a combination of maximum velocity and maximum inundation depth. Inundation depth was considered as contributing more to the hazard than flow velocity and therefore received a higher weight (0.75 vs 0.25).

Relative weights for floods

The 20 year return period flood has a five times higher probability of occurrence than the 100 year flood and therefore received a five times higher weight (0.83 vs 0.17). The same ratio was applied in estimating the relative contribution to the hazard of depth vs velocity. The difference of this ratio of 5:1 vs 4:1 in the case of HCF can be explained by the fact that the contribution to the hazard of the velocity in the HCF is considered slightly higher because HCF has a higher density. At the same velocity HCF has a higher momentum than water and is therefore more hazardous in the sense that it can cause more damage.

Relative weights for flowslides

For flowslides only the maximum flow velocity map was considered as indicator. In this regard, it is worth to mention that – for this kind of phenomena, characterized by a peculiar kinematics in the propagation stage – consequences related to the impact of the flowing mass to the exposed buildings can be predicted on the basis of the value assumed by its maximum velocity at the impact (Faella and Nigro, 2003; Faella, 2005).

Relative weights for landslides on open slopes

Three maps were used in assessing the landslide hazard: 1) The classified slope stability map, 2) the map with historic landslides and 3) the potential maximum runout map. Most weight was given to the maps that resulted from the deterministic slope stability analysis and runout assessment: 0.60 and 0.30 respectively. A small weight (0.10) was assigned to historic landslides although one can argue that since these slides have occurred, stability has been restored. However, it cannot be excluded that historic events may be the trigger of new, future events. In addition, one can also argue that historic slides may indicate instable conditions in their immediate vicinity.

Standardization methods

Where the weighing procedure gives the relative importance of each criterion with respect to the other criteria, the standardization procedure rescales each criterion internally to a scale of 0 to 1. The way this was done is given behind the description of the criteria (Fig. 17). For different types of maps different methods can be applied. Continuous data (values) can be rescalled using one of the following rescalling functions: 1) linear, 2) goal, 3) concave and 4) convex – see figure 18. On the horizontal axis are the original criteria (map) values and on the vertical axis the corresponding standardized (or normalized) values between 0 and 1.

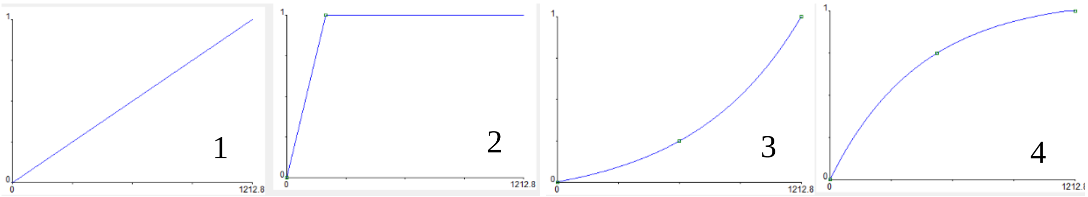


Figure 18 Rescaling functions for continuous value maps: 1) linear, 2) goal, 3 concave and 4) convex. See text for further explanation.

In type 1, linear the highest value in the map gets value 1, the lowest gets value 0. All intermediate map values get intermediate values through linear interpolation. In type 2 a user-defined map value (i.e. goal value) gets the normalized value 1. All map values above this threshold will also get the normalized value 1 assigned. The lowest value gets 0 and all intermediate values get their values through linear interpolation. In type 3 and 4 the interpolation techniques are either convex or concave; the user can define the exact shape of the curve and can also define maximum thresholds, similar as in type 2. There is strong comparison between the standardization functions and the vulnerability curves used for e.g. flood vulnerability assessment. Typically the flood vulnerability curves relate – for a specific element at risk – the water depth to degree of damage on a scale of 0 to 1.

For non-value criteria like thematic maps, the following weighting methods are available:

Direct: the user specifies a value for the relative importance of each factor himself. Weights are automatically normalized.

Pairwise Comparison: the user goes through all unique pairs and assigns Saaty weights, i.e. user specifies the relative importance for each pair of factors in fixed phrases or with a slide bar. From these weights, normalized weights are calculated.

Rank Order: the user specifies the rank-order of the relative importance of all factors, either using the rank sum method or the expected value method. From the specified rank-order, normalized weights are calculated.

The resulting generic multi-hazard map

The grouping of the critera, the choice of standardization method and the assignment of the weights is a subjective process that incorporates expert judgement and perceptions of the evaluators. The design of the tree is a time-consuming group process that should reflect the compromises between the various stakeholders involved in the SMCE process. When all evaluators agree on all the steps and decisions that resulted in defining the criteria tree, they should also agree on the resulting output map. In this case that is the generic multi-hazard map that is shown in figure 19. This so-called composite index map shows on a scale from 0 to 1 which areas are most hazardous (1) and which areas the least (0). In figure 19 the dominance of landslides on open slopes as most hazardous process is clearly visible in the end result.

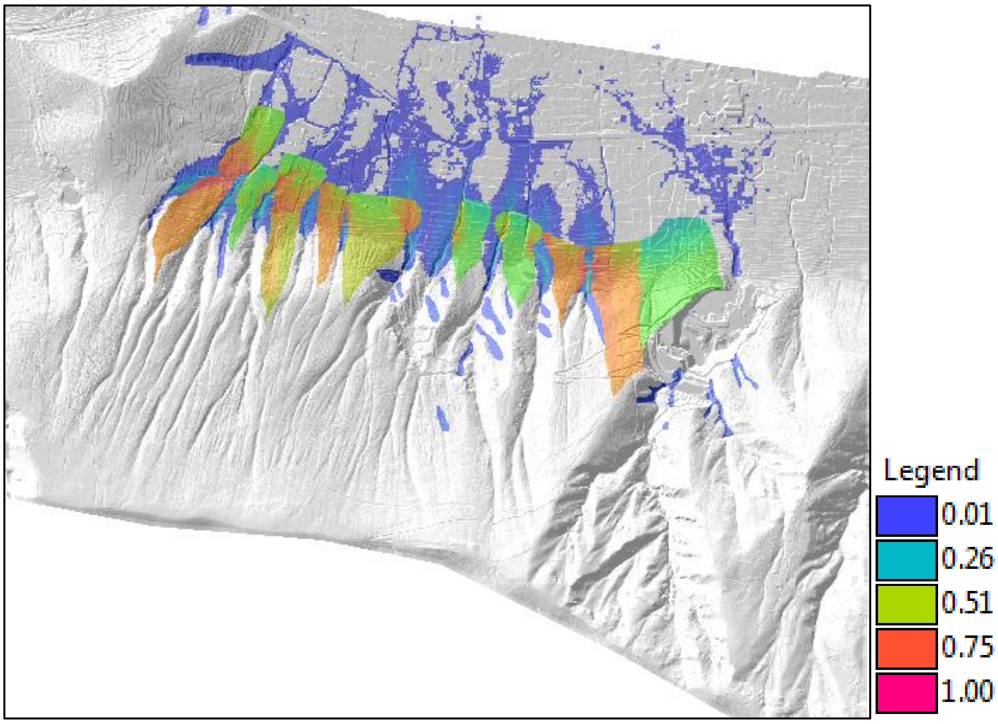


Figure 19 Composite index map for multi-hazard. A low score indicates least hazardous and a high score most hazardous.

4.3.2 Design of the criteria tree for generic multi-hazard vulnerability assessment

In this analysis we considered three different types of vulnerability: environmental, physical and vulnerability. In the following sections will be described how these types of vulnerability were assessed.

Environmental vulnerability

Environmental vulnerability evaluates the potential impacts of events on the environment (flora, fauna, ecosystems, biodiversity). As a proxy indicator we have used the landuse map which consisted of four units (see figure 12): 1) urban areas, 2) forest, 3) orchards and small fruits, and 4) unknown. Each of these units was assessed for its envirionmental quality with using a direct-weight-assignment method. Urban areas received the lowest environmental quality grade (0) and forest the highest (1). The unit “Orchards and fruits” received the intermediate grade of 0.5. This same value was assigned to the areas where the landuse was not known.

Physical vulnerability

Physical vulnerability is the potential for physical impact on the built environment. It is defined as the degree of loss to a given element-at-risk or set of elements-at-risk resulting from the occurrence of a natural phenomenon of a given magnitude, and expressed on a scale from 0 (no damage) to 1 (total damage). Physical vulnerability is related to the characteristics of the elements-at-risk, and to the hazard intensity and is determined by the spatial overlay of exposed elements-at-risk and hazard footprints.

In this study we used the following main groups of indicators for assessing the physical vulnerability: 1) Building vulnerability (based on contruction material and number of floors), 2) Immediate area surrounding the buildings (< 20m) for property damage, and 3) the potential for damage (based on landuse and building size).

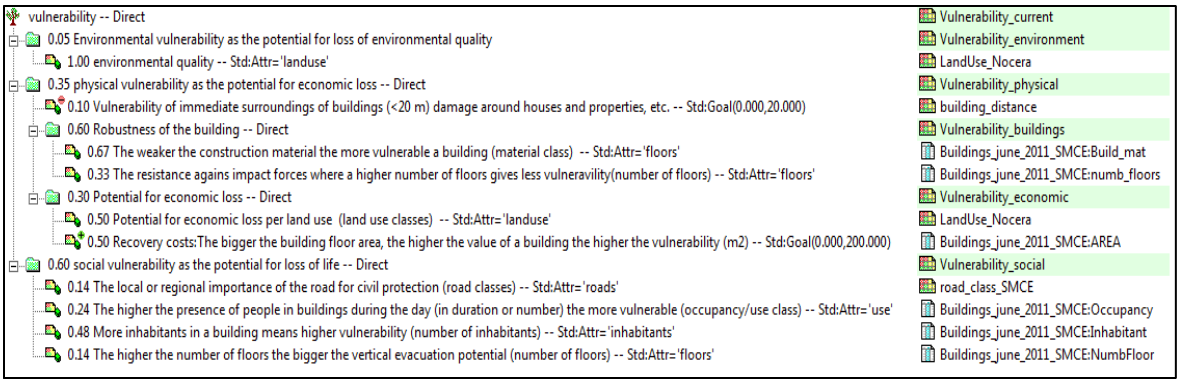
Social vulnerability

Social vulnerability is the potential impact of events on groups within the society and it considers public awareness of risk, ability of groups to self-cope with catastrophes, and the status of institutional structures designed to help them cope.

In the analysis of the social vulnerability we have used the following indicator groups: 1) Roads (based on their importance for immediate rescue services), 2) building occupancy to estimate the amount of people present during day-time, 3) building inhabitants to estimate the amount of people present during nighttime, and 4) the number of floors as means for vertical evacuation.

The criteria tree

Figure 20 shows the criteria tree for the multi-hazard vulnerability assessment. The final composite index map “vulnerability_current” is calculated based on the three vulnerability groups that were described previously. The assignment of the weights to each of the three vulnerability types is highly subjective is obviously related to the objective of the risk assessment. In this particular case special emphasis was given to the social vulnerability (weight = 0.6) with physical vulnerability on a second place with a weight of 0.35. The environmental vulnerability was given the lowest weight (0.05).



vulnerability -- Direct	Vulnerability_current
0.05 Environmental vulnerability as the potential for loss of environmental quality	Vulnerability_environment
1.00 environmental quality -- Std:Attr='landuse'	LandUse_Nocera
0.35 physical vulnerability as the potential for economic loss -- Direct	Vulnerability_physical
0.10 Vulnerability of immediate surroundings of buildings (<20 m) damage around houses and properties, etc. -- Std:Goal(0.000,20.000)	building_distance
0.60 Robustness of the building -- Direct	Vulnerability_buildings
0.67 The weaker the construction material the more vulnerable a building (material class) -- Std:Attr='floors'	Buildings_june_2011_SMCE:Build_mat
0.33 The resistance agains impact forces where a higher number of floors gives less vulneravility(number of floors) -- Std:Attr='floors'	Buildings_june_2011_SMCE:numb_floors
0.30 Potential for economic loss -- Direct	Vulnerability_economic
0.50 Potential for economic loss per land use (land use classes) -- Std:Attr='landuse'	LandUse_Nocera
0.50 Recovery costs:The bigger the building floor area, the higher the value of a building the higher the vulnerability (m2) -- Std:Goal(0.000,200.000)	Buildings_june_2011_SMCE:AREA
0.60 social vulnerability as the potential for loss of life -- Direct	Vulnerability_social
0.14 The local or regional importance of the road for civil protection (road classes) -- Std:Attr='roads'	road_class_SMCE
0.24 The higher the presence of people in buildings during the day (in duration or number) the more vulnerable (occupancy/use class) -- Std:Attr='use'	Buildings_june_2011_SMCE:Occupancy
0.48 More inhabitants in a building means higher vulnerability (number of inhabitants) -- Std:Attr='inhabitants'	Buildings_june_2011_SMCE:Inhabitant
0.14 The higher the number of floors the bigger the vertical evacuation potential (number of floors) -- Std:Attr='floors'	Buildings_june_2011_SMCE:NumbFloor

Figure 20 Criteria tree for multi-hazard vulnerability. the final outcome – the composite index map, or decision – is in this case the map “vulnerability_current”, as defined at the top of the right-hand column.

The physical vulnerability is sub-divided into three sub-categories that describe 1) the robustness of the structure, 2) its immediate surroundings, and 3) the potential for economic loss on the other with respective weights of 0.6, 0.1 and 0.3. The robustness was characterized by the criteria “building materials” and “number of floors”. The potential for economic loss is characterized by the “building floor area” and by the “landuse” map.

The social vulnerability was assessed using four input criteria: 1) The road system as being essential transportation lines for civil protection services; 2) The presence of people in the buildings during day-time based on its occupancy type; 3) The presence of people during night-time based on the registred number of inhabitants per house; and 4) the number of floors to indicate the potential for vertical evacuation. The weights assignment was done using the direct method after long discussion with experts and stakeholders.

The generic multi-hazard map

Figure 21 shows the end result of the generic vulnerability criteria tree. Obviously the highest vulnerability values are associated with the buildings and their immediate surroundings, as well as with the landuse type “urban area”. The road network, as essential lifeline during rescue and civil protection operations, is also clearly distinguishable in the vulnerability map.

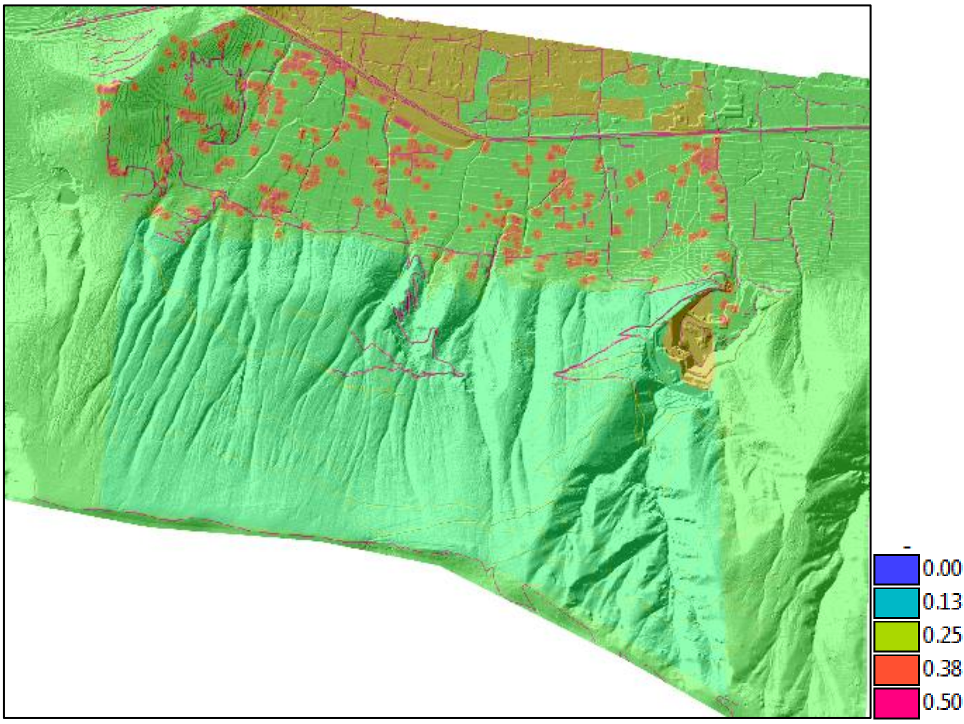


Figure 21 Composite index map for multi-hazard vulnerability. A low score indicates least vulnerable and a high score most vulnerable.

4.3.3 The multi-hazard risk map – approach 1

Figure 22 presents the final generic multi-hazard risk map as the product of the hazard and vulnerability maps. This index map – also on scale of minimum 0 and maximum 1, gives an impression of the relative spatial distribution of the risk in the study area. One can clearly identify “risk hotspots” where both hazard and vulnerability are relatively high. These areas should be the first targets when one considers risk reduction measures.

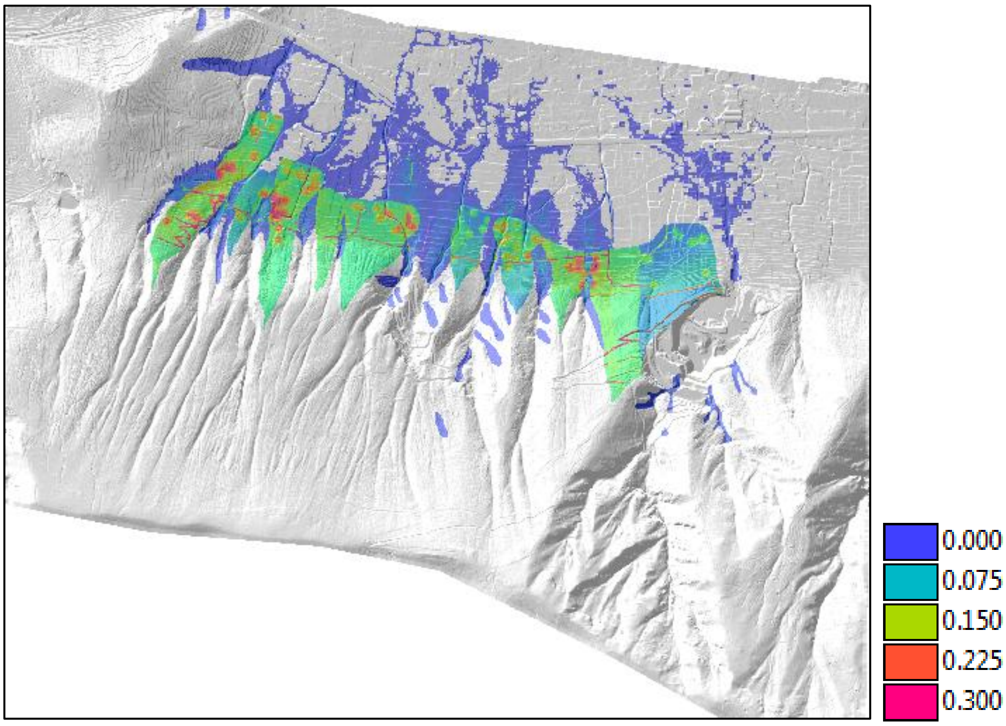


Figure 22 The generic multi-hazard risk map; high values repressent areas of highest risk, low values areas of lowest risk. In this analysis landslides hazard was given a five times higher because of its higher frequency of occurence.

4.3.4 Example of a scenario analysis: effects of landslide mitigation

Suppose mitigation measures are installed to reduce the hazard due to landslides from 1 in 20 years to 1 in 100 years. Such measures will reduce the absolute levels of risk in the area – something SMCE is not very well capable of capturing – but it also changes the spatial characteristics of the residual risk. This is shown in figure 23 where risk due to flow-like mass movement hazards are much more pronounced than in figure 22 where the highest risk levels are associated with the landslide on open slopes hazard.

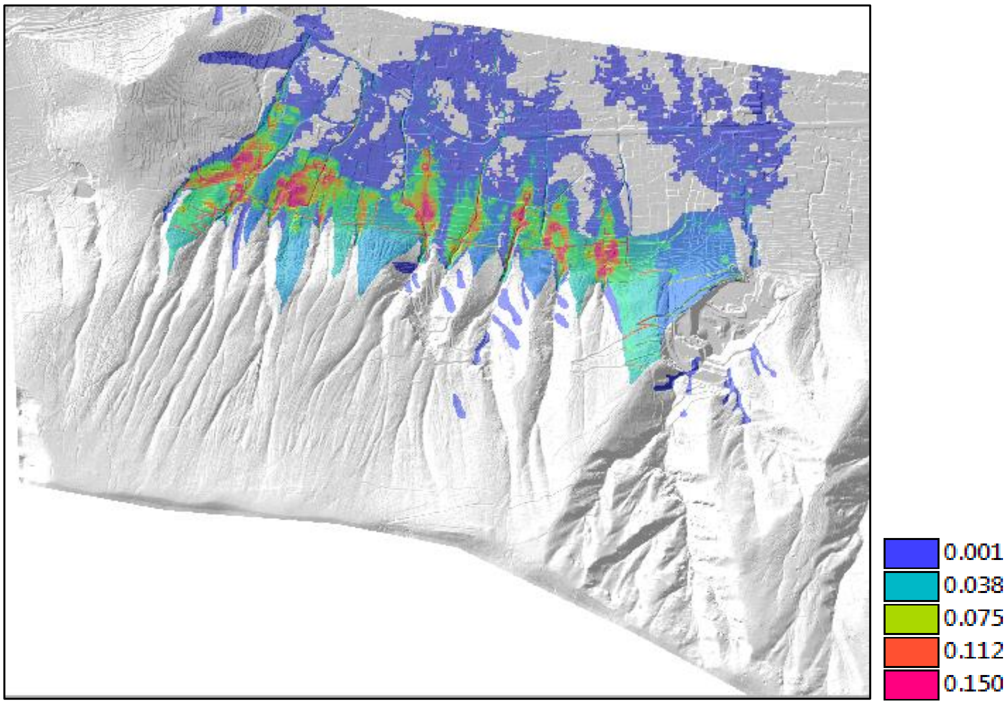
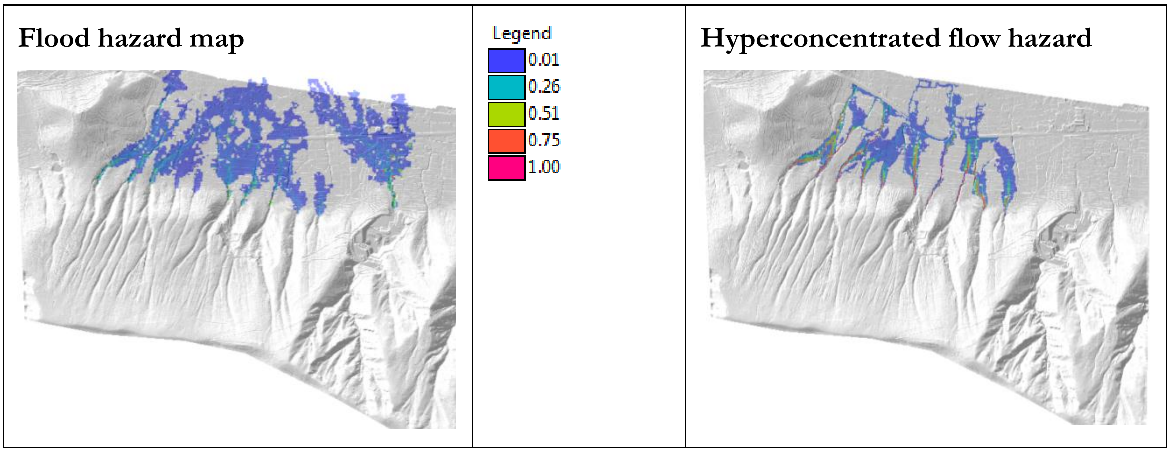


Figure 23 The generic multi-hazard risk map in case all hazards are equally weigthed – i.e. when mitigation works have been put in place to reduce landslide hazard from 1 in 20 years to approximately 1 in 100 years.

4.4 APPROACH 2: HAZARD SPECIFIC MULTI-HAZARD RISK ASSESSMENT

4.4.1 Hazard assessment

In this second approach the same hazard criteria tree is used as in approach 1 – see figure 17, but now the four individual hazard maps are used, rather than the final hazard map. These maps are defined in the green-shaded column on the right-hand side of figure 17 and have the names: 1) hazard_hyper_conc_flow; 2) hazard_flood; 3) hazard_debris_flow; and 4) hazard_landslides. Figure 24 shows the calculated composite index maps of these four hazards.


Flood hazard map

Hyperconcentrated flow hazard

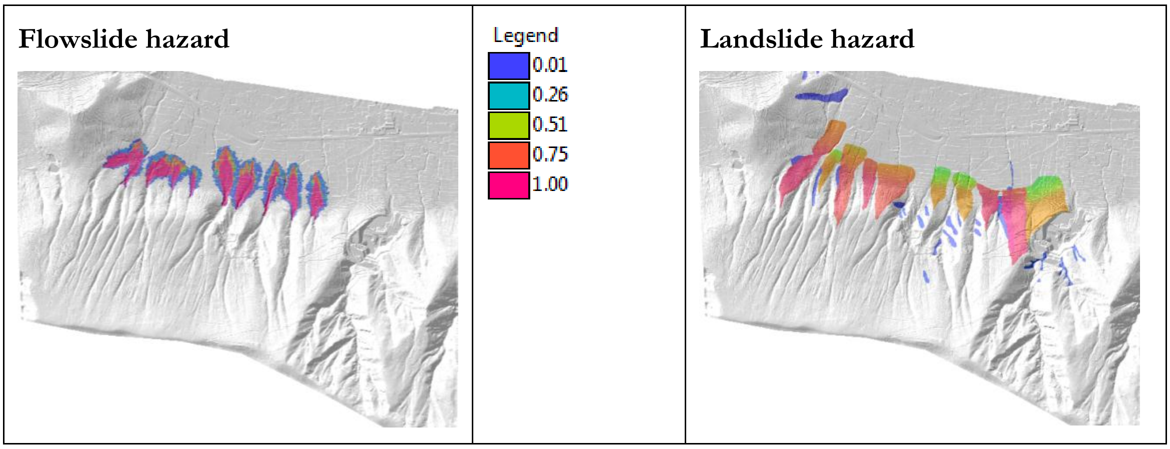
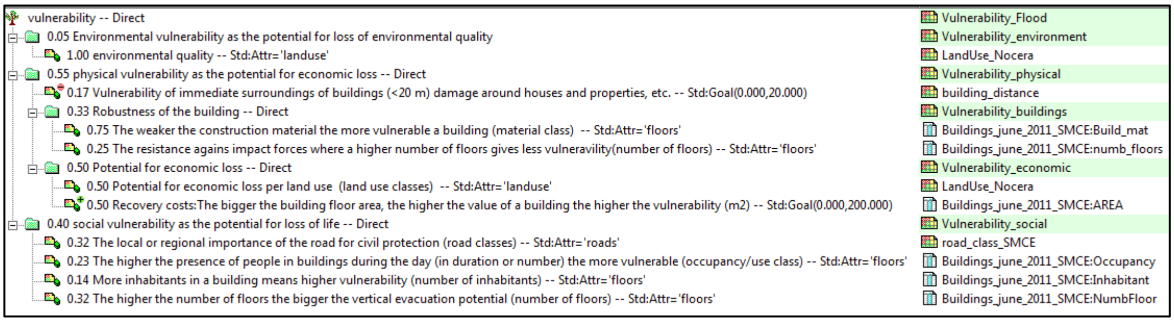


Figure 24 The composite index maps that represent the four hazardous processes. Top-left: floods, top-right: Hyperconcentrated flows, bottom-left: flowslides bottom-right: landslides on open slopes.

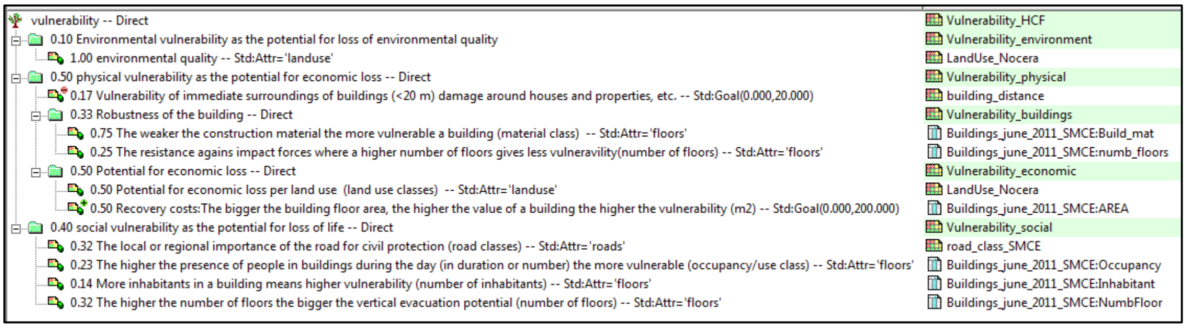
4.4.2 Hazard related vulnerability

In this approach it is assumed that vulnerabilty is hazard dependent. The exposed elements at risk will suffer damage and loss in different ways and to a different degree for the different hazards. For instance, flooding phenomena may cause damage primarily to the contents of the buildings, to furnature, electric appliences, carpets and wall decoration where landslides on open slopes may actually destroy walls and cause the (partial) collaps of the structure. Therefore for each hazard a hazard-specific vulnerability map is needed which means that for the four hazards four separate vulnerability criteria trees must be constructed. These are shown in figures 25 to 28. The structure of the trees is the same; the differences are in the assignment of weights and the standardization methods. The corresponding risk maps are shown in figure 29.



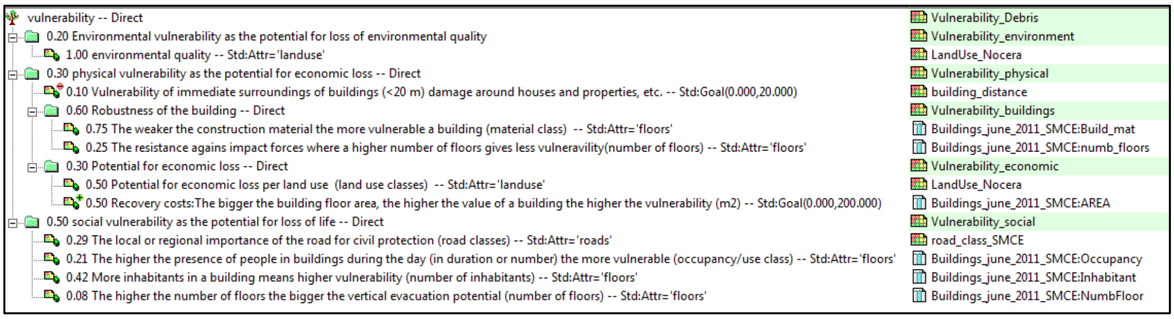
```
vulnerability -- Direct                                                                                     Vulnerability_Flood
  0.05 Environmental vulnerability as the potential for loss of environmental quality                       Vulnerability_environment
    1.00 environmental quality -- Std:Attr='landuse'                                                        LandUse_Nocera
  0.55 physical vulnerability as the potential for economic loss -- Direct                                  Vulnerability_physical
    0.17 Vulnerability of immediate surroundings of buildings (<20 m) damage around houses and properties, etc. -- Std:Goal(0.000,20.000)   building_distance
    0.33 Robustness of the building -- Direct                                                               Vulnerability_buildings
      0.75 The weaker the construction material the more vulnerable a building (material class)  -- Std:Attr='floors'   Buildings_june_2011_SMCE:Build_mat
      0.25 The resistance agains impact forces where a higher number of floors gives less vulneravility(number of floors) -- Std:Attr='floors'   Buildings_june_2011_SMCE:numb_floors
    0.50 Potential for economic loss -- Direct                                                              Vulnerability_economic
      0.50 Potential for economic loss per land use  (land use classes)  -- Std:Attr='landuse'              LandUse_Nocera
      0.50 Recovery costs:The bigger the building floor area, the higher the value of a building the higher the vulnerability (m2) -- Std:Goal(0.000,200.000)   Buildings_june_2011_SMCE:AREA
  0.40 social vulnerability as the potential for loss of life -- Direct                                     Vulnerability_social
    0.32 The local or regional importance of the road for civil protection (road classes) -- Std:Attr='roads'   road_class_SMCE
    0.23 The higher the presence of people in buildings during the day (in duration or number) the more vulnerable (occupancy/use class) -- Std:Attr='floors'   Buildings_june_2011_SMCE:Occupancy
    0.14 More inhabitants in a building means higher vulnerability (number of inhabitants) -- Std:Attr='floors'   Buildings_june_2011_SMCE:Inhabitant
    0.32 The higher the number of floors the bigger the vertical evacuation potential (number of floors) -- Std:Attr='floors'   Buildings_june_2011_SMCE:NumbFloor
```

Figure 25 Vulnerability criteria tree for floods



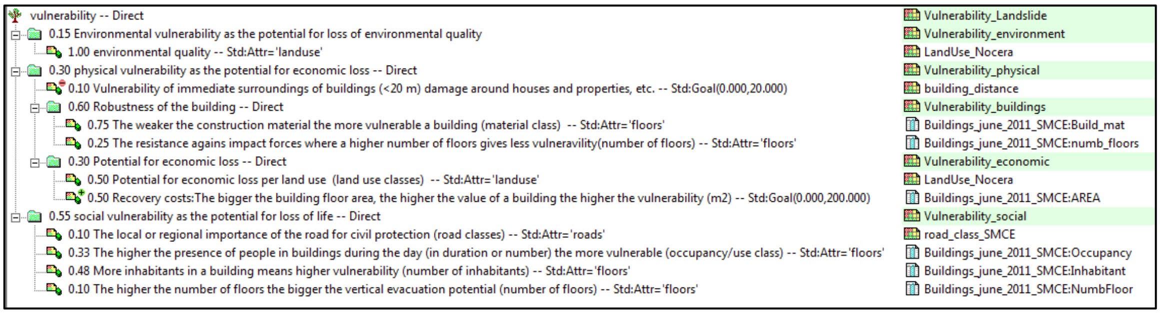
vulnerability -- Direct	Vulnerability_HCF
0.10 Environmental vulnerability as the potential for loss of environmental quality	Vulnerability_environment
1.00 environmental quality -- Std:Attr='landuse'	LandUse_Nocera
0.50 physical vulnerability as the potential for economic loss -- Direct	Vulnerability_physical
0.17 Vulnerability of immediate surroundings of buildings (<20 m) damage around houses and properties, etc. -- Std:Goal(0.000,20.000)	building_distance
0.33 Robustness of the building -- Direct	Vulnerability_buildings
0.75 The weaker the construction material the more vulnerable a building (material class) -- Std:Attr='floors'	Buildings_june_2011_SMCE:Build_mat
0.25 The resistance agains impact forces where a higher number of floors gives less vulneravility(number of floors) -- Std:Attr='floors'	Buildings_june_2011_SMCE:numb_floors
0.50 Potential for economic loss -- Direct	Vulnerability_economic
0.50 Potential for economic loss per land use (land use classes) -- Std:Attr='landuse'	LandUse_Nocera
0.50 Recovery costs:The bigger the building floor area, the higher the value of a building the higher the vulnerability (m2) -- Std:Goal(0.000,200.000)	Buildings_june_2011_SMCE:AREA
0.40 social vulnerability as the potential for loss of life -- Direct	Vulnerability_social
0.32 The local or regional importance of the road for civil protection (road classes) -- Std:Attr='roads'	road_class_SMCE
0.23 The higher the presence of people in buildings during the day (in duration or number) the more vulnerable (occupancy/use class) -- Std:Attr='floors'	Buildings_june_2011_SMCE:Occupancy
0.14 More inhabitants in a building means higher vulnerability (number of inhabitants) -- Std:Attr='floors'	Buildings_june_2011_SMCE:Inhabitant
0.32 The higher the number of floors the bigger the vertical evacuation potential (number of floors) -- Std:Attr='floors'	Buildings_june_2011_SMCE:NumbFloor

Figure 26 Vulnerability criteria tree for hyper concentrated flow (HCF)



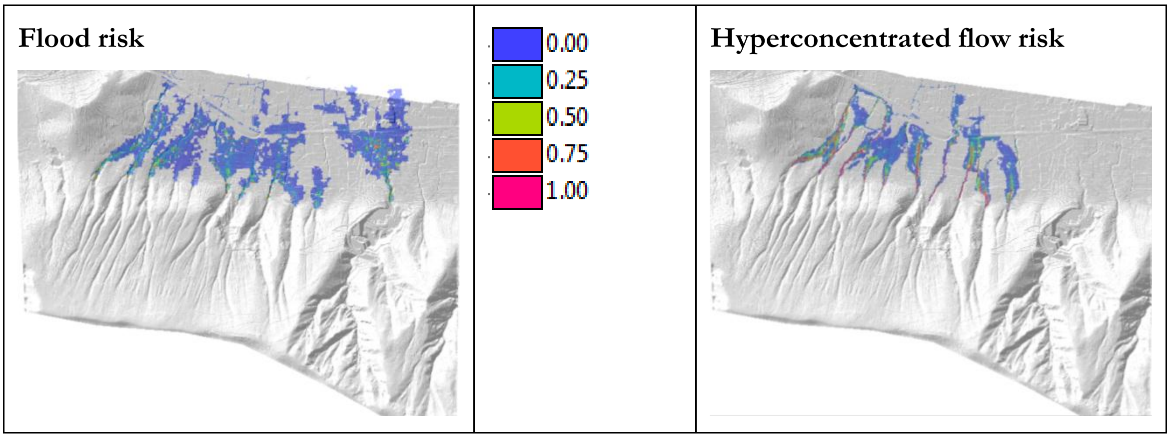
vulnerability -- Direct	Vulnerability_Debris
0.20 Environmental vulnerability as the potential for loss of environmental quality	Vulnerability_environment
1.00 environmental quality -- Std:Attr='landuse'	LandUse_Nocera
0.30 physical vulnerability as the potential for economic loss -- Direct	Vulnerability_physical
0.10 Vulnerability of immediate surroundings of buildings (<20 m) damage around houses and properties, etc. -- Std:Goal(0.000,20.000)	building_distance
0.60 Robustness of the building -- Direct	Vulnerability_buildings
0.75 The weaker the construction material the more vulnerable a building (material class) -- Std:Attr='floors'	Buildings_june_2011_SMCE:Build_mat
0.25 The resistance agains impact forces where a higher number of floors gives less vulneravility(number of floors) -- Std:Attr='floors'	Buildings_june_2011_SMCE:numb_floors
0.30 Potential for economic loss -- Direct	Vulnerability_economic
0.50 Potential for economic loss per land use (land use classes) -- Std:Attr='landuse'	LandUse_Nocera
0.50 Recovery costs:The bigger the building floor area, the higher the value of a building the higher the vulnerability (m2) -- Std:Goal(0.000,200.000)	Buildings_june_2011_SMCE:AREA
0.50 social vulnerability as the potential for loss of life -- Direct	Vulnerability_social
0.29 The local or regional importance of the road for civil protection (road classes) -- Std:Attr='roads'	road_class_SMCE
0.21 The higher the presence of people in buildings during the day (in duration or number) the more vulnerable (occupancy/use class) -- Std:Attr='floors'	Buildings_june_2011_SMCE:Occupancy
0.42 More inhabitants in a building means higher vulnerability (number of inhabitants) -- Std:Attr='floors'	Buildings_june_2011_SMCE:Inhabitant
0.08 The higher the number of floors the bigger the vertical evacuation potential (number of floors) -- Std:Attr='floors'	Buildings_june_2011_SMCE:NumbFloor

Figure 27 Vulnerability criteria tree for flowslides



vulnerability -- Direct	Vulnerability_Landslide
0.15 Environmental vulnerability as the potential for loss of environmental quality	Vulnerability_environment
1.00 environmental quality -- Std:Attr='landuse'	LandUse_Nocera
0.30 physical vulnerability as the potential for economic loss -- Direct	Vulnerability_physical
0.10 Vulnerability of immediate surroundings of buildings (<20 m) damage around houses and properties, etc. -- Std:Goal(0.000,20.000)	building_distance
0.60 Robustness of the building -- Direct	Vulnerability_buildings
0.75 The weaker the construction material the more vulnerable a building (material class) -- Std:Attr='floors'	Buildings_june_2011_SMCE:Build_mat
0.25 The resistance agains impact forces where a higher number of floors gives less vulneravility(number of floors) -- Std:Attr='floors'	Buildings_june_2011_SMCE:numb_floors
0.30 Potential for economic loss -- Direct	Vulnerability_economic
0.50 Potential for economic loss per land use (land use classes) -- Std:Attr='landuse'	LandUse_Nocera
0.50 Recovery costs:The bigger the building floor area, the higher the value of a building the higher the vulnerability (m2) -- Std:Goal(0.000,200.000)	Buildings_june_2011_SMCE:AREA
0.55 social vulnerability as the potential for loss of life -- Direct	Vulnerability_social
0.10 The local or regional importance of the road for civil protection (road classes) -- Std:Attr='roads'	road_class_SMCE
0.33 The higher the presence of people in buildings during the day (in duration or number) the more vulnerable (occupancy/use class) -- Std:Attr='floors'	Buildings_june_2011_SMCE:Occupancy
0.48 More inhabitants in a building means higher vulnerability (number of inhabitants) -- Std:Attr='floors'	Buildings_june_2011_SMCE:Inhabitant
0.10 The higher the number of floors the bigger the vertical evacuation potential (number of floors) -- Std:Attr='floors'	Buildings_june_2011_SMCE:NumbFloor

Figure 28 Vulnerability criteria tree for landslides on open slopes



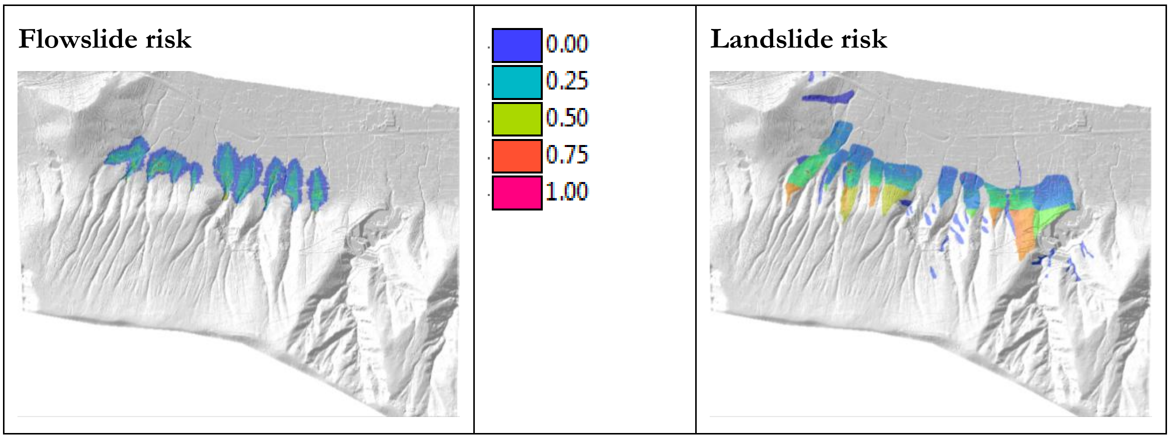
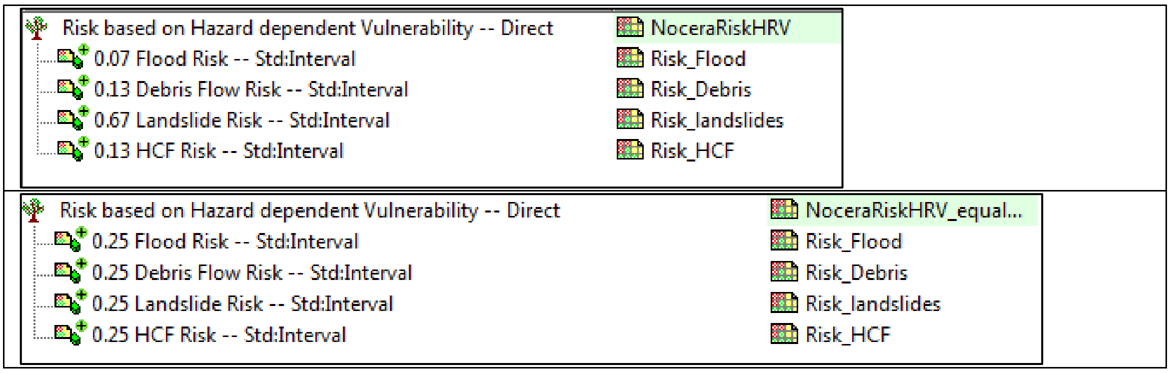


Figure 29 Risk maps for floods (top-left), hyperconcentrated flows (top-right), flowslides (bottom-left) and landslides on open slopes (bottom-right).

4.4.3 Multi-hazard risk maps – approach 2

For the aggregation of the four hazard-related risk maps into a final multi-hazard risk map, two additional criteria trees were designed, shown in figure 30: one for the current situation (with a landslide hazard level corresponding to a return period T = 20 years) and one for a future situation where the landslide hazard relates to a return period T = 100 years. The corresponding risk maps are shown in figures 31 and 32.



Risk based on Hazard dependent Vulnerability -- Direct — NoceraRiskHRV
- 0.07 Flood Risk -- Std:Interval — Risk_Flood
- 0.13 Debris Flow Risk -- Std:Interval — Risk_Debris
- 0.67 Landslide Risk -- Std:Interval — Risk_landslides
- 0.13 HCF Risk -- Std:Interval — Risk_HCF

Risk based on Hazard dependent Vulnerability -- Direct — NoceraRiskHRV_equal...
- 0.25 Flood Risk -- Std:Interval — Risk_Flood
- 0.25 Debris Flow Risk -- Std:Interval — Risk_Debris
- 0.25 Landslide Risk -- Std:Interval — Risk_landslides
- 0.25 HCF Risk -- Std:Interval — Risk_HCF

Figure 30 Two criteria trees for aggregating the four risk maps into a multi-hazard risk map (NoceraRiskHRV – Hazard Related Vulnerability). On top the criteria tree where landslides have approximately four times the weight as the other risk maps (current situation) and below, the criteria tree with hazards having the same weight (situation after landslide hazard mitigation).

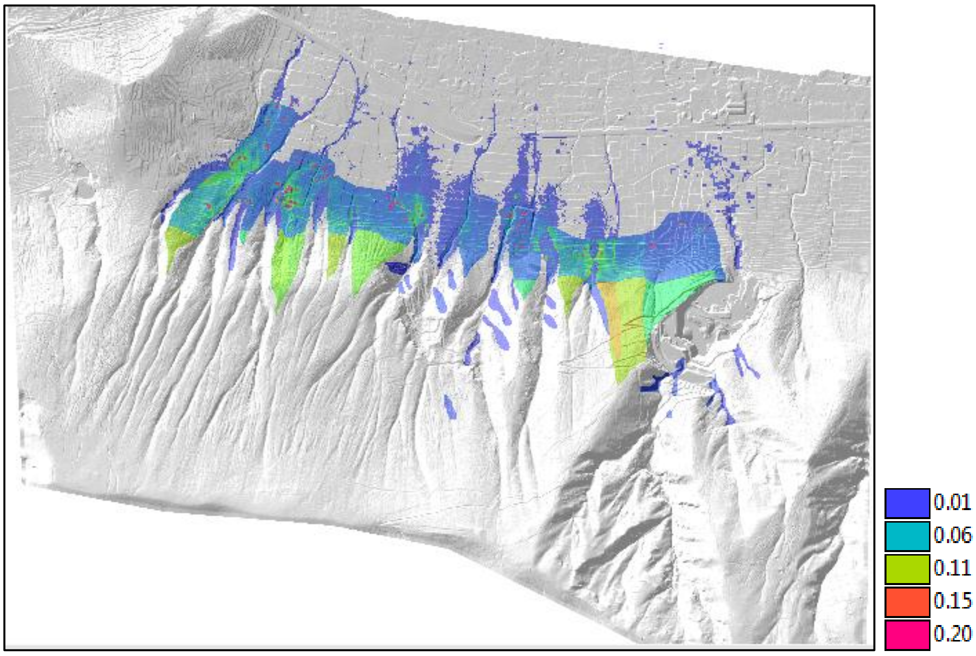


Figure 31 Composite index map of the multi-hazard risk map according to approach 2 with landslides five times the weight of the other hazards. To be compared with figure 22.

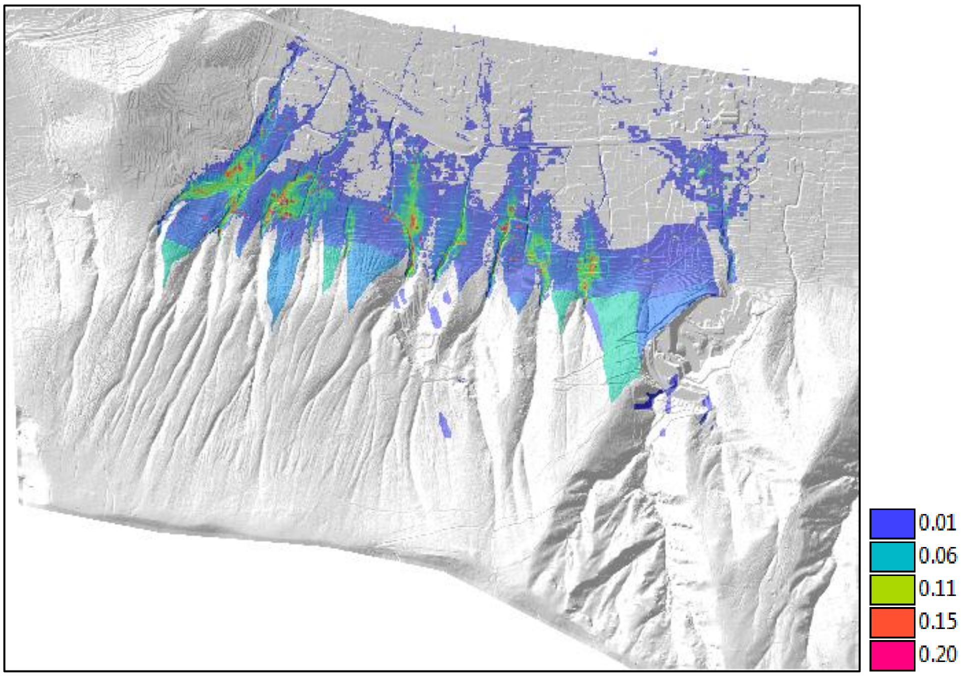


Figure 32 Composite index map of the multi-hazard risk map according to approach 2 with equal weigths for all hazards. To be compared with figure 23.

Comparing the risk maps that have resulted from approach 1 and 2 show that there are significant differences in the spatial distribution of the relative levels of risk. One cannot say which approach is better based on the outcome because both maps are the result of a group process. If team of evaluators have agreed that approach one is "better" than approach 2, the decision is the risk maps in Figure 22 and 23. If they give preference to approach 2 the maps in Figures 31 and 32 are the final decision.

5 CONCLUSIONS

This deliverable set out to demonstrate the use of Spatial Multi-Criteria Evaluation (SMCE) as a qualitative tool for the assessment and zoning of multi-hazard risk for a case-study site in Italy. The study focussed on a slope near Nocera Inferiore where the following hazards were identified: floods, hyper-concentrated flows, mud-flows and landslides.

In this document we have given a short introduction to the theory of SMCE (chapter 2), presented the available data obtained from mathematical modelling and surveying (chapter 3) and demonstrated the application of SMCE to qualitative multi-hazard risk assessment (chapter 4). In this chapter we will conclude with some strengths and weaknesses of SMCE for Multi Hazard Risk Assessment.

5.1 STRENGTHS

Integration of multiple parameters

Quantitative hazard assessment usually depends on a single parameter to indicate the hazard's magnitude. In the case of floods, this usually is the water depth. Flood hazard is then defined as the probability of a certain flood depth at a certain location within a given period of time (see also chapter 1). This definition doesn't consider flow velocity, duration, warning time and other flood-related parameters that also contribute to the "hazardness" of a flood; i.e. to its ability to cause damage. By singeling out depth as THE "hazard" parameter, other flood characteristics are ignored which may result in flood hazard maps that do not correlate with flood damage maps after an event occurred. Maybe flow velocity or duration would have given a better result, or maybe the combination of all three parameters would have been best. In this document we have demonstrated that SMCE allows the incorporation of multiple parameters (criteria) in defining flood hazard. This quality allows a wider definition of hazard than in quantitative methods.

In the case of vulnerability the issue of multi-parameter definition is even more acute. Vulnerability has a wide range of interpretations and multiple definitions exist. It refers to social, physical and environmental factors that cannot be captured in its complexity by a single parameter. In the Nocera Inferiore example we combined ten criteria to evaluate this multi-dimensional aspect of vulnerability, ranging from land use information to building occupancy.

Multi-hazard assessment

In the same manner that SMCE allows the incorporation of multiple parameters for hazard or vulnerability assessment, so does it allow the integration of multiple hazards into an integrated multi-hazard assessment. In this example was demonstrated (chapter 4) how four separate hazards were combined. The estimated return periods of the hazards were used in the assignment of weights to emphasize which hazard is dominant. In the Nocera case that was landslides.

Intrinsic logic

The SMCE procedure makes the assessors apply a certain intrinsic logic which – if followed through in a systematic manner - will result in a logical conclusion. For each criterion, the assessors must decide how it will contribute to the risk: Is it a cost or a benefit? (see section 2.3). For instance flow-depth is a benefit which means that higher depths constribute positively to higher hazard which will contribute to higher risk. The same holds for number of inhabitants in a building. The higher the number, the higher the vulnerability and therefore it will contribute positively to risk. For landslide run-out distance (the maximum distance, measured from the foot of the slope, until where landslides can come) the opposite holds. The shorter the distance a house is separated from the foot of the slope, the more likely a landslide may affect it. The further away the less chance a landslide will travel that far. Therefore the less the distance the more it contributes to risk.

Applicability

SMCE does not require a predefined set of data to make the assessment, nor does the dataset need to be complete. For instance in this Nocera Inferiore example we did not have the depth information for the mudflows, only the maximum flow velocity map. Still we carried out the analysis. SMCE allows the assessors to evaluate the hazard, vulnerability and risk with the data that is available. That is why Castillanos (2008) used SMCE in Cuba, because no data was available to carry out a quantitative method. Of course when model simulation or empirical data area available for relevant variables these could or should be used. This flexability increases its applicability.

Inclusiveness

SMCE is not only a tool to calculate a result, but it is also a procedure to facilitate collaborative decision making. It allows multiple stakeholders – also with conflicting views and different perceptions – to go through the process in small steps. The stakeholders can use the procedure of SMCE to reach agreement on the objectives of the risk map, the set of criteria and the processing of this information. If agreement exists at all stages of the SMCE-procedure, they must also agree on the outcome: the risk map. In this way SMCE adds to the decision-making process in the sense that it identifies agreements and disagreements between the stakeholders, that it brings understanding, supports learning-by-doing and that it reveals areas where further information is needed.

Althernatively it is possible to have different stakeholders make individual assessmentd with individually varying criteria trees (.e.g with respect to vulnerability) and identify areas of agreement and disagreement with understanding of rationale. Moreover, the compensatory nature of the the methodology may lead that the overall risk assessment for different stakeholders may be the same but for different reasons. E.g. some may find an area hazardous but not so vulnerable, others might find it vulnerable ut not so hazardous, and still arrive at the same assessment of risk, without agreeing in the step-wise agreement approach as used in this demonstration.

It should be noted though that due to the technical GIS environment and the lack of a real stakeholder management system ILWIS SMCE clearly has not been developed for multi-stakeholder use by stakeholders themselves.

Sensititivity analysis

SMCE can easily be used for sensitivity analysis to find out how much uncertainty in one of the criteria – or its weights or normalization – affects the outcome. In some cases this may help in the discussion if it shows that a disagreement between stakeholders does not have serious implications for the result. Sensitivity analysis serves to test the robustness of the decision with respect to uncertainties in the parameter maps, weights, value functions and decision rules.

5.2 WEAKNESSES

Subjectivity

The main characteristic of SMCE is that there are no rules in designing the criteria tree, in the assignment of the weights or in the normalization process. In fact, defining the value functions is one of the major discussion topics in the multi-criteria evaluation procedure. The assessor is most likely to be a group of people (experts, stakeholders). They either form a team or a coalition, but together they have to reach agreement on the value functions for each parameter included in the assessment. This should avoid possible bias from individual members, but raises new problems like composition of the expert group (number and backgrounds of the experts) and the interaction within the group. This can result in discussion and bartering about the value functions which may seem unscientific. However, given scientific uncertainty about complex phenomena of mass movement and flooding it is currently the best that can be achieved.

Replicability

SMCE is a very flexible tool that can be applied in many cases with very different underlying datasets. This makes comparison between two studies difficult, if not impossible, because the criteria used may be completely different, may be differently organized in the criteria tree or may have received different value functions. There are no standards.

This also may result in opportunistic behavior in the assessor-team because there are no criteria about the completeness of the datasets. On one hand it is a strength of SMCE that makes it widely applicable, also in data poor conditions, but on the other hand it is also a weakness because it is up to the assessor teams to define whether or not all relevant criteria are included in the assessment.

Meaning

The result of SMCE, the decision, is a so-called composite index with values between 0 and 1. In the example of the risk assessment that we described in chapter 4, a high score means that the conditions at those locations are very suitable for high risk – i.e. high hazard and high vulnerability values. A value close to zero means that the risk is low. However, the composite index map values per se do not have meaning. The values are dimensionless and cannot be interpreted outside their context. They only have meaning compared with other values within the map and provided that standard value functions and weights have been applied to different locations or different alternatives, relative, not absolute comparisons could be made.

Comparability

The fact that the composite index map values can only be interpreted in comparison with other values within the map makes it difficult to compare different scenarios in SMCE. For instance in section 4.3.4 we presented a scenario with landslide mitigation measures and how that would affect the spatial risk distribution. In that example it was possible to see that the new spatial risk distribution differs from the scenario without mitigation measures, but it was not possible to see differences in absolute risk values. Both maps show the risk index values on a scale from 0 to 1. One would have to drill back into the problem structure to arrive at the input maps to understand the origin of changes in hazard, vulnerability and risk.

5.3 FUTURE DIRECTIONS

As mentioned current methodology and technology for collaboration and exploration among a multitude of stakeholders to obtain a band-width of hazard and vulnerability assessments is non-existent. For instance a statistical understanding of group preferences could not be provided with current state of knowledge. However both the more technical assessment of hazard and the more societal and economic assessment of vulnerability could benefit from involvement many stakeholders in current assessments but also assessments changing over time as insights progress. Therefore it would be beneficial to develop methods and tools that would allow, with the help of web applications to survey large numbers of stakeholders across many localities and in such a way work towards standards of practice. Interestingly the technological advances of the last five years in the field of geoinformatics, web based SMCE, spatial data infrastructure, and social media have created the coundary conditions for such development (Boerboom and Alan, 2012). It would be good to build on these new developments to work towards standards for value functions similar to the vulnerability curves so that different localities in regions will be compared in similar ways.

What appeared to been missing in the methodologies and technologies is a scenario development and management approach. Ideally we would like to explore the possibility of changing input indicators because of changing intervention options, but also the possibility to vary interpretation and judgement and explore in a systematic way the consequences for risk.

6 REFERENCES:

Beinat, E. 1997. Value Functions for Environmental Management, Dordrecht etc., Kluwer.

Boerboom, L. G. J. & Alan, Ö. O. 2012. Implementation, Challenges and Future Directions of Integrating Services from the Gis and Decision Science Domains: A Case of Distributed Spatial Multi-Criteria Evaluation. OSGeo Journal, 10, 49-54.

Borrows, P. (1999): Issues for flood warning in extreme events. Report of RIPARIUS Expert Meeting 1. Centre for Ecology and Hydrology (CEH), Wallingford, UK.

Burrough, P.A. and McDonnell, R.A. (1998): Principles of Geographical Information Systems. Oxford University Press, UK.

Carver S. J. (1991) Integrating multi-criteria evaluation with geographical information systems, International Journal of Geographical Information Systems, 5(3); 321-339.

Cascini L. (2004) - The flowslides of May 1998 in the Campania region, Italy: the scientific emergency management. Italian Geotechnical Journal, 2: pp. 11-44.

Cascini L., Ferlisi S., Vitolo E. (2008) – Individual and societal risk owing to landslides in the Campania region (southern Italy). Georisk, 2(3), pp. 125-140. doi: 10.1080/17499510802291310

Castellanos Abella, E.A., (2008) Multi - scale landslide risk assessment in Cuba. PhD thesis University of Utrecht

Chen, K., Blong, R. and Jacobson, C. (2001): MCE-RISK: integrating multicriteria evaluation and GIS for risk decision-making in natural hazards. Environmental modelling and software 16. pp 387-397.

Corominas, J., Mavrouli, O. (coordinators) (2011) - Guidelines for landslide susceptibility, hazard and risk assessment and zoning. Deliverable 2.4 of the Work Package 2.1 - Harmonisation and development of procedures for quantifying landslide hazard. SafeLand Project - 7th Framework Programme Cooperation Theme 6 Environment (including climate change) Sub-Activity 6.1.3 Natural Hazards.

Corominas, J., Mavrouli, O. (coordinators) (2012) - QRA case studies at selected "hotspots". Synthesis of critical issues. Deliverable 2.11 of the Work Package 2.3 - Development of procedures for QRA at regional scale and European scale. SafeLand Project - 7th Framework Programme Cooperation Theme 6 Environment (including climate change) Sub-Activity 6.1.3 Natural Hazards.

Densham, P.J. (1991): Spatial decision support systems, In: D. J. Maguire, M. S. Goodchild and D. W. Rhind (eds) Geographical information systems: principles and applications, London: Longman, pp. 403 - 412.

Faella, C. (2005) – Flowslide effects on costructions. Panel Report. Proceedings of the International Conference on “Fast Slope Movements – Prediction and Prevention for Risk Mitigation” (Picarelli L. ed.), Naples (Italy). Vol. 2, 53-61, Pàtron Editore.

Faella, C., Nigro, E., (2003) – Dynamic impact of the debris flows on the constructions during the hydrogeological disaster in Campania-1998: failure mechanical models and evaluation of the impact velocity. Proceedings of the Interantional Conference on “Fast Slope Movements – Prediction and Prevention for Risk Mitigation” (Picarelli L. ed.), Napoli. Vol. 1: 179-186. Pàtron Editore.

Gendreau, N. (1998): Protection objectives in flood-risk prevention. Proceedings of the British Hydrological Society International Conference, Exeter, UK 6-10 July 1998, p. 145-154.

Geneletti, D. (2002): Ecological evaluation for environmental impact assessment. PhD thesis. Netherlands Geographical Studies 301.

Geo-Slope (2004a) – Slope stability analysis with SLOPE/W, user's guide version 6.02. GEO-SLOPE International Ltd., Calgary, Alberta, Canada.

Geo-Slope (2004b) – Groundwater seepage analysis with SEEP/W, user's guide version 6.02. GEO-SLOPE International Ltd., Calgary, Alberta, Canada.

Herwijnen, M. V. 1999. Spatial Decision Support for Environmental Management, Amsterdam, Free University Amsterdam.

Hwang, C.L. and Masud, A.S.M. (1979): Multi-objective decision-making – methods and applications: a state of the art survey. Springer, Berlin.

Lorenz, C.M. (1999): Indicators for sustainable river management. PhD-thesis, Vrije Universiteit Amsterdam, the Netherlands.

Malczewski, J. (1999): GIS and multi-criteria decision analysis. Wiley and sons, Inc. USA. Pp 392.

Malczewski, J. 2006. Gis-Based Multicriteria Decision Analysis: A Survey of the Literature. International Journal of Geographical Information Science, 20, 703-726.

Narasimhan, H. and Faber, M.H. (coordinators) (2012) - Quantitative risk-cost-benefit analysis of selected mitigation options for two case studies. Deliverable 5.3 of the Work Package 5.1 - Toolbox for landslide hazard and risk mitigation measures. SafeLand Project - 7th Framework Programme Cooperation Theme 6 Environment (including climate change) Sub-Activity 6.1.3 Natural Hazards.

O'Brien, J.S., Julien, P.Y., Fullerton, W.T. 1993. Two-dimensional water flood and mudflow simulation. Journal of Hydraulic Engineering ASCE, 119(2): 244-261.

Penning-Rowsell, E.C. & Tunstall, S.M. (1996): Risks and resources: Defining and managing the floodplain. In: Andersen, M.G., Walling, D.E. and Bates, P.D. (Eds) Floodplain resources. John Wiley and Sons, Ltd. London, UK.

Pfeffer, K. (2003): Integrating spatio-temporal environmental models for planning ski runs. PhD thesis. Netherlands Geographical Studies 311.

Rothenberg, J. (1975): Cost-Benefit analysis: A methodological exposition. In (eds) Guttentag, M. and Strüning E.L. Handbook of evaluation research. Sage Publications, USA.

Saaty, T.L. (1980): The analytical hierarchy process: Planning, priority setting and resource allocation. McGraw-Hill, USA.

Scolobig, A. and Bayer, J. (coordinators) (2012) - Design and testing: a risk communication strategy and a deliberative process for choosing a set of mitigation and prevention measures. Deliverable 5.7 of the Work Package 5.2 - Stakeholder process for choosing an appropriate set of mitigation and prevention measures. SafeLand Project - 7th Framework Programme Cooperation Theme 6 Environment (including climate change) Sub-Activity 6.1.3 Natural Hazards.

Scott Morton, M. S. (1971): Management Decision Systems; Computer-based support for decision-making. Boston, Division of Research, Graduate School of Business Administration, Harvard University.

Sharifi, M.A., Van den Toorn, Rico, A. and Emmanuel, M. (2002): Application of GIS and Multicriteria Evaluation in locating sustainable boundary between the Tunari National

Park and Cochabamba city (Bolivia). Journal of Multi-Criteria Decision Analysis 11, pp. 151-164.

Sharifi, M.A. and Retsios, V. (2003): Site selection for waste disposal through spatial multiple criteria decision analysis. In: Proceedings of the 3rd International conference on decision support for telecommunications and information society DSTIS, 4-6 September 2003, Warsaw, Poland. 15 p.

Témez, J.R. (1991): Planificación hidrológica-ordenación de zones inundables, CEDEX, Madrid, Spain.

Ullman, D. G. 2006. Making Robust Decisions: Decision Management for Technical, Business, & Service Teams Trafford Publishing.

Zucca, A. (2005): Sviluppo sostenibile del territorio: Agenda 21 locale e valutazione ambientale strategica. Proposta di metodologie per la gestione dell'informazione spaziale nei processi decisionali. Unpublished PhD thesis, Università degli studi di Milano-Bicocca