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A COLLABORATIVE WEB-GIS BASED DECISION SUPPORT PLATFORM FOR RISK MANAGEMENT OF NATURAL HAZARDS

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Thèse de doctorat

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Pour le Doyen de la Faculté des géosciences et de l'environnement

Professeur Suren Erkman

Dedicated to my beloved mother …

Abstract

One of the main problems in risk management is the lack of good communication as well as efficient and effective collaboration between the agencies, services and organizations in charge of risk prevention, mitigation and management. The involvement of various stakeholder groups is an important component of risk prevention and mitigation. This calls for an integrated and coordinated approach which helps responsible stakeholders in managing risk, starting from risk identification to the decision-making process for achieving the best combination of risk reduction strategies. As natural hazards and associated risks are spatial in nature, web-based decision support tools integrated with Geographic information systems (GIS) have been increasingly considered as useful instruments for providing decision support. Taking the advantages of modern web, spatial and open-source technologies to achieve a centralized and integrated framework, in this research, a web-GIS based collaborative decision support platform is proposed for risk management with involvement of various stakeholders. The principal purposes of this research are: (1) to conduct a systematic and integrated risk management approach with diverse involvement of different stakeholders; (2) to explore the possibility and application of interactive web-GIS decision support tools for the analysis, communication and exchange of decision support information between risk management stakeholders and (3) to propose an innovative approach to potentially enhance collaboration activities between stakeholders through interactive and participatory approaches.

The conceptual inputs of this study are based on the initial feedback, semi-structured interviews and observations obtained from the field visits and stakeholder meetings carried out in three case studies of Europe: the Małopolska Voivodeship of Poland, Buzău County of Romania and the Friuli-Venezia-Giulia region of Italy. Even though some platforms exist in study areas, no single case has a platform at hand which enables as flexible and collaborative approach for the formulation and selection of risk management measures as attempted in this study. Moreover, most platforms have focused mainly on inventory of events, risk visualization and dissemination of information. In this research, a prototype is realized and focused on the risk analysis, formulation and selection of potential measures through the use of an interactive web-GIS based interface integrated with a Multi-Criteria Evaluation (MCE) tool. This platform is regarded not only as a web platform for centralized sharing of risk information but also for ensuring an integrated framework where involved stakeholders can analyse risk and evaluate risk reduction measures. For the prototype development, a three-tier client-server architecture

backed up by Boundless (OpenGeo) was applied with its client side development environment. This developed prototype was presented to the local and regional stakeholders of the study areas and feedback was collected to understand their perspective in determining whether the platform is useful and applicable for their activities in risk management. The prototype was also further evaluated with students to obtain feedback on different aspects of the platform as well as to analyse how the application of interactive tools could assist students in studying and understanding risk management.

The main part of this research was carried out within the Marie Curie Research and Training Network "CHANGES: Changing Hydro-meteorological Risks as Analyzed by a New Generation of European Scientists" funded by European Commission's 7th framework program (www.changes-itn.eu, 2011-2014, Grant No. 263953).

Résumé

L'un des principaux problèmes dans la gestion des risques est le manque de bonne communication et de collaboration efficace entre les services, agences et organisations chargés de la prévention, l'atténuation et la gestion des risques. La participation des différents groupes d'acteurs est une importante composante de la prévention et l'atténuation des risques. Cela demande une approche intégrée et coordonnée, qui aide les parties prenantes responsables de gérer le risque, depuis l'identification des risques jusqu'au processus de prise de décision, à obtenir la meilleure combinaison des stratégies de réduction des risques. Comme les dangers naturels et les risques liés à ces dangers sont de nature spatiale, les outils d'aide à la décision basés sur le web et intégrés aux systèmes d'informations géographiques (SIG, GIS en anglais) ont été considérés de plus en plus comme des instruments utiles. En prenant les avantages du web moderne, les technologies géospatiales et open-source pour obtenir une structure intégrée et centralisée, une plateforme collaborative web-SIG est proposée pour la gestion des risques avec la participation des différentes parties prenantes. Les principaux objectifs de cette recherche sont 1) de proposer une approche systématique et intégrée de gestion des risques avec la participation des différents parties prenantes; 2) d'étudier la possibilité et l'application des outils interactifs web-SIG d'aide à la décision pour l'analyse, la communication et l'échange d'informations entre les parties prenantes de la gestion des risques and 3) de proposer une approche novatrice pour améliorer potentiellement les activités de collaboration entre les parties prenantes grâce à des approches interactives et participatives.

Les apports conceptuels de cette étude sont basés sur les premiers feedback, les entretiens semi-structurés et les observations obtenues lors des visites sur le terrain et des réunions avec les parties prenantes menées sur trois sites d'études en Europe, dans les régions de Voïvodie en Pologne, de Buzău en Roumanie et du Frioul-Vénétie julienne en Italie. Même si certaines plates-formes existent dans les zones d'études, aucune n'a une plate-forme qui permet une approche flexible et collaborative pour formuler et la sélectionner des mesures de gestion des risques comme ce qui est tenté dans cette étude. De plus, la plupart des plates-formes existantes sont principalement concentrées sur l'inventaire des événements, la visualisation des risques et la diffusion de l'information. Dans cette recherche, un prototype est réalisé et centré sur l'analyse des risques, la formulation et la sélection des mesures potentielles en utilisant une interface interactive web-SIG intégrée à un outil d'évaluation multicritères (MCE). Cette plate-forme est considérée non seulement comme une plate-forme web pour le partage centralisé des informations des risques, mais aussi comme un outil pour assurer un cadre intégré où les parties prenantes concernées peuvent analyser les risques et évaluer les mesures de réduction des risques. Pour le développement du prototype, une architecture client-serveur à trois niveaux renforcée par Boundless (OpenGeo) a été appliquée avec son environnement de développement côté client. Ce prototype a été présenté aux parties prenantes locales et régionales des zones d'études. Leur feedback a été collecté pour comprendre leurs points de vue et déterminer si la plate-forme est utile et applicable pour leurs activités en matière de gestion des risques. Le prototype a également été évalué avec les étudiants pour obtenir des commentaires sur les différents aspects de la plate-forme et pour analyser la façon dont l'application des outils interactifs pourrait aider les étudiants à analyser et comprendre la gestion des risques.

La partie principale de cette recherche a été réalisée dans le cadre du projet européen FP7-Marie Curie « CHANGES: Changing Hydro-meteorological Risks as Analyzed by a New Generation of European Scientists » financé par la Commission Européenne (www.changes-itn.eu, 2011-2014, Grant No. 263953).

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Acronyms

AHP	Analytic Hierarchy Process
ALARP	As Low As Reasonably Practicable
ANP	Analytic Network Process
API	Application Program Interface
CBA	Cost-Benefit Analysis
CDF	Cumulative Distribution Function
CP	Compromise Programming
CSS	Cascading Style Sheets
DBMS	Database Management System
DEFINITE	DEcisions on a FINITE set of alternatives
DEM	Digital Elevation Model
DSS	Decision Support System
ELECTRE	ELimination Et Choix Traduisant la REalité
EPSG	European Petroleum Survey Group
FTP	File Transfer Protocol
FVG	Friuli Venezia Giulia
GIS	Geographic Information System
GML	Geographic Markup Language
GNSS	Global Navigation Satellite System
GWC	Geo Web Cache
GXP	High level components for GeoExt based applications
HTML	Hyper Text Markup Language
HTTP	Hyper Text Transfer Protocol
IGIS	Internet GIS
IRDAT	L'Infrastruttura Regionale dei Dati Ambientali e Territoriali
IRM	Integrated Risk Management

ISI	Institute for Scientific Information
ISO	International Organization for Standardization
ISU	Emergency Situation Inspectorate
ITN	Initial Training Network
JPEG	Joint Photographic Experts Group
JSON	JavaScript Object Notation
MCDM	Multi-Criteria Decision Making
MCE	Multi-Criteria Evaluation
MVC	Model-View-Controller
OGC	Open Geospatial Consortium
PEAR	PHP Extension and Application Repository
PHP	Hypertext Preprocessor
PNG	Portable Network Graphics
PROMETHEE	Preference Ranking Organization METHod for Enrichment of Evaluations
QGIS	Quantum GIS
REST	REpresentational State Transfer
RS	Remote Sensing
SDK	Software Development Kit
SDSS	Spatial Decision Support Systems
SIDS	Sistema Informativo Territoriale per la Difesa del Suolo
SMCE	Spatial Multi-Criteria Evaluation
SMISU	Sistemul de Management Informaţional pentru Situaţii de Urgenţă
SOPO	System Osłony Przeciwosuwiskowej
SQL	Structured Query Language
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
URL	Uniform Resource Locator
WCS	Web Coverage Service
Web-HIPRE	HIerarchical PREference analysis on the World Wide Web

WFS	Web Feature Service
WFS-T	Web Feature Service-Transaction
WMS	Web Map Service
WPS	Web Processing Service
XML	eXtensible Markup Language

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Chapter 1: Introduction

1.1 Background

Natural hazard is a “natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage” (UNISDR, 2009a). Natural hazards include geophysical, geological or geomorphological hazards such as floods, droughts, landslides, earthquakes and tsunamis. Over the years, disasters caused by natural hazards have become common and 324 disasters were reportedly registered in 2014 (CRED, 2015). Even though this was reported as the third lowest number of disasters in the last decade, millions of people are still affected worldwide, especially in lower-income countries. This is not only because of the changes in climate conditions but also because of the effects of population growth and urbanization in hazard prone areas, which have led to a higher exposure of people and infrastructures to natural and anthropogenic hazards (Middelmann, 2007). Hazard alone does not constitute risk and turn into a disaster unless there are negative consequences on communities or probabilities of human related loss (Sudmeier-Rieux, 2011). All components of risk (i.e. hazard, exposed objects and vulnerability) need to be evaluated and considered for disaster risk reduction, mitigation and prevention. A good understanding of these components is fundamental (Bokwa, 2013) and it must be first analysed to manage risk. The potential risk due to a hazardous event must therefore be identified and assessed. Based on the outcomes of risk assessment and in the case of unacceptable risk, appropriate risk mitigation measures need to be implemented in the affected areas by responsible authorities and decision makers. The understanding of risk management framework would allow risk managers and authorities not only to identify potential areas at risk but also to take appropriate mitigation measures considering different factors contributing to risk. This needs to be properly presented and communicated to the involved stakeholders so that better informed decisions can be made. In this aspect, advanced decision support tools could assist in providing risk information with informed choices based on an integrated and systematic approach of risk management. Risk information is spatial in nature, and with the advancement of web and spatial technologies, it has become possible not only to visualize and disseminate spatial information over the web but also to analyse and process interactively (Dragićević, 2004). This progress in web-based Geographical Information Systems (GIS) helped advancing (collaborative) decision support than traditional analysis and decision-making approaches (Dragićević and Balram, 2004).

1.2 Motivation

Over the past decades, researches in decision support systems (DSS) have been carried out for various purposes such as hazards modelling, forecasting, assessment, planning and management, early warning systems and so on (Lazzari and Salvaneschi, 1999; Ahmad and Simonovic, 2006; Hearn et al., 2006; Pasche et al., 2007). However, previous researches covered one or several parts of the risk management framework, either in risk assessment, risk reduction or forecasting/monitoring of natural hazards. There is a need for integrated approaches and applications, which allows stakeholders in understanding the whole process of risk management starting from risk identification to the decision-making process for risk reduction. In addition, most web-GIS based applications in risk management have mainly focused on data visualization and dissemination (Müller et al., 2006; Salvati et al., 2009; Giuliani and Peduzzi, 2011; Frigerio et al., 2014). Pre-defined (calculated) risk scenarios and information were made available and uploaded beforehand in such platforms in order to visualize and access necessary information, limiting the possibility of interactive risk assessment, identification and selection of potential mitigation measures with involvement of different stakeholders. The widely usage of developed tools can also be limited due to their adaptability, mobility and complex system designs. Nowadays, with the use of open-source solutions and technologies, responsible organizations can benefit in terms of cost, flexibility and freedom, community support and accountability. For example, OpenStreetMap data can be extracted and used for rapid damage assessment (Schelhorn et al., 2014; Westrope et al., 2014).

Therefore, in this research, a web-GIS based decision support platform is designed and proposed to support responsible stakeholders in risk management of hydro-meteorological hazards such as floods, debris flows and landslides. An online prototype of the platform is realized based on the open-source architecture and solutions. This developed platform is envisaged as an integrated platform in which risk managers can not only analyse risk but also select and evaluate appropriate risk reduction measures with other involved stakeholders through a collaborative decision-making framework. Furthermore, common risk information can be shared between responsible organizations and institutions through this centralized web platform. Such an integrated approach is important in risk management since the best combination of management practices can be achieved through coordinated and collaborative efforts (Hansson et al., 2008). In this way, different stakeholders are engaged and involved in the decision-making process of risk management. Different opinions and valuations of stakeholders are taken into account aiming to achieve a common goal (Jankowski and Nyerges, 2001). The conceptual input of this platform is based on the initial feedback and observations obtained from field visits and stakeholder meetings carried out within case study sites of the European FP7 CHANGES project (www.changes-itn.eu) in Romania, Italy and Poland.

1.3 Research objectives

This research highlights the significance of an integrated and collaborative risk management approach with engagement of various stakeholders. The main objectives of this research are:

- To conduct a systematic and integrated risk management approach with diverse involvement of different stakeholders, linking components of risk assessment and risk reduction for the decision-making process;
- To explore the possibility and application of interactive web-GIS decision support tools for the analysis, communication and exchange of decision support information between risk management stakeholders; and
- To propose an innovative approach to potentially enhance collaboration activities between risk management stakeholders through interactive and participatory approaches, enabling a transparent and better informed decision-making process.

For this purpose, the practical web-based application is proposed for formulation and selection of different risk reduction measures based on the analysis of risk information, integrating a web-GIS framework with a Multi-Criteria Evaluation (MCE) method for collaborative decision support with participation of various stakeholders. This decision support application aims:

- To assist risk managers in analysing impacts and consequences of natural hazards using a quantitative approach;
- To assist authorities and decision makers in the decision-making process for the formulation and selection of different risk management strategies using a MCE approach;
- To assist in potentially enhancing collaboration activities between risk management stakeholders using a collaborative web-GIS based framework; and
- To contribute findings and practices to the open-source research community in natural hazards and risk management using open-source software solutions.

1.4 Research questions

The main research questions are identified as follows:

1) What are the encountered difficulties in taking more informed decisions, looking through the lens of a long-term perspective in risk prevention and mitigation?
2) How to identify the most efficient option, making good use of available resources and encouraging the involvement of various stakeholder groups?
3) How to facilitate and integrate the involvement of stakeholders in risk management and decision making?
4) How to potentially enhance collaboration and coordination activities between responsible stakeholders in risk management?
5) What is the possibility of applying a decision support tool based on open-source solutions in study areas?

1.5 Structure of the thesis

This thesis was developed as a part of the European Marie Curie Initial Training Network (ITN): "CHANGES: Changing Hydro-meteorological Risks as Analyzed by a New Generation of European Scientists" (2011-2014) under the 7th Framework Program. The organization of the thesis is divided into several chapters based on two main parts of risk management framework developed within the platform: risk analysis (estimation) and risk reduction (treatment). Apart from the introduction, background and conclusion chapters (i.e. Chapter 1, 2, 3 and 7), the rest of the chapters are based on the already published peer-reviewed ISI journal publications, conference proceedings and articles.

Chapter 2 and 3 give a general overview of the risk management framework, decision support and open-source technologies applied for the development of web-GIS based decision support tools in risk management.

Chapter 4 presents a quantitative (raster-based) risk analysis tool, which is the first component of the web-GIS based decision support platform. The purpose of this study is to assist the experts (risk managers) in analysing impacts and consequences of a certain hazard event in a considered region. The outcomes of this risk analysis tool provide an essential input to the decision-making process in the selection of risk management strategies by responsible authorities and decision makers. In the platform, the users can import necessary maps (hazard layers in raster format and object layers in vector format) and vulnerability information to analyse areas at risk. Based on these provided information and additional parameters, loss scenarios (amount of damages and number of fatalities) of a hazard event are generated on the fly and visualized interactively within the web-GIS interface of the platform. The annualized risk is calculated based on the combination of resultant loss scenarios with different return periods of the hazard event. A prototype version is realized and demonstrated using a regional data set from one of the case study sites, Fella River of North Eastern Italy, of the CHANGES project.

Chapter 5 presents a collaborative web-GIS framework integrated with a multi-criteria evaluation tool, which represents the second component of the decision support platform. The objective is to support the engagement of different stakeholders and encourage a collaborative, decision-making process for risk management. The conceptual framework is based on initial data collected from field visits and stakeholder meetings carried out in three case study areas of the CHANGES project: the Małopolska Voivodeship of Poland, Buzău County of Romania and the Friuli-Venezia-Giulia region of Italy. Based on the needs and issues identified in each case study, this chapter also presents how such a platform could potentially assist and enhance the interactions between risk management stakeholders in formulating and selecting risk management measures. The prototype is presented to the local and regional stakeholders of the study areas during the dissemination meetings of the project. Collected feedback of stakeholders is then discussed to understand their perspectives in determining whether the platform is useful and applicable for their activities in risk management.

Chapter 6 presents the evaluation exercise carried out with university students for the collaborative part of the decision support platform. The purpose of this exercise is to obtain feedback in details on the conceptual and technical aspects of the platform as well as to analyse how the application of such interactive tools during an exercise could assist students in studying and understanding risk management. The feedback obtained from students is then discussed for future research directions of the developed collaborative web-GIS based decision support framework.

Chapter 7 finally concludes the thesis with summaries and findings of the researches carried out and future perspectives of this presented research work.

Chapter 2: General background in risk management

In the previous Chapter 1, we introduced natural hazards and briefly explained that these natural processes alone do not represent risk unless there are some elements being exposed and threatened (such as buildings, infrastructures and people) (Alexander, 2004). Definitions of risk have been evolved and perceived differently by different sectors due to its multi-dimensional nature and concept (Haimes, 2009). Risk is defined by Einstein (1988, p. 1076) as "the multiplication of hazard and potential worth of loss since the same hazard can lead to entirely different consequences depending on the use of the affected terrain risk". In recent years, risk management approaches have shifted from active control and mitigation approach against hazards to a more integrated and comprehensive risk approach (Figure 2.1) (EEA, 2010).

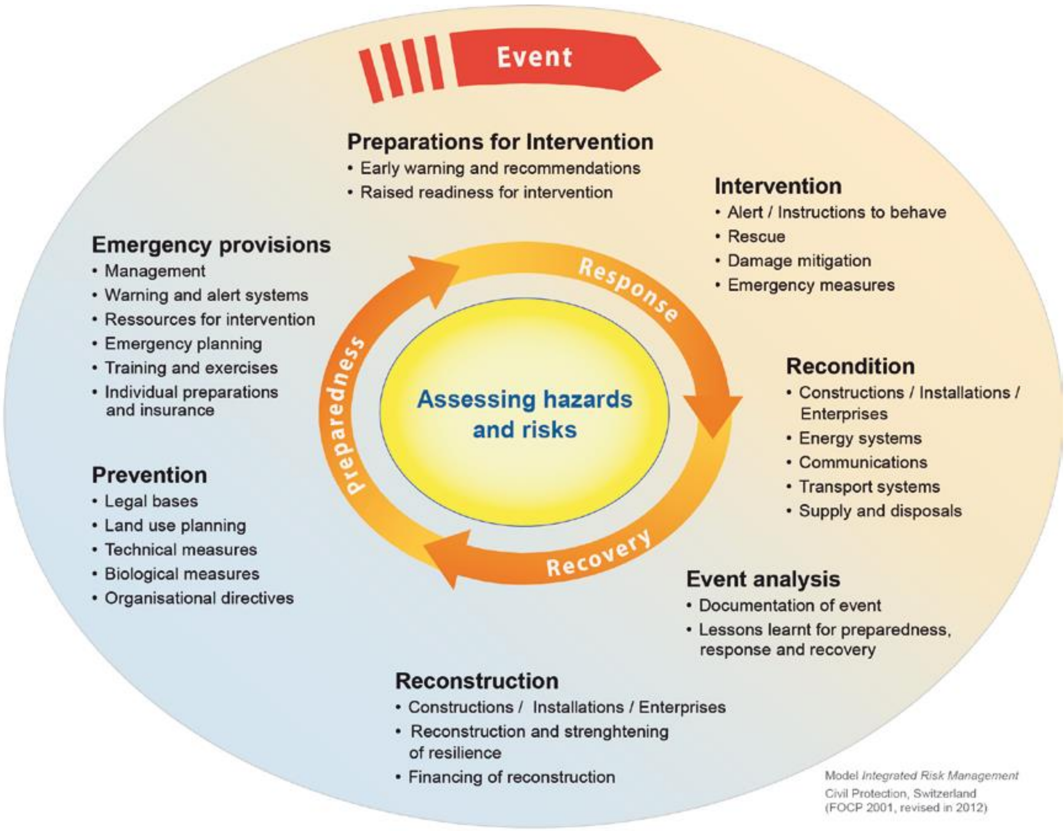


Figure 2.1. Integrated risk management framework (Source: FOCP, 2014).

This integrated risk management (IRM) approach is based on the basic risk management framework defined by the International Organization for Standardization (ISO) as illustrated in Figure 2.2. It consists of two main stages: risk assessment (identification, analysis and evaluation) and risk treatment (preparedness, response and recovery). It starts with the identification of potential causes and consequences of sources and events. This is followed by an analysis process to estimate the level of risk and an evaluation process to determine whether risk is acceptable. In the case of unacceptable risk, risk reduction actions are taken in the stage of risk treatment. The framework also includes a communication and consultation process at all stages with responsible stakeholders including the affected population. Monitoring and review process is also included as an ongoing and iterative process to re-assess the affected landscape and the effectiveness of measures implemented. A similar process flow of IRM is also described in Bonin et al. (2009) based on Boutellier and Kalia (2006), and Habegger (2008).

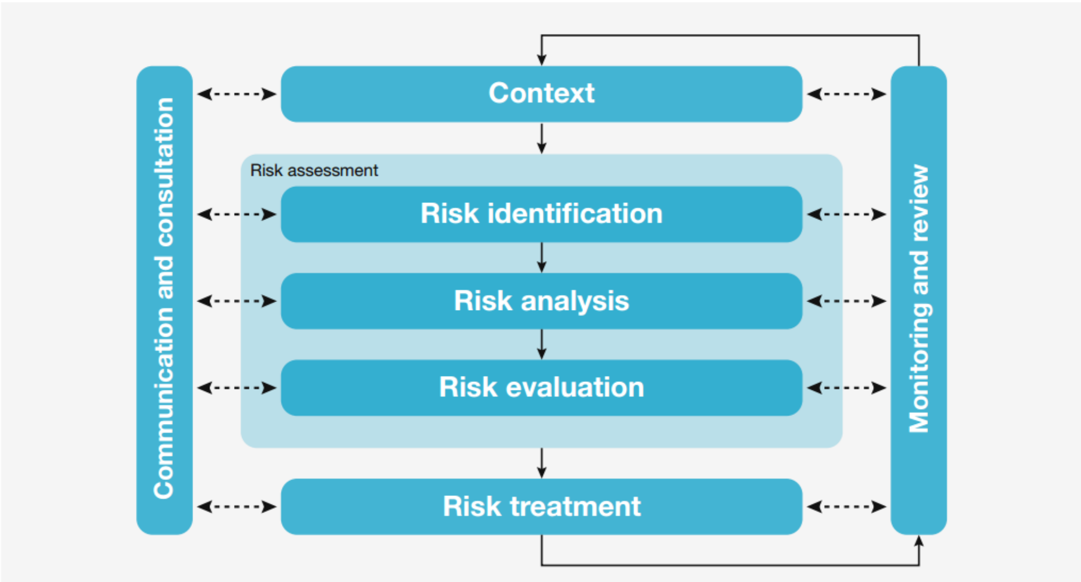


Figure 2.2. The IRM process as described in ISO 31000 (Source: FOCP, 2014).

This approach requires an active engagement and participation of stakeholders at all levels of risk management. This is one of the four conditions which need to be fulfilled to achieve IRM (FOCP, 2014): integrated hazard analysis, integrated risk assessment, integrated action planning and integrated participation. Engaging local stakeholders in the process can help in gathering knowledge of the local hazard events and their associated risks at a local scale (EEA, 2010). Sustainable and coordinated risk management measures can also be derived from this integrated and participative approach, fostering a shared understanding of risk and establishing a societal consensus in risk reduction and management.

According to Crozier and Glade (2005), Fell et al. (2005) and ISSMGE TC32 (2004), definitions of some important terms of risk management are as follow:

Risk: Measure of the probability and severity of an adverse effect to life, health, property, or the environment. Quantitatively, Risk = Hazard x Potential Worth of Loss.

Acceptable risk: A risk which everyone impacted is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.

Tolerable risk: A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible, and needing to be kept under review and reduced further if possible.

Intolerable risk: A risk that society is not prepared to live with and which must be reduced, removed, or avoided.

Risk assessment: The process of making a decision recommendation on whether existing risks are tolerable and present risk control measures are adequate, and if not, whether alternative risk control measures are justified or will be implemented. Risk assessment incorporates the risk analysis and risk evaluation phases.

Risk analysis: The use of available information to estimate the risk to individuals or populations, property or the environment, from hazards.

Risk estimation: The process of deriving a measure of the probability and severity of loss to the elements at risk by the integration of hazard and consequence analysis. This can be carried out quantitatively or qualitatively.

Risk evaluation: The stage at which values and judgement enter the decision process (explicitly or implicitly) by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk mitigation: A selective application of appropriate techniques and management principles to reduce either likelihood of an occurrence or its adverse consequences, or both.

Risk management: The systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, mitigating and monitoring risk.

2.1 Stakeholder involvement

Aaltonen and Kreutz (2009) mentioned stakeholders as those who have an interest in a certain decision either as individuals or representatives of a group. Stakeholders consists of people who influence (or can influence) a decision as well as those affected by that decision. In another way, it is a combination of the public sector, private sector and the civil society. Alternatively, Morss et al (2005) stated that stakeholders are not a coherent entity but a collection of individuals, and each of them uses different information to address different goals in a unique context. Multi-stakeholder engagement ensures strong stakeholder support and is a catalyst for proactive commitment in disaster issues. Disaster risk reduction has an important linkage with the involvement of diverse stakeholders. Besides, lack of good communication and collaboration between stakeholders responsible for prevention, mitigation and management is one of main issues in risk management (De Marchi and Scolobig, 2012).

IRM brings a participatory, cross-sectoral and transparent approach in risk management (APFM, 2009). It calls for coordination of stakeholders at various levels and can be best adopted using participatory process so that stakeholders are involved not only in risk assessment but also in developing appropriate combination of management strategies, along with monitoring and review during its implementation. A diverse range of stakeholders are brought together to share information, knowledge and harmonize different objectives in achieving common goals. Since various groups of stakeholder have different needs depending on their areas of interest, respective roles and responsibilities, participation methods are varied with a varying degree of involvement in the process (APFM, 2006). Figure 2.3 illustrates the levels of stakeholder participation: provision of information, hearings, consultation, collaborative decision-making and delegation of responsibilities.

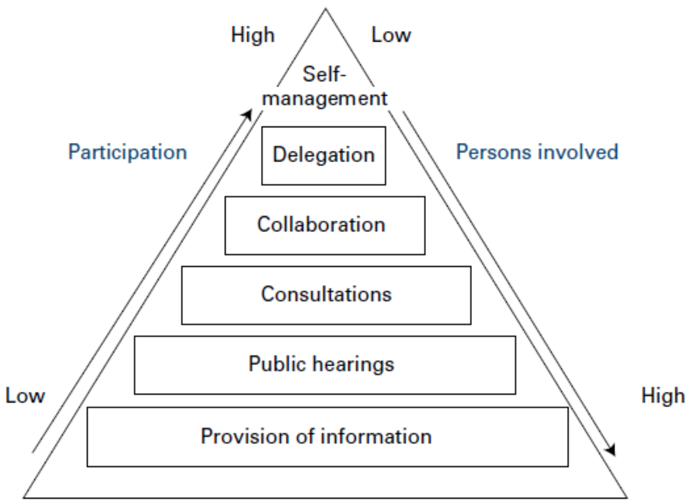


Figure 2.3. Levels of stakeholder participation (Source: APFM, 2006).

There are particular requirements for successful and sustainable involvement of stakeholders, and the most vital one is to build trust through information sharing and iterative interaction. However, there are no universal solutions which facilitate the involvement of concerned stakeholders and the civil society (APFM, 2006). Besides, it can be a time-consuming and resource-intensive work. It demands for the identification of appropriate stakeholders, realization of their issues under consideration and assisting their participation through a reasonable, fair, accountable and transparent process.

2.2 Risk Assessment

Risk assessment is defined as "the process of making a decision recommendation on whether existing risks are tolerable and present risk control measures are adequate, and if not, whether alternative risk control measures are justified or will be implemented" by Technical Committee on Risk Assessment and Management (ISSMGE TC32, 2004). The purpose is to determine if a risk may be acceptable or tolerable. If not and classified as too high, actions to reduce risk should be taken. Risk assessment and its quantification are main parts of risk management (Schmidt et al., 2011). The components of a risk assessment process within the risk management framework are shown in Figure 2.4 (Fell et al., 2005). The risk assessment process is multidisciplinary and consists of hazard analysis, consequence analysis (characteristic of elements at risk and their vulnerability) and estimation (calculation) of risk. In this section, the scope is limited to risk estimation and evaluation.

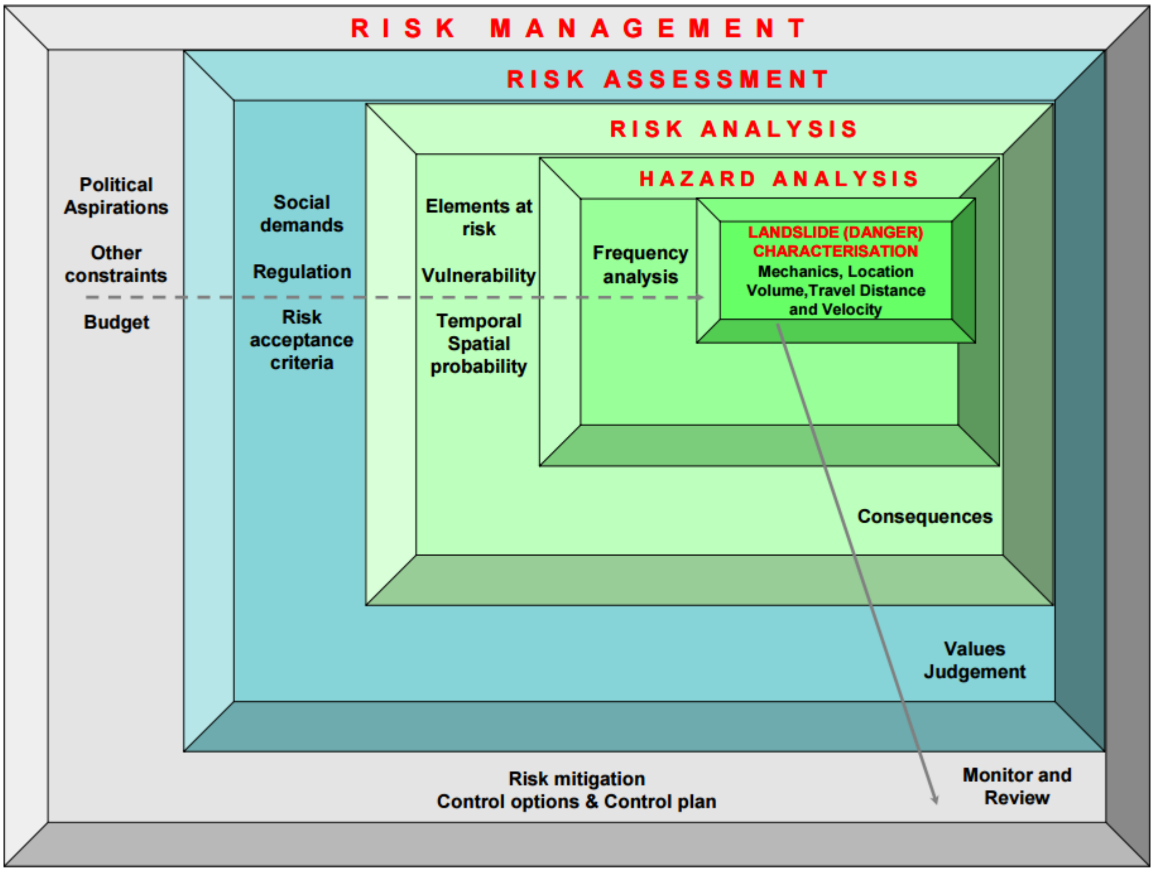


Figure 2.4. Components of the integrated risk management framework (Source: Fell et al., 2005).

For management purposes, a comprehensive and accurate risk assessment is necessary considering its essential role in risk management. Risk assessment should be able to support the decision-making and risk treatment process for the effectiveness of risk management (Carreño et al. 2007). There are several assessment methods (qualitative, quantitative and semi-quantitative) depending on the study scale, data availability and aims of the analysis (Lee and Jones, 2004; Glade et al., 2005; van Westen et al., 2006; Corominas et al., 2014). Qualitative methods are based on descriptive rankings, weighted indexes and classification systems, leading to descriptive and ordinal risk estimation. On the other hand, quantitative methods use numerical scales and ranges of values, leading to risk estimation in terms of economic values or number of people killed (Mavrouli et al., 2014).

2.2.1 Risk Estimation

The quantitative assessment has become an essential practice in risk management (Fell and Hartford, 1997). According to Fell et al (2005), risk can be quantified as:

$$R = H \times E \times V \times W \qquad (2.1)$$

where H is the hazard (i.e. multiplication of frequency and probability of the hazard reaching to elements at risk); E is the probability of presence of the elements at risk (exposition); V is the vulnerability of elements at risk to that hazard event; W is the amount (monetary) value or net present value (number of people) of the exposed elements at risk. A simple conceptual and spatial diagram of this process is illustrated in Figure 2.5. It is important to analyse where these hazard events can occur and with what frequency, as well as the elements exposed to hazard events and their vulnerability (i.e. degree of loss).

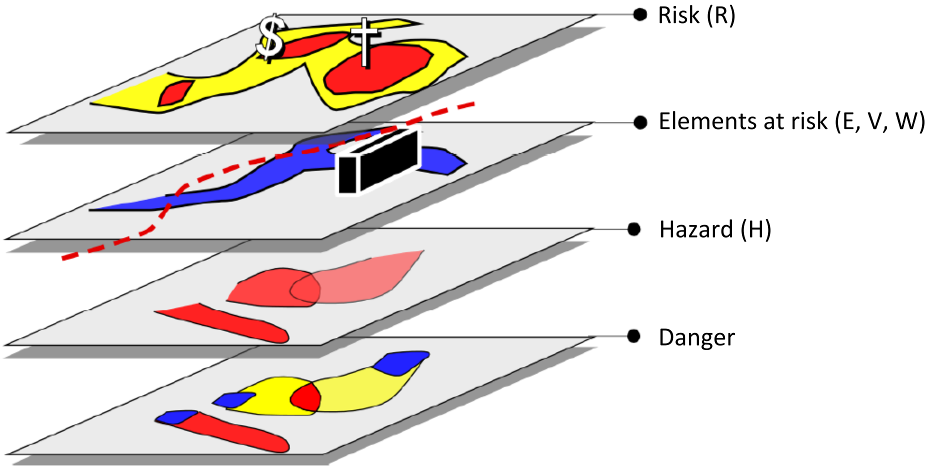


Figure 2.5. Spatial illustration of the elements of risk based on Jaboyedoff and Nicolet (2015).

However, it should be stressed that such a quantitative approach provides a limited estimation of risk. It only considers direct damages to elements at risk in monetary terms, and thus, indirect damages and consequences are not included. Risk assessment should consider potential economic, social and environmental consequences due to a hazardous phenomenon in a period of time (Carreño et al, 2005). Besides, due to the complex nature of risk assessment, study scale and lack of data in practice, many aspects of the risk cannot be fully quantified (Jaboyedoff et al., 2014). In such cases, qualitative approaches are adopted and considered as useful. They are often based on approaches using spatial multi-criteria evaluation (SMCE) (Castellanos Abella and van Westen, 2007; Raaijmakers et al., 2008) and risk matrix (Pine, 2008; FEMA, 2001) for risk prioritization and ranking. SMCE is a MCE method, a decision support methodology, but it works in a spatial manner and is based on the weighting and combination of spatial criteria (in the form of maps) to produce a composite map at the end. An example of composite risk index map produced based on a semi-quantitative, expert-based SMCE approach is illustrated in Figure 2.6, as carried out by Castellanos Abella and van Westen (2007) for landslide risk assessment at a national scale in Cuba. Even though this method can be subjective, it is a useful instrument for decision-making as an initial screening process, especially for a large-scale study area and when there is insufficient data, inventories and resources to perform a detailed risk assessment.

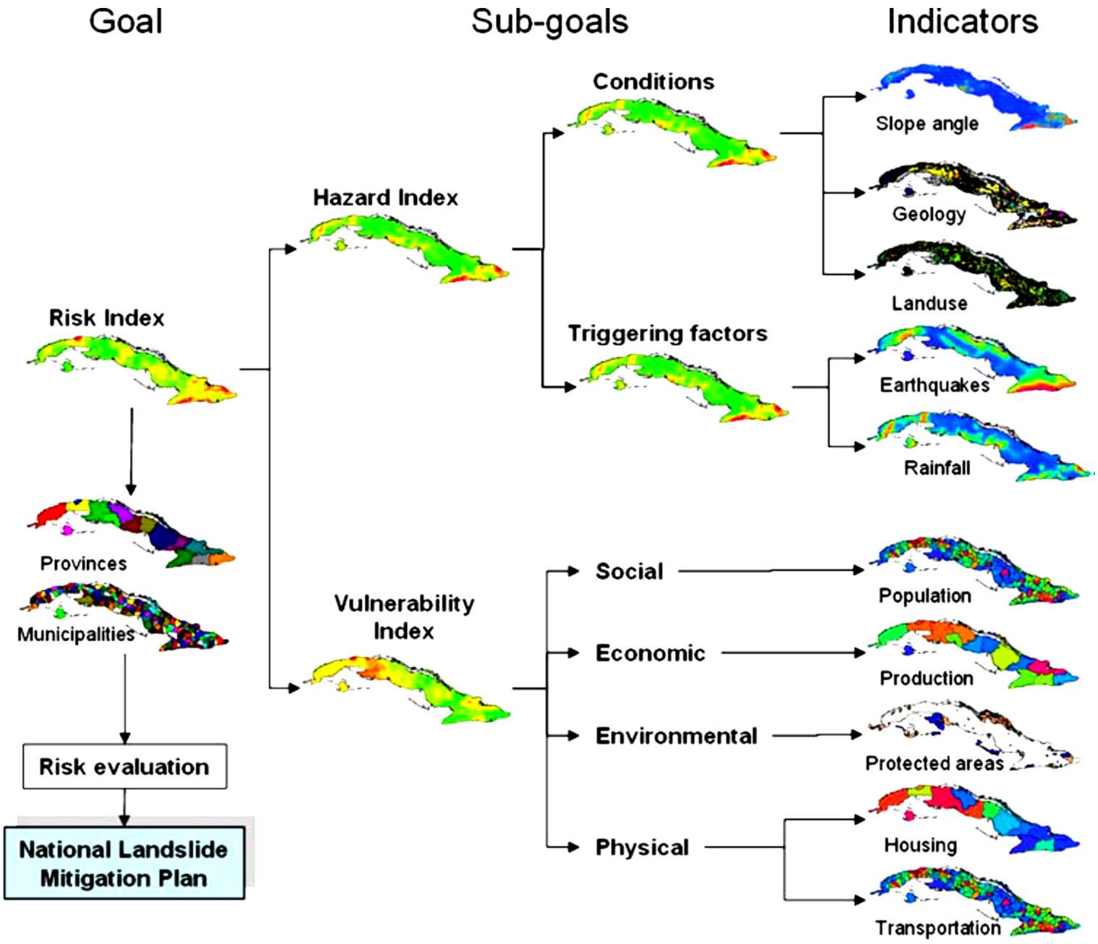


Figure 2.6. A landslide risk assessment model using SMCE (Source: Castellanos Abella and van Westen, 2007).

Risk ranking methodologies have been developed since the nineties (Haimes, 2008). Qualitative approaches based on risk matrices are widely adopted due to its simplicity and effectiveness to risk management. Risk matrix is a tool which allows classifying and ranking risks in qualitative classes based on an assessment of their levels of impact (consequences) and probability (likelihood). An example risk reporting matrix is illustrated in Figure 2.7, to determine levels of risk (low, medium and high) in different colours (green, yellow and red) respectively. The classes of likelihood range from 'not likely' to 'near certainty' with an increase in probability of occurrence. Similarly, the level and types of consequences range from 'minor' to 'catastrophic' with an increase in damage to property, for example. These defined classes and their definitions are varied depending on the institutional framework where the risk matrix is applied. Risk matrices may be regarded as a subjective and approximate tool for estimation of risk. However, they are useful for prioritizing risks qualitatively in many settings. Still cautions need to be given in using risk matrices despite its simple appearance. The limitations of risk matrices are discussed in Cox (2008) such as uncertainty associated to inputs and outputs as they require subjective interpretation by different users, and this may result opposite rankings of the same risks.

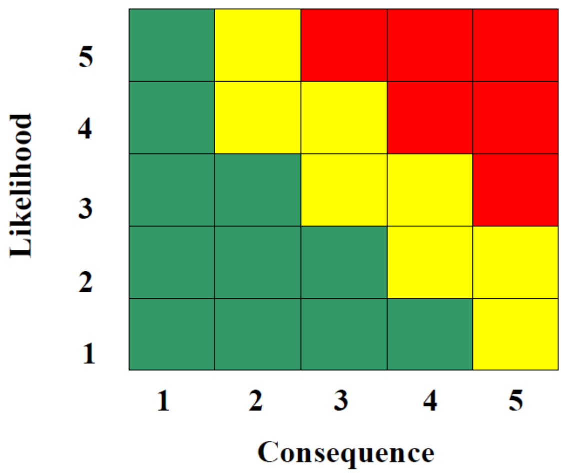


Figure 2.7. A risk matrix (Source: DoD, 2006).

2.2.2 Risk evaluation

Risk evaluation is regarded as "the process of determining the significance of a risk to the individual, organization or community" (Crozier and Glade, 2005). It is "the stage at which values and judgements enter the decision process, explicitly or implicitly, including consideration of the importance of the estimated risks and the associated social, environmental and economic consequences, in order to identify a range of alternatives for managing the risks (ISSMGE TC32, 2004)." This process involves the determination of whether risk is acceptable, tolerable or intolerable. The *acceptable risk* is a risk which impacted community is prepared to accept while *tolerable* risk is a range of risk which community can live with it to secure certain benefits. The latter is non-negligible and needs to be reduced as low as reasonably practicable (ALARP) (Fell et al., 2005; ISSMGE TC32, 2004). The *inacceptable risk* must normally be reduced regardless of the cost. There are several factors which affect one's attitude and perception to these risks (AGS, 2000) such as insurance plans, available resources to reduce risk and his/or her past exposed experiences to risk. The acceptable risk level (individual and societal risk) is not universally established and varies from country to country (Bell et al., 2005) according to their standards. For example, the Geotechnical Engineering Office (Hong Kong) set acceptable (individual) risk for landslides and boulder falls as 1 x 10^{-5} and 1 x 10^{-4} is for new and existing developments respectively (Moore et al., 2001; Crozier and Glade, 2005). On the other hand, cumulative F-N curves are used for the acceptability of societal risk though this is not universal (Fell et al., 2005; Crozier and Glade, 2005). An example F-N diagram is shown in Figure 2.8, illustrating the frequency of exceeding N victims per year as a function of N due to landslides, for example.

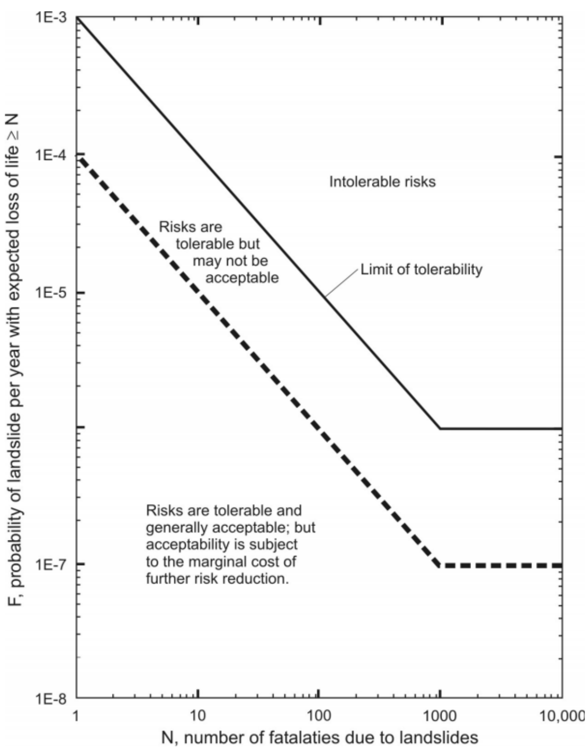


Figure 2.8. A F-N diagram for societal risk criteria (Source: Crozier and Glade, 2005).

2.3 Risk Treatment

The outcomes of the risk assessment process serve as an important input for this stage of risk management, depending on whether risks are tolerable or intolerable. Risk treatment is a process for risk modification and involves the selection and implementation of one or more options. In this section, the focus is placed on preparedness (and prevention) phase of IRM cycle before an event is occurred. There are many options (alternatives) which can be applied in order to reduce the risk based on factors contributing to risk, for example, modifying the impacts of affected elements by reducing their vulnerability or reducing the intensity of the hazard through the implementation of some structural control measures in the area. According to Fell et al. (2005), some possible mitigation options include: reducing the frequency of a hazard, reducing the probability of the hazard reaching the element at risk, and reducing the exposure and vulnerability of the element at risk. Other management options include: avoiding the risk, transferring the risk and postponing the decision (in case of uncertainty and further investigations are needed to be carried out).

Definitions of different terms for mitigation measures are listed based on UNISDR (2009a), Holub and Hubl (2008), Hubl and Fiebiger (2005), and Wilhelm (1997):

- **Structural measures:** All physical measures to reduce or avoid natural hazards and their associated impacts, including the application of engineering techniques for hazard-resistance in structures or systems.
- **Non-structural measures:** All non-physical measures using knowledge, practice or agreement to reduce impacts and risks, typically concentrating on the identification of hazard-prone areas and limiting their use either temporarily or permanently.
- **Active measures:** Measures to reduce the consequences of hazard by altering the characteristics of hazard such as magnitude or frequency.
- **Passive measures:** Measures based on the principle of spatial separation of elements at risk (such as endangered people and objects) from the hazardous area.

Risk management measures for floods and landslides account for both temporal and spatial dynamics of the hazard, the distribution and vulnerability of elements-at-risk (Fuchs et al., 2013). Regardless of temporary or permanent implementation, measures can be categorized into structural and non-structural as well as passive and active measures. The following table 2.1 shows the categories of mitigation measures, as defined in Holub and Hubl (2008).

Table 2.1. Categories of risk mitigation measures (Source: Holub and Hubl, 2008).

	Active	**Passive**
Permanent	Soil bio-engineering Forest management measures Technical measures	Spatial planning and land-use Hazard mapping Local structural measures

Temporary	Immediate measures	Information and warning Exclusion zones and evacuation

Not only hazard mitigation measures should be considered but also measures addressed to affected elements at risk and spatial planning should be taken into account within the natural hazard reduction framework (Kanonier, 2006). Spatial planning is a part of IRM and plays an important role in prevention to assure appropriate use of potentially affected areas (FOEN, 2006). The IRM requires a combination of active and passive measures for risk reduction (Holub and Hubl, 2008), and therefore, there is a need for coordinated efforts between responsible authorities and organizations (such as sectoral and spatial planning) in selection of efficient and effective measures. Risk management is an iterative process which needs to be monitored for the re-evaluation of the situation after the implementation of risk management measures.

Chapter 3: General background in decision support for risk management

In Chapter 2, we presented concepts and key elements of risk management framework. Risk can be reduced or mitigated through the implementation of integrated risk management measures as previously discussed. However, responsible authorities and decision makers face major informational and financial challenges in developing and prioritizing mitigation measures. Collaborative interactions and coordinated efforts amongst stakeholders are important in producing such coordinated mitigation strategies. Available resources and financial means need to be used efficiently and effectively for risk reduction.

Increasingly, risk related information has become widely available with the help of advanced geospatial technologies. However, in many cases, individuals do not require more information, but need assistance in interpreting existing information and determining what is needed to make informed decisions (Hearn et al, 2006). Information needs to be well communicated and presented so that better informed decisions are made. In this case, decision support systems are regarded as useful tools for providing support and assistance to the decision makers. EEA (2010) also mentioned that it may be desirable to implement such kind of comprehensive information and decision support systems. This would support the impact assessment of natural hazards and the decision-making process in selection of appropriate risk reduction measures. Geographical information systems are also essential for understanding the spatial distribution of risks associated with natural hazards due to its powerful ability in analysis, processing and visualization of spatial data. Due to these additions to the decision-making process, they have been increasingly integrated as a major component in the decision support tools (Tkach and Simonovic, 1997) for natural hazards and risk management.

3.1 Decision support systems

With the evolution of the technology, decision support systems have been developed (Power, 2007). They have emerged as an important component of computer-based information systems since around early 1970s, and the concept of DSS is generally considered as having originated with the study of Gorry and Scott-Morton (1971) (Keenan, 1996). Many definitions of DSS exist in the literature, however, there is a general view that these systems aim to support decision makers and facilitate decision processes in making informed choices, rather than replacing managerial judgment and automating the decision process (Keen and Scott-Morton, 1978;

Keenan, 1996; Arnott, 2006). A decision support system is defined as an interactive, computer-based system that assist users in the process of decision-making (Finlay, 1994), targeting to improve users' effectiveness in the process. A DSS can be particularly useful and beneficial when some of these following characteristics are identified in the process (Keen and Scott-Morton, 1978):

- the existence of a large data set to analyse and process;
- the need of computational ability in the process;
- the existence of time pressure;
- the need of judgment in the process, either to identify alternatives or to select a solution.

3.1.1 Multi-criteria based decision support

Data mining, artificial neural networks and multi-criteria decision making (MCDM) approaches have been widely used in the development of DSSs for finding relationships between the data, training knowledge to apply in decision-making patterns, and for ranking options based on the user criteria and preferences (Shim et al., 2002b; Kuo et al., 2002; Power and Ramesh, 2007). A fundamental component of a DSS is to provide functions which support choices amongst feasible alternative solutions. Alternatives can be compared and evaluated using Cost-Benefit Analysis (CBA) or MCDM approaches (Janssen, 1992). CBA requires evaluation of alternatives in monetary terms, and general decision rules such as cost-benefit ratio, internal rate of return and net present value are used. However, there are other important and competitive aspects of the decision problem, which are difficult to evaluate and quantify such as environmental and social aspects (van Herwijen, 1999). Particularly in the field of natural hazard and risk management, these aspects should be considered in the decision process to achieve integrated, appropriate and sustainable management strategies. In this section, we briefly introduce the concepts and approaches of MCDM.

The decision problems with conflicting objectives can benefit from the application of MCDM techniques by making it more rational, explicit and efficient (Hobbs et al., 1992). Belton and Stewart (2002) defined MCDM as "an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter". These techniques are based on the objectives and preferences of decision makers as well as the criteria values associated with each alternative to produce a ranking of alternatives (Zeleny, 1982; Janssen, 1992; Vincke, 1992; Tkach and

Simonovic, 1997). The criteria may be quantitative or qualitative, and they may also be considered spatially depending on the study objective, criteria and decision problem at hand. The performance table used to evaluate alternatives against criteria is presented schematically in Figure 3.1. The performance value of an alternative for a criterion is represented either as a black dot (point) or map, where a_1-a_3 represents alternatives and c_1-c_4 represents criteria.

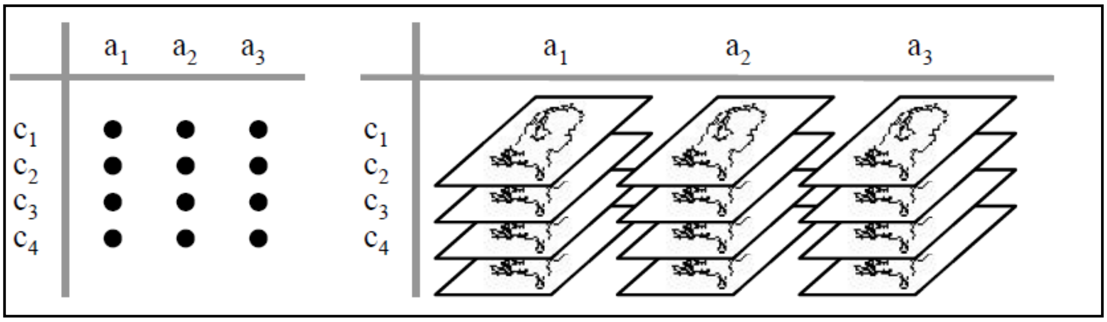


Figure 3.1. Illustration of non-spatial and spatial performance tables of a decision problem (Source: van Herwijen, 1999).

MCDM methods can be categorized into three main groups (Goicoechea et al., 1982; Tkach and Simonovic, 1997; Guitouni and Martel, 1998):

(1) **Outranking**: uses pairwise or global comparisons of alternatives in terms of each criterion. Every pair of alternatives is evaluated and an outranking relation is produced. ELECTRE (Roy, 1991; Figueira et al., 2005) and PROMETHEE (Brans and Mareschal, 2005) methods are the most frequently applied outranking methods (Mendoza et al., 2006).

(2) **Multi-attribute utility and value**: apply additive or multiplicative models for the aggregation of single criterion evaluations. AHP (Saaty, 1980; Zahedi, 1986) and TOPSIS (Hwang and Yoon, 1981) methods are ones of the most popular methods in this group.

(3) **Mathematical programming**: is characterized by iterative and progressive process, seeking to discover alternatives which are closest to achieving desirable goals associated with each criterion. Among other approaches, Compromise Programming (CP) (Zeleny, 1973) and Goal Programming (Mendoza, 1987) methods are the most studied methods.

3.1.2 (Web) GIS based decision support

As natural hazards are location dependent, risk management activities can benefit from geographical representations. Geospatial technologies such as Remote Sensing (RS), GIS and Global Navigation Satellite System (GNSS) are increasingly utilized as a tool to support decision making in risk management (Thomas and Kemec, 2007). For example, hazard mapping, analysis of the trends and patterns of population growth and settlements, spatial and land use planning, allocation of resources for response activities and so on. GIS has been portrayed as a decision support technology since the early beginnings in the 1960s, and GIS applications have provided necessary information for decision making in diverse fields such as environmental and natural resources management, regional and land use planning, natural hazards management and so on (Jankowski, 1995). Particularly in risk management, GIS plays a central role in the process of risk assessment and can be used to calculate potential damages in the affected area caused by a hazard event. This outcome helps risk managers and decision makers to take appropriate preventive measures (Peggion et al., 2008). However, GIS does not provide explicit decision support abilities (Carver, 1991), for example, the selection of a suitable alternative option to reduce risk. In this case, decision support tools and methods can be integrated or used in combination with GIS to provide better decision support capabilities (Malczewski, 2006). This combination of technologies is referred to as Spatial Decision Support Systems (SDSS), and plays an increasing role in geographic information science. Different levels of integration can be considered as discussed in the studies (Carver, 1991; Fedra, 1993; Jankowski, 1995; Malczewski, 2006). Many researches have been done in the development of SDSS applications in various fields (Tkach and Simonovic, 1997; Matthews et al., 1999; Rinner, 2003; Sugumaran et al., 2004; Levy et al., 2007).

With the emergence of the World-Wide Web in approximately 1995, DSS and GIS technologies have been further extended and applied for online applications (Power, 2007; Bhargava and Power, 2001). Power (1998) defined a web-based DSS as “a computerized system that delivers decision support information or decision support tools to a manager or business analyst using a thin-client web browser like Netscape Navigator or Internet Explorer.” The web technologies used for DSS is reported in Bhargava and Power (2001) and overview of web-GIS techniques are described in Peng and Tsou (2003), Green and Bossomaier (2002) and Fu and Sun (2010). Examples of non-spatial decision support tools are Web-HIPRE (Mustajoki and Hamalainen, 2000) and DEFINITE (Janssen and van Herwijnen, 1994). Web mapping and decision support features are combined, and examples of such web-GIS based decision support applications include Rinner and Malczewski (2002), Shim et al. (2002a), Yu et al. (2007) and Jankowski et al. (2008).

Many researches in the literature used the term web-based (spatial) decision support for different purposes, regardless of the degree of integration between web-GIS and decision methods. Such web platforms integrate GIS for visualization and analysis of spatial data, with or without the use of (spatial and non-spatial) decision methods explicitly. For example, Sugumaran et al. (2000) proposed a decision support tool, limiting to visualization and data retrieval for floodplain management. Yu et al. (2007) presented a web-GIS DSS for slope land hazard warning based on real-time rainfall monitoring (Figure 3.2). Similarly, Rao et al. (2006) described a prototype tool for resource management and assessment of environmental quality, based on feature extraction and assessment tools. They do not, however, apply core decision support methods in their applications. Nevertheless, outcomes of such tools can be used to support the decision-making process.

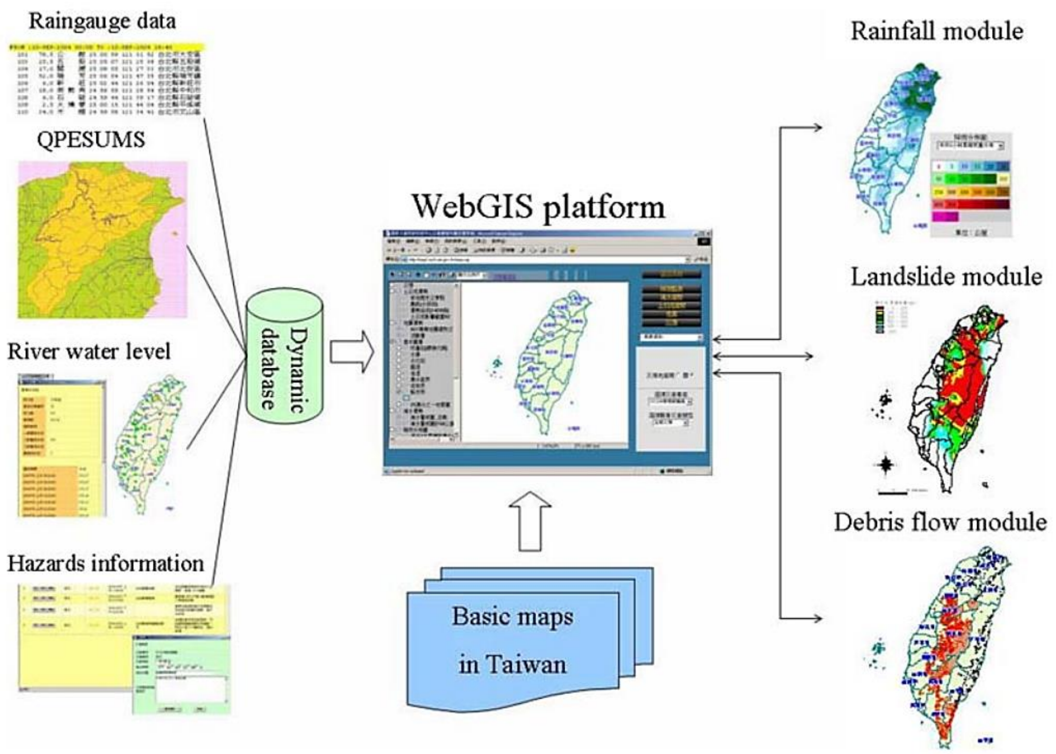


Figure 3.2. Components of the web-GIS platform for slope land hazard warning (Source: Yu et al., 2007).

3.1.3 Examples of decision support applications

A variety of decision support applications have been evolved in the field of natural hazard and risk management research. These applications are developed to provide decision support in different phases of risk management framework. As risk systems are rather complex, decision support tools are particularly relevant to assist the processes of risk analysis, evaluation and multi-criteria evaluation for selection of potential alternatives for risk reduction. In this section, some examples of existing decision support tools are briefly presented, focusing on the planning and management of natural hazards.

Chen et al. (2001) introduced a program called *MCE-RISK* for risk-based decision-making, with an example to determine priority areas for bushfire hazard reduction. It includes modules for data standardization, weighting, MCE-GIS methods, and sensitivity analysis. Within this program, different MCE-GIS methods such as TOPSIS and CP are also incorporated for comparisons of the same decision problem. *ANFAS* (Prastacos et al., 2004) is a web-based decision support system for simulation of river floods and estimation of potential impacts, used by decision makers and stakeholders. To compare flood scenarios and estimate the impacts, different modules are integrated: GIS databases, hydraulic models and impact assessment procedures. Data obtained from different sources are also integrated in specific databases to be applied in these modules. The results can be visualized in the form of graphs and maps or can be downloaded using specially designed software. Besides, Pasche et al. (2007) proposed a decision support tool called *Kalypso Planner-Client* that enables spatial planners to create planning scenarios and mitigation measures for the evaluation of their hydrological, ecological and economic impact. This is integrated into an open source GIS-based system for flood risk modelling, based on Open Geospatial Consortium (OGC) standards to ensure a high level of interoperability of the spatial data. A review of existing tools for long-term flood risk management is reported in the FLOODsite (2007) project report.

The decision-making process involves exchange of information, discussion and negotiation between involved stakeholders (Wang and Cheng, 2006). Levy et al. (2007) applied a multi-criteria DSS for flood management in an urbanized Japanese watershed. This proposed framework used analytic network process (ANP) for weighting of criteria, aggregation and prioritization of emergency management options with the preferences of stakeholders. It aims to assist in enhancing communication between stakeholders and improving emergency management resource allocation through the visualization, analysis and integration of emergency management information. Participative and collaborative decision support is further promoted by Simonovic and Akter (2006), White et al. (2010), Aye et al. (2016b) and Evers et al. (2016) for group decision making.

3.2 Architecture of web-GIS decision support applications

A web-based DSS may include a GIS component to facilitate spatial data retrieval, display and analysis, depending on the purpose of the study. It combines several components including user interfaces, computational models and spatial databases. The improvement of access to information can be achieved by integrating GIS in decision support systems. Developing a DSS in combination with web-GIS support can provide its end users in making better informed decisions referenced to a geographical location. The term Internet GIS (IGIS) is defined as "network-based geographic information services that can utilize wired or wireless Internet protocols to access geographic information, spatial analysis tools and GIS Web services" by Peng and Tsou (2003). They described IGIS as client/server systems in which basic functions (i.e. presentation, program logic and database) are distributed between client and server. Based on the client-server architecture, clients send requests to services running on a server and receive appropriate information in response. Typically, a client is a web browser and the server-side includes a web server, GIS server and database together with other supporting tools (Figure 3.3). The client-server model can be a multi-tier architecture where geo-processing is divided into server-side and client-side tasks (Alesheikh et al, 2002). This architecture is used to facilitate the maintenance of the application and its functionality can be upgraded or modified at any time without affecting the end user's computer system (Sugumaran et al, 2004; Zhang and Goddard, 2007).

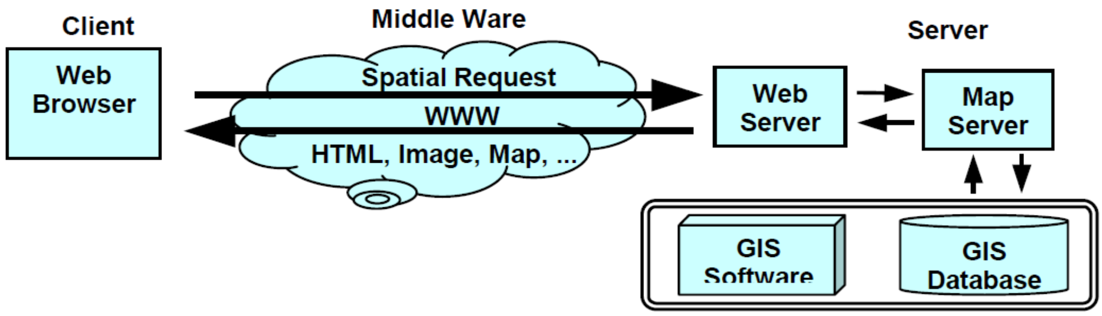


Figure 3.3. A Typical web-GIS model for the development (Source: Helali, 2001).

There are two types of approaches based on the location where the actual information and processing tasks occur: client-side and server-side processing. Server-side based web SDSS are found in the literature and on the Internet since 1996 (Rinner, 2003). The server-side approach uses a thin client, and most of the processing is performed on a server. The client-side approach uses a thick client in which processing is mainly carried out on the user's computer system. Both of them have their advantages and disadvantages, and thus, the decision on which architecture may depend on the user requirements and the solution has to meet.

3.2.1 Thin and thick client

In a *thin-client* system (Figure 3.4), the clients only have user interfaces to communicate with the server and display the results. Most of the processing is done on the server and therefore, the server computers typically have more power than the client to manage the centralized resources (Alesheikh et al, 2002). For the web-based applications, there is no need to install additional software and only a browser is sufficient in most cases, and it can be accessed from every web-terminal (Kobben et al, 2010). Besides, the system performance is not dependent on the client. Therefore, if there is a need to revise or update the system's functionality, it can be done on the server-side easily without affecting the client users. However, the speed of the system can be limited due to the processing task on the server and the connection of the network.

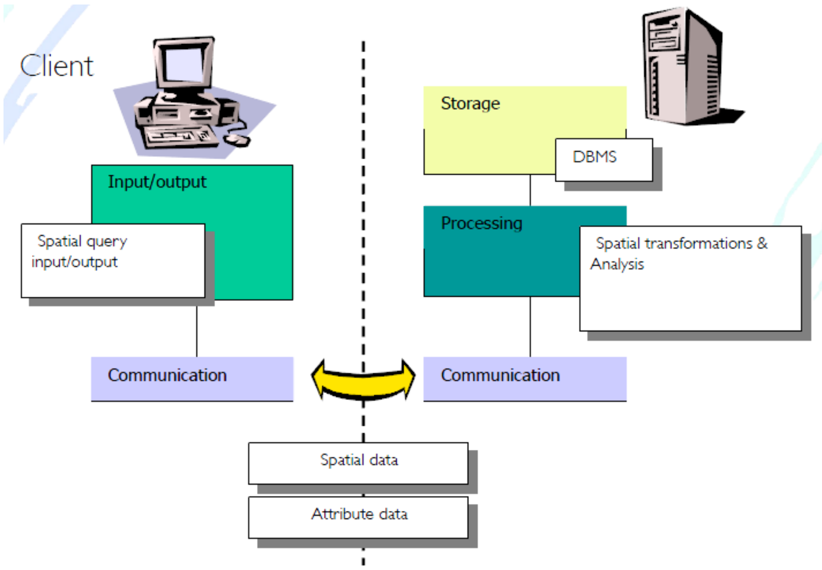


Figure 3.4. A schematic diagram of the server-side processing approach (Source: Kobben et al, 2010).

In a *thick-client* system (Figure 3.5), a high degree of processing is done on the client and it can be varied from no server involvement to a fairly amount of server processing. In this case, the client application can be more intelligent and is capable to process data more locally. Hence, it appears to be faster and basically can work temporary offline. Nevertheless, the performance mainly depends on the hardware of the client side and complex software needs to be installed. As a consequence, access to the application from any clients can be limited, unlike a web-based thin-client solution (Kobben et al, 2010), as more resources are needed to be present at the client side to be able to use the application.

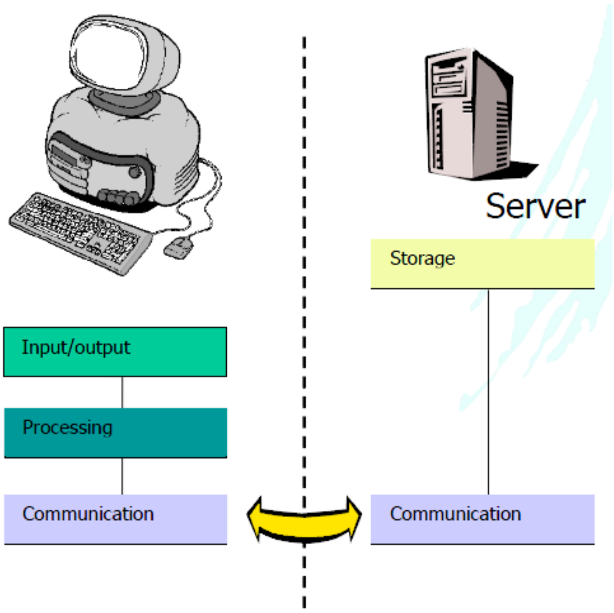


Figure 3.5. A schematic diagram of the client-side processing approach (Source: Kobben et al, 2010).

3.2.2 Three-tiered client-server architecture

N-tier architecture is applied in many developments due to its easy maintenance of the application and data layers (Sugumaran and Sugumaran, 2007). The typical architecture of a web-based spatial decision support application uses a three-tiered architecture based on a client-server manner. Based on open-source technologies and solutions, a paradigm of such architecture is illustrated in Figure 3.6. Aside from being free, one of the main advantages of utilizing open-source solutions is that it can easily be tailored to meet the requirements of end users. A client-side approach is not adopted as it requires additional installation of software and plug-ins on the client side which can affect the usability and flexibility of the system.

As shown in Figure 3.6, the server-side typically includes a Web server, a map server that provides GIS services and a geo-database for storage of spatial and non-spatial data. The map server acts as a common platform for the exchange of geospatial data and services. The Web server transfers spatial and non-spatial data between the client-side and the map server. The client-side interface allows end users to interact with the spatial application. An example sequence diagram of the communication between client and server components is illustrated in Figure 3.7.

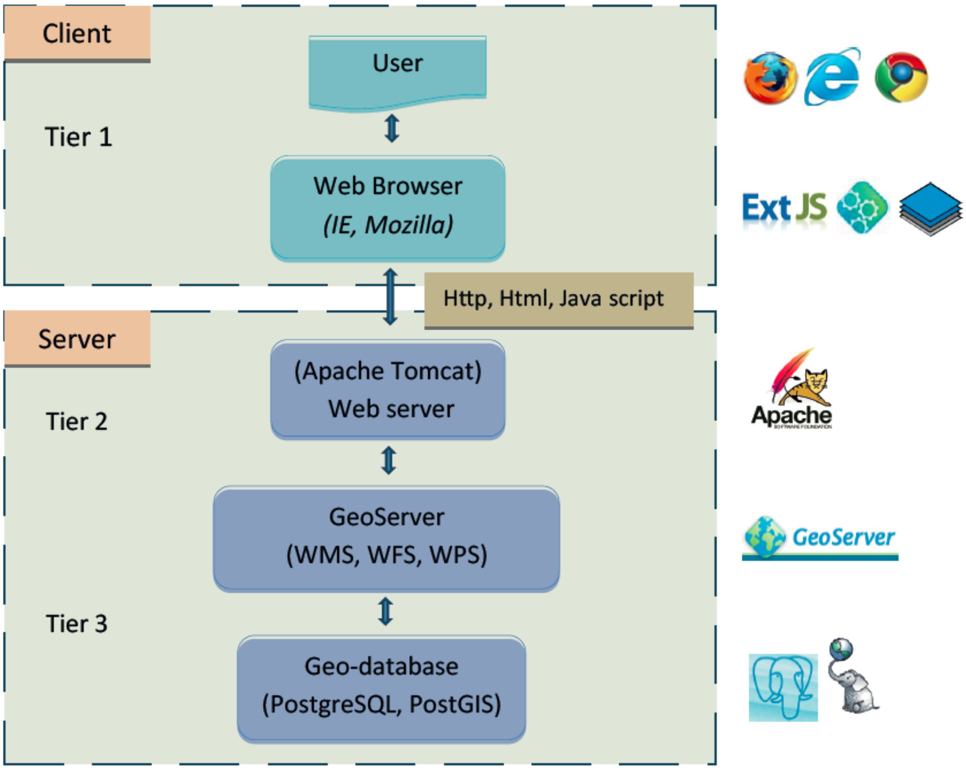


Figure 3.6. Schema of the three-tiered client-server architecture for the web-GIS applications.

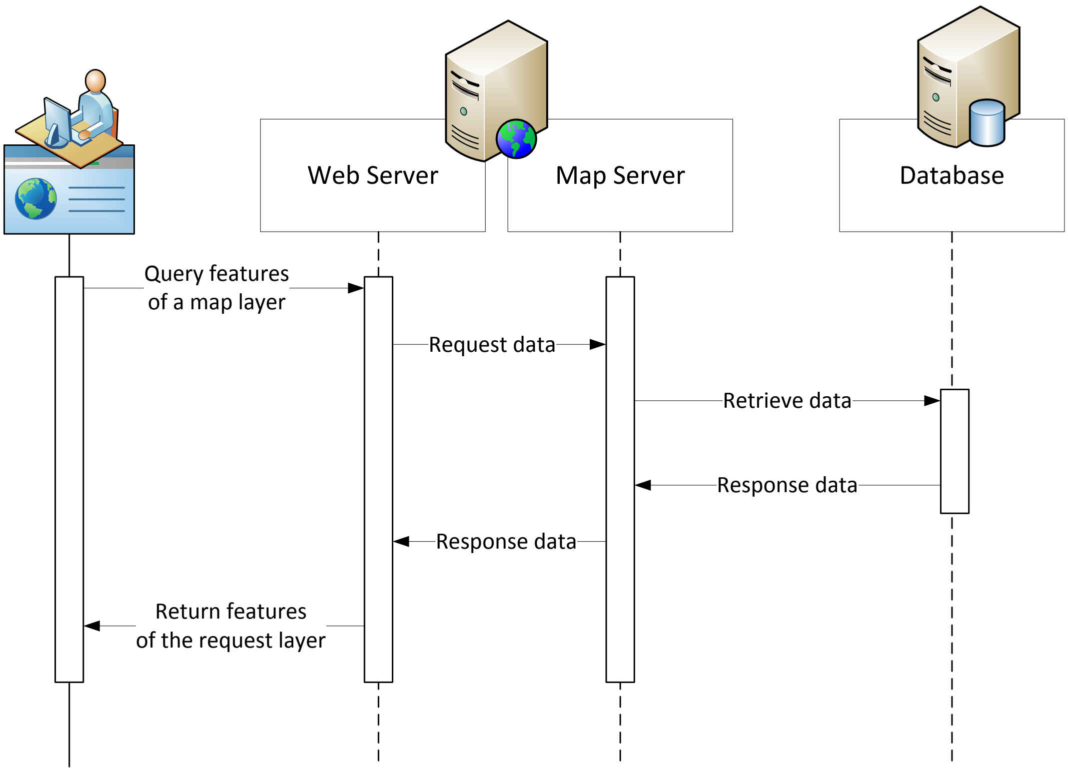


Figure 3.7. A diagram illustrating the communication between client and server components upon the user request to retrieve features of a map layer from the client side.

In the following sub-sections, respective web services, standards and open-source components of the presented architecture are introduced.

3.2.2.1 Geo-database

A lot of progress has been observed in the management of spatial and non-spatial data in an integrated database management system (DBMS) called a geo-database, and this progress has been largely contributed by OGC (Zlatanova and Stoter, 2006).

PostgreSQL is a powerful, open source object-relational DBMS with well-defined and open access protocols, operating on all major operating systems (PostgreSQL, 2016). **PostGIS** is an open-source spatial extension to PostgreSQL that implements the OGC's "Simple Features for SQL Specification". It is used to store and query location and mapping information, providing spatial objects such as geometry, geography and raster for the PostgreSQL database (PostGIS, 2016). It spatially enables the PostgreSQL server, and can be utilized as a backend spatial database for GIS applications (Balbo et al., 2013). Besides, it provides additional functions and index enhancements for analysis and processing of spatial objects. This enhanced the ability of the main PostgreSQL database, providing a fast, reliable and feature-rich DBMS (Boundless, 2016). Importantly, PostGIS database can be used in conjunction with GeoServer as a data source, allowing to publish spatial data online through standard OGC web services. Server-side and general-purpose scripting languages such as PHP and Python also provide PostgreSQL functions to connect and perform necessary operations within the geo-database through SQL (Structured Query Language) queries.

3.2.2.2 Map engine server

GeoServer is a Java-based, open-source software server for sharing, analysing and editing of geospatial data from different spatial data sources. Using open standards of OGC, geospatial data are published and displayed on the Web with a great flexibility and interoperability (GeoServer, 2016). Many OGC standards are implemented in GeoServer including Web Map Service (WMS), Web Feature Service (WFS & WFS-T), Web Coverage Service (WCS) and Web Processing Service (WPS), forming a core component of the geospatial web. GeoServer is available as a standalone servlet and can be used with existing application servers such as Apache Tomcat or Jetty. For faster display, **GeoWebCache** (an open-source Java web application) can be used with GeoServer to cache images from different sources, helping to accelerate the delivery of map tiles

(Boundless, 2016). Figure 3.8 illustrates data formats, services and functions offered by GeoServer.

Figure 3.8. GeoServer and its supporting functions (Source: Boundless, 2016).

GeoServer supports the most widely used standards for web-oriented geo-spatial applications as defined by OGC (2016):

- **Geographic Markup Language (GML)** is an eXtensible Markup Language (XML) grammar for encoding spatial features. It serves as a modelling language for GIS and an open exchange format for spatial transactions on the Web.
- **Web Map Service (WMS**) allows a client to request geo-registered map images from one or more distributed geospatial databases. The response is geo-registered map images (rendered as JPEG, PNG, etc.) that can be displayed in a web browser.
- **Web Feature Service (WFS)** allows a client to retrieve and update geospatial data encoded in GML from multiple Web Feature Services at the feature and feature property level, rather than sharing geographic information at the file level using File Transfer Protocol (FTP).
- **Web Processing Service (WPS)** allows a client to request the execution of a geospatial process such as polygon overlay. It facilitates the publishing of geospatial processes and clients' discovery of and binding to those processes.

- **Web Coverage Service (WCS)** allows a client to request coverage data in the forms that are useful for client-side rendering based on given spatial constraints and other query criteria.

GeoServer also provides **REST** API (REpresentational State Transfer) to programmatically configure and manage the data served by GeoServer such as workspaces, stores, layers and styles. Using this extension, clients can configure a GeoServer instance through simple HTTP calls to perform operations such as GET, DELETE, PUT, POST, etc. Specific object representations can also be obtained in XML and JSON formats. A simple diagram of a REST process is shown in Figure 3.9, where the clients GET a current state representation of something from GeoServer and PUT that representation back to modify, in which object's state is modified. This process can be performed through **cURL** utility, a command-line URL handler for executing HTTP requests and transferring files.

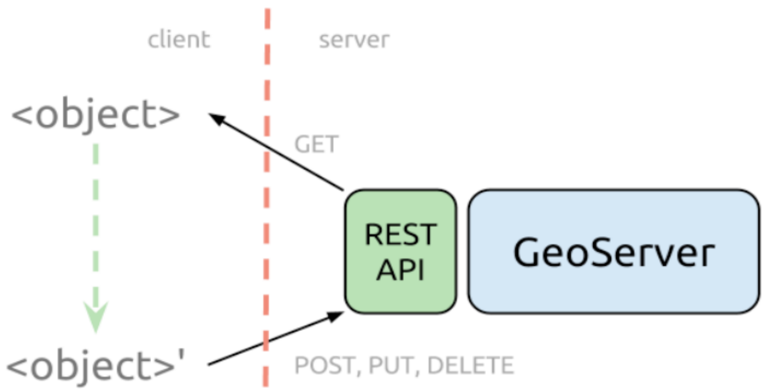


Figure 3.9. REST interface of GeoServer (Source: Boundless, 2012).

3.2.2.3 Client-side development libraries

For the client-side user interface, a variety of open-source software libraries and solutions are available for the web mapping development.

GeoExt is an open-source JavaScript library for the creation of rich web mapping applications. It combines OpenLayers with ExtJS to build customizable widgets, making it easy to build powerful desktop-styled web-GIS applications for viewing, editing, and styling of geospatial data (GeoExt, 2016).

OpenLayers, a high-performance, feature-rich and open-source JavaScript library, is a key component of GeoExt for displaying and editing of geospatial data in desktop or mobile browsers. It can be used for easy integration of dynamic maps in any web pages (OpenLayers, 2016).

Ext JS is a feature-rich JavaScript library for the creation of cross-platform HTML applications, which enables a most comprehensive Model-View-Controller (MVC) architecture in building applications. It features high-performance user interface widgets and templates including chart options, scalable grids, layouts and trees. A robust data package is also included to serve data from any data sources (Sencha, 2016).

Chapter 4: Quantitative risk analysis (estimation)

This chapter presents a quantitative risk analysis tool for flood and landslide hazards. The aim of the presented tool is to assist the experts (risk managers) in analysing the impacts and consequences of a certain hazard event in a considered region, providing an essential input to the decision-making process in the selection of risk management strategies by responsible authorities and decision makers. It is one of the main modules of the collaborative decision support platform (see Chapter 5). A prototype is developed based on the Boundless (OpenGeo Suite) framework and its client-side environment. Within this platform, the users can import necessary maps and information to analyse areas at risk. Based on provided information and parameters, loss scenarios (amount of damages and number of fatalities) of a hazard event are generated on the fly and visualized interactively within the web-GIS interface of the platform. The annualized risk is calculated based on the combination of resultant loss scenarios with different return periods of the hazard event. The application of this developed tool is demonstrated using a regional data set from one of the case study sites, Fella River of north-eastern Italy, of the CHANGES project.

This chapter is extracted and modified based on the published peer-reviewed ISI journal article: Aye, Z. C., Jaboyedoff, M., Derron, M. H., van Westen, C. J., Hussin, H. Y., Ciurean, R. L., Frigerio, S., and Pasuto, A.: An interactive web-GIS tool for risk analysis: a case study in the Fella River basin, Italy, *Nat. Hazards Earth Syst. Sci.*, 16, 85-101, doi:10.5194/nhess-16-85-2016, 2016.

4.1 Introduction

During recent years, natural hazard and risk assessment has become a major topic of interest among natural and social scientists, engineering professionals, endangered communities and local administrations in many areas of the world (Aleotti and Chowdhury, 1999). At the same time, hazardous processes in mountainous environments such as landslides, debris flows and floods have also increased in terms of frequency, magnitude and impact, as a result of climate change combined with continuously growing settlement areas (Sterlacchini et al., 2014). An increase in occurrences of such hazard events can be expected in the future due to the extreme rainfall events associated with climate change. Landslides happen in different geological and environmental settings in Europe each year (EM-DAT, 2003; EEA, 2010) and are mostly triggered by intense and long rainfall (Krejčí et al., 2002; Zêzere et al., 2005; Guzzetti et al., 2007; Brunetti et al., 2010), though other factors such as rapid snowmelt, earthquakes and human activities also contribute to the occurrences of these events. Natural processes alone present no risk unless they threaten some elements at risk (Alexander, 2004). Therefore, it is important to analyse where these hazard events can occur and with what frequency, as well as the elements exposed to hazard events and their vulnerability (i.e. degree of loss), leading to the identification of areas at risk. Einstein (1988, p. 1076) defined risk as "the multiplication of hazard and potential worth of loss since the same hazard can lead to entirely different consequences depending on the use of the affected terrain risk".

Risk assessment and management includes the estimation of the level of risk, followed by an evaluation of whether this level of risk is acceptable. If this is not the case, the adaptation of appropriate measures needs to be taken for risk mitigation (Aleotti and Chowdhury, 1999; Dai et al., 2002; Crosta et al., 2005; Sassa and Wang, 2005; Fell et al., 2008). The acceptable risk is defined as "a risk which everyone impacted is prepared to accept" (ISSMGE TC32, 2004) and varies from country to country (Bell et al., 2005). For management purposes, risk assessment should be able to support the decision-making process in order to contribute to the effectiveness of risk management (Carreño et al., 2007). Therefore, a comprehensive and accurate risk assessment needs to be carried out, realizing its important role in the risk management framework. There are several assessment methods which can be applied depending on the study scale, availability of data and aims of the analysis (Lee and Jones, 2004; Glade et al., 2005; van Westen et al., 2006; Corominas et al., 2014), which can be grouped into qualitative, semi-quantitative and quantitative methods. The quantitative assessment of hazard and risk has become an essential practice in risk management (Fell and Hartford, 1997). This approach should quantify the expected losses as the product of the probability for a given intensity, costs of exposed elements at risk or number of exposed people, and their associated vulnerability (Uzielli et al., 2008). However, risk assessments are often complex in nature and many aspects of the risk cannot be fully quantified (Jaboyedoff et al., 2014) due to the lack of data, scale of study or other socio-economic aspects of study area. Therefore, if insufficient data are available for a quantitative assessment, qualitative approaches are adopted, which are often based on spatial multi-criteria evaluation (SMCE) methods (Castellanos Abella and vanWesten, 2007; Raaijmakers et al., 2008) and risk matrix approaches (Pine, 2008; FEMA, 2001) for risk prioritization, ranking and evaluation. SMCE is a multi-criteria evaluation method but in a spatial manner, based on the weighting and combination of spatial criteria (maps) to produce a composite map. The risk matrices are also widely adopted due to its simplicity, making it possible to classify and prioritize risk in qualitative classes depending on the levels of impact and probability of a hazard event. In this study, the scope is limited to quantitative risk estimation (analysis).

Geographical Information Systems (GIS) play a central role in natural hazard risk assessment referenced to a geographical location (Peggion et al., 2008). Nowadays, with the support of advanced internet developments, open-source data, software and technologies, it has become much easier to exchange and analyse spatial information on the web through web-GIS based applications. Web-GIS is the combination of web technologies and GIS for data handling and analysis of spatial data on the web, simplifying the exchange of data and providing structural information to users without needing to install additional stand-alone software (Yang et al., 2005). In recent years, a number of studies have been conducted on the design and development of web-GIS applications for different purposes in the field of natural hazards and risk management (Lan et al., 2009; Frigerio and van Westen, 2010; Pessina and Meroni, 2009; Furdu et al., 2013; OpenQuake, 2015). However, most web platforms have focused mainly on risk visualization and dissemination of information (Müller et al., 2006; Salvati et al., 2009; Giuliani and Peduzzi, 2011; Frigerio et al., 2014) while risk assessment applications still remain as desktop-based applications such as CAPRA-GIS (a modular and free GIS for probabilistic risk analysis of natural hazards) or the InaSAFE (a free and open-source plugin to calculate impact scenarios for natural hazards) of Quantum GIS (QGIS) software. Further research needs to be done on the development of interactive risk analysis and management tools, taking the benefits of advanced web and web-GIS technologies to achieve a centralized and integrated framework. A good example of such developments for earthquake risk assessment was realized based on Geonode (an open-source platform for the creation, sharing and collaborative use of geospatial data) and OpenQuake engine (an open-source software for seismic risk assessment) by the Global Earthquake Model (GEM) foundation. Moreover, with the use of open data, it has become possible to perform rapid damage assessment using OpenStreetMap (Westrope et al., 2014) and its base data can be extracted (Schelhorn et al., 2014) and integrated in web-GIS applications for analysis.

The aim of this research work is to contribute to the practice of the open-source research community through the development of an interactive, open-source web-GIS-based risk analysis tool for natural hazards such as floods and landslides. Section 4.2 presents the background methodology, workflow and architecture used for the development of the prototype together with the data model design and calculation procedures of the prototype risk tool. In Sect. 4.3, we demonstrate the components of the prototype using a regional data set from the Fella River basin area in Italy, where flash floods, river floods and debris flows are frequent and cause severe consequences. Finally, a discussion of limitations and potential improvements of the presented risk analysis tool is reported.

4.2 Background framework and methods

An overview diagram of the prototype platform is presented in Fig. 4.1, where the risk analysis module is one of the main modules. The data management module acts as an essential input to the risk analysis module in order to provide the necessary data (i.e. hazards, elements-at-risk and vulnerability information) for the calculation of loss and risk scenarios. The purpose of the loss component is to quantify the probability of losses either in monetary values or fatalities caused by a hazard event in a specific area for a certain time period. The risk component produces a risk curve which shows the relationship between frequency and its associated losses of hazard events. When the resultant risk level is not acceptable, the results of risk analysis are applied in the decision-making process for formulation and selection of appropriate control measures for the purpose of risk reduction. In this chapter, we mainly focus on the structure of the risk analysis module along with its supporting data management module. The targeted users of this module are mainly experts who are responsible for providing and analysing risk information especially for hydro-meteorological hazards such as floods and landslides.

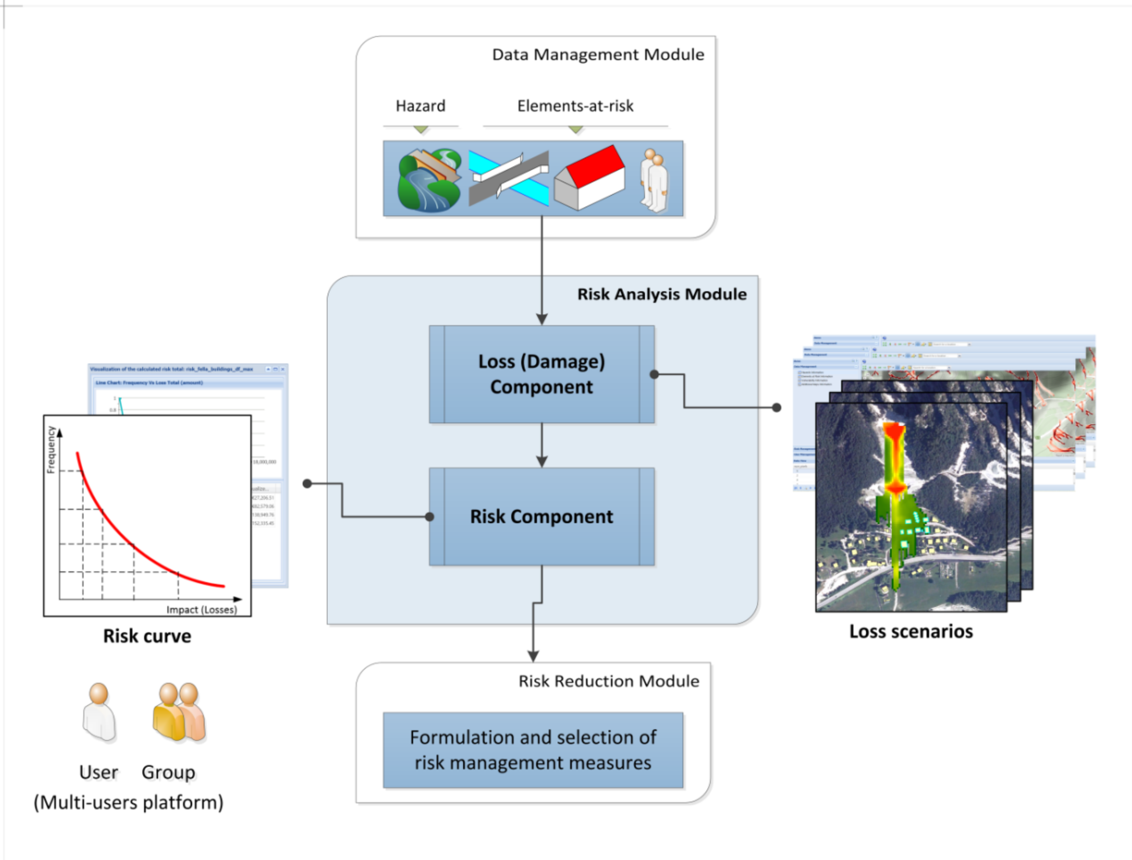


Figure 4.1. Overview diagram illustrating the main modules of the prototype web-GIS platform. For the user interactions, the risk analysis module is mainly intended for expert users (risk managers) while various stakeholder groups can be involved in the risk reduction module for the decision-making process in the formulation and selection of different risk management measures.

4.2.1 Definitions of loss and total risk

We define the term "loss scenario" as a scenario with estimated number of fatalities and physical damage to assets in monetary value, which are caused by a specific hazard event with a given intensity for a certain return period. According to Hungr's (1997) definition, intensity represents "a set of spatially distributed parameters describing the destructiveness of a hazard". Intensity can be defined quantitatively using various parameters, e.g. in the case of debris flow, depth of accumulated deposit, impact pressure, kinetic energy per unit area, etc. The return period is the inverse of the average frequency of events with intensities above a given threshold. The physical losses of a certain category of elements at risk for a given frequency of a hazard event can be quantified as (van Westen et al., 2014):

$$\textit{Loss (L) = Spatial Probability (SP) x Vulnerability (V) x Amount (A)} \qquad (4.1)$$

where SP is the expected spatial probability values of modelled hazard zones (either a map or a value between 0 and 1) depending on data availability and considered hazard event/type; *V* is the level of potential damage (or degree of loss) of the affected elements-at-risk resulting from the hazard event of a given intensity (Fell and Hartford, 1997); *A* is the quantity (number of people) or economic (monetary) value of the affected elements-at-risk.

In this study, only the *physical vulnerability* of the elements at risk is being considered. The physical vulnerability represents the expected level of damage and can be quantified on a scale of 0 (no damage) to 1 (totally destroyed) in function of the intensity of the phenomenon (Fell et al., 2005). In the prototype, vulnerability data can be represented in the form of data ranges (i.e. a range of minimum and maximum intensity values corresponding to a certain minimum and maximum vulnerability value) or a function with or without class (type) information for a specific category of elements at risk. An example of vulnerability curve is illustrated by the cumulative distribution function (CDF) in Fig. 4.2, with its defining equation (Kotz and van Drop, 2004; Haimes, 2008):

$$CDF = F(x) = \begin{cases} 0, x < a \\ \dfrac{(x-a)^2}{(b-a)(c-a)}, a \leq x \leq c \\ 1 - \dfrac{(b-x)^2}{(b-a)(b-c)}, c < x \leq b \\ 1, x > b \end{cases} \quad (4.2)$$

where *x* is a given intensity value; *a* is the lowest intensity value; *b* is the highest intensity value; *c* is a varying value between *a* and *b* values. The CDF is initiated as an example to experiment the possibility of applying a certain vulnerability curve (function) in the loss calculation of this prototype version. The parameter values used to generate this curve are fed directly by the expert user (after having the possibility to perform a detailed analysis outside of the web platform). Therefore, uncertainties could be associated with the expert knowledge of the users.

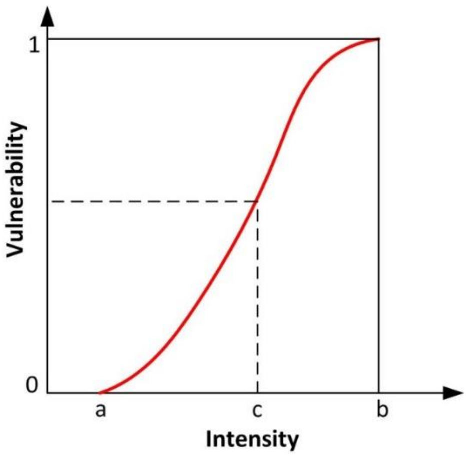


Figure 4.2. An example illustration of a generic vulnerability curve using a Cumulative Distribution Function (CDF). The input parameters a, b and c are obtained from the user to generate the vulnerability curve with or without class (type) information for a certain category of elements-at-risk.

The resulting loss scenarios (either fatalities or damages) of a specific hazard event with different return periods are then combined to compute the annualized "risk" total (R) per year. It can be represented in the form of a risk curve (van Westen et al., 2010). In this study, the staircase-shaped curve is applied for the calculation of total risk as illustrated in Fig. 4.3, showing the contribution of the selected loss scenarios to the annualized total risk (R). Therefore, the resulting annualized risk here represents the area below the staircase rather than the area under the fitted (black) curve of the combination of frequency and loss of all scenarios:

$$R = \sum_j R_j \tag{4.3}$$

$$R_j = f_j \times L_j \tag{4.4}$$

$$f_j = f(L_j) = \frac{1}{T_j} - \frac{1}{T_{j+1}} \tag{4.5}$$

where R_j is the annual risk of the scenario j; f_j is the frequency (inverse of the return period T) of the scenario j; L_j is the loss of the scenario j.

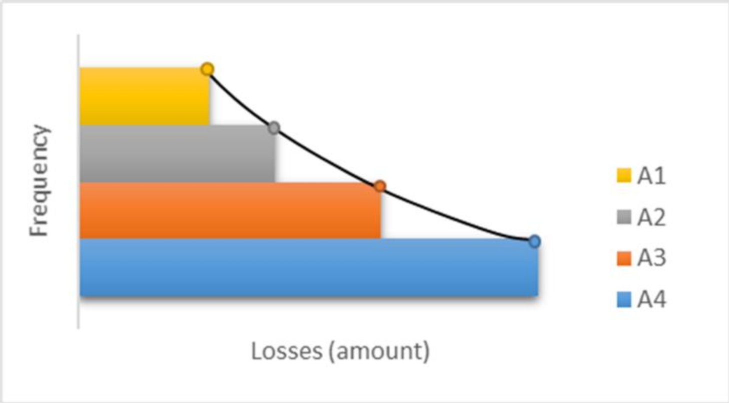


Figure 4.3. An example of risk curve in the form of staircase. A1–A4 represents the area derived from the loss calculation for four return periods. Each A1–A4 contributes to the risk total (R) of the considered hazard event (e.g. debris flows).

A simple conceptualized diagram for the generation of loss and risk scenarios is shown in Fig. 4.4, where hazard (e.g. debris flows) scenarios with different return periods are overlaid with the elements-at-risk map (e.g. buildings) in order to obtain the intensity associated with each affected object and calculate their vulnerability values, which are finally multiplied with the amount or value of the affected objects. The spatial probability values of the hazard scenarios are also considered in the loss calculation, if available. These resultant loss scenarios are then combined to obtain the total annualized risk. The background layers of debris flows (Hussin et al., 2014a), building maps and vulnerability curves of the example illustrated in Fig. 4.4 are parts of the research results of two European projects: CHANGES and IncREO.

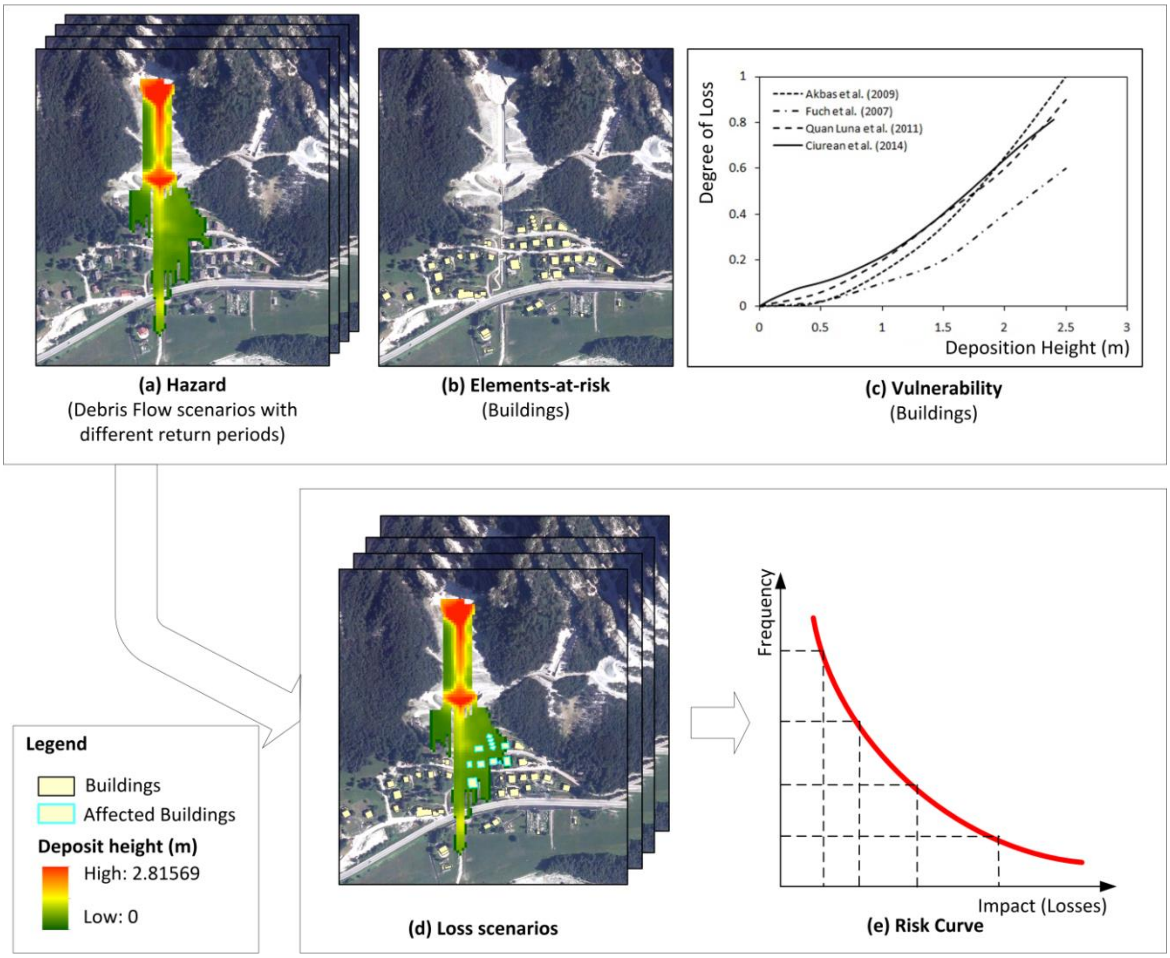


Figure 4.4. A simple illustration of the generation of loss scenarios and risk curve (adopted from van Westen et al., 2014 with data from Ciurean et al., 2014; Hussin et al., 2014a). (a) Debris flow scenarios with varying colours represent the deposit height (m) of accumulated debris materials for four return periods. (b) Building map consists of the related information such as value and material type of each building. (c) Vulnerability curves of the buildings illustrate a comparison of the considered area's debris flow vulnerability curve with existing ones from the literature. (d) The generated loss scenarios based on (a), (b) and (c). (e) The final risk curve derived from the combination of four loss scenarios with its respective frequency.

4.2.2 Workflow of the risk analysis module

The conceptual workflow of the loss component (Fig. 4.5) is composed of three main parts: hazard, elements-at-risk and vulnerability information. In a first step, the user can select an uploaded hazard map of a certain hazard type. The spatial probability information (either as map or value) can be entered depending on the availability of spatial probability information and selected hazard type. This spatial probability value is given based on the knowledge of the expert user and thus, it can be subjective. If no information is given or available, a spatial probability value of 1 is assumed in the calculation. The user can then move to a second step for the selection of the corresponding elements-at-risk map and enter additional information such as the amount (cost values) and type (class) information depending on the chosen elements at risk, if available. This input information is important in the loss calculation not only to match the existing attributes of a given elements at risk with its corresponding vulnerability information in the next step but also to calculate the estimation of damages. For example, in the case of buildings, the user can indicate the amount (monetary) value and building type (e.g. reinforced concrete, masonry, etc.) information within the selected buildings layer. If no amount information is given or available, only number of affected elements-at-risk calculation is possible (e.g. the number of buildings exposed to the selected hazard scenario). Finally, in a last step, if no vulnerability information is given or available, a vulnerability value of 1 (complete damage) is assumed. If vulnerability data are available, the user can indicate whether it is a "data ranges" or "function", which is either uploaded or created in the data management module by the user. The user then matches the selected vulnerability information with the given class (type) information of the selected elements-at-risk layer. Finally, the loss scenario is calculated on the fly based on these given input data. The resulting calculated loss scenario can be visualized interactively in the web-GIS interface of the platform. This process is repeated for all available hazard scenarios with different return periods and for all elements at risk. The option of setting the spatial probability and vulnerability values to 1 is made available in the case where the associated spatial probability of a hazard event or vulnerability information of elements at risk is not available. Since lack of data is an issue in reality and it is not always possible to obtain a complete data set.

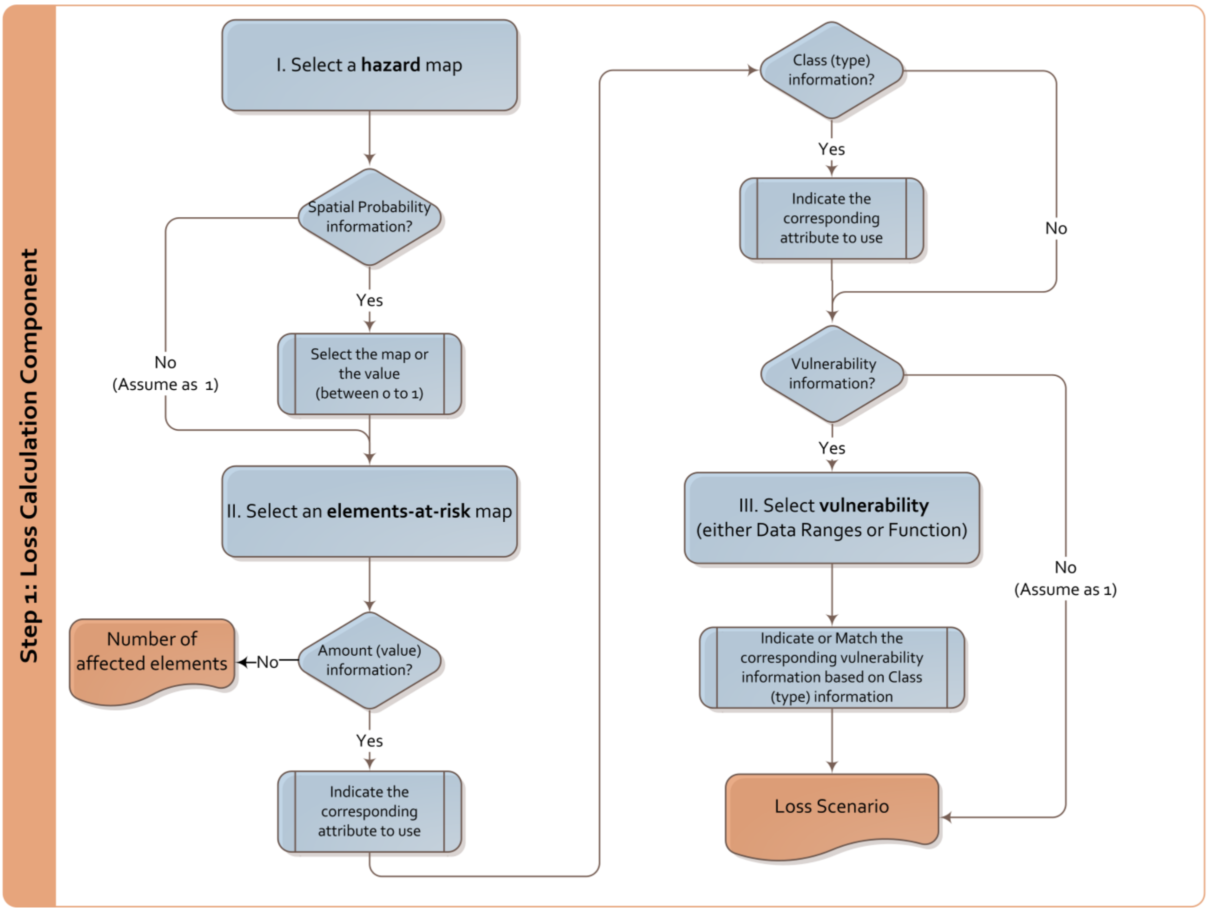


Figure 4.5. Workflow of the loss calculation component, illustrating the three main types of input information (hazard, elements at risk and vulnerability) with additional parameters for the generation of loss scenarios. For example, if the buildings (as elements at risk) have no amount (monetary) information, only the affected number of buildings can be obtained.

The resulting loss scenarios with different return periods are then combined to produce an annualized risk based on the staircase approach as mentioned above in Eq. (4.3) and Fig. 4.3. At least three different loss scenarios of the same hazard event with different return periods are required to calculate the annualized risk and visualize the risk curve within the platform. This process starts with the summation (aggregation) of the losses (L_j) for each loss scenario of a certain elements-at-risk. Then, each loss total is multiplied with the respective frequency value ($f_j = 1/T_j - 1/T_{j+1}$) to obtain the annual risk (R_j) for each step of the staircase curve (Fig. 4.3), and finally, the summation of all steps (R_j) produces the total annualized risk (R) for the considered hazard event. The step-by-step conceptual workflow of this risk calculation component is shown in Fig. 4.6, and this process can be repeated for different types of hazards. In the current version of the prototype, we did not consider whether hazards are dependent or not. Moreover, we only considered calculating the area under the staircase-shaped curve, and therefore, there are possibilities to improve the calculation of the entire area under the curve. In addition, the calculation was carried out for the whole study area rather than per administrative units.

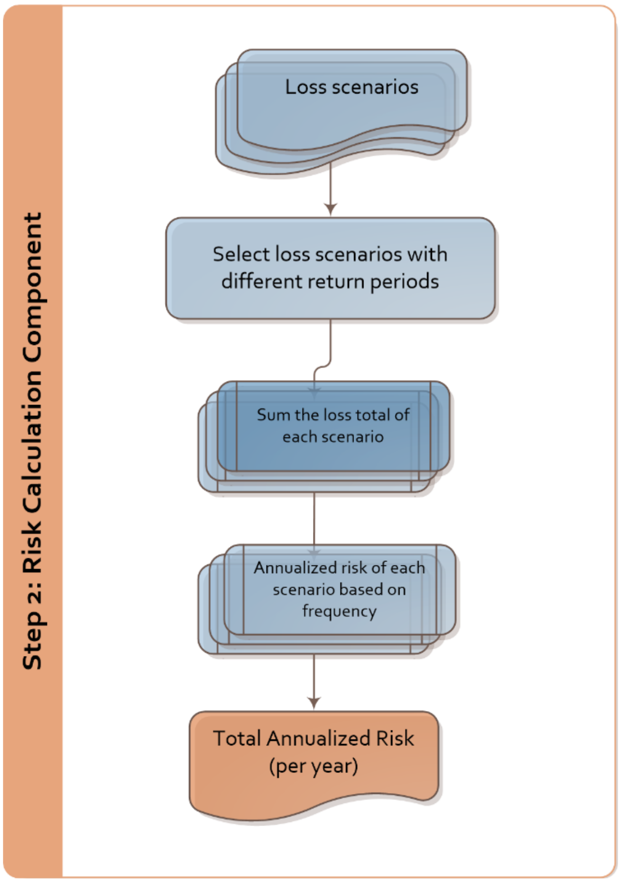


Figure 4.6. Workflow of the risk calculation component. The loss scenarios with different return periods are combined to obtain the total annualized risk (per year) based on the staircase approach.

4.2.3 Background architecture

The background architecture of the platform is based on the three-tier client-server architecture model, facilitating the maintenance and upgrade of the platform at a later time without needing the users to make changes at the client side (Sugumaran et al., 2004). The processing is done mainly on the server side and only a web browser is needed for the users to access the platform (Aye et al., 2015). The Boundless (formerly OpenGeo) framework was adopted to develop this prototype version of the platform. It offers a complete open-source geospatial architecture with modular components (Boundless, 2016). Only open-source components and standards are specifically chosen for the development of this web platform. The PostGIS database is integrated for data storage of spatial data. GeoServer and GeoWebCache are used for application servers to access and render the spatial data through web map services. GeoExt, ExtJS and Open-Layers (JavaScript libraries) are applied for the user interface framework of the interactive web map application across web browsers and mobiles. Moreover, it also provides a client-side software development kit (SDK) environment to build JavaScript-based, complete and customizable web mapping applications. This prototype platform is based on GXP template (a JavaScript SDK) for developing high-level GeoExt based applications with OpenLayers 2. The presented risk analysis and other supporting modules are developed as plugins (dependencies) within the platform. The possibility to develop such customized plugins makes the implemented tools extensible and reusable when and where needed, allowing a faster prototyping with integration of existing map tools and functionality in the web-GIS platform.

4.2.3.1 Schema design

A part of the data model of the prototype platform, focusing mainly on the presented risk analysis module, is illustrated in Fig. 4.7 together with its supporting data management module. (see Appendix IV for the full schema). The input information related to the hazards, elements-at-risk maps and vulnerability information are recorded in the tables of *hazards*, *elements-at-risk* and *vulnerability*, respectively. These three tables belong to the data management module.

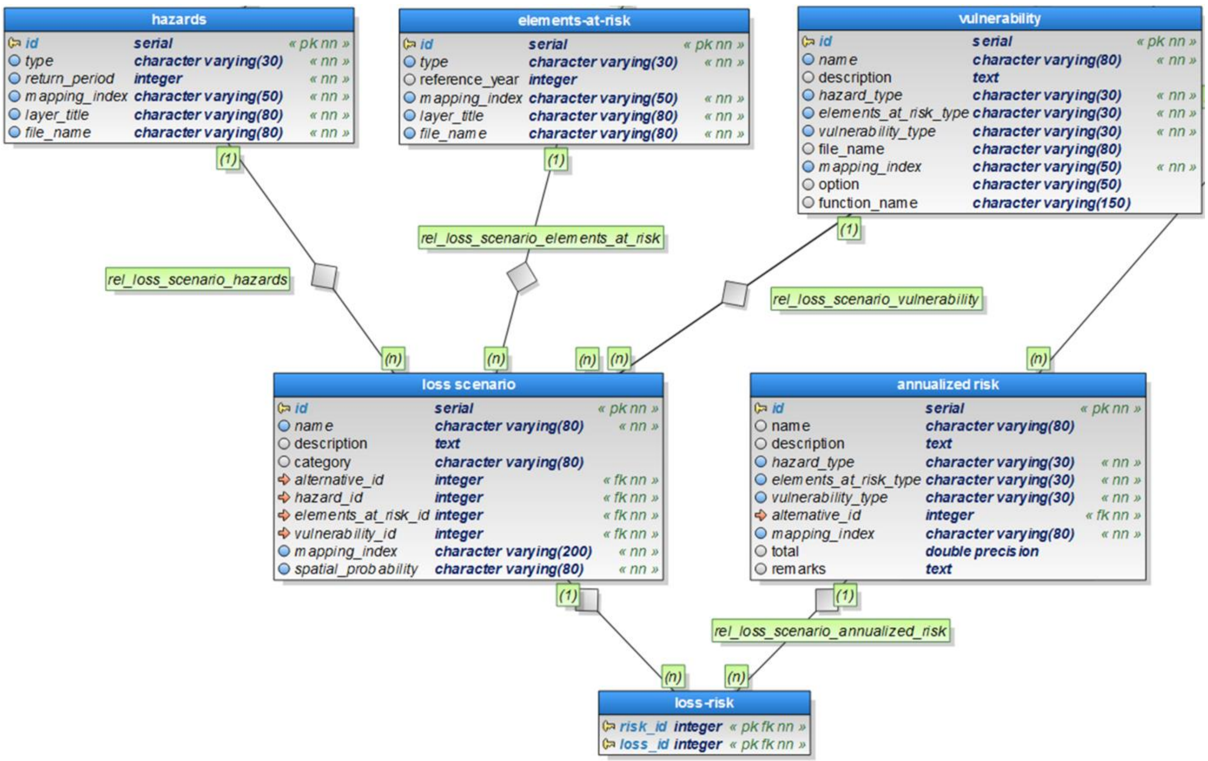


Figure 4.7. Data Model of Data Management (hazards, elements-at-risk and vulnerability tables) and Risk Analysis (loss scenario, loss-risk and annualized risk tables) modules. Three types of information can be seen in each table: the actual column name (e.g. id), the type of the column (e.g. serial) and the attribute of the column (e.g. <<pk nn>> represents that this is a primary key column and null values are not allowed for this column). For the full data model with other modules, see Figure 2 and 3 of Appendix IV.

The *hazards* table records the information related to each hazard map such as type (e.g. floods), return period (e.g. 100 years), name of the hazard map, etc. Similar type of information is also recorded in the *elements-at-risk* table for all elements-at-risk layers (e.g. replacement value, type and population information). In the *vulnerability* table, information related to vulnerability data or function curves is recorded. In all cases, the *mapping_index* attribute serves as an important look-up index to link each record in parent tables (e.g. *elements-at-risk*) with its corresponding child tables (e.g. Fella buildings) in the database and published layers in the GeoServer. The child tables are created dynamically upon the user uploads of layers (e.g. Fella buildings). Thus, such tables are not included (illustrated) in the fixed schema design of Fig. 4.7, and their respective column attributes can be varied depending on the uploaded data (see Figure 3 of Appendix IV for the illustration of such spatial tables). Like the other tables, the information related to each loss scenario such as name, description and category of the scenario is recorded in the *loss scenario* table, and this table is linked to the other three tables (*hazards*, *elements-at-risk* and *vulnerability*) in order to retrieve the input information which is necessary for the calculation of a specific loss scenario. For the follow-up calculation of the annualized total risk of a certain hazard with different return periods, this *loss scenario* table is linked with *annualized risk* table through a *loss-risk* table since a total risk scenario includes at least three or more loss scenarios with different return periods. The *annualized risk* table contains the information related to the calculated annualized risk total such as name, description and total amount (per year). The *mapping_index* attribute of this table links to its associated child table which stores the summary information of loss and annualized risk for considered return periods of a certain hazard event.

4.2.3.2 Processing steps for calculating losses and risk

For the loss calculation component, the processing is done mainly within the PostGIS database on the server side and the results of each calculated scenario are published to GeoServer for visualization in the web platform. GeoServer's REST (Representation State Transfer) configuration is used to programmatically configure operations such as creating a new feature type or data store in GeoServer. These published layers can be visualized and edited within the web-GIS interface through Web Map Services (WMS) and Web Feature Services (WFS) of OGC (Open Geospatial Consortium) standards. In the Data Management module, map layers (hazard maps in raster format, and elements-at-risk maps in vector format) can be imported into the database and GeoServer for processing and visualization. The vector layers are stored in a data store linked to the PostGIS database. However, the raster layers are stored separately in a coverage store and in the PostGIS database without having the link between them. For this purpose, the *raster2pgsql* tool (a raster loader for raster data into a PostGIS raster table) is used through a PHP (a server-side scripting language) script to store the uploaded raster in the PostGIS database for the loss calculation.

The algorithm for the calculation of a loss scenario within the database has the following steps (buildings as elements-at-risk, in this case):

1. Create a loss table populated with the records derived from the following sub-queries:
    a. Perform a spatial intersection (ST_Intersects) operation on the hazard intensity raster map and elements-at-risk map based on geometry (spatial) intersection;
    b. Perform a clip (ST_Clip) operation to crop the intersected raster;
    c. Perform a polygonised (ST_DumpAsPolygons) operation to obtain a geometry (in this case, a polygon) with values representing a raster band value;
    d. Perform count, minimum, maximum and average operations on pixel values of the clipped polygons to obtain the hazard intensity values, grouped and ordered by each affected unique identifier of the objects.
2. Add new columns to this created loss table and fill in the respective attribute values (based on the given input information) to calculate loss estimates as follows:
    a. Extract spatial probability values for each affected object (either from maps or given value);
    b. Extract vulnerability values for each affected object by mapping in the vulnerability look-up table or calculating using the given vulnerability function based on the respective intensity values;
    c. Extract the corresponding types and monetary values for each affected object by matching in the elements-at-risk map;
    d. Multiply spatial probability, vulnerability and amount value of each affected object as explained in Eq. (4.1) and update the loss table accordingly.

3. Register the record of this calculated loss table in the loss scenario table of Fig. 4.7, so that the information can be retrieved later.

As a final step, this calculated loss table is published to the GeoServer for visualization in the platform as mentioned above, using cURL (client URL) and GeoServer's REST configuration. This REST service facilitates the process between the client and GeoServer (e.g. in XML format, Extensible Markup Language) through HTTP (Hyper Text Transfer Protocol) calls to create, retrieve or update information of something in GeoServer – for example, to add a new style or change the name of a certain published layer in GeoServer (only if the logged-in user has the authorization to do so).

After calculating each loss scenario for different return periods of a considered hazard, the algorithm for the total annualized risk is performed as follows:

1. Create a total risk table that stores the information about a collection of considered loss scenarios (i.e. return period, frequency, number of affected elements-at-risk, loss and annual risk values)
    a. Populate the table with records of return period, frequency and its corresponding losses;
    b. Update the table's risk attribute value to compute the annual risk (the calculation as explained in Sect. 4.2.2 and Fig. 4.6)
2. Register the summed annual risk total record in the *annualized risk* table of Fig. 4.7 along with additional information.
3. Register the relationship record in the *loss-risk* table of Fig. 4.7 to link between loss and annual risk scenarios.

The snippets for loss and risk calculation are accessible at the following link for interested readers: https://bitbucket.org/snippets/zaye/.

4.3 Demonstration of the prototype

4.3.1 Case study of Fella River basin, Italy

The Fella River is a left tributary of the Tagliamento River, the dominant river system in the Friuli-Venezia Giulia region, northeastern Italy (Cattaneo et al., 2006). The study area is 247 km2 in size (Fig. 4.8) and the catchment has an average altitude and mean precipitation of 1140ma.s.l. and 1920 mm, respectively (Sangati, 2009). The drainage has a torrential regime due to the concentrated rainfall in intense and erosive showers, the steep topography and the lithology consisting a large part of limestone and dolomite. In addition, the area is seismically active and characterized by a high distribution of landslides (Borga et al., 2007). Extreme precipitation events leading to hydro-meteorological hazards such as flash floods, landslides and debris flows are frequent in the area, resulting in catastrophic consequences and damages to infrastructure worth hundreds of millions of euros and human casualties (Scolobig et al., 2008).

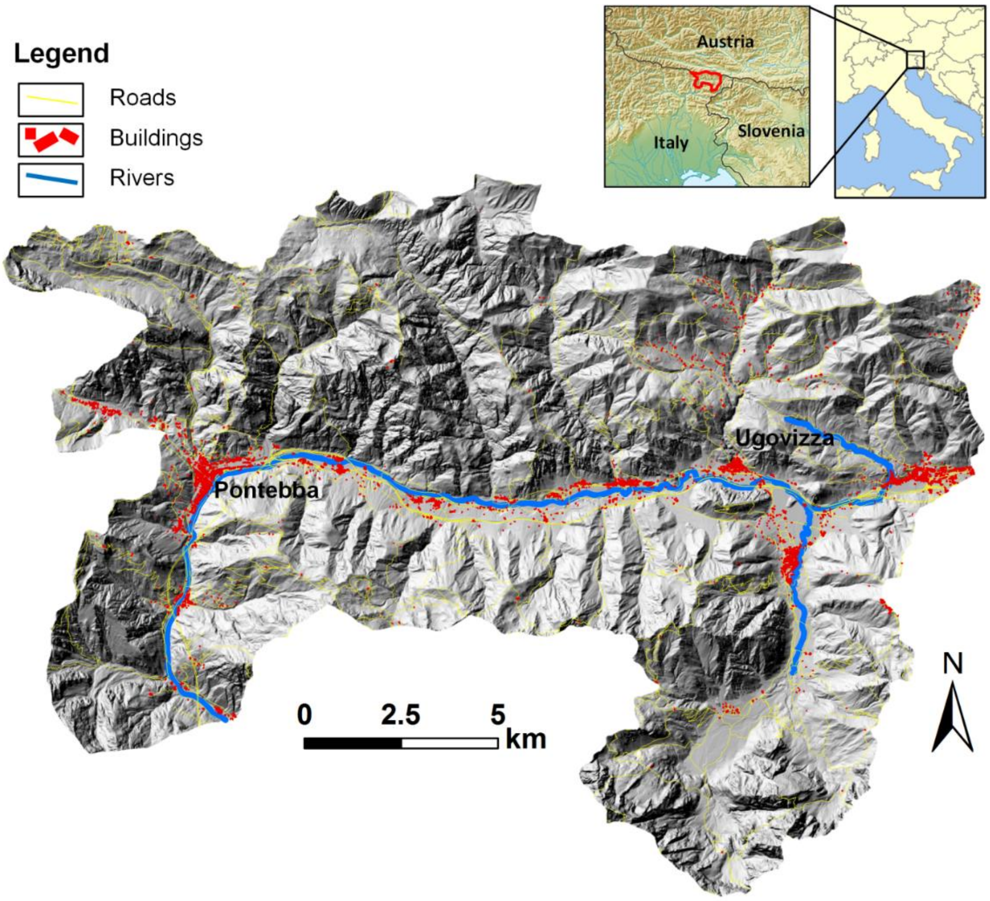


Figure 4.8. The Fella River study area, Friuli-Venezia Giulia region, northeastern Italy (Data from Chen et al., 2014; Ciurean et al., 2014; Hussin et al., 2014b).

In August 2003, a major alluvial event occurred, triggering landslides and debris flows mobilizing about 1 million cubic metres of debris material and causing a major flood on the whole Fella River basin (Fig. 4.9). Moreover, shallow and deep-seated landslides and flash flooding also occurred in this area (IncREO, 2014). Despite being scarcely populated, the valley represents an important transportation and communication corridor in the region, with a high interest of local authorities and population in tourism activities. Therefore, an expansion of touristic and recreational areas could result in more elements at risk affected and thus an increase in potential risks to hydrometeorological hazards.

Figure 4.9. Debris flow events in Fella River basin in August 2003 (©Civil Protection of Friuli-Venezia Giulia region, Italy).

4.3.2 Fella River data set

For debris flow hazards, four types of events have been modelled by Hussin et al. (2014b): frequent, minor, moderate and major with related estimated return periods of 1–10 years, 10–25 years, 25–100 years and 100–500 years, respectively. This model is an empirical regional-scale model with some limitations that gives only the run-out extent. By using the expert-based approach and comparing with past events, impact pressure intensities are given to these run-outs. The modelled impact pressure (in KPa) is considered as the intensity parameter for the debris flows. Figure 4.10 illustrates the major debris flow event of a part of the Fella study area for the return periods of 100–500 years. The modelled debris flows have not all occurred. However, they are all possible debris flows that could occur in the study area if they were to be triggered, and based on a susceptibility analysis of the most likely areas to be debris flow sources in the future. Their intensities (including run-out distance and extent) correspond to similar events with a return period scenario that have occurred in the past. The set of modelled debris flows were simulated according to a calibration with debris flow events occurring in each return period scenario.

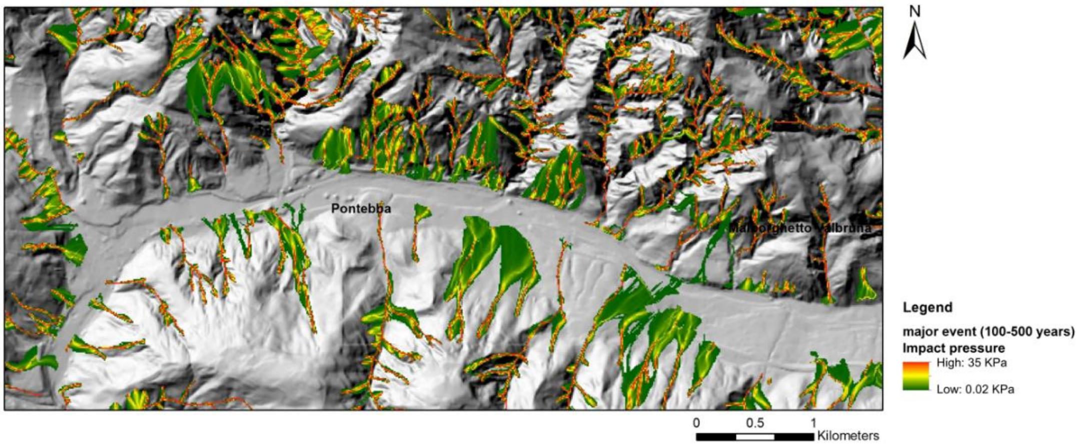


Figure 4.10. Debris flow (maximum intensity) of major event with return periods of 100–500 years (Hussin et al., 2014b).

The elements-at-risk database contains information about building characteristics such as location, occupancy type, material of construction, number of floors, building's value (minimum and maximum) and number of people occupying the building (during tourist and non-tourist seasons) (Ciurean et al., 2014). The building database was developed using an initial digital data set which was subsequently updated and validated through GIS-desktop and field mapping, which gave information about the building geometry, type, use, etc. Building value was calculated based on existing cadastral information, whereas population at individual building level was estimated using a dasymetric mapping technique. An illustration of the building classification based on construction material and numbers of floors in Pontebba commune is given in Fig. 4.11.

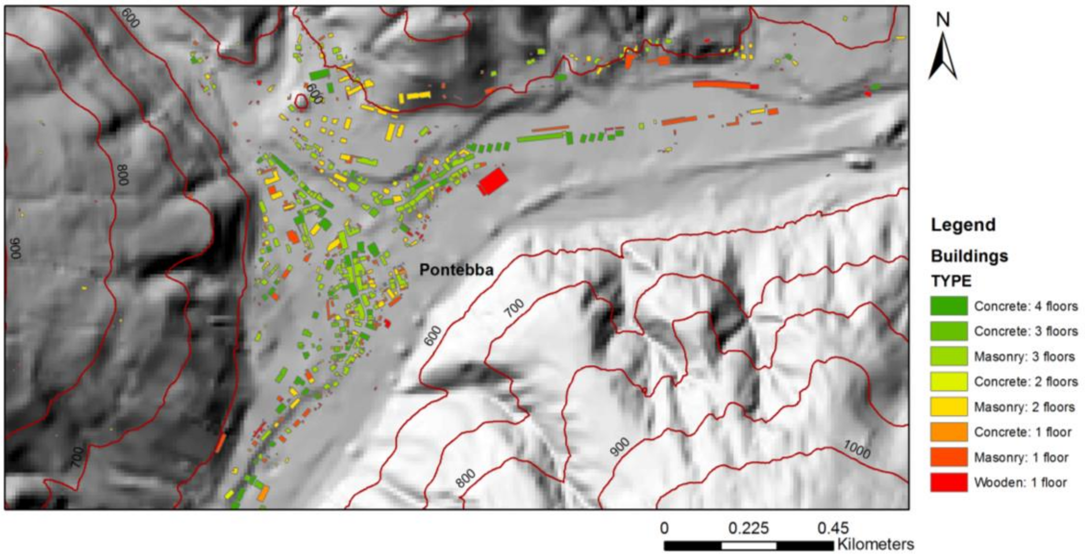
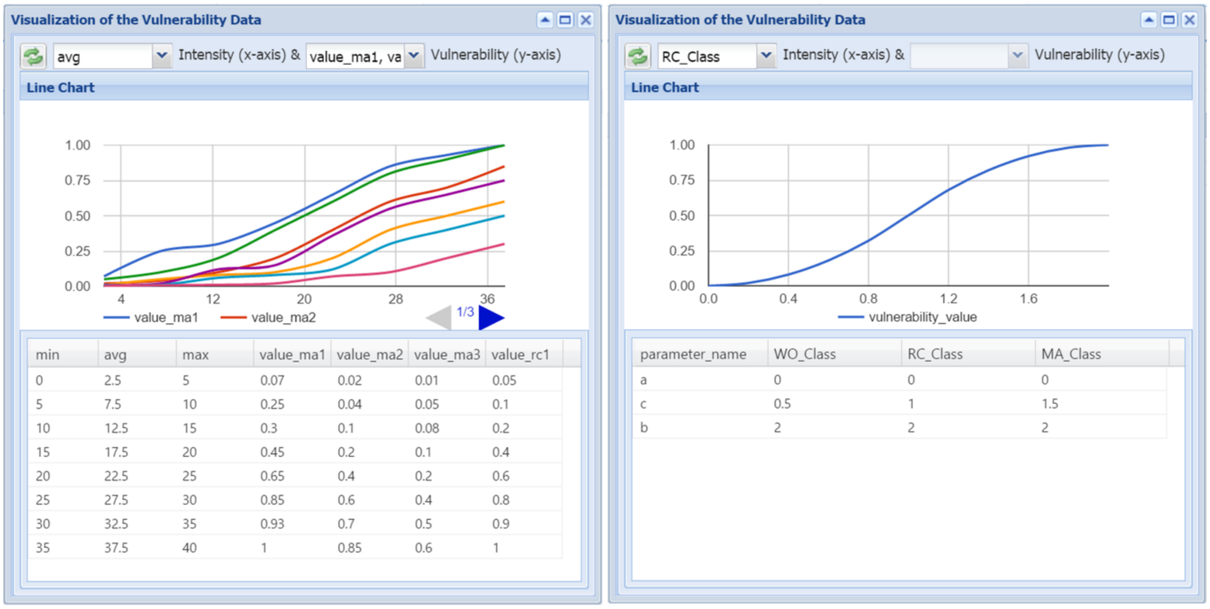


Figure 4.11. Classified building information in Pontebba commune, Fella River basin (Ciurean et al., 2014).

4.3.3 Uploading of Fella data in the data management module

As a first step to calculate loss and risk scenarios, the input data needs to be imported into the platform through the data management module, i.e. hazard intensity maps, elements-at-risk maps and associated vulnerability information. If available, the spatial probability map associated with a certain hazard event can also be uploaded into the system to be included in the calculation. For example, spatial probability of debris flow can be calculated by overlaying the modelled debris flow areas with actual inventories corresponding to each return period. All debris flow areas that are part of the historical inventory are given a spatial probability of 1. The spatial probability of the simulated debris flows that do not overlap with past events are calculated by dividing the total area of the historical events of a given return period scenario by the total area of the modelled debris flows of that scenario (Hussin et al., 2014b). The users can upload data in .tiff format for raster images or zip format for vector shapefiles. The additional properties of the imported layers are also recorded in the system, such as type and return period (in case of hazards), and the indication of whether the imported map reflects the current situation or a possible future situation after implementing certain measures (for risk reduction module of the platform). Upon successful upload of maps to the system, the users can visualize, edit, query and style the layers in the web-GIS interface of the platform.

For the vulnerability component, the user can enter data in the form of numerical values (data ranges) or functions to calculate vulnerability curves. The “data ranges” is a discrete range of minimum and maximum degree of loss values associated with the corresponding minimum and maximum intensity of a certain hazard event, and it can be uploaded by the users in .csv, excel and .txt formats. The “function” option is used to create a continuous CDF together with its specific parameter values, as defined by the users and explained in Eq. (4.2). The CDF must fulfil two mathematical requirements: (a) the depending variable, i.e. degree of loss, should be confined by the [0–1] interval; and (b) it should increase steady and monotonic with the interval of the explaining variable, i.e. intensity (Papathoma-Köhle et al., 2012). Such examples of probability functions are the Weibull, Fréchet, log-logistic, triangular, beta, etc. The visualization of vulnerability curves obtained by using both options is demonstrated in Fig. 4.12a and b, where the average curves obtained from a set of data ranges and a generic CDF are illustrated respectively. The import interfaces of the hazard and vulnerability components are included in Appendix I for demonstration.



(a) (b)

Figure 4.12. (a) Visualization of the vulnerability curves generated using data ranges. The curves are drawn based on the average intensity values for different building material types such as masonry 1 floor, reinforced concrete 1 floor, etc. (b) Visualization of the vulnerability curve generated using the CDF. The curve is drawn based on Eq. (4.2) for the building material type (e.g. reinforced concrete). The input parameter values a, b and c are given by the user.

4.3.4 Risk analysis module

Each loss scenario is then calculated in the Loss Component of the Risk Analysis module using the available maps and information in the system. As explained in Sect. 4.2.2, the loss component is composed of three main parts: hazards, elements-at-risk and vulnerability information for calculation of a new loss scenario (see Appendix I for the loss interface). The users can first select a “hazard” map amongst the existing ones depending on the hazard type (e.g. debris flows or floods) and its corresponding spatial probability data can be entered either in the form of map or input value in the range of 0 to 1. For the "elements-at-risk" part, the same concept applies, allowing the users to select an existing map (e.g. buildings) as well as to enter additional parameters such as amount (e.g. building value) or different class information (e.g. material type) of the selected elements-at-risk layer. Only the number of affected elements at risk can be calculated if no monetary information of the elements at risk is given. In the "vulnerability" part, the user can indicate whether vulnerability information is available or not. In the case of no information, we assume that the affected elements will be totally destroyed (i.e. vulnerability value equals 1) regardless of hazard intensity. If not, the user can select the available vulnerability information based on its data type (either data ranges or function). Then, the user can match the vulnerability data with classes of objects (e.g. material types) accordingly to retrieve the corresponding vulnerability value of a certain intensity level on each affected object.

Based on these three types of input information, a new loss scenario is calculated according to the loss algorithm described in Sect. 4.2.3.2. Thereafter, the user can visualize each calculated loss scenario (Fig. 4.13) where the economic loss (damage) of each affected building by the debris flow hazard can be seen in the pop-up of the map interface. The additional information used to calculate the loss is also presented such as minimum, maximum and average intensity values, vulnerability value based on the building's material type, spatial probability and monetary value of the building.

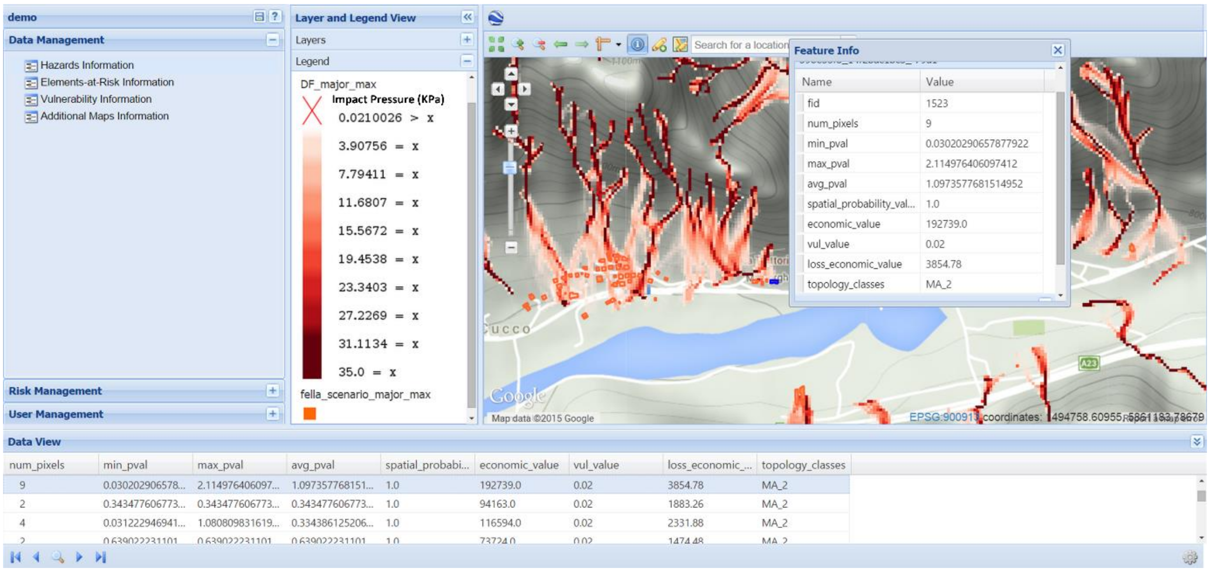


Figure 4.13. Visualization of the calculated loss scenario, illustrating the affected buildings with economic losses for the debris flow major event (maximum intensity in KPa).

This loss calculation process is repeated for all return periods of a given hazard (in this case, debris flows). After that, these loss scenarios with different return periods of the debris flow event are combined to calculate the annualized risk, as mentioned in Sect. 4.2.3.2. At least three or more loss scenarios with different return periods are required for the Risk Component of this module (see Appendix I for the risk interface). The visualization of calculated minimum (Fig. 4.14a) and maximum (Fig. 4.14b) risk curves for debris flow events in the Fella River study area is demonstrated, along with affected number of buildings and their corresponding losses for each return period of the calculated scenarios.

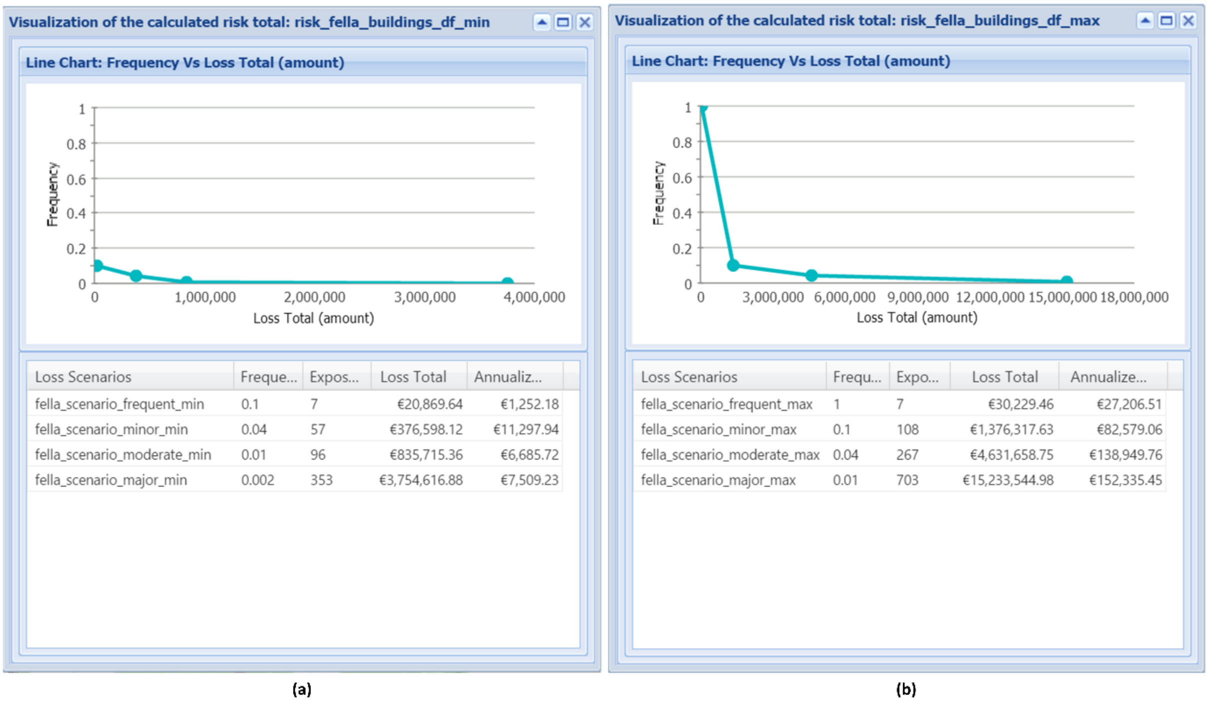


Figure 4.14. (a) Visualization of the debris flow risk curve (minimum). (b) Visualization of the debris flow risk curve (maximum).

According to the calculation results, Fig. 4.14 shows that high return period events (i.e. low-frequency events) caused higher losses compared to the low return period events (i.e. high-frequency events). For the maximum intensity scenarios of debris flow, the economic losses of the major event reached EUR 15 million (703 houses were affected) while the most frequent event was only EUR30 thousand (seven houses were affected). The variation in risk estimation can be indicated with minimum and maximum values of total economic losses – for example, in the case of major debris flow event, the difference ranges from EUR 3.7 to 15 million. The total annualized risk for debris flow is estimated approximately from EUR 0.026 to 0.4 million (for minimum and maximum scenarios, respectively).

For the same study area, risk assessment has been carried out by Chen et al. (2014) in which a multi-hazard quantitative risk assessment model was developed using a historical hazard inventory and GIS technology for risk curves generation and annualized risk calculation. The results of the web-GIS risk analysis tool were compared with the ones produced by Chen et al. (2014). For number of affected buildings, the difference varied from 0 to 100 with an increase in return periods of the events. Fewer buildings were affected as a result of calculations in the web-GIS tool with a difference of 4–10 buildings for minor events, 38–40 buildings for moderate events and 90–100 buildings for major events, while there was no difference for frequent events. Within the web-GIS tool, 5x5m cell sizes of the debris flow raster maps (with 100x100m tile sizes) were used for calculation within the PostGIS database. This cell grid size (5x5 m) was chosen since it gives better approximate results when compared to Chen et al. (2014), according to the test results obtained by using different cell size raster maps. If a building polygon was overlapped to multiple pixels of the debris flow raster map, the maximum intensity value of the overlapping pixels was used to retrieve the vulnerability value for loss calculation. A spatial probability value of 1 was applied in the loss calculation for the underestimated (modelled) debris flow maps. This value was chosen based on the expert knowledge and assumption that this area witnessed debris flows in the past completely (i.e. historic debris flow events). Debris flows that have occurred in channels in the past are more likely to also occur in the future. Due to discrepancies in raster cell size and spatial probability values, the calculated loss values showed a difference of about EUR7 million for major events while comparable results were achieved for moderate, minor and frequent events.

4.4 Discussion and conclusion

This chapter has presented the design and development of a web-based risk analysis tool which aims to assist in analysing the impact of flood and landslide events on society and people, with the demonstration of the prototype using a data set from Fella River basin located in north-eastern Italy, where frequent floods and landslides occur with severe consequences for the infrastructure and mountainous community in the region. The presented tool is developed as a module of a prototype decision support platform so that the risk managers can not only analyse areas at risk but also formulate and compare different risk reduction measures with involvement of other stakeholders from different institutions and organizations (see Chapter 5 for the collaborative framework of the platform). This risk analysis tool has been developed based on the feedback of local stakeholders during a workshop organized in Malborghetto

Valbruna municipality of Fella River basin in September 2014. The stakeholders indicated their strong interest in the potential development of a spatial-query-based risk analysis tool along with a cost–benefit analysis tool for comparison of different risk reduction measures in the area. As a first step, this prototype scenario-based risk analysis module was developed. As stakeholders suggested, the possibility of integrating a spatial-query-based tool could further facilitate the risk analysis process in a much more interactive, query-based environment (for example, drawing a polygon query for risk calculation in the web-GIS interface of the platform for a certain area of interest).

This prototype represents an essential step towards a more complex risk analysis platform. Further improvements of the developed risk analysis tool can be identified. For example, the vulnerability component could be advanced with the integration of additional vulnerability curves for specific hazards and elements-at-risk types. For the loss component, at its current state, loss scenarios are calculated one by one based on input parameters, and therefore, the manual input iteration time of the same process could be reduced with the integration of a batch processing mode. This can be done for all loss combinations of hazards with different return periods and elements-at-risk scenarios. The uncertainty of the chosen input parameters in the process should also be communicated to the user. Besides, it is also planned to integrate qualitative hazard intensity layers in vector format in the loss calculation. For the risk component, more accurate ways of calculating the total annualized risk under the area of risk curves (i.e. over the combination of loss scenarios with frequency) could be explored, and visualization of risk curves could be improved by considering different hazards for multi-hazard risk assessment. In this study, all input data required were available and imported into the platform. However, availability of hazard intensity (raster) maps and elements-at-risk information can be rather limited for such kind of full quantitative risk analysis, especially in developing countries. Therefore, other approaches dealing with lack of data should also be further integrated within the platform – for example, a qualitative impact-probability matrix to assess and compare different situations for affected elements at risk at object level based on expert and local knowledge of the territory. Data scarcity can also be overcome through simulation based on value distribution for missing variables and/or adding variables to the existing data, and this would lead to obtaining exceedance curves by running several and random simulations.

This prototype tool was developed based on Boundless architecture and its client-side environment due to its flexible and extensible open-source components, making it possible to implement a faster prototyping of the tool. Regarding technical improvements of the tool, the loss scenarios were generated in the spatial database hosted on the server side of the web application. Therefore, raster and vector layers had to be imported into the database to perform spatial operations and published to GeoServer for visualization purposes in the platform. If the calculation processing of loss scenarios could be directly carried out using Web Processing Services (WPS), the importation and publishing procedures to the database and GeoServer could be minimized. Furthermore, moving forward to implementing WPS for loss and risk calculation could assist in particular for recalculation of loss and risk scenarios dynamically for different risk reduction measures, at least for preliminary risk calculations without needing the users to re-upload the new updated hazard raster maps. In that case, it would greatly simplify and reduce the complexity of the steps used to recalculate risk for reduction measures, which is required for the risk reduction module of the platform. Additionally, risk calculation could benefit from the use of remote data sources from other available web map servers and services provided by responsible organizations of the study area.

To conclude, regardless of some limitations of the presented approach, the prototype tool was successfully realized as one of the main outcomes of the decision support platform, and its possible application was demonstrated to the stakeholders and tested using a real data set from the Fella River basin study area. This prototype plays an important role in obtaining feedback and suggestions from potential stakeholders and users of the application, possibly leading to a full-scale development of the system based on a user-centred designed approach. Additionally, rather than being a standalone risk analysis tool, this tool has been integrated within a decision support platform. The great benefit lies in achieving an integrated risk management framework which supports the end users and stakeholders in better understanding the entire process of risk management starting from risk identification to the selection of risk management strategies, while providing a centralized and collaborative multi-users platform. Furthermore, this simple risk analysis tool is developed based on a generalized framework with use of open-source software and architecture, and hence it offers a high degree of replicability and mobility in other study areas. Unlike desktop-based applications, the end users need not install additional plug-ins or GIS software to analyse risk, and the resultant risk information can be visualized and shared amongst the users for efficient communication and dissemination over the web, benefiting from web-GIS and web technologies. Several functionalities for improvements are possible for future development such as qualitative impact-probability matrix for risk analysis at object levels, integration of additional vulnerability curves and simulation approaches as well as for working with (semi) qualitative hazard intensity maps.

Some of the mentioned aspects to be improved in this work (such as CBA, spatial query-based and qualitative vector-based hazard intensity layers for loss calculation) are already considered and included in an on-going research project for natural hazards and risk management in Canton Vaud, Switzerland.

Chapter 5: Collaborative risk management framework

This chapter presents a collaborative framework of an interactive web-GIS platform integrated with a multi-criteria evaluation tool for the second component of the decision support platform. The objective is to support the engagement of different stakeholders and the encouragement of a collaborative, decision-making process for flood and landslide management. The conceptual framework is based on initial data collected from field visits and stakeholder meetings carried out in three case study areas of the CHANGES project: the Małopolska Voivodeship of Poland, Buzău County of Romania and the Friuli-Venezia-Giulia region of Italy. Based on the needs and issues identified in each case study, this chapter also presents how such a platform could potentially assist and enhance the interactions between risk management stakeholders in formulating and selecting risk management measures. The developed prototype was presented to the local and regional stakeholders of the study areas and feedback was collected to understand the stakeholders' perspectives in determining whether the platform is useful and applicable for their activities in risk management. Feedback from stakeholder responses indicates that stakeholders found the prototype not only useful, but innovative and supportive in potentially assisting their activities. However, feedback also highlighted several aspects of the platform that can be improved for the development of a full-scale system to apply in practice. This includes the engagement of stakeholders toward higher levels of participation and a more extensive evaluation of the platform by carrying out concrete group exercises in the study areas.

This chapter is extracted and modified based on the published peer-reviewed ISI journal articles:

- Aye, Z. C., Sprague, T., Cortes, V. J., Prenger-Berninghoff, K., Jaboyedoff, M., Derron, M.-H.: A collaborative (web-GIS) framework based on empirical data collected from three case studies in Europe for risk management of hydro-meteorological hazards, *International Journal of Disaster Risk Reduction*., 15, 10-23, doi:10.1016/j.ijdrr.2015.12.001, 2016.
- Aye, Z. C., Jaboyedoff, M., Derron, M.-H., and van Westen, C. J.: Prototype of a web-based participative decision support platform in natural hazards and risk management, *ISPRS International Journal of Geo-Information*., 4(3), 1201-1224, doi: 10.3390/ijgi4031201, 2015.

5.1 Introduction

In broad terms, collaborative decision-making within the context of disaster risk management can be defined as the "combination and utilization of resources and management tools by several entities to achieve a common goal" (Kapucu and Garayev, 2011, p. 366). Collaborative interactions are increasingly required under complex decision-making processes to facilitate knowledge and contributions of different stakeholders and actors towards better-informed decisions (Edelenbos et al., 2011; Failing et al., 2007). These interactions may evolve throughout the different stages of a decision-making process (Bardach, 2005; Jankowski et al., 1997; Ranger et al., 2010). In practice, decision-making processes for risk management vary depending on a variety of factors including which stakeholders and actors are involved in the process, what are the mechanisms of deliberation, what are the values and interests of the involved parties, and the spatial distribution of risks. In the case of widespread spatial distribution of risk, for example, multiple municipal jurisdictions and higher (whether it be regional or even national) levels of authority will be involved in the management process. The degree to which different actors are involved depends also on the legal and regulatory structure in place which can prescribe both formally and informally the roles and responsibilities of the different actors.

The term "actor" is understood as apart from the term "stakeholder" as it describes the agents of action in decision making, referring quite literally to who can take actions and have power in the decision-making process. Borrowing from Scharpf (1997, p. 43), actors are identified as individuals or entities "…that are actually involved in the policy process and whose choices will ultimately determine the outcome". In a broader sense, the term "stakeholder" means any individual, group, or organization which has an interest in the issue at hand, as well as those who are potentially affected by decisions, actions, and plans (Baede et al., 2007, p. 87), including individuals who are not aware that they will be affected. There are overlaps between the two terms where, for example, a mayor has both an interest and power in decision making for reducing risk in his or her community. In contrast, a member of the general public may have an interest in the outcome of a risk reduction measure decision but might not have any power in the decision-making process.

It is important to establish an understanding of the key actors and stakeholders as they often determine priorities for risk reduction goals and influence the formulation and selection of risk reduction measures. The outcome of the selection of measures varies depending upon the perceived benefits of these measures given the available information. Risk management measures targeting flood and landslide risks must also account for information including both the temporal and spatial dynamics of the hazard itself and the distribution and vulnerability of elements at risk (Fuchs et al., 2013). Uncertainties in the spatial-temporal distribution of risks often require a combination of measures, grouped into management alternatives. Hence, the identification of potential alternatives is a continuous iterative process to achieve a specific combination of measures towards implementing risk management strategies (Hutter, 2006). In addition, the complexity of the decision-making process increases due to the different and competing objectives which should be considered in the evaluation of alternatives (for example, immediate vs. sustainable benefits in the long term). According to Balbi et al. (2012), decision criteria are related not only to direct costs or benefits from the implementation, but also to other indirect and non-tangible aspects such as socio-economic development and environmental protection. Consideration of these many aspects supports the use of multi-criteria evaluation (MCE) tools that can facilitate the evaluation of the variety of consequences in a risk management problem without measuring them only at the monetary scale (Meyer et al., 2007). These tools can be used in combination with GIS and spatial information technologies through online platforms to reach and involve a wide range of stakeholders and actors in the decision-making process.

Due to the rapid development in modern web, GIS, and spatial information technologies, it has become possible to deliver and communicate risk information to a wider range of communities, facilitating the participation of different stakeholders in collaborative decision-making. Rapid exchange of spatial information can be enabled through web-GIS platforms shared by several entities allowing access to risk related information at various spatial and temporal scales. These platforms can feature decision support systems (DSS), which are widely recognized as computer-based systems developed to assist decision makers through interactive tools to enhance understanding of a management problem (Salewicz and Nakayama, 2004). DSSs generally go beyond the need of centralizing all necessary information while assisting in the interpretation of available knowledge, formulation, and evaluation of choices (Rizzoli and Young, 1997). Such systems can thereby assist problem analysis without taking over the decision maker's responsibility for their choices and actions (Harsh et al., 1989). The main goal and expected outputs of the decision support applications should be discussed and agreed with those who are involved in the use of these applications. Prototypes of these decision support applications provide a form of user requirement analysis (Evers, 2008) and can facilitate the contribution and integration of the needs of potential users, evaluation and potential improvement of the support system itself (Mysiak et al., 2005).

In this chapter, a collaborative decision support framework for the management of hydro-meteorological risks, integrating an interactive web-GIS interface with a MCE tool is presented. The aim is to assist stakeholders in the formulation of potential risk reduction measures and the elucidation of criteria preferences for the selection of those measures. The preliminary empirical inputs of the framework were based on initial data collection methods in the form of semi-structured interviews and observations obtained from field visits and stakeholder meetings carried out in three case study areas: the Małopolska Voivodeship of Poland, Buzău County of Romania and the Friuli-Venezia-Giulia region of Italy (as shown in Fig. 5.1). These cases were chosen primarily based on their physical characteristics. All are located in mountainous areas prone to hazards including flash floods, river floods, landslides, and debris flows. A prototype was developed based on these preliminary empirical inputs and then presented to the stakeholders for feedback during the dissemination meetings of the project.

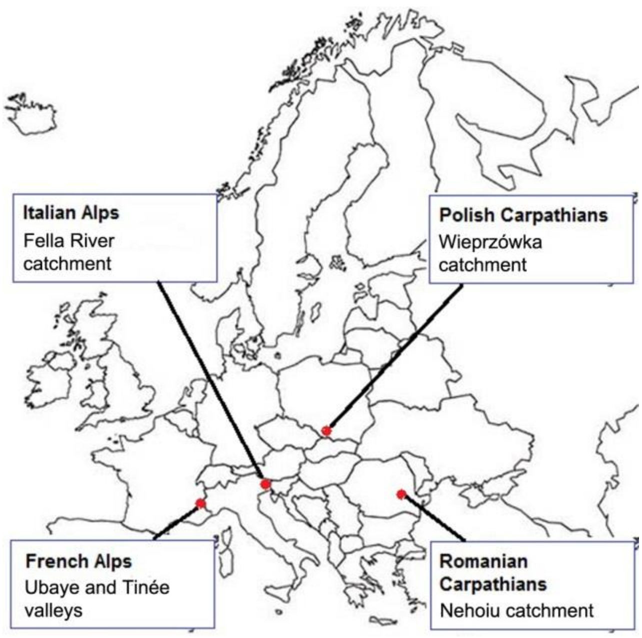


Figure 5.1. All case study sites of the CHANGES project (Source: Prenger-Berninghoff et al., 2014).

The structure of this chapter is organized as follows. Section 5.2 introduces the need for collaborative decision-making and interactions. Section 5.3 discusses important considerations in the development of a collaborative decision-making tool based on initial data collection from the case study areas, including for establishing an understanding of the key actors and about the potential for application of a web-based collaborative decision support platform. Section 5.4

describes the background methodology and workflow of the collaborative decision-making framework. Section 5.5 presents background architecture, data model design and additional specific configurations used for the development of the prototype. Section 5.6 demonstrates the prototype with an example case study area, Malborghetto Valbruna commune of Italy. Section 5.7 presents the feedback collected in different study areas and discusses how it could support and enhance collaboration and exchange activities between the participating actors. Finally, we conclude this chapter by discussing the presented framework and its potential for in-practice implementation along with relevant aspects for platform improvement.

5.2 Need for collaborative decision-making in risk management

One of the main problems in risk management is the lack of good communication as well as efficient and effective collaboration between the agencies, services and organizations in charge of risk prevention, mitigation and management (De Marchi and Scolobig, 2012). Collaborative decision-making addresses this issue and attempts to bring together all concerned parties across and within various horizontal and vertical levels. Encouraging collaboration helps establish individual and community ownership, legitimization of implemented policies and measures, and continued commitment and involvement in risk management efforts. An additional benefit is that collaboration provides an opportunity to enhance interactions between the involved stakeholders through improved cooperation and coordination for risk management activities (Gulati et al., 2012; Fuks et al., 2008). Collaborative decision-making generally takes place with “active” involvement of stakeholders. This “active” involvement is understood within this research to reflect the need for ownership in a given decision-making process in which stakeholders contribute ideas, influence decision-making criteria, and assist in selecting a final action (including non-action). In this way, stakeholders are invited to contribute actively in the planning and decision-making process in risk management.

In order to initiate collaborative decision-making in risk management, it is necessary to facilitate mechanisms and tools that support bringing different stakeholders together. Diverse interests, views and approaches need to be coordinated and cooperated so that effective risk management can be applied and implemented (Wanczura, 2006). This has also been stressed by the European Commission (2009), which underlines the requirement of linking all stakeholders involved in the development and implementation of measures that can significantly influence disaster prevention. However, often the management of natural risks is carried out by disconnected actors, especially those engaged in civil protection, sectoral[1] and spatial planning. Linkages and an exchange among actors involved do not always exist. Such a lack of collaboration may result in a lack of synergies and duplicated measures (Sapountzaki et al., 2011; Greiving et al., 2012). Mitigation measures derived from a collaborative effort can assist in the creation of a wide range of appropriate, acceptable, cost-effective, and sustainable risk management solutions that respect the characteristics, needs and priorities of a certain risk prone location and its inhabitants. Therefore, attempts should be made to link the diverse range of stakeholders in the field of risk management, especially as the key to an integrated risk management is the need to engage different stakeholders (i.e. involved experts, authorities, policy, decision-makers and civil society) in a participative and collaborative manner.

5.3 Preliminary empirical inputs from data collection in case study areas

Preliminary empirical inputs of the framework were based on semi-structured interviews and observations obtained from field visits and stakeholder meetings carried out in three case study areas of the project. The field visits were conducted in coordination with CHANGES project partners at the local and regional level of each case study site to ensure representation of both local and higher administrative levels. This enabled the ability to visit sites where past events have occurred, and to be in contact with those who had been affected by and who had dealt with the aftermath of these events. During meetings with stakeholders, semi-structured interviews were conducted with a list of guiding questions that were translated and asked in the native language. This list was comprised of open-ended general questions asked in each case and assisted in gathering information about past events, current issues, and potential interest in a decision support tool. Observations were additionally made following a general observational protocol created for the purpose of establishing a basic understanding of the physical aspects of the case study context and in identifying the key actors. The data obtained through the interviews and observations was analysed and provided important insight into the responsibilities of different actors in the institutional frameworks (and how these operate in practice) and additionally identified collaboration needs between certain actors, existing information systems and tools, and the potential application of a web-based collaborative decision support platform. The information gathered also provided more information regarding the damages that have occurred in the case study areas in recent years due to extreme hydro-

[1] Sectoral planning includes geological services, environmental protection agencies and water boards.

meteorological hazards (Fig. 5.1). The municipalities within Wieprzówka catchment in Poland, faced extreme flood events in 2005, 2007, and 2010 in Wieprz and Andrychów; the lattermost event in 2010 affected the entire country. Landslides have also occurred within this site, including one in Stryszawa municipality in the village of Lachowice in 2001. In the Nehoiu catchment in Romania, one of the most violent flash flood events occurred in 2005, taking with it homes and critical infrastructure within the town of Nehoiu. In 2003, the Fella basin in northern Italy experienced torrential rainfall producing an extremely violent flash flood and debris flow covering multiple communes, resulting in extensive structural damage and causing two casualties. Accordingly, all three cases have experienced challenges within the last two decades in terms of securing, preparing, and protecting their inhabitants and territory from the impacts of these extreme events.

The following sub-sections first highlight the key actors and stakeholders as well as the typical informational inputs used in the decision-making process. It is described in general terms and for each case study site, emphasizing the roles and responsibilities of the various actors and stakeholders collaborating and contributing to decision-making. This is followed by a section identifying existing platforms found in the case study sites. Though some platforms exist, no single case has a platform at hand which enables as flexible and collaborative approach for the formulation and selection of risk management measures as attempted in the web-based prototype platform presented in this study.

5.3.1 Key actors and stakeholders in decision making

Several patterns emerged in understanding how decision making for risk management functions at a local (municipal or town) level. Stakeholders and actors all provide different information inputs to the primary decision maker. In all three case study sites, this local decision maker is the mayor who has the legally defined responsibility to provide for the safety and security of his or her citizens. The decisions to be made by this individual rely on a variety of informational inputs provided by a wide range of other stakeholders and actors. This can be in the form of (but not limited to) technical information provided by geological services, environmental protection agencies, and water board authorities (all three of which are addressed as “sectoral planners” in this research). Knowledge is also gathered from the experience of emergency responders and managers such as police, civil protection, firefighters, and aid agencies. Local knowledge provided by the public provides a further input for the information which can be received, interpreted and used by the primary local decision maker (for example, the mayor). In some cases, this local knowledge provided by members of the public and municipal technicians acts as a substitute for the lack of available technical knowledge (such as risk and hazard maps) and is considered to be highly valuable as it often is the information that is most reflective of the local terrain and population needs and interests.

In the case of the Wieprz municipality in *Poland*, the key technicians and officers include the local professional and volunteer fire departments. Though the mayor is legally responsible for the safety of the population, many of the decision making responsibilities can be and in some cases are delegated to these technicians particularly in the case of an emergency. In this way, the technicians also act as decision makers for disaster risk management and hold important local knowledge. This knowledge is also used during the peace time (the time when there is no emergency), and helps influence the development and implementation of measures such as landslide stabilization. In this case, additional technicians working in the municipality conduct studies to determine, for example, where the stabilization of a landslide for a local church should be and how it should be constructed. Of important note is that in some cases, villages within the municipalities also have a village leader. They act as the primary overseer and coordinator for the village's activities and day to day life and issues. The villages do not necessarily have in-house technicians to provide risk information; however, this can be provided via external services such as the regional water authority or the local water authorities (the *Spółka wodna*) as well as from the municipality itself. Municipal boards and councils work with the mayor as part of the entirety of decision making bodies at the local level. At this level, studies are also provided by private planning firms, especially in the case of development of individual or groups of parcels. County and regional levels also play a role in the availability of information and resources at the local level. At this level, agencies such as the Regional Directorate of Environmental Protection in Krakow, the Regional Water Management Board in Krakow, and the Polish Geological Institute provide information in the form of studies and maps. This information includes the recently developed coverage of landslide hazards from the Polish Geological Institute, environmental impact assessments from the Regional Directorate of Environmental Protection, and area or parcel specific flood risk maps from the Regional Water Management Board.

In the town of Nehoiu in Buzău county, *Romania*, the local level decision maker is still the mayor but the input of technical informational resources (for example, landslide and flood risk maps) that are available for use in the decision-making process is substantially limited as compared to the resources available in the other two cases. This is in large part due to financial constraints. Local technicians and particularly urban planners in the town hall largely rely on expert knowledge, and specifically their expert knowledge of the territory. There is also a village representation system in Romania. This acts largely as an information network and assists in relaying local knowledge such as changes in the physical structure of the territory including if there has been a minor landslide or debris flow. Through this network, village representatives are the responsible conduits between more isolated villages and the decision makers in the town (equivalent municipal) level. At this local level, the town police, the emergency volunteers, and the local environmental protection inspector also act as key providers of local level information in decision making for the town hall administration. Additional key actors include the private forestry agencies who are responsible for enforcing decisions involving the clearing, planting, and maintaining of forests. It was noted especially within the Romanian case study that the current maintenance of forest cover and the efforts these agencies make in balancing this coverage against the demands of the timber industry proved to be substantially important in planning for landslide and debris flow risks. As compared to Poland, there is no local fire department and therefore no local actor in this capacity who contributes to the decision-making process. Instead, in this case heavy reliance is placed on the county level.

Located within the county level, the Emergency Situation Inspectorate (ISU) Buzău is the primary emergency management actor and often fulfils the responsibilities that would be attributed to trained local level emergency personnel. Information and indeed often decisions for prevention as well as emergency plans and actions are generated and come from ISU Buzău and other county level actors such as the Institute of Geography (for example, information for landslide assessment and risk mapping) and private planning firms such as BLOM Romania (for example, flood risk mapping and information). At the county level, additional actors include the Bucharest Environmental Protection Agency (who provide environmental assessments and guidance on building permit requirements) and the Buzău Ialomita Branch of the Romanian Waters National Administration (who provide flood risk and hazard maps in cooperation with BLOM Romania).

Within the town of Malborghetto Valbruna in the FVG region in *Italy*, there are also a variety of actors involved in the local decision-making processes. These include the local fire brigades, the local civil protection and volunteer civil protection, as well as the local administrative offices (for example, the mayor, technicians). There is a strong volunteer network for civil protection at the local level in which members from each community are involved and can also provide an informational input. Similarly to the Romanian case, this helps bolster an understanding of changes in terrain and encourages better use and integration of local knowledge into the decision-making process. This information is used in conjunction with information provided by municipal technical officers and urban planners who are responsible for the layout and management of the municipality territory.

Information is also provided at higher administrative levels (e.g. provincial and regional levels) for risk and hazard mapping and related information by the Soil Defence Services, the Forest Services, as well as the Geological Service and the Water Basin Authority of the Isonzo, Tagliamento, Livenza, Piave, and Brenta-Bacchiglione. These offices provide information on a range of scales including municipality to individual parcel scale. Information and guidance on adherence to environmental protection standards is provided by the Agency for the Protection of the Environment of FVG. Architects and private planning firms also provide important informational inputs but have a less direct influence in the decision-making process as they take and combine the information provided by the above mentioned higher level administrative actors and provide this in the form of local level (municipal) and parcel level plans but do not create additional information of their own. With regard to higher administrative level decision making power, it is important within this case to note that though the mayor, as in the other cases, is the legally responsible entity for local level decision making, in-practice, there is substantial influence from the Regional Civil Protection in terms of what physical, structural measures are put in place. This decision making power and influence is seen especially during an emergency in which the management actions and resources needed for response exceeds the capacities of the municipality. The actions and indeed measures put in place by the Regional Civil Protection also tend to have a lasting impact during the peace time following such an event.

5.3.2 Potential application of a collaborative web-GIS platform

In the case study sites, facilitation of interactions between different actors would allow for a general improvement of communication processes, as an exchange of data, information and other important aspects related to risk reduction does not always take place. For example, research undertaken in the case study sites reveals that either a dearth or a merely weak interaction exists between spatial planners and emergency managers[2]. This also holds true for

[2] For further information within this focus, it is recommended to consult the authors' previous work in Prenger-Berninghoff et al. (2014).

the existing links and interactions between sectoral and spatial planners during peace time. In the *Polish* case study site, interviews pointed at existing links between spatial planners and representatives from both the geological survey and the regional water board. Since it is the planners' responsibility to collect sufficient information about natural hazards and to properly consider risks in the planning process, the interaction between information providers and information users is indispensable. In the *Romanian* case site, although examples of overlapping objectives of spatial and sectoral planners were identified, a close cooperation could not be recognized. Accordingly, training for planners about the use of hazard maps and a better interaction with information providers could be an asset. In the *Italian* study site, river basin authorities, as stated by Law 183/1989, are responsible for monitoring and preventing geo-hydrological events. Activities carried out by river basin authorities include the preparation of basin plans, the provision of advice on flood prevention, and the elaboration of hazard and risk maps (Bianchizza et al., 2011). Hazard and risk information can be regarded as an important evidence base that spatial planning can make use of in order to purposefully deal with natural risks. In this context, coordination between spatial planners and providers of hazard and risk information can be considered crucial. As previously mentioned, successful risk reduction necessitates an interdisciplinary, collaborative approach (DeGraff, 2012; Sapountzaki et al., 2011; Prenger-Berninghoff and Greiving, 2014), and thereby, the sharing and dissemination of information is communicated quickly and more effectively (UNISDR, 2009b).

Regarding the existing platforms and tools observed in the case study sites, in *Poland*, there is an application (ARCUS, 2005) which is specially designed for reporting information about events from the municipality to the district level, allowing the creation of a database and exchange of information between different levels. This system is primarily useful for the regional center of crisis management as it provides a comprehensive list of available measures and resources in case of emergency. In addition, there exists an online information system for landslides named "System Osłony Przeciwosuwiskowej" (SOPO), which is currently under development in the Polish Carpathians, to better identify landslide exposed areas for purposes of urban planning and formulation of adequate land-use regulations (Prenger-Berninghoff et al., 2014). For the *Romanian* case study, a main operational platform called "Information Management system for Emergency Situations" (Sistemul de Management Informaţional pentru Situații de Urgenţă, SMISU) exists at the regional level, which is an integrated management system used by the Emergency Situation Inspectorate (ISU) with informational input from both local and national levels. It has been mentioned during an interview with ISU Buzău that the system could be improved by better integrating scientific results into practice. In *Italy*, efforts are being carried out to support the exchange of information between the regional agencies and municipal authorities that are involved in risk management activities. These efforts include geo-information systems that have been implemented such as the "Sistema Informativo Territoriale per la Difesa del Suolo" (SIDS) which is the Territorial Informative System for the Soil Defence. Through that system, regional technicians from Civil Protection can upload reports coming from citizen's alerts. The Geological Service, Forest Services and IRDAT (the cartography institution of the region) can integrate information about elements at risk and hydraulic structure databases. Within this platform, the Geological Service can also cross-validate and follow-up with the documentation process of hydro-geological events being reported by the Civil Protection. Furthermore, there exists an information system to assist information sharing and updating of emergency plans at the municipal level. This platform "Aree di emergenza" is managed by the Regional Civil Protection. In this way, responsible authorities and citizens can access hazard maps, the location of critical infrastructures and emergency procedures according to different accessibility rights (RiMaComm, 2013).

According to the observations and semi-structured interviews taken in all case study areas, there is no existing collaborative decision support platform and no other system that meets the purpose of formulation and selection of different risk reduction strategies with the involvement of all relevant stakeholders. Several information platforms and inventory databases were mentioned by stakeholders; however, they mainly serve for emergency preparedness and response activities and as hazard information inventories. Despite ensuring the provision of information, which can be commonly used and exchanged, they do not assist in the decision-making process for a collaborative formulation and selection of appropriate measures. Particularly, in the Polish site, it was mentioned that the municipality has the best knowledge of risk; however, the municipality does not have proper instruments and tools to work towards reducing the risk before a disaster occurs. It would be of value if such a DSS existed in the selection of different measures since the prevention phase is the most important phase in their opinion. Based on these and the abovementioned issues, potential benefits for application of a collaborative platform were identified. In the *Polish* case study, a centralized web-based system could further help in distributing relevant information more effectively and could help simplify the search for adequate information. In the case of *Romania*, it could enhance the general coordination between actors involved and assist in selecting the most efficient risk management strategy and measures depending on available funds and resources. In the *Italian* case site, an interactive platform would not only provide opportunities for an exchange of information among users of the system but could also facilitate the establishment of closer links. This may lead to a more effective collaboration between the different actors in the study areas by interactively involving them in making decisions on risk reduction measures.

5.4 Framework of the collaborative web-GIS platform

The main purpose of the proposed collaborative platform is to inform and assist the stakeholders involved in the formulation and selection of risk reduction measures based on available risk information and stakeholders' preferences. The web-based environment enables collaborative interactions by allowing accessibility to different stakeholders while facilitating a transparent elucidation of preferences for the selection of measures. With respect to legal responsibilities, a real collaborative decision-making is not always possible and is beyond the ability of the decision support systems. This platform supports the collaborative interactions between stakeholders in a better-informed and transparent decision-making environment, rather than providing the collaborative decisions itself. The framework is designed in a generic way so as to be applicable in different areas and to enable a high level of flexibility in its application. The type of users, the level of involvement and interaction in the platform depends on the institutional settings and the users' respective roles and responsibilities in a certain study area.

A preliminary but essential requirement is to identify where areas at risk are. This may vary in detail depending on the data availability, which is the output of qualitative, semi-quantitative or quantitative risk assessments. In the prototype platform, potential losses and damages of affected elements can be calculated (if data for risk assessment is available) for the considered study area (see Chapter 4). Based on this available (or calculated) risk information (Fig. 5.2), in a *first phase*, expert actors (for example, sectoral and spatial planners) can propose preliminary risk management alternatives (i.e. a combination of measures) based on their expertise and knowledge of the local territory. Involving planners in this process could be useful not only for sharing of hazard information but also for the development of spatial plans and zoning regulations in the hazard prone areas. The land regulations (or planning) alternatives proposed by planners could be considered as one of the potential solutions, and thus, opinions of different expert stakeholders including planners are taken into account in the decision-making process. In a *second phase*, a multi-criteria evaluation process with involved actors and stakeholders is carried out for the selection of alternatives. Different views and prioritizations are taken into account by providing weights on decision criteria (Keeney, 1992; Mendoza and Martins, 2006). This assists in attempting to achieve the most appropriate solution while considering several urgent objectives and encouraging collaboration, additionally helping legitimize the final decision that can be accepted by the majority (Simão et al., 2009).

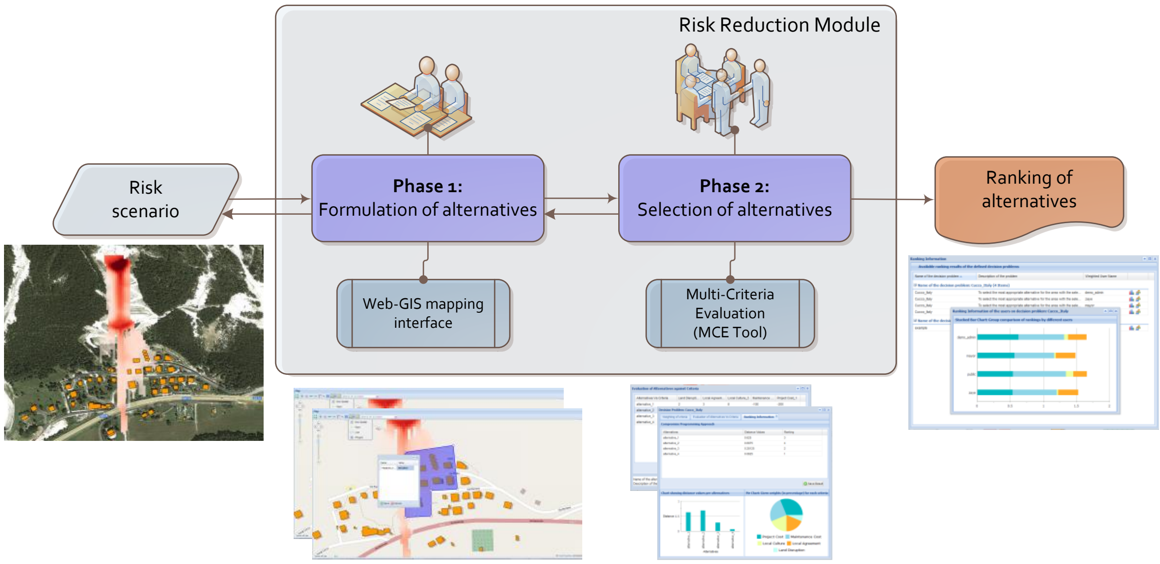


Figure 5.2. A collaborative two-phase framework of the risk reduction module of the prototype platform. Risk scenarios are obtained from the risk analysis module (see Figure 4.1 and Chapter 4). Different types of users exist and the detailed interaction of who is involved in which phases is explained in Table 5.1.

The prototype platform accounts for three main types of users: moderator, experts and decision makers. All users have the possibility to be stakeholders, depending on whether they have an interest (or stake) or are affected by the topic at hand. The term actor more explicitly refers to the decision maker user type, as this user makes choices that directly determine the outcome. Table 5.1 summarizes these types of users and their interactions according to the different phases of Fig. 5.2.

Table 5.1. Types of users and interactions in the collaborative web-GIS based platform.

User Types	Roles	Examples of users	User interactions
Moderator	An administrative user to create, assign and manage the roles of different users within a workspace (study area). Either an independent user or selected	Representatives of an institution with capacity to moderate the collaborative process.	Phase 1 and 2.

	among other expert users to act as a moderator of the decision-making process.		
Experts	Generally belong to organizations that are responsible for providing and using relevant risk information. For example, hazard, elements-at-risk maps, vulnerability information and evaluation of potential measures related to flooding and landslides.	Representatives from one or from different sectoral planning authorities such as the geological survey, hydraulic services and basin authorities as well as spatial planners.	Phase 1 and 2 according to the respective institutional structure and their decision-making roles in the study area.
Decision makers	Generally belong to actors who are responsible for taking decisions.	Mayor of the municipality, representatives of civil protection, expert users and public representatives.	Phase 2. Phase 1 for necessary adjustments within the iterative process of defining alternatives.

5.4.1 Formulation and selection of alternatives

An “alternative” scenario is defined as a combination of structural and/or non-structural risk reduction measures. This research uses the understanding provided by Holub and Hubl (2008, p. 83) who described structural measures as “all physical measures to mitigate natural hazards” whereas non-structural is referred to measures which “concentrate on identifying hazard prone areas and limiting their use temporarily or permanently”. The focus is placed mainly on these two categories due to an emphasis taken by this research on coordinated actions for mitigation and preparedness rather than event management. The formulation of management options can be grouped into four types: protection, accommodation of infrastructure, strategic retreat, and the action of ‘doing nothing’ (Niven and Bardsley, 2013). Table 5.2 describes an example list of potential measures grouped into management alternatives.

Table 5.2. Example of potential measures grouped into management alternatives (based on Holub and Hubl, 2008; Niven and Bardsley, 2013).

Management alternatives	Examples of potential risk management measures	
	Structural	**Non-Structural**
Protection or mitigation	Engineering protection measures implemented along the catchment, channel track or deposition area, engineering works with the possibility to expand or address multi-functional requirements	Forest management measures, spatial and land-use planning, shared loss through private insurance schemes, early warning, education and awareness raising for self-protecting behaviors
Accommodation of infrastructure	Local structural measures, adapted building design, operation of protection works (e.g. dams or levees), maintenance of engineering measures (e.g. check dams)	Contingency and emergency plans
Strategic Retreat	-	Exclusion zones. Establishment and management of protected areas
Do Nothing	No specific action is carried out. Delay in or no implementation of measures.	

Based on the available risk information, preliminary alternative scenarios are proposed by experts such as a dike, relocation of the exposed settlement or restriction of building new houses in the area. Allowing expert users to interactively propose risk management measures not only promotes the coordination activities but also facilitates the centralized sharing of information between different organizations. While it is a preliminary proposition of potential alternatives, it is nevertheless an important phase to achieve the combined risk management strategies for the integrated risk management framework. The potential reduced risk for each alternative scenario can also be recalculated by updating the existing maps and data used in risk calculation (i.e., hazards, assets maps with occupancy of people and vulnerability data). In the prototype, risk analysis module is developed to support the decision-making process as presented in Chapter 4. For this initial identification phase of possible alternatives, only expert users are mainly involved because of their technical capacities and responsibilities. However, decision maker users can provide their feedback on the proposed (preliminary) alternatives during the next selection phase, and therefore, this process is considered as a two-way, iterative process with all concerned stakeholders.

The alternatives proposed by the experts are applied in the *second phase* for the selection and ranking of alternatives with the participation of involved actors and stakeholders since the need to involve experts, decision makers and the society is a key to risk management for the implementation of effective and efficient risk management strategies (APFM, 2006). In this study, selection of alternatives is based on one of the MCE methods as these methods consider different alternative options of a decision problem with the aim of addressing trade-offs between alternatives with inclusion of more additional important criteria than the traditional cost-benefit analysis (Munda, 2004). In this context, we used “decision criteria” to convey information about relevant impacts of management alternatives. According to Meyer et al. (2007), criteria should be measurable in quantitative or qualitative terms and meaningful to the decision makers. It also allows the representation of different (conflicting) views of stakeholders and facilitates the decision-making process through the comparison of alternatives (Kiker et al., 2005). To compare between different management alternatives, the effect of each alternative should be evaluated against each criterion. Thereby, selected criteria should highlight the extent to which objectives of the problem are satisfied by the management alternatives.

There exist a number of MCE methods in the literature such as the Analytic Hierarchy Process (Zahedi, 1986; Saaty, 2001), goal programming (Mendoza, 1987; Romero, 1990), ELECTRE (Roy, 1968) and compromise programming (Zeleny, 1973; Zeleny, 1974; Nirupama and Simonovic, 2002). For the prototype platform, Compromise Programming (CP) method is used to calculate the ranking of alternative options due to its simplicity, transparency and easy adaptation to different settings of problems, and it has been recommended to be applied in disaster risk management problems (Simonovic, 2010). This method identifies alternatives which are closest to the ideal solution as determined by distance values (measures of closeness). It supports the selection of an optimum solution assuming that decision makers seek a solution which is as close as possible to the ideal one (Romero and Rehman, 1989). This ideal solution is defined as the vector of best values of evaluated criteria derived from a payoff matrix A of Equation (5.1) (an evaluation matrix of m Alternatives against n Criteria), depending on the types of the criteria (cost or benefit).

$$A = [a_{ij}] = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \tag{5.1}$$

subject to

a_{ij} = Evaluation value of Alternative i for Criteria j

m = number of alternatives

n = number of criteria

The distance measure of an alternative $L_p\ (x)$ is "a function of the criteria values themselves, the relative importance of the various criteria to the decision makers (α_i), and the importance of the maximal deviation from the ideal solution (p)" as illustrated in Equation (5.2) (Simonovic, 2010, p. 274).

$$L_p\left(x_p^*\right) = Min\left\{ L_p\left(x\right) = \left[\sum_{i=1}^{r} \alpha_i^p \left(\frac{Z_i^* - Z_i\left(x\right)}{Z_i^* - Z_i^{**}}\right)^p\right]^{\frac{1}{p}} \right\} \tag{5.2}$$

subject to

$x \in X$

$1 \le p \le \infty$

$Z_i\left(x\right) = A_i\left(x\right) =$ the evaluation value of an alternative (x) for the considered criterion (i)

Z_i^* = the maximum function value of the considered criterion

Z_i^{**} = the minimum function value of the considered criterion

α_i = the weight (relative importance) of the considered criterion

p = the importance of the maximal deviation from the ideal solution

r = the number of criteria

Thereafter, the compromise solution is calculated based on the defined values with given α_i and p, to determine the distance value of each alternative from the ideal solution. The "best compromise solution" is determined by selecting the alternative with minimum distance value with a given parameter p (value of 2 is suggested by Simonovic (2010)) and a fixed set of decision maker's preferences. The "most robust compromise solution" can also be achieved through a systematic sensitivity analysis or the iteration of Equation (5.2) with various sets of decision maker's preferences α_i with one value of distance parameter p (again with value 2), where there is an alternative which scores a high rank for most of the various sets of defined preferences (Simonovic, 2010).

5.4.2 Workflow of the risk reduction module

The conceptual workflow of the *alternative formulation* process is demonstrated in Figure 5.3. Depending on whether the proposed alternative scenario consists of measures to be localized (mapped) on the map, the expert can either sketch measures using the interactive web-GIS based sketching tool or upload the vector layer (shape file) using the upload option. The sketching tool provides the necessary functionality to draw geometry vector features as in desktop-based GIS applications and allows the user to save the sketched layer with necessary information such as the type and name of each sketched measure within the proposed alternative scenario. These formulated alternative scenarios can then be visualized amongst users within the platform to support the on-line participatory and decision-making process.

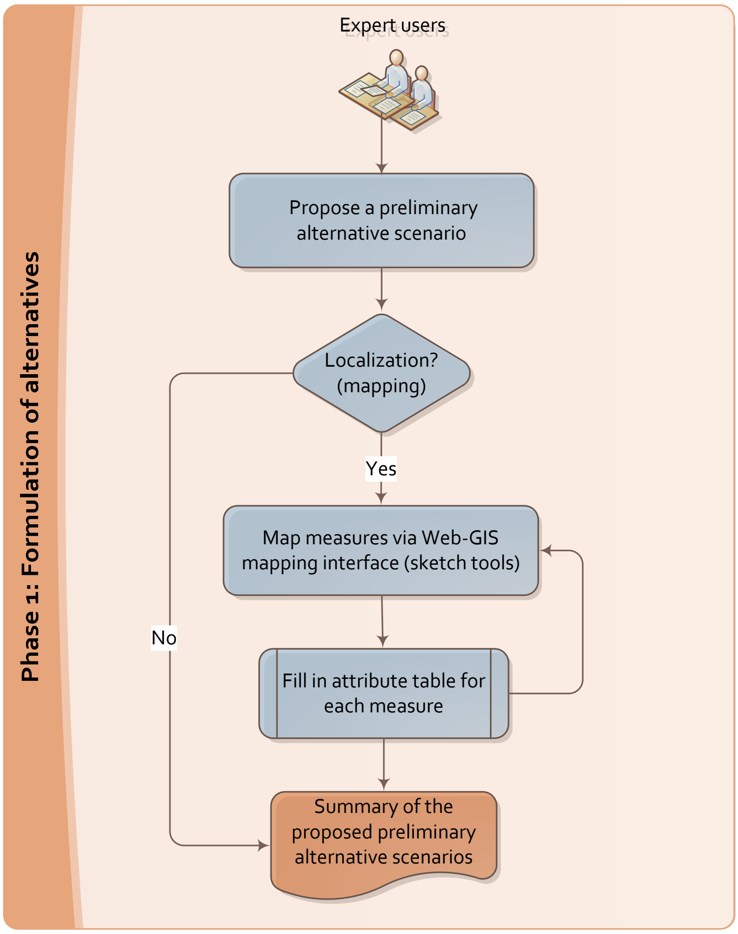


Figure 5.3. Workflow of the alternative formulation component, illustrating two possible options (sketching or upload) with additional parameters for the formulation of a new alternative scenario.

The conceptual scheme of the *alternative selection* process is demonstrated in Figure 5.4. The expert user acts as a moderator to moderate the decision-making process in selection of alternatives. Firstly, the criteria to be evaluated for each alternative are defined by the experts to consider in the decision problem. These criteria can be adjusted and defined with the feedback given by decision makers. Each criterion can be either qualitative or quantitative depending on the nature and data availability of that criterion; for example, local agreement of a certain alternative scenario can be either in terms of qualitative scale or quantitative voting count. After this step of criteria definition, the moderator carries out the evaluation process of each alternative against all criteria to obtain the impact (evaluation) matrix (Equation 5.1). Upon the completion of the evaluation process, the moderator assigns the participants to give their weights (preferences) of the criteria. These weight sets are then used to produce ranking of alternatives for each participant based on CP method (Equation 5.2). At the end of weighting process, a negotiation process takes place in order to achieve a final agreeable solution. The aggregation of all weight sets could be done by implementing aggregation methods (Lansdowne, 1996; Barzilai and Lootsma, 1997; Wei et al., 2000) in the platform to combine individual weight sets of participants into a group weight set. At present, however, it is unlikely that we can possibly give a weighting (balance) to different groups of stakeholders due to their different responsibilities in decision making. Besides, it is clear that the hierarchy of the decision-making process and respective responsibilities of stakeholders is far beyond this study. We can consider that the final decision is limited to the local decision makers who have the legal responsibilities for safety of the citizens of the considered study area. For example, the mayor is the main decision maker and responsible for any decisions made by the municipality. However, this could be different according to the country context where the platform is applied.

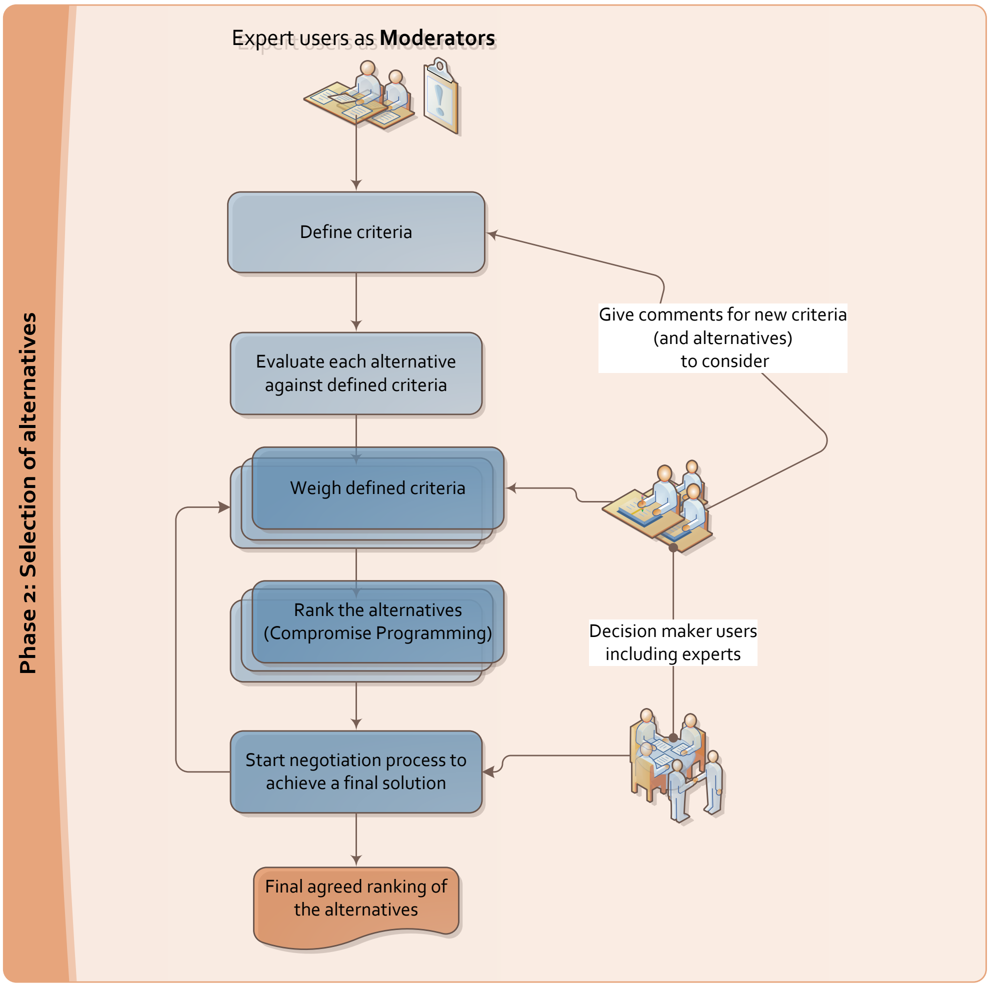


Figure 5.4. Workflow of the alternative selection component, illustrating different steps of the decision-making process with all involved stakeholders for the selection of alternative scenarios.

5.5 Architecture of the platform

The web-GIS interface is integrated within the decision support platform to visualize maps, exchange (spatial) risk information and provide certain geo-processing capabilities on the web, which can be accessible by different organizations located in the case study site. The background architecture of the prototype is based on the client-server architecture model in which clients send requests to a server and receive appropriate information in response. The client-server model was chosen in order to facilitate the maintenance of the application and allow its functionality to be upgraded or modified at any time without involving the end user's computer system (Sugumaran et al., 2004). In a thin-client application, the clients only have user interfaces to communicate with the server and display the results. Most of the processing is thus done on the server, and hence, the server computers typically have more power than the client to manage the centralized resources (Alesheikh et al., 2002). For the web-based applications, complex software is not needed on the client side and only a browser is sufficient for most cases (Kobben et al., 2010). Besides, the system performance is not dependent on the client, and therefore, if there is a need to revise or update the system functionality, it can be done on the server-side easily without affecting the clients. However, the speed of the application could be limited as the processing take places on the server and the internet connection of the client's network. Recently, Sun (2013) compared server-client and cloud-based web–GIS platforms for enabling participatory decision makings. Cloud computing approaches can be adopted if maintenance costs and user accessibility turned out to be a bottleneck issue.

As briefly presented in the Section 4.2.3 of Chapter 4, the development of the prototype is based on Boundless (formerly OpenGeo suite) framework (Fig. 5.5) and its client side SDK application.

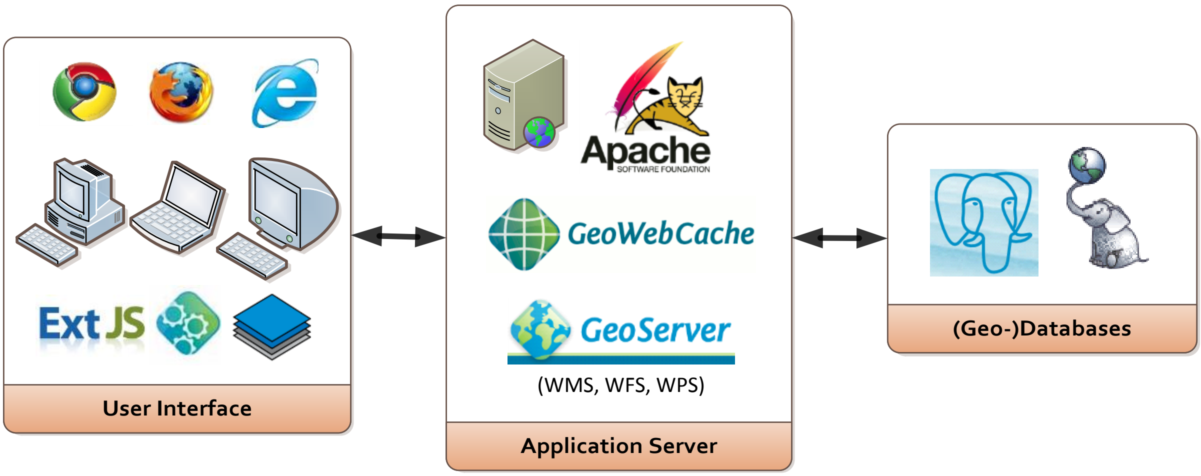


Figure 5.5. Open-source software stack of the prototype.

The Boundless SDK backed by OpenGeo suite is used to build and deploy the prototype platform since it provides tools for creating JavaScript-based web applications with customizable components and data utility classes, which are based on GXP (a Javascript SDK for developing high level GeoExt based Applications), GeoExt and OpenLayers. This GXP component extends map related functionality to the equivalent classes in Ext and is configured to work with GeoExt and provides the powerful ability to create self-customized plugins and widgets for the application development. The different modules of the platform are developed as separate plugins (dependencies) and declared as add-ons components within the main JavaScript application, which facilities the plugging and unplugging of designed components within the platform as needed. The built-in plugins and widgets make the development phase faster and make it easier to integrate existing map tools and functionality within the platform.

The prototype application is also configured to work with PEAR (PHP Extension and Application Repository, a framework and distribution system for reusable PHP components) Mail library in order to send emails from the platform by the administrative users to the participants for the weighting of criteria in the platform. In addition, the deployed web application is combined with Bootstrap (an open source framework for creating websites and web applications containing HTML and CSS design templates) framework for customized HTML (Hyper Text Markup Language) and CSS (Cascading Style Sheets) templates.

5.5.1 GeoServer configuration (Roles, users and services)

Within the GeoServer, it is possible to configure different user groups, roles and services based on the needs of the web application for the map related services. In the platform, as there exists the different levels of stakeholders' involvement, two user groups are defined within the GeoServer for different access rights to the map layers: admin and public. The users of the admin group (moderator and experts) can access to all the services provided by GeoServer (i.e., WMS, WFS, WPS, WCS, and GWC) and its respective methods while the public group can only access WMS and WFS services within the application interface. As a result of this configuration, the public group users can only visualize the maps and query the feature (layer) information with associated styles and legends while having no rights to make any changes to the accessed layer. This access is configured through Spring Security Check (a framework which provides a powerful and customizable authentication and access-control to Java based applications) of GeoServer depending on the logged in roles of the users.

5.5.2 Schema design

In the prototype platform, different case study sites (workspace) can be defined and each study site corresponds to a schema within the main database of the application, meaning the study data are stored accordingly within the specific schema of the database (see Appendix IV for the full schema design). Figure 5.6 shows the data model of the *alternative formulation* component of the prototype platform. Each of the alternative scenarios (including "Do Nothing" scenario) is associated with hazard, elements-at-risk maps and vulnerability information which have been uploaded into the platform. Upon the creation of a new alternative scenario with sketch option, a new table is created dynamically to store the mapped measures of that scenario along with its attribute information, which is then linked to *alternatives* table via an attribute named *mapping_index* (see Figure 3 of Appendix IV for the illustration).

In the data model of the *alternative selection* component (Figure 5.7), each decision problem (i.e., a *matrix* table) has the relationships with *alternatives* and *criteria* tables to be evaluated against each other. The resulted evaluated values of each alternative for all criteria are stored in the impact matrix (i.e., *matrix_values* table) as explained in Equation (5.1) of Section 5.4.2 in order to calculate the rankings of alternatives based on the weights given by the different participants. The assigned participants' weight sets are stored accordingly in the *weights* table referencing to a specific decision matrix. Using the CP method (Equation (5.2) of Section 5.4.2), the calculated ranking results of each participants are then saved in the *ranking_results* table along with the distance (measure of closeness) values of considered alternatives for a certain decision problem.

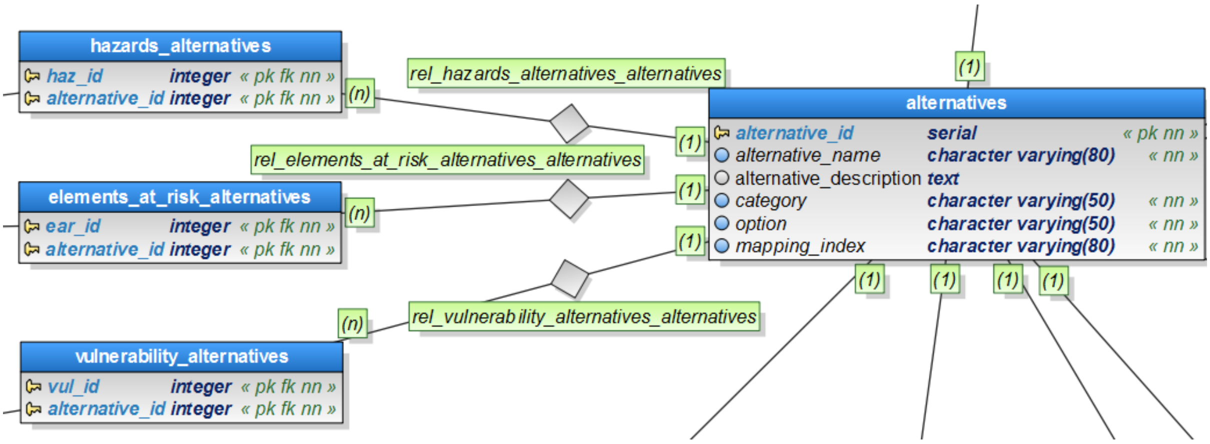


Figure 5.6. Data Model of the alternative formulation component. The three relationship tables (hazards_alternatives, elements_at_risk_alternatives and vulnerability_alternatives) are linked to the corresponding tables (hazards, elements-at-risk and vulnerability) tables of Data Management module of the platform (Fig. 4.7 of Chapter 4). Three types of information can be seen in each table: the actual column name (e.g. alternative_id), the type of the column (e.g. serial) and the attribute of the column (e.g. <<pk nn>> represents that this is a primary key column and null values are not allowed for this column). For the full data model with other modules, see Figure 2 and 3 of Appendix IV.

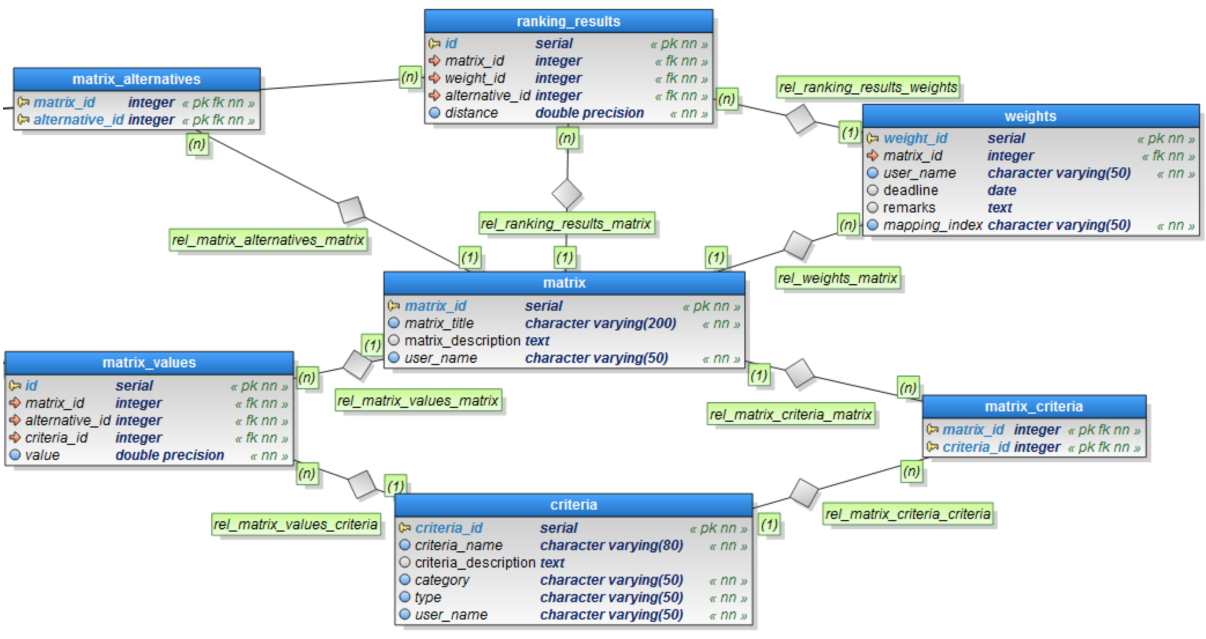


Figure 5.7. Data Model of the alternative selection component. The relationship table (matrix_alternatives) is linked to the alternatives table of the alternative formulation component (Fig. 5.6). Three types of information can be seen in each table: the actual column name (e.g. matrix_id), the type of the column (e.g. serial) and the attribute of the column (e.g. <<pk nn>> represents that this is a primary key column and null values are not allowed for this column). For the full data model with other modules, see Figure 2 and 3 of Appendix IV.

5.6 Demonstration of the prototype

5.6.1 Case study of Malborghetto Valbruna municipality, Italy

The prototype application is demonstrated based on a local scale case study site. Malborghetto Valbruna municipality is located in the Friuli-Venezia-Giulia (FVG) region of the North-Eastern Italy, bordered with Austria and Slovenia (Scolobig et al., 2008). The hydro-meteorological hazards such as flash floods and landslides occur frequently in this study area and it is one of the highest rainfall areas in Italy as well as in Europe. The heavy rainfall in combination with the other conditions triggered debris flow channels, and in August 2003, the major landslide events occurred and caused a major flood of the Fella River (Figure 5.8). Malborghetto Valbruna (with a population of about 1028 inhabitants) is one of the municipalities located in the Val Canale valley of the Fella River basin. During this event of August 2003, the damages occurred to the whole valley was estimated about 435 million Euros (Scolobig et al., 2008). This study area serves as an interesting example due to its decision problems for implementation of mitigation measures after the event in 2003. There was a debate regarding the efficacy of hydraulic works versus flood management measures to increase resilience by incorporating local people and their knowledge in the decision making process (Scolobig et al., 2008). Furthermore, there were overriding political interests in maintaining occupation of the valley in the face of continuous outmigration, which resulted in a preference for big structural mitigation measures to be implemented as an effective option in order to prevent relocation of few houses in the area (Prenger-Berninghoff et al., 2014).

Figure 5.8. Debris flow events occurred in Malborghetto-Cucco in August 2003 (© Civil Protection of FVG region, Italy).

5.6.2 Definition of a workspace (case study site)

A "workspace" belongs to a certain case study site for the groups of users to access, store and update all related information of that study site in the database. This workspace can only be created by the responsible administrative user of the study site and it is configured to automatically generate a database schema with default tables upon a new workspace creation as explained in Section 5.5.2 (Figure 5.9). Within the existing workspace, admin user can create and assign roles to user accounts according to the responsibilities of the involved stakeholders in the study area. The users can also switch to another workspace if they are assigned to more than one study area and can access the available data and functionality depending on their assigned roles within the platform.

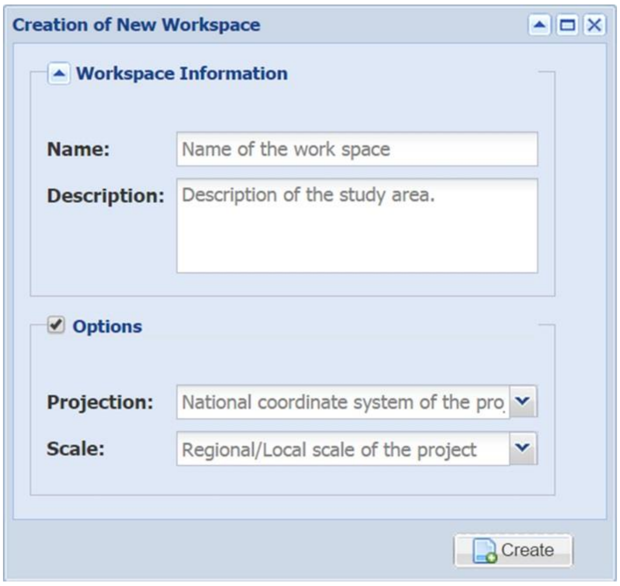


Figure 5.9. Creation of a new study site (workspace).

5.6.3 Steps of the collaborative process

Based on a typical structure of the decision-making process (Bardach, 2005; Failing et al., 2007; Jankowski et al., 1997; Ranger et al., 2010), the demonstration of the collaborative platform is composed of the following steps (Fig. 5.10):

- *First phase*:
  1. Formulation of preliminary risk management alternatives;
- *Second phase*:
  2. Formulation of objectives in terms of decision criteria;
  3. Evaluation of risk management alternatives against decision criteria;
  4. Weighting of decision criteria by involved stakeholders and
  5. Comparison of ranking of alternatives to support final agreement.

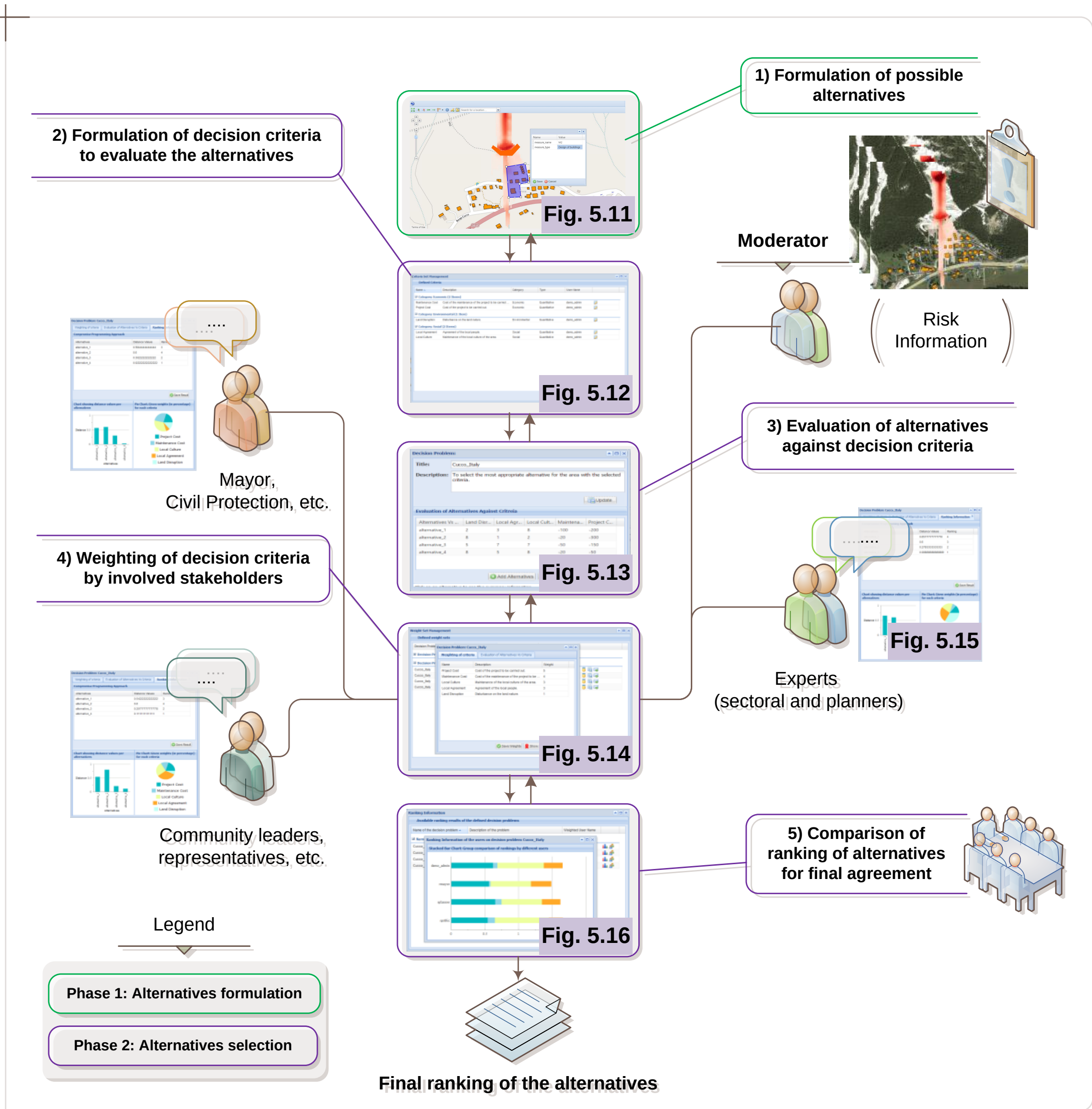


Figure 5.10. Steps of the collaborative decision-making process of the platform. Steps 1-5 are demonstrated with sequential figures 5.11-5.16, which are identified by number as a reference to their place in the general workflow of the framework. Only the user groups involved in Step 4 are illustrated in this figure.

5.6.3.1 Formulation of preliminary risk management alternatives (Step 1)

In this step, expert users can formulate their own preliminary drafts (sketches) of risk reduction measures using the interactive web-GIS interface based on the available risk information. In this manner, involved expert users that may have different expertise and preferences for risk management can interactively propose measures. Figure 5.11 illustrates an example where an expert user proposes to adapt the building design and implement local structural measures for some houses exposed to debris flows in the area. The modelled debris flow map of Cucco village, Malborghetto municipality, is based on forward-prediction modelling with latest Digital Elevation Model (DEM) obtained in June 2008, using the best performing parameter values obtained from the back-analysis of the 2003 debris flow event (Hussin et al., 2014a). The debris flow and building asset maps of Cucco are obtained from the research group of two European projects: CHANGES and IncREO (http://www.increo-fp7.eu/).

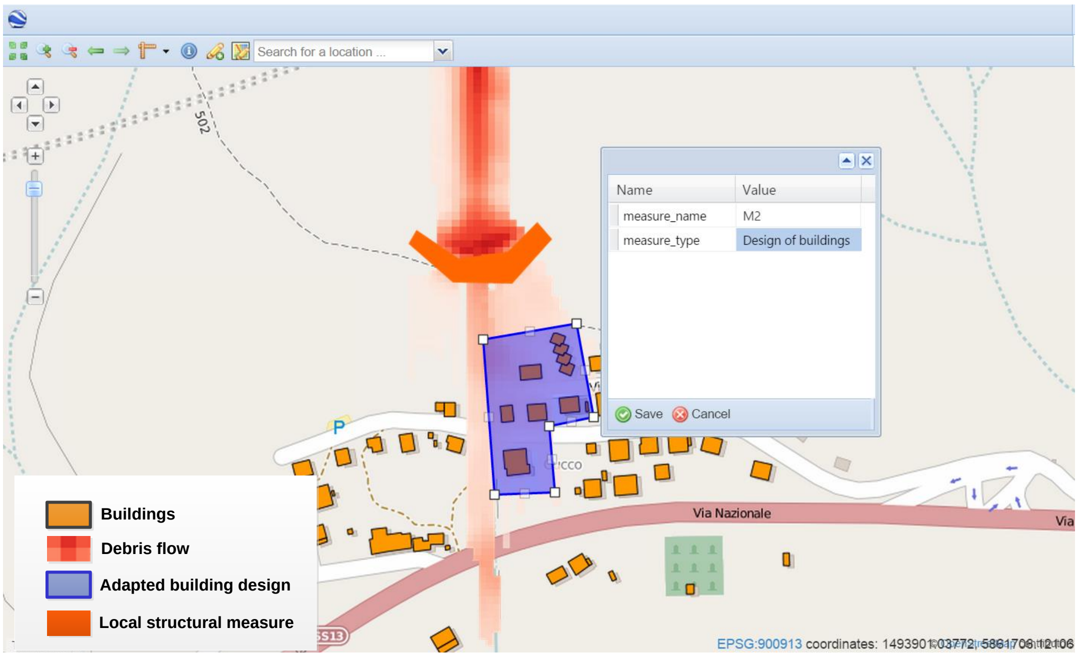


Figure 5.11. An example proposition of risk reduction measures by an expert user through a sketching tool of the prototype platform.

5.6.3.2 Formulation of objectives in terms of decision criteria (Step 2)

The formulation of decision criteria beyond the conventional cost-benefit analysis allows for the evaluation of other important and competitive objectives of the decision problem at hand. During this step, expert users can propose criteria to evaluate and compare differences between preliminary alternatives. Three main categories of criteria can be defined in the prototype platform: economic, social and environmental criteria with qualitative or quantitative indicators. Within the prototype, criteria are initially defined (proposed) by the expert users (an example shown in Fig. 5.12). Decision maker users can also give feedback on the criteria suggested by experts as part of the iterative process of using the web platform. This collaboration between experts and decision makers supports the evaluation of different alternatives based on decision criteria.

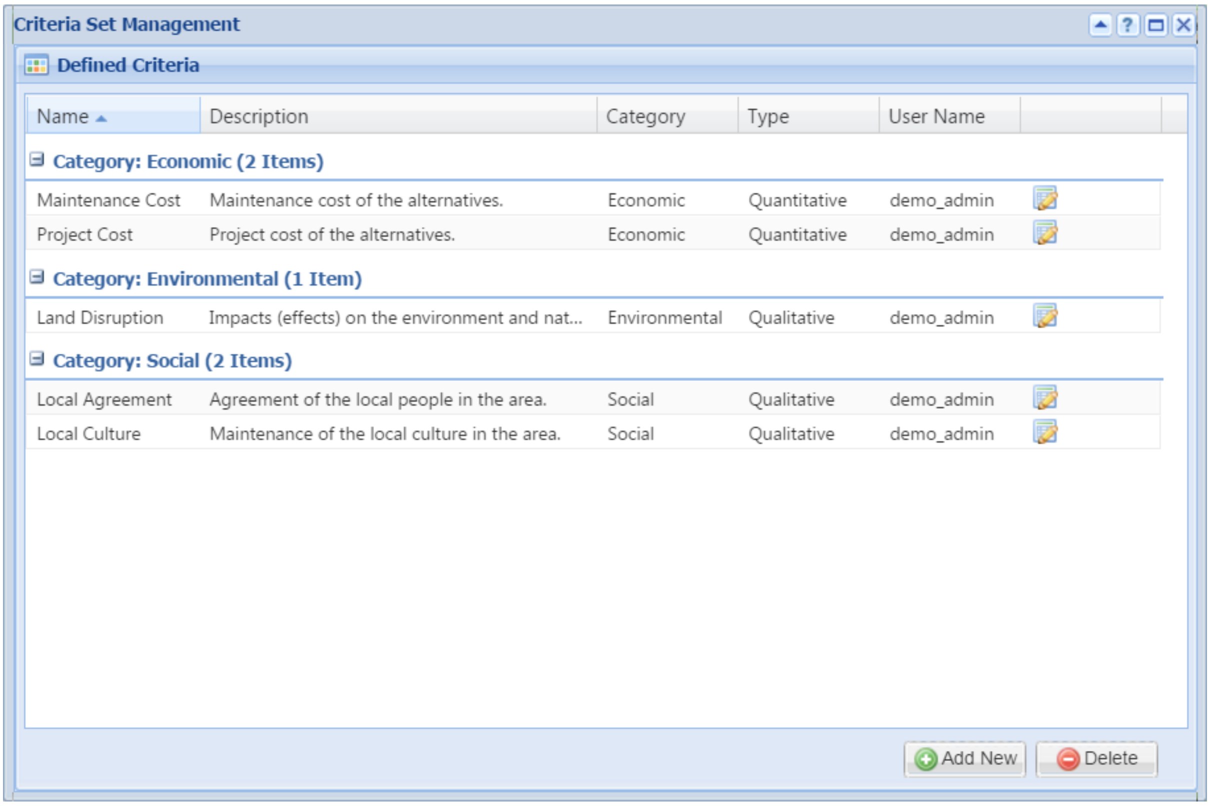


Figure 5.12. An example list of defined criteria (both qualitative and quantitative) in the prototype platform.

5.6.3.3 Evaluation of risk management alternatives against decision criteria (Step 3)

The effects of designed alternatives (Step 1) in terms of the decision criteria (Step 2) are used as inputs for the evaluation process of alternatives (Step 3). For this step, the moderator user would need to specify an "evaluation matrix" to compare the performance of each alternative against each criterion (Fig. 5.13). Only expert users are allowed to modify the performance values depending on their roles and expertise in a certain study area. Based on the criteria, such values should be ideally maximized (benefits) or minimized (costs). The expert users can evaluate the alternatives' performances using either a quantitative or a qualitative scale according to the type of criterion. The qualitative scale is used to describe how an alternative performs for a specific criterion which cannot be expressed in quantitative terms. This can include, for example, if the impact on the environment caused by a specific alternative is very high.

This evaluation matrix corresponds to the matrix A (see equation 5.1 of Section 5.4.1) and after the preparation of this matrix, in order to calculate the rankings of the alternatives based on Compromise Programming method (see equation 5.2 of Section 5.4.1 for calculation procedure), the moderator allocates the involved participants (i.e. a group of decision makers) to assign their weights on the criteria in the next step.

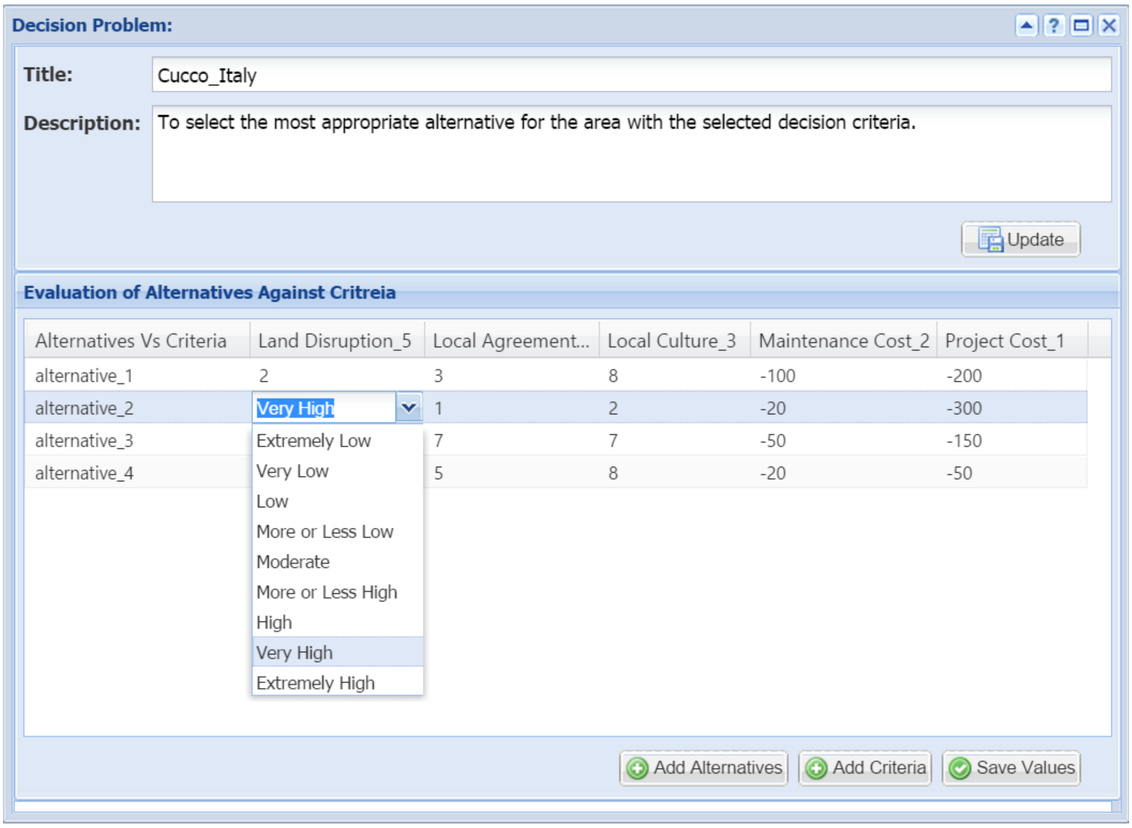


Figure 5.13. An example evaluation matrix of the defined decision problem in the prototype platform.

5.6.3.4 Weighting of decision criteria by involved stakeholders (Step 4)

In this step, different stakeholders are invited to the selection process to weigh the decision criteria, according to their preferences. This step can be repeated when necessary to align participants' interests in achieving a favourable ranking at the end. Firstly, the moderator needs to allow participants into the decision-making process and can set a time frame for the weight assignment if needed. Secondly, participants can log into the platform and access the available information (for example, designed management alternatives and criteria) to indicate their preferences on the given criteria. To do so, a simple numeric scale is used (as shown in Fig. 5.14). Such a choice of weighting scale was implemented in the prototype to simplify the complexity in determining preferences. Furthermore, during this weighting process, each decision maker user can also propose additional criteria and alternatives to the expert users to be considered through the "signal" option in the interface.

Each weight set is then normalized (in which weight values are divided by the total weights) to be used for ranking of alternatives using CP method. The ranking of alternatives is based on weighted aggregation method to combine the performance values of alternatives (obtained from Step 3) into one overall measure. Thereby, defined criteria and their evaluation of values against each alternative are aggregated based on the weighting preferences of the decision makers (Tkach and Simonovic, 1997). The combination of Step 3 and Step 4 produces the individual ranking of preferred alternatives which are recommended for implementation.

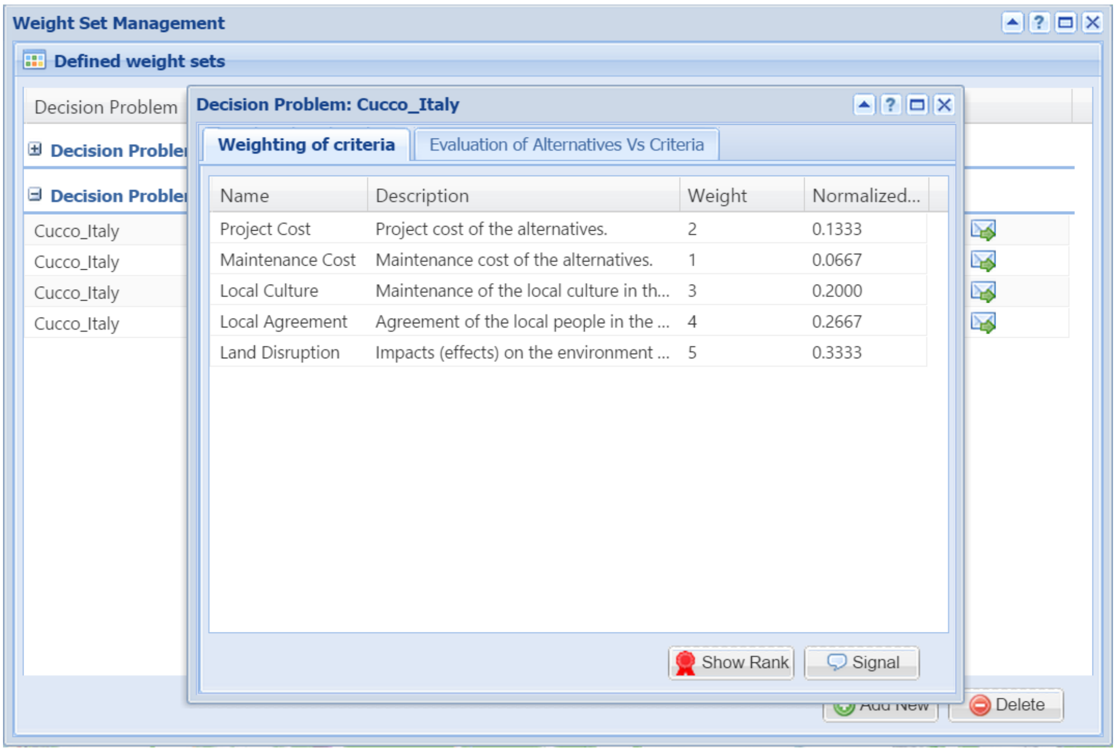


Figure 5.14. An example of the weighting process of the participating user in the prototype platform, in which the land disruption criterion is highly weighted by the user (with a weight of 33%).

5.6.3.5 Comparison of ranking outcomes to support final agreement (Step 5)

At the end of the weighting process, each decision maker user can visualize their own immediate ranking results of the alternatives and justify it using weights provided for the criteria (Fig. 5.15). This ranking of alternatives (distance value or closeness of measure to the ideal solution) is calculated dynamically and immediately with the given weight set of the user and evaluation matrix using the CP method (Equation 5.2 of Section 5.4.1).

The comparison of ranking information resulting from other decision maker users can also be visualized (Fig. 5.16) in the platform for the purpose of negotiation to achieve a final agreeable outcome of alternatives and a visible expression and communication of different preferences. As mentioned in Section 5.4.2, an aggregation method could be applied, however, aggregation methods need to be further explored since the aggregation of all weight sets could introduce a decision bias in the decision making if it is not properly aggregated based on the responsibilities of stakeholders in the specific study area. Nevertheless, these ranking outcomes of different stakeholder groups serve as a good starting point for the negotiation process and the moderator can later assign a final agreeable weight set in the platform. We consider that the decision support tool aims to assist the users in making better and informed decisions by providing necessary inputs and information while the final decision still needs to be made by local decision makers according to their legal responsibilities and institutional structures of the study area.

Within the platform, the decision maker users can not only assign weights and rank the alternatives but can also visualize alternatives and related risk information as provided by the expert users through a simplified interface of the platform.

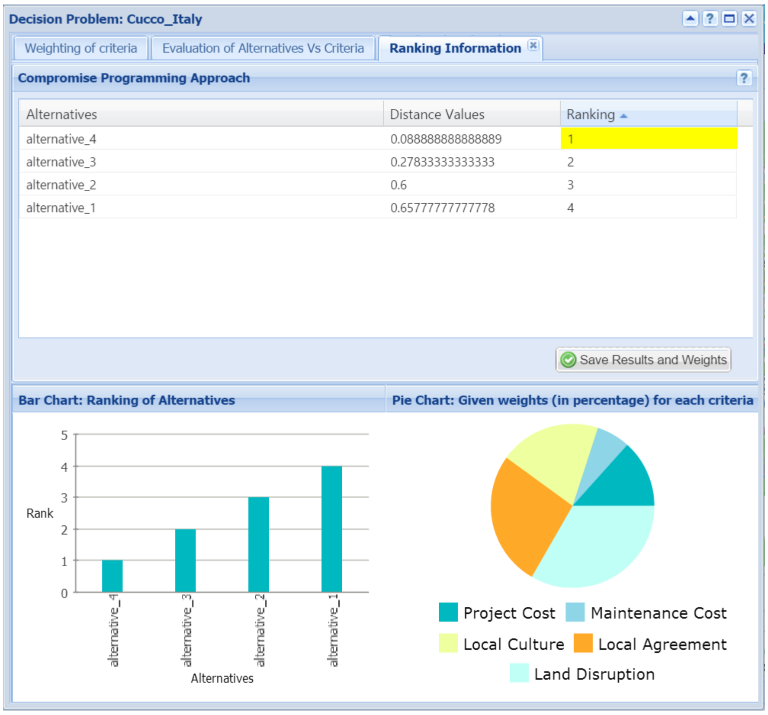


Figure 5.15. Visualization of own ranking result (based on the given weights in Fig. 5.14) in the prototype platform. The upper grid and lower left bar chart represent the ranking order of alternatives (i.e. in this case, alternative 4 is ranked first). The right lower pie chart represents the given weights (%) of a participating user for defined criteria.

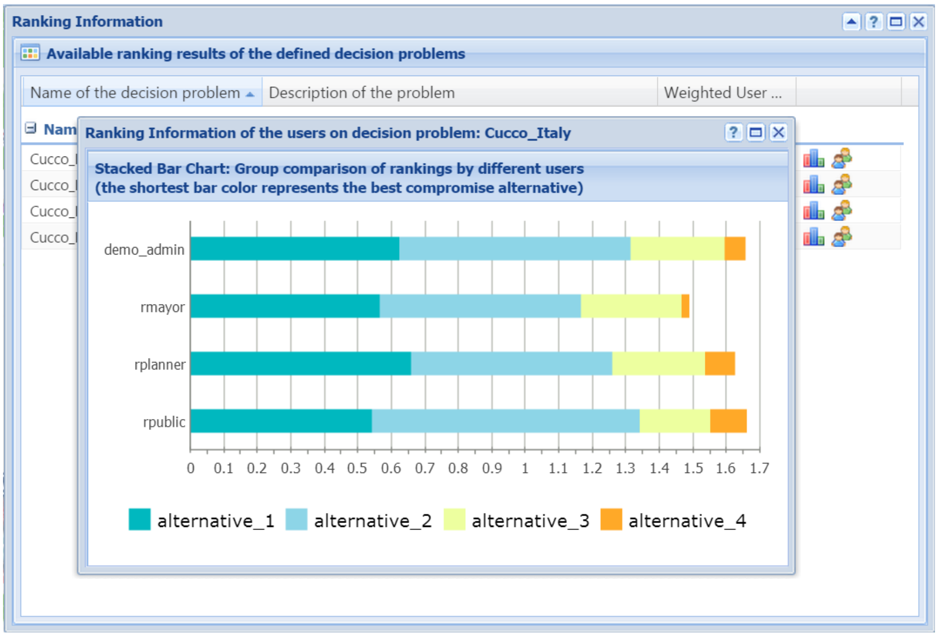


Figure 5.16. Comparison of individual ranking results in the prototype platform, where the alternative with the shortest bar portion (distance value) is considered as the best solution (i.e. in this case, alternative 4 for all participating users).

The presented approach encouraged the involvement of different groups of stakeholders in a participative and collaborative manner via an interactive web-based platform, aiming to achieve a better decision-making process with the use of open-source software tools in selection of a wide range of mitigation measures. This approach considered not only economic criteria but also other important criteria such as agreement of local population and potential effects on the environment in long term. Consideration of multiple criteria and the preferences of stakeholders in the decision-making process is particularly relevant in the case study area of 2003 event, where the enormous and costly structural mitigation works were implemented to prevent outmigration and to protect the existing small settlements in the area while residual risk and long-term maintenance of structures continue to exist in the future development. In addition, the construction of protection works initiated by regional Civil Protection faced opposition that the local interest groups were not consulted during the decision-making process, claiming that local knowledge could propose better alternatives (Scolobig et al., 2008). This stressed the importance of such approach with all concerned parties in decision making, which is why the presented two-phase collaborative framework is realized for the development of a web-based platform.

5.7 Feedback from case study areas

During the dissemination meetings of the CHANGES project in 2014, this developed prototype was presented to the stakeholders in three case study regions to collect their preliminary feedback and suggestions. At the end of the prototype presentation and follow-up discussion, one-page feedback forms in the stakeholders' native languages were given to the participants. This feedback form (Appendix II) included three different sections. The first section consisted of establishing an understanding (gathering opinions) of the platform followed by five Likert scale questions (5 point: Extremely Bad (1) to Excellent (5)): usefulness, innovativeness, user-friendliness, practice and supporting collaborative ability of the prototype. The second section asked participants about what aspects of the platform could be improved, while the third section provided an open space for additional comments and suggestions on the platform.

A total of 49 feedback responses were obtained from the three case study sites and are presented in Fig. 5.17 according to the average scores given by the participants for the five questions. In *Poland*, out of 17 responses obtained, the *innovativeness* of the platform achieved the best score while the rest of the categories scored more than or equal to 4 (meaning more than Good or Good in terms of the scale used for the analysis). In *Romania*, out of 19 responses obtained, the *usefulness* and *innovativeness* of the platform achieved the best score around 4.3 (meaning more than Good) while the rest of the categories scored around 3.8 (meaning Good enough). In *Italy*, out of 13 responses, the *usefulness* and *supporting ability* of the platform achieved the best score out of the five categories as 3.8 (can be interpreted as Good enough). From looking at the average scores of the total responses, innovativeness and usefulness ranked as first and second respectively, followed by supporting ability, user friendliness and practice aspects of the platform.

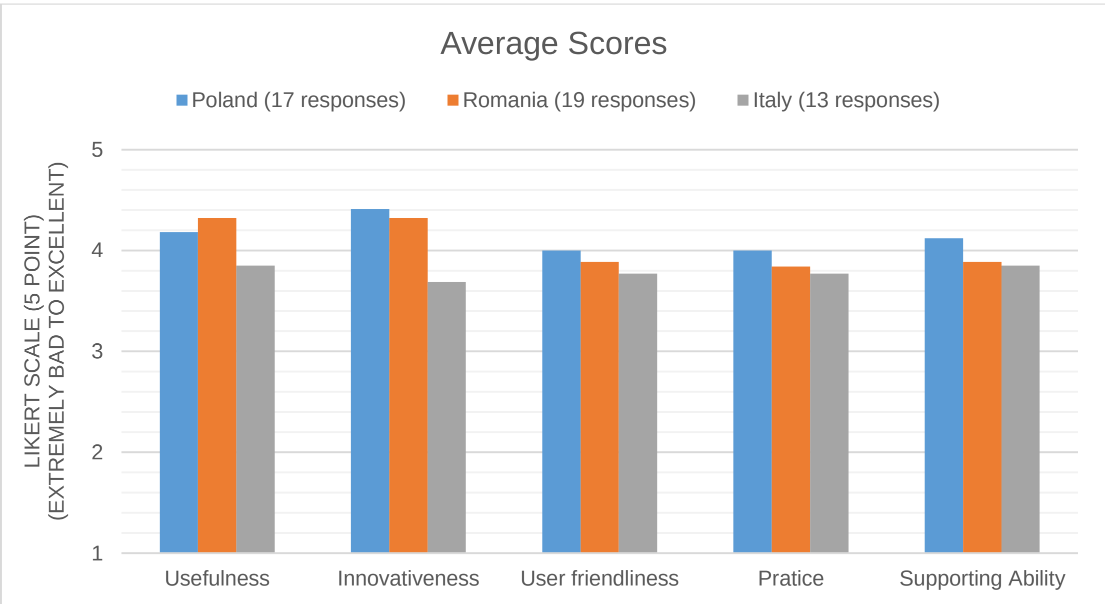


Figure 5.17. Collected feedback (section 1) based on a 5-point Likert scale (of Extremely Bad to Excellent).

An analysis was also made of the open-ended commentary given by stakeholders on the categories (keywords) in section 1 and section 3 of the feedback form. The main points of the commentary are provided in the following statements:

- a *useful* instrument not only in decision making but also in many other aspects including awareness raising;
- an *innovative* idea which allows the participation of different stakeholder groups in the selection of coordinated risk management strategies. Nevertheless, the question remains of engaging potential stakeholders to get involved in the participation process, and therefore, further solutions such as positive incentives would need to be explored to improve the applicability of the platform;
- a *collaborative* approach which contributes to decision making and could potentially enhance the collaboration between involved stakeholders; however, it still needs to be further evaluated and tested by creating concrete group exercises with stakeholders to assess and verify how they interact with each other through the web platform;
- the availability of manuals and training exercises could help in assisting users and could also improve the *usability* and understanding of the platform;
- the *applicability* of the platform in different contexts could be a potential issue because of the generic nature of the platform.

Table 5.3 highlights the main points extracted from the feedback of stakeholders based on the first two sections of the feedback form and provides insights on the strengths and weaknesses of the platform and its potential improvements.

Table 5.3. Main points extracted from feedback responses given by local and regional stakeholders of the three study areas.

Poland	Romania	Italy
Section 1: Opinions of the platform		
• A useful community-based tool, especially for the participation of different social groups, simplifying exchange of information between experts, ordinary users and local community. • A useful platform and it would be good if people have a chance to vote, and if authorities and people would be willing to engage and to give weights • The idea of the platform makes a good impression, however, a lot of work is still required to be a useful platform.	• A useful instrument in decision making (reflecting the concepts of risk governance) and enhances collaboration between stakeholders with simultaneous involvement of public authorities. • A useful tool which reduces the time, resources used and the costs. In addition, the decisions can be taken from different locations which results in a reduction of the response time. • A useful tool which gives users the possibility to understand the phenomena and decision. • The tool would be useful for the local administration and can be efficient, but only after the implementation of a few practical (instructional) exercises. • A real support for the safety of citizens and their properties. • The idea is very good and at some point, it can be applied at a national level.	• A good and useful instrument to support decision making and to evaluate different decisions by comparing technical and social parameters. • A multi-user access platform that allows the interested parties to conclude and trade solutions. The users could have different roles and competences, and their opinions are equally important and considered.

Section 2: Aspects should be improved		
• A voting system for the alternatives. • A possibility to constrain the changes in application by time so that an expert user can analyse what the users did. • An introduction of weights only by experts, and a better way of weighting criteria and a comparison of weights of decision makers with those of experts. • A better user interface and all the components are required to refine and test with a few examples. • A possibility for both local and regional scope.	• A step-by-step decision making support guide. • A more intuitive and simpler tool considering the reduced instruction level (expert knowledge) of the users. • Aspects related to the practice and applicability in decision making. • A possible adaption to the institutional structure and legislation of the applied study areas • A possibility to use the platform from multiple locations at multiple scales and multi-user (commune, region, different involved institutions, researchers, etc.) would be important.	• A tool for cost-benefit analysis to compare the alternatives under the aspect of intervention type. • Quantification of cost-benefit analysis for both economic and social options (site) under consideration. • A possibility to add spatial queries for risk analysis and alternatives. • A possibility to easily import and make use of available data. • A simplification of the interface.

Finally, the feedback of stakeholders on the prototype platform feeds as an important input for potential development of a full-scale system to apply in practice. The future research directions include:

- the integration of cost-benefit analysis and interactive spatial query tool to further analyse and evaluate the consequences of the natural hazard events;
- the application of different MCE approaches with sensitivity analysis to achieve a more robust solution in decision making;
- the aggregated weighting process which takes into account the balance of weights of involved decision makers depending on the institutional framework of a certain study area;
- the clarification of interaction with end-users and stakeholders for specific requirements in study areas;
- the engagement of the stakeholders and a way to motivate them for participation and
- the training courses and concrete exercises with involved stakeholders to evaluate and test the functionality of the platform in practice.

5.8 Discussion and conclusion

We presented a collaborative web-GIS based prototype platform applied in the field of natural hazards and risk management mainly for floods and landslides. The purpose is to assist the involved stakeholders and actors in the formulation and selection of risk management strategies using an interactive web-GIS interface and CP approach. The development of the platform was strengthened by preliminary empirical data collected from each case study through field visits and stakeholder meetings within the CHANGES project. Considering the need for flexibility to apply to different study sites, the institutional framework of the platform can be adjusted according to the respective roles and responsibilities of the stakeholders involved in a certain study area. This flexible collaborative framework extends beyond the conventional use of GIS in three aspects: enhancing spatial data access, exchange and dissemination; supporting spatial data visualization and exploration; and creating a highly adaptable tool for spatial data analysis and processing for risk management activities (see Dragićević 2004 for these three aspects of web-based GIS studies). Moreover, this platform could assist in interactions between different experts at same level (horizontally) as well as between experts and decision makers across different levels (vertically) through the presented two-phase collaboration approach. The first phase opens up an opportunity for experts to propose potential strategies, permitting an enhance adaptability of the platform in different study areas. The coordinated risk management strategies can be best adopted through such a participatory process with the involvement of responsible expert stakeholders (APFM, 2006). Furthermore, the second phase helps address the issues identified in the case study areas such as the lack of coordination between some stakeholders responsible for risk management and can enable a higher level of cooperation by providing a MCE tool for the comparison of different alternatives. Aside from the presented framework, we have also attempted to demonstrate how the potential use of such a platform could be beneficial to the stakeholders through the feedback collection conducted in the study areas. In general, the stakeholders found the platform innovative, useful and supportive while several aspects of the platform need to be improved. This included the desire for more active engagement of stakeholders in the process, validation of the platform through interactive real-time exercises and integration of additional supportive tools in the platform. These provided crucial topics for continued research of the prototype such as usability of the collaborative web-GIS platform, and such evaluation could start with testing groups (e.g. master students) to identify needs for improvements (see Chapter 6 for the evaluation exercise). Future research could consider the possibility of integrating spatial MCE approaches to address the spatial component in a more explicit way. This is for example by looking where a certain alternative could be spatially and suitably located within a study area at risk.

To conclude, in complement to the attention drawn on collaboration activities between stakeholders, this research also stressed widely recognized needs for adaptive risk management strategies. Particularly in European mountain regions, there is a need to widen the range of appropriate, cost-effective and sustainable risk management options (Holub et al., 2012). According to the data collected from case study areas, effectiveness and sustainability are topics of particularly high relevance. There is, furthermore, a need to make efficient use of resources and to identify the most efficient alternative in a long-term perspective. This should also take into account the existing socio-economic and environmental objectives of each alternative during the decision-making process. Consequently, this highlights the importance of taking a more collaborative approach between different actors and stakeholders to achieve a common goal within the existing constraints. In addition, the implementation of such a collaborative decision support platform helps in the integration of all arguably necessary components from the eyes of the participating users (especially key decision makers) in a centralized manner to facilitate the easy access and sharing of information but also in a way that assists the decision-making process. This can be considered as going beyond a typical information exchange platform. Developing such a platform would be beneficial to the community, and could facilitate coordination across sectors and also support the kind of coordination called for under the Hyogo Framework for Action (United Nations, 2005). However, it must be stated that the development of such a platform is not intended to replace any existing participation methods but rather to act in complement and to contribute innovative practices and techniques for the community. Hence, the platform is not aimed at substituting the decision makers' responsibilities, but rather to assist in making decisions by providing additional supportive information and tools.

Chapter 6: Prototype evaluation with students

The developed collaborative framework of the prototype platform was further evaluated with students to obtain in-depths feedback on the conceptual and technical aspects of the platform as well as to analyse how the application of such interactive tools during an exercise could assist students in studying and understanding risk management. During the exercise, different roles (authorities, technicians, community) were assigned to each group of students for identification and selection of risk mitigation measures in a study area: Cucco village located in Malborghetto Valbruna municipality of North-Eastern Italy. Data were collected by means of written feedback forms on specific aspects of the platform and the exercise. The subsequent analysis of the feedback reveals that students with previous experience in GIS responded positively and showed interests in performing exercises with such kinds of interactive tools for learning, compared to the ones with fewer or no GIS experience. These results also show that the prototype is useful and supportive as a decision support tool in risk management while user-friendliness, interactivity and practical aspects of the platform could be further improved.

This chapter is extracted and modified based on the published journal article: Aye, Z. C., Charrière, M., Olyazadeh, R., Derron, M.-H., and Jaboyedoff, M.: Evaluation of an open-source collaborative webGIS prototype in risk management with students, *Journal of Spatial Information Research*, doi: 10.1007/s41324-016-0018-x, 2016.

6.1 Introduction

Under the framework of CHANGES project, an online collaborative web-GIS platform is developed for risk management of hydro-meteorological hazards, in particular floods, debris flows and landslides. This platform is regarded not only as a web platform for centralized sharing of risk information but also for ensuring an integrated framework where involved stakeholders can analyse risk and evaluate risk reduction measures. One of the main aims of the platform is to assist and integrate stakeholders' inputs into the formulation and selection of different risk management measures through an online participation approach. The collected preliminary feedback from local and regional stakeholders of the case study sites were presented and discussed in the previous chapter 5.

As a further step, presented in this chapter, the prototype was tested with Master students from the University of Lausanne. The purpose is not only to obtain in-depths feedback on the different aspects of the platform (such as visualization, accessibility, usefulness, user-friendliness and so on) but also to analyse the potential of such interactive tools for students' learning process related to natural hazards and risk management. In this chapter, sections are organized as follows: section 6.2 presents the structure and study area of the evaluation exercise carried out with students. The feedback results of the tested prototype are then presented and discussed in Section 6.3. Finally, the conclusion (section 6.4) includes reflection on the results of the presented work and potential perspectives on the developed platform.

6.2 Structure of the evaluation exercise

The evaluation of the prototype with students is also believed to assist in learning about risk management with a real world problem of decision making. This kind of activity can be regarded as "active learning" in which students are involved "in doing things and thinking about the things they are doing" as defined by Bonwell and Eison (1991, p.2). This is meaningful and important as the activities can contribute to the understanding of concepts to be learned (Wiggins and Mc Tighe, 1998).

This exercise took place, during a morning session of a course on risk communication, with eight Master students (majoring in Geology, Risk analysis and monitoring, Environmental risks, Social environment) at the University of Lausanne in April 2015. The exercise was composed of three main stages: risk identification, formulation and selection of alternatives (a combination of measures). These steps followed an integrated risk management approach with involvement of different stakeholder groups (McGahey et al., 2008). The structure of the exercise is illustrated in Figure 6.1. The students (in groups) played the roles of different stakeholders depending on the stages of the exercise (i.e. stages 2 and 3). The necessary information (for example, creation of user accounts, uploading of maps, etc.) was prepared by the moderator (teacher), considering the limited time allocated to the exercise. In a real life setting, the moderator would be an administrative user with the capacity to moderate the whole process, and could be one of the expert stakeholders (i.e. sectoral planning authorities and spatial planners).

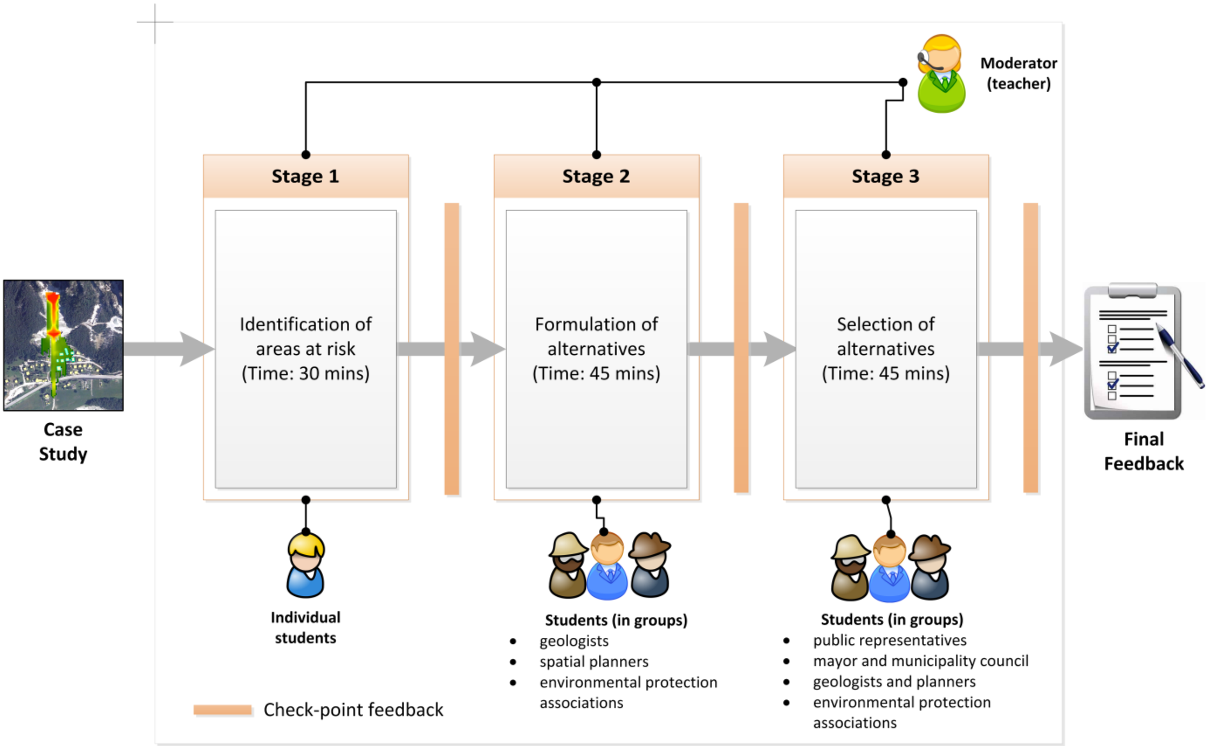


Figure 6.1. Structure of the evaluation exercise of the prototype.

As a guide, the following documents (Appendix III) were handed out to the students at each stage of the exercise:

- *log-in* access information to the platform,
- a *scenario* sheet of step-by-step instructions,
- a *role description* sheet of the stakeholders' roles for group exercises, and
- a *check-point feedback* form for prototype evaluation, to be filled out at the end of each stage. The form included:
    - information of the students (i.e. name, major, GIS experience and assigned stakeholder roles);
    - an open question on the analysis of the presented problem;
    - five to ten Likert[3] scale questions (5 points: Not at all to Absolutely) for specific aspects of the interface and functionality;
    - two open questions on improvements and suggestions on the presented stage of the prototype.

[3] A psychometric response scale, originally developed by Likert [14]. The students were asked to indicate their level of preferences or agreement with each statement mentioned in the questionnaires.

At the end of the exercise, the students were asked to fill two *final feedback* forms: *user evaluation* and *exercise feedback*. The *user evaluation* feedback evaluated the overall prototype such as innovativeness, interactivity, usefulness, user-friendliness, satisfaction and effectiveness as a decision support tool, rather than detailed aspects as in the check-point feedback. The *exercise feedback* evaluated the exercise itself in order to gain understanding and opinions of students on the exercise in terms of usefulness for learning and understanding, helpfulness in understanding of how real world situation works, stimulation of interests in risk management topic and in doing further exercises which involve interactive tools. All the feedback forms are associated with basic information of the students such as name, major of master, GIS and role-playing experiences, and their assigned stakeholder roles depending on the different stages of the exercise.

6.2.1 Study area of the exercise

Cucco village is located in Malborghetto-Valbruna municipality (North-Eastern Italy). This study area is also one of the case study areas of the CHANGES project and input risk data used for this exercise are the research outcomes of the project. This area was affected by debris flows in August 2003 and a dozen houses were approximately damaged due to the breaching of an existing barrier. After this event, new mitigation measures (such as retention basin, dam and channel) were placed by the Civil Protection of the Friuli-Venezia Giulia (FVG) region. Two houses were also relocated. The potential future scenario of debris flow in the area was modelled based on forward-prediction modelling to identify remaining risk and assess the effects of existing mitigation measures in the area (Hussin et al., 2014a).

6.2.2 Three stages of the exercise

In the *first* stage of the exercise (see Figure 6.1), individual students were asked to identify the areas at risk in Cucco. For this purpose, debris flow hazard and building footprint maps were uploaded beforehand into the platform by the moderator. In this exercise, the students conducted their analysis by simply overlaying these two layers and visualizing the areas being touched by debris flow in the web-GIS interface of the platform. However, in the prototype, potential losses of affected elements can be calculated using the risk analysis tool (see Chapter 4).

After identifying the areas at risk, the next step was to determine the possible measures to protect those areas. In the *second* stage of the exercise, students worked in three groups and were assigned with stakeholder roles that are representative of a real-life situation: geologists, spatial planners and environmental protection associations. The task of each group was to design its own alternative scenario, which is a combination of possible risk reduction measures (both structural and/or non-structural measures). Potential structural measures include creation of new mitigation measures or structural adjustments of the existing measures or houses. Non-structural measures concern non-physical actions such as the relocation of houses, natural regeneration in the area or establishment of an early warning system. Each group of students proposed its own alternative scenario by mapping (sketching) measures in the platform. In the check-point feedback form, along with the evaluation of respective functionalities of this stage, the students were asked to explain why their scenarios should be considered as the most appropriate compared to other groups.

The alternative scenarios proposed by different groups were then evaluated and ranked in the *third* stage of the exercise in order to select one single alternative scenario. For the simplification, within this exercise, criteria were pre-defined by the moderator (in real life, an expert) to evaluate the performance of the alternatives derived from the second stage. The corresponding performance values of alternatives against criteria were also evaluated by the moderator in advance due to the time constraints of the exercise. Four groups of students were re-assigned in this stage: public representatives, mayor and municipality council, geologists and planners, and environmental protection associations. The task of each group was to rank the alternatives by assigning weights to the defined criteria. In other words, depending on the role of each group, the students were asked to classify the importance of the criteria (with a scale of 1: the least important to 5: the most important criteria). Within the platform, each group could assign weights and visualize their ranking outcomes of alternatives in comparison with the ones of the other groups. A negotiation process (using the chat function) was started with the other groups to try to achieve a final ranking of the alternatives on which every group agree. In the check-point feedback form, students were asked to comment on the results of their given weights and ranking outcomes as well as to provide feedback on certain functionalities of the interface such as visualization of charts for criteria weights and alternative rankings.

6.3 Results and discussion

6.3.1 Check-point feedback

At the end of each stage of the exercise, the check-point feedback was used to evaluate certain components of the prototype as explained in Section 6.2. To demonstrate the use of the *open analysis question* of the check-point feedback, results obtained from the second and third stage of the exercise are presented.

For the second stage, measures designed by the "geologists" group of students are illustrated in Figure 6.2 as an example. This group proposed a combination of measures which included the improvement of the retention basin, of the barrier nets and of the protection forests in the area. In their opinions, structural measures are effective and sustainable despite the high cost of implementing such measures. Similarly, the "planners" group also proposed structural measures: the structural adjustments of the houses and the implementation of individual measures such as small walls and metal plates for the protection of houses. However, as opposed to the other groups, the group of "environmental protection associations" proposed non-structural measures to reduce the risk such as awareness raising, early warning system and relocation of houses. They believed that those would be better than structural measures as the latter might give the illusion to the people that they are fully protected. These feedback results show that students performed well in role-playing and proposed different mitigation measures according to their assigned roles of stakeholders. This reflects the real life situation in which measures are perceived differently by various stakeholders, underlining the needs of a collaborative approach to achieve a combined and coordinated risk management strategy. This participatory exercise thus demonstrated why such an approach with engagement of different expert stakeholders is important in risk management.

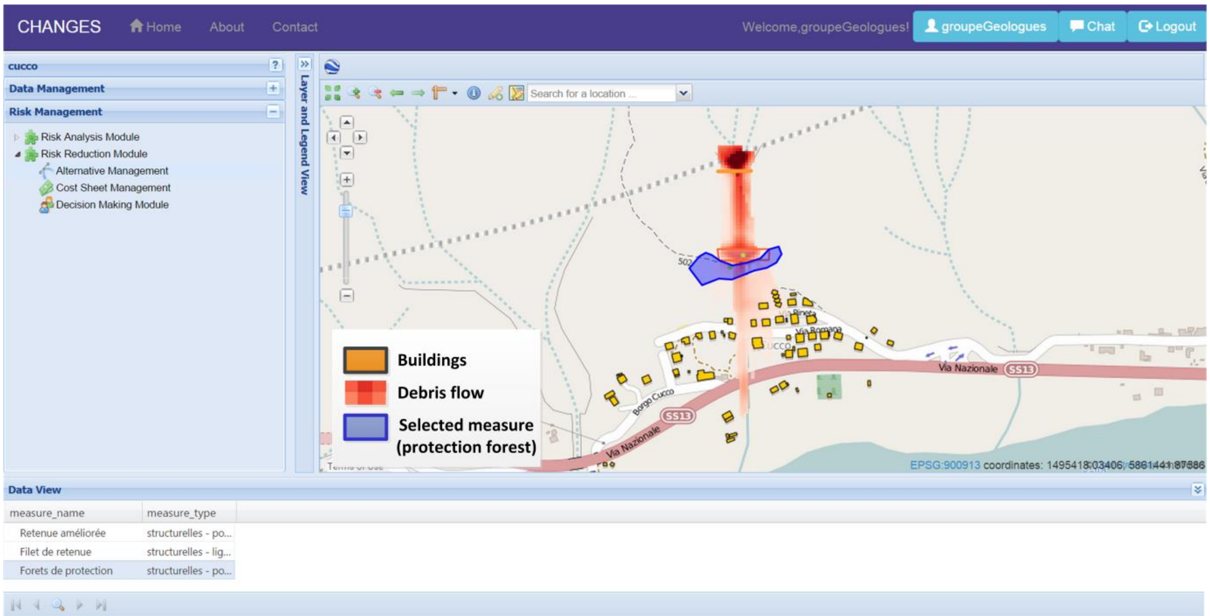


Figure 6.2. An alternative scenario designed by a group of students (geologists).

Criteria weights and alternative rankings produced by the group of “environmental protection associations” at the third stage of the exercise are illustrated in Figure 6.3. Amongst all criteria, the lesser effects on the nature and the effectiveness to protect people, in their opinions, are the most important criteria to take into account while the total cost of the alternative is the least important one. Consequently, alternative 3 (i.e. relocation and nature regeneration in the area) was ranked first according to their given criteria weights. On the other hand, alternative 1 (i.e. enlarging the retention basin) was obtained for the group of “geologists and planners". This group also mentioned that this ranking outcome is satisfactory as it corresponds to their proposed measures and given weights. However, for the “mayor and municipality council” group, the cost criteria is quite important as it is an obvious essential criteria for a politician. However, the agreement of population was also perceived to be of huge importance as politicians usually care about the absence of popular disagreement with their decisions and about the safety of people. This group hence considered these three criteria as equally important. As a result, alternative 2 (i.e. an early warning system combined with structural adjustments to the houses) was ranked first by this group. Similarly, the group of “public representatives” also reached to the same alternative, considering that local agreement should be a high priority along with the cost and safety criteria. This feedback reflects that diverse views of stakeholders need to be taken into account in the decision-making process to achieve a common goal in risk management.

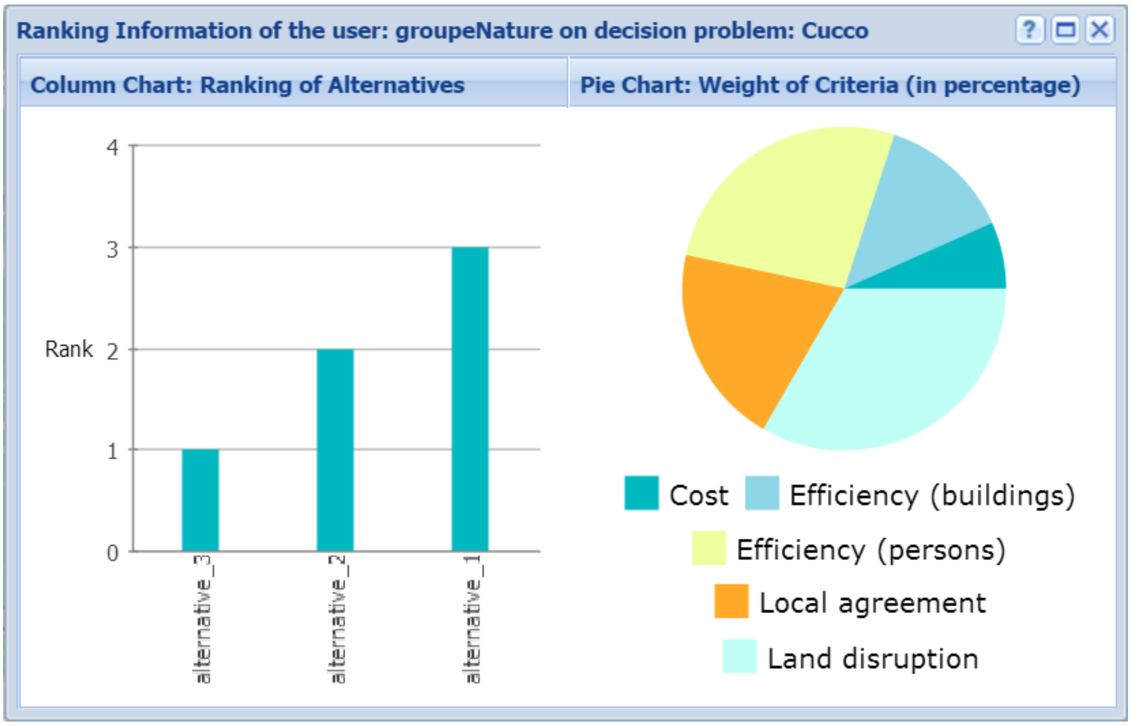


Figure 6.3. Ranking outcomes of alternatives (left) produced by a group of students (environmental protection associations) based on assigned weights (right).

The *Likert scale questions* of the check-point feedback were related to various aspects of the interfaces, tools and functionality such as user-friendliness, satisfaction, usefulness, supporting ability, relevance and understanding of contents. A total of 21 rating questions were collected for three stages of the exercise. Table 6.1 presents selected feedback with respective average scores given by the participating students. The score ranges from a scale of 1 (Not at all) to 5 (Absolutely). As can be seen in the table, the user friendliness of sketching interface could be improved (average score = 3.5). This is maybe due to the layer styling option, which can be improved by restricting the sketching tool to enable only either point, line or polygon geometry features in the same layer. However, students mentioned that sketching functionality (i.e. "create" and "editing" feature tools) is useful in designing measures (average score = 4). In the third stage of the exercise, the chart options were found helpful in visualizing criteria weights and comparing alternatives with others (average scores > 4). Overall, the transparency of decision-making process achieved an average score of 3.9, in which students with experience in GIS (75%) scored 4.7 and the rest (25%) scored only 1.5. This difference can explain why a high transparency score is not achieved as expected.

Table 6.1. Selected check-point feedback (with average scores) given by students.

Selected questions	Average scores
How easy was it to find the maps you needed to visualize?	3.9
How easy was it to sketch measures in the map interface?	3.5
How useful is the "create" and "editing" feature tools?	4
How helpful would it be if a toolbox of mitigation measures was available?	4.5
How understandable is the weighting scale?	4.3
How helpful is the pie-chart visualization (criteria weights)?	4.4
How helpful is the comparison of ranking outcomes with other groups?	4.3
How transparent is the decision-making process?	3.9

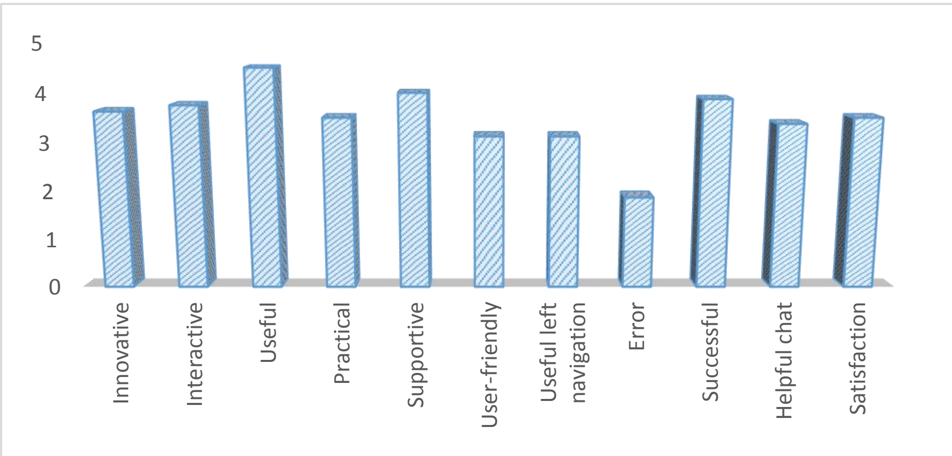
Regarding the *improvement and suggestion questions*, feedback of students included:

- the visibility of layer and legend view tab should be expanded and made more pronounced;
- the geographical coordinates on the map should be available;
- the hazard zone in the raster image should be made more understandable;
- the compatibility of browsers for 3D Google Earth visualization tool should be improved;
- the readability of the interface should be improved;
- the visibility and user-friendliness of tools for the creation of alternative scenarios should be enhanced;
- the weighting scale of the criteria should be indicated;
- the (stacked) bar chart visualization for ranking outcomes should be clearer;
- the explanation of the terminology usage in the interface should be provided and the chat option should be made more accessible.

6.3.2 Final feedback: prototype

In the first section of the *evaluation feedback* form, students were asked to explain (in a few words) their understanding of the tested prototype. Students mentioned that it is a good decision tool for the formulation and the selection of risk reduction scenarios with all concerned stakeholders in a given risk zone. Moreover, it was stated that the tool is not only useful to communicate hazards and related impacts but also to enhance the collaboration between different experts in risk management. It was also mentioned that the tool allows the inclusion of different privileged criteria for the parties in the decision-making process for the selection of alternatives. According to the responses, the purpose of the platform was well-understood, and therefore, one of the important evaluation aspects of the exercise was fulfilled.

The average scores for overall aspects of the prototype are shown in Figure 6.4. The students found the platform useful (average score = 4.5) and supportive as a decision support tool (average score = 4). Meanwhile, user friendliness of the interface and the usefulness of the main left navigation panel could especially be improved (average scores of 3.1 for both). This feedback also shows that the prototype platform is successful in performing its intended task (average score = 3.9). The overall user satisfaction achieved an average score of 3.5, which is acceptable considering the unavailability of tutorial documentation and training of students before the exercise.



Q1. Is the prototype innovative?

Q2. Is the prototype interactive?

Q3. Is the prototype useful?

Q7. How useful is the left navigation panel to find information needed?

Q8. How often does the prototype have errors and need to refresh?

Q9. How successful is the prototype in performing its intended task?

Q4.	Is the prototype practical?	**Q10.**	How helpful is the chat functionality between users?
Q5.	Is the prototype supportive as a decision support tool?	**Q11.**	Are you satisfied with the prototype overall?
Q6.	Is the prototype easy to use?		

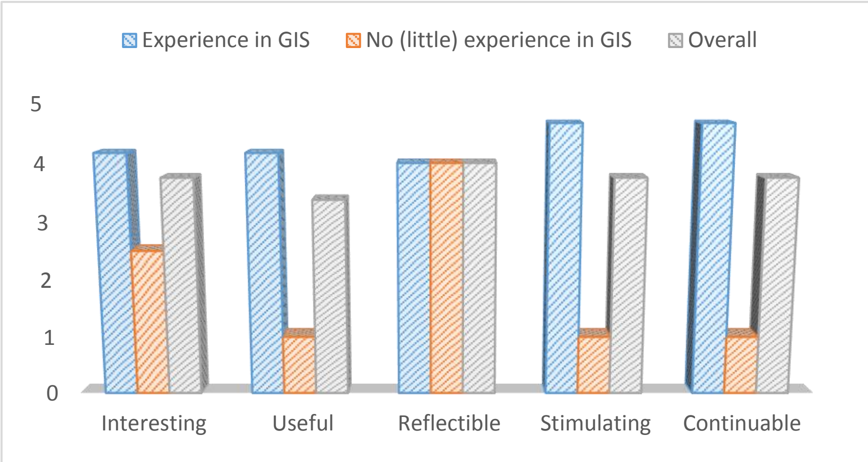
Figure 6.4. Feedback on the platform (overall) based on a 5-point Likert scale.

Concerning the overall aspects to improve, students stated that the tool needs to be more interactive, accessible, user-friendly and intuitive. During a short discussion after the exercise, students also mentioned that the availability of a step-by-step video explanation, manual or training documentation of the tools and modules would be helpful in using the platform. Moreover, some students mentioned that the applicability of the platform in the real world by the authorities could be limited as risk management is quite complex. It was agreed that potential ways of encouraging and engaging stakeholders in the collaborative process should be further explored. Besides, it should be noted that the purpose of a decision support platform is to assist stakeholders in making better-informed decisions by providing necessary information and tools. Hence, the legal responsibility of stakeholders and the primary decision-maker remains according to the institutional context of the study area where this platform is applied.

6.3.3 Final feedback: exercise

The first section of the *exercise feedback* form asked students about what they had learned from this exercise. Note that all participating students had previous experience in role-playing. Students mentioned that it is a multi-disciplinary tool for decision making and the exercise was very useful as they were able to see the effects of the same problem from different points of view. They have also learned how an optimal decision can be reached considering different aspects at the same time and with other stakeholders.

Figure 6.5 shows the average ratings of the five questions asked in the second part of the exercise feedback form. According to the responses, the students with experience in GIS (75%) found the exercise quite interesting, useful and helpful while almost excellent in stimulating their interests in risk management topic and in doing other exercises with such interactive tools. On the other hand, the students with few or little experience in GIS (25%) found that the exercise is quite helpful in understanding of how real situation works while results were quite low for the other questioned aspects. This result is not surprising as these students did not have experience working with similar software, and thus, the feeling of being uncomfortable doing the exercise and using the platform for the first time is believed to have some effects. If this exercise should be reproduced, this aspect could be improved by giving training to students before the actual exercise.



Q1. Is this exercise interesting?
Q2. Is this exercise useful for your learning and understanding?
Q3. Is this exercise helpful in understanding of how real situation works?
Q4. Does this exercise simulate your interests in risk management topic more?
Q5. Would you like to do other exercises with interactive tools?

Figure 6.5. Feedback on the exercise based on a 5-point Likert scale.

Regarding the aspects of the exercise to be improved, students commented that more time for the exercise is needed to present and discuss the results with others in order to reach a best consensus solution at the end. It was mentioned that the exercise gave them a good idea of the difficulties that can be faced in participative decision making and risk management. Students with no or few experience in GIS stated that the use of the platform could be more simple and adaptable for those who never worked in a mapping environment before (or alternatively, training can be given to them). Nevertheless, less-experienced students found the exercise interesting for the understanding of risk management scenarios because this topic is not addressed in their major, i.e. social environment.

Concerning the allocated time frame of the exercise, we believe that at least one half-day should be allocated. Thus, sufficient time is given not only for providing a good amount of explanation of the theoretical framework of the platform but also for the follow-up discussion with students at every stage of the exercise. This could enhance the usefulness aspect of the exercise in learning and understanding the presented topic. During the exercise, it was observed that students were less confused and adapted to the exercise as time went by. The students especially enjoyed the third stage of the exercise where they had to assign preference weights on criteria according to their played roles and where they compared the outcomes with other groups for the selection of alternatives. This is maybe due to the apparent simplicity of this part of the platform. Or maybe because this is the most interesting part of the exercise as interactions take place between groups (unlike in the other stages: individually or within groups). Discussion within some groups also got a little heated as they debated over which measures to propose in the second stage of the exercise. However, all groups managed to finish the tasks within the specific time frame. Interestingly, one student, in particular, expressed that "collaboration is hard" when being asked to explain what they learn from this exercise. In addition, some students raised questions and showed interest in the approach used for the decision-making process.

6.4 Conclusion

In this chapter, we presented how the evaluation of the collaborative decision support platform was carried out with students majoring in environmental topics. The role of students in this exercise was to evaluate the prototype as well as to learn the process of risk management through the selection of alternatives for risk reduction. It allowed them analyse the presented problem, propose and select a solution by working together with other students towards a common goal. Students brought their own experiences and background knowledge as they come from different specialized majors. Conflicting interests and values between different groups were observed in the course of the exercise. For example, structural measures were more favoured by the "geologist" group while the "environmental protection associations" group favoured non-structural ones. To achieve the most appropriate and sustainable solution, all potential alternatives should be considered and compared against each other in terms of economic, social and environmental criteria. This exercise reflected the real inter-disciplinary situation in which the involvement of various experts, decision makers and the community is crucial to achieve a sustainable and combined risk management strategy, particularly in the case of the areas such as the ones studied in the CHANGES project where limited funds are available and weak links of interaction activities exist among risk management stakeholders.

Overall, the analysis of the feedback shows that the prototype is quite supportive and useful as a decision support instrument with good performance in carrying out its intended task. However, aspects such as user-friendliness, interactivity and practical aspects of the platform could be further improved for its application in practice. In general, this feedback is also in accordance with the preliminary feedback given by stakeholders during the dissemination meetings carried out in three case studies of the CHANGES project in 2014. As students suggested, provision of manual documentation and video demonstrations would be helpful in familiarising with the platform. Nevertheless, students' learning seems to benefit from the evaluation of the platform. Students with GIS experience responded positively and showed great interest in active learning with such interactive tools, compared to the rest which had limited or no GIS experience. However, this can be improved by giving training to those who are not familiar with GIS applications, if such innovative and interactive hands-on exercises were to be developed for relevant courses at the university. Nonetheless, all students agreed that this exercise reflected the real situation and improved their understanding of the decision-making process in risk management. This feedback provided an important input not only in further improving the research but also as a potential application of the platform for active learning with students. Some of the improvements are considered in the adaptation and application of the platform for environmental risk-related exercises with Bachelor students, which is a current and continued research work.

Chapter 7: General conclusion and perspectives

To obtain preliminary inputs and identify encountered issues in decision making for risk mitigation activities, in this research, stakeholder meetings and field visits were carried out in three case study areas of Europe. Based on the observations obtained from study areas, several issues were identified: 1) the limited financial funds; 2) the (in several but not all cases) outmigration problem in the mountainous areas and 3) the lack of coordination activities between authorities dealing with risk management. For example, in Italian study area, large-scale and high cost structural mitigation works have been implemented due to the desire to reverse outmigration in the area and in order to protect the existing small settlements. This shows the needs to consider other important criteria and weigh the benefits of alternatives against long-term maintenance and residual risk consequences for the future development. Effectiveness and sustainability is particularly relevant and important in these areas. There is a need to make efficient use of the available resources and to identify the most efficient option in a long-term perspective by taking into account the existing socio-economic, environmental objectives and cost-benefits of each option during the decision-making process with all involved stakeholders.

In this case, participative decision support tools could assist stakeholders: 1) in providing necessary information with informed choices; 2) in encouraging the participation and collaboration of stakeholders in decision making and 3) in producing a wide range of appropriate and innovative cost-effective, sustainable risk management solutions. Despite the presence of various applications in the study areas, there was no decision support platform which serves the purpose of analysing risk, formulating and selecting risk management solutions interactively and collaboratively through a web-GIS based platform. This highlighted the importance and possible application of such a decision support platform in study areas, which assists stakeholders in analysing consequences of potential hazard events and achieving the common goal of risk reduction for selection of measures within existing constraints. This contributes to answer some of the initially identified research questions such as:

1) What are the encountered difficulties in taking more informed decisions, looking through the lens of a long-term perspective in risk prevention and mitigation?
2) How to identify the most efficient option, making good use of available resources and encouraging the involvement of various stakeholder groups?

Therefore, in this research, a collaborative web-GIS based decision support framework (Figure 7.1) is proposed for collaborative risk management of natural hazards (especially for floods, debris flows and landslides), aiming to answer the following research questions:

3) How to facilitate and integrate the involvement of stakeholders in risk management and decision making?
4) How to potentially enhance collaboration and coordination activities between responsible stakeholders in risk management?

A prototype platform is realized based on open-source software architecture, offering a high degree of replicability and mobility in other study areas. It can be easily adapted and applied, benefiting from the uses of open-source technologies. Unlike desktop-based applications, the users need not install additional plug-ins or GIS software. This platform can not only be regarded as a centralized sharing of risk related data and information but also as a decision support tool in understanding the process of risk management, starting from analysing the impacts of natural hazards to the selection of risk reduction measures for decision making with involved stakeholders.

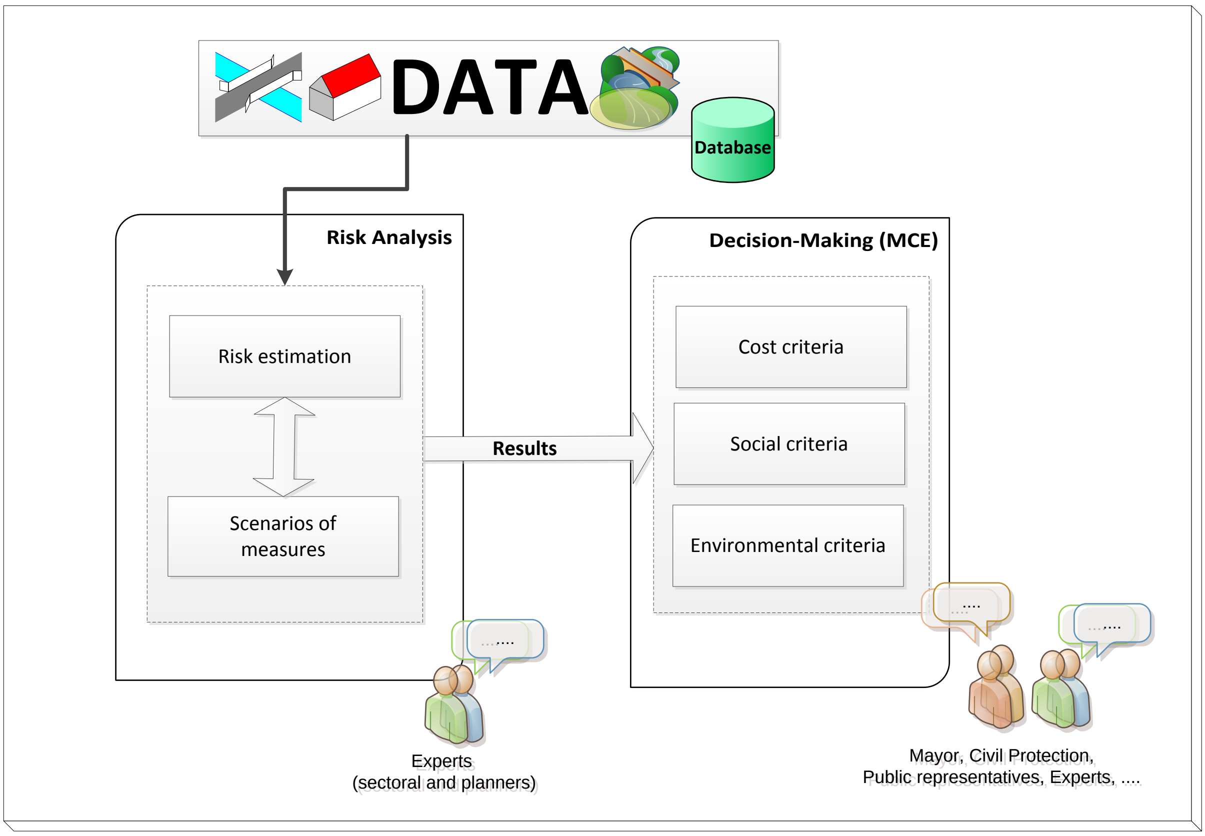


Figure 7.1. An overview of the collaborative decision support framework with involvement of different stakeholder groups.

This decision support framework is composed of two main parts: risk analysis and risk reduction. The purpose of the first part is to assist risk managers in analysing the impacts and consequences of a certain hazard event in a considered region. This is an important input to the decision-making process for the selection of risk management strategies with all involved actors and stakeholders. For this work, a prototype tool is achieved which allows users to calculate and produce risk curves interactively based on the inputs information of hazards, objects and vulnerability. This tool calculates risk as a whole according to the extent of the input layers, for example, at a local or regional scale. The more interactive and spatial-query-based risk calculation is also possible with the integration of an additional option for defining a study zone. For example, by drawing a polygon zone in the mapping interface for an area of interest. This functionality is already included in an on-going research project for risk management of natural hazards in Switzerland, in which semi-qualitative hazard intensity maps are used for risk estimation. There are several functionalities for further improvements such as integration of additional vulnerability curves, batch processing mode for different return periods of hazards, calculation of the total annualized risk under the risk curve than a staircase-shaped approach, and possibility of implementing WPS services for risk calculation. Nevertheless, this risk analysis tool served as an initial and essential point for obtaining stakeholders' feedback as well as for the possibility of implementing a full-scale risk analysis tool based on the needs of stakeholders to where it could be potentially adapted and applied. Moreover, integrating this process in a decision support platform made it more beneficial to the stakeholders for the follow-up decision-making process.

For the second part of the framework, the aim is to facilitate, integrate and encourage the involvement of different stakeholders in a collaborative, decision-making process for the identification and selection of potential risk management measures. This would enable a more transparent and better informed decision-making process with the use of available risk information. An innovative two-phase collaborative framework is proposed, which allows both horizontal and vertical interactions between stakeholders in different organizations. The prototype is presented to the local and regional stakeholders of the study areas, to understand its potential use and benefits in supporting coordination and collaboration activities between stakeholders. Stakeholders from three study sites provided favourable responses in this framework and platform, especially in Poland and Romania. Generally, stakeholders found it useful, innovative and supportive while addressing several aspects of the platform to be improved for the application of a full-scale system in practice. For example, this included active engagement of stakeholders, interactive real-time exercises with stakeholders and integration of additional supportive tools. Some of these improvements are already considered in the continued and on-going research works. The additional functionalities are also possible for future research works such as a toolbox of risk mitigation measures, comparison of ranking outcomes by different MCE approaches, sensitivity analysis, and so on.

Furthermore, this collaborative prototype was tested and evaluated with university students to collect feedback on the conceptual framework as well as the technical aspects of the platform. Through the role-playing exercise with students, conflicting interests and values between different groups of stakeholders were observed. This reflected the real world situation in which the involvement of various stakeholders is key to achieve an integrated and coordinated risk management strategy. In general, feedback results show that the prototype is supportive and useful with good performance in carrying out its tasks. However, user-friendliness, interactivity and practice aspects could be further enhanced. This evaluation exercise further leads to the analysis of how the use of such interactive tools during the exercises with real case examples could assist students in studying and understanding risk management, which is a continued research work of an on-going innovative teaching project at the university. This research work is further adapted for learning purpose in environmental risk course and tested with Bachelor students of the spring semester 2016.

Based on the obtained evaluation feedback with stakeholders and students, possibilities and application of the platform are identified, attempting to answer the last research question:

5) What is the possibility of applying a decision support tool based on open-source solutions in study areas?

We have seen that there are certain benefits in applying a collaborative framework in risk management, allowing different stakeholders to collaborate through a centralized and interactive web-GIS decision support platform. The greater benefits lie in having the possibly to choose the most suitable and efficient option, considering the sharing of limited resources (Prenger-Berninghoff et al., 2014). However, there are also some practical concerns raised by stakeholders regarding the applicability of such a collaborative platform in a real life setting. Because of the complex nature of the decision-making process and institutional framework of the area where the platform is applied, levels of stakeholders' participation in the decision-making process could be greatly varied from place to place. The final decisions are thus yet to be made by the main decision makers, while the tool could only provide necessary information to facilitate and support the process of decision-making. This applies the same in encouraging stakeholders to participate, coordinate and collaborate activities between each other in the risk management process. The potential solutions such as legal enforcement, positive incentives and demands of formal collaborations between organizations are essential to successfully achieve such a collaborative and integrated framework, while the application of the platform is one of the possible solutions which attempts to potentially promote and enhance collaboration activities between responsible stakeholders. Another concern is that it might not always be possible to involve all stakeholders via web in the endangered areas. This could be due to the lack of internet access or technical capacity of the stakeholders to be able to use the platform. These limitations are beyond the ability of a decision support tool, despite its usefulness, support and reproducibility.

Even though there exist such limitations, stakeholders mentioned that it is a useful, supportive decision-making instrument which reflects concepts of risk governance, enhances collaboration with the participation of different stakeholder groups and reduces the resources (e.g. time and cost) needed to take a decision. It is important that the platform can be used from multiple locations at multiple scales with multi-users. For the further possibilities in applying such decision support tools, in Poland, planning stakeholders stated that this platform could also be adapted for the purpose of evaluating different planning proposals. In Romania, emergency management stakeholders mentioned their interests in adapting the platform to take into account the Romanian legislation and structure of the national emergency management system. In Italy, it was mentioned that the platform could be simplified and adapted to the specific needs of stakeholders, and addition of cost-benefit analysis including quantification of both economic and social aspects would be an asset in the decision support platform. The next steps for the in-practice application could include organization of instructional training courses, performing of concrete exercises with stakeholders for evaluation, improvement and adaptation in a certain study area, engagement of stakeholders for active participation, and additional improvements on the developed framework and platform such as integration of relevant (existing) data from other platforms in the study area and a cost-benefit analysis tool to supplement the process of multi-criteria evaluation for the selection of available options.

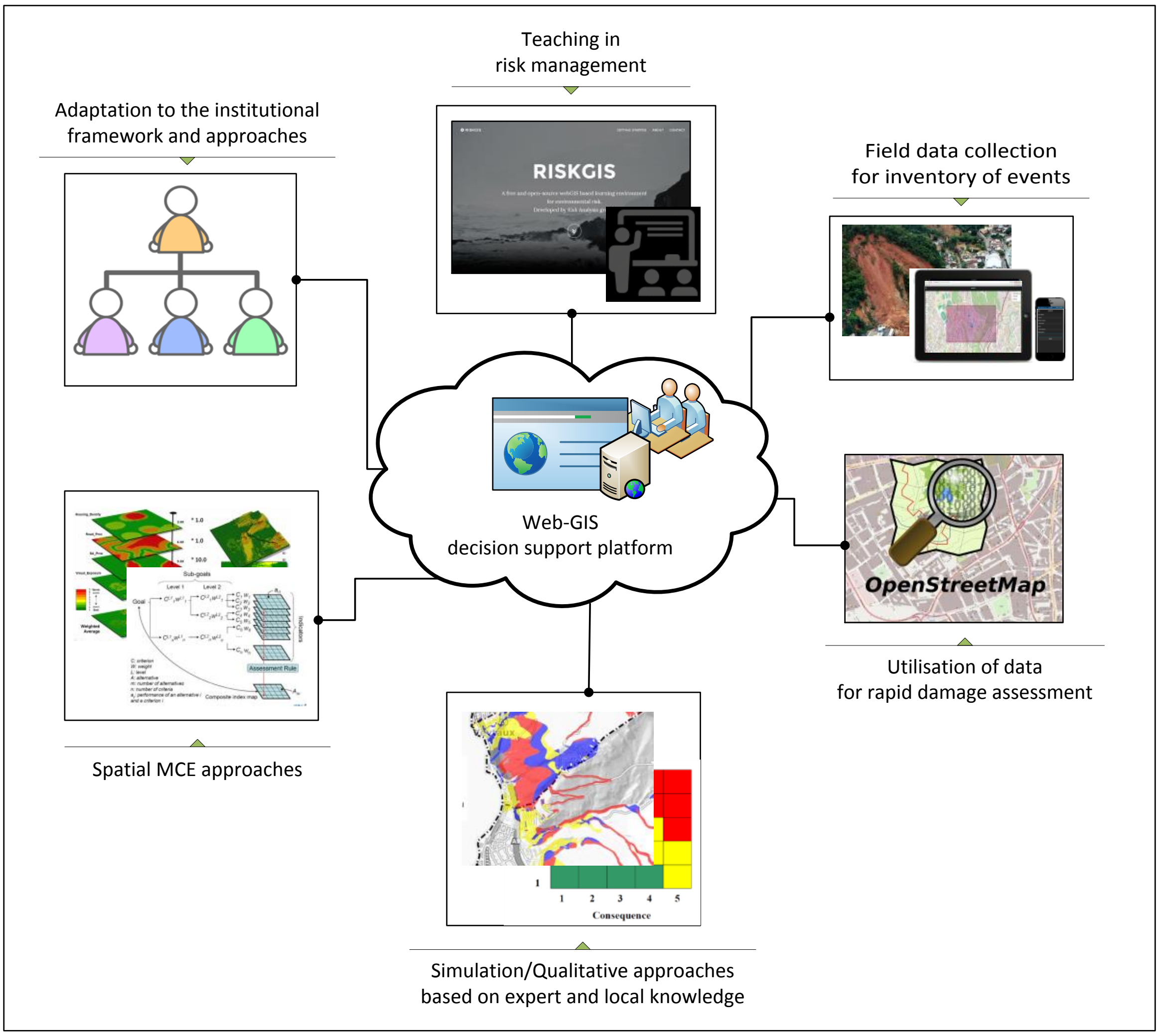


Figure 7.2. Illustration of the potential future perspectives and applications linked to the presented PhD research work.

Future research directions (Figure 7.2) linked to the presented research include:

- Extraction and integration of OpenStreetMap data for rapid damage assessment when a complete inventory is not available for affected elements at risk;
- Integration of simulation and qualitative approaches to deal with lack of data based on expert and local knowledge of the territory;
- Possibility to integrate field data collected using mobile applications, for the purposes of establishing an inventory of events and performing further analysis on the collected data to identify hot spot locations;
- Possibility to integrate simulations for evaluation of measures depending on the considered intervention types;
- Possibility to integrate spatial MCE approaches for consideration of the spatial component in a more explicitly way;

- Application of the platform for teaching in risk management with students using real case examples and
- Adaptation of the framework and platform according to the certain approaches and institutional framework of a certain study area to where it is applied.

To conclude, in this research, a collaborative web-GIS based decision support framework was achieved, fulfilling three main research objectives:

- To carry out a systematic and integrated risk management approach,
- To potentially enhance collaboration activities between stakeholders and
- To explore the possibility and application of decision support tools.

The first objective is achieved through the proposed web-GIS framework, allowing stakeholders to perform an integrated approach systematically, starting from risk analysis to the decision-making process. With a centralized and participative approach, the second objective is further achieved, encouraging the involvement of different stakeholders in various phases of the risk management framework. This allows in potentially enhancing coordination and collaboration activities between stakeholders. During the dissemination meeting with stakeholders in study areas, they have mentioned that this is an innovative idea which allows the participation of different stakeholder groups in the selection of coordinated risk management strategies. The possible application of the proposed collaborative framework is further demonstrated through the preliminary and in-depths evaluation of the prototype with stakeholders and university students, which contributed in achieving the third research objective, along with initial observations and inputs obtained from the study areas through semi-structured interviews, field visits and stakeholder meetings.

This PhD research highlighted the importance of a systematic, integrated and collaborative risk management approach with involvement of multi-stakeholders, through the application and demonstration of a collaborative decision support prototype platform in case studies of the CHANGES project. This research work offered the possibility to carry out risk analysis, formulation and selection of measures within an integrated framework, bridging across responsible stakeholders and their respective organizations in risk management for improved communication and exchange of decision support information. Besides, using open-source standards and solutions, it contributed to the open-source research community in this field of natural hazards and risk management, making it possible to reproduce and adapt based on the specific needs.

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Appendices

Appendix I: Supplementary materials (Chapter 4)

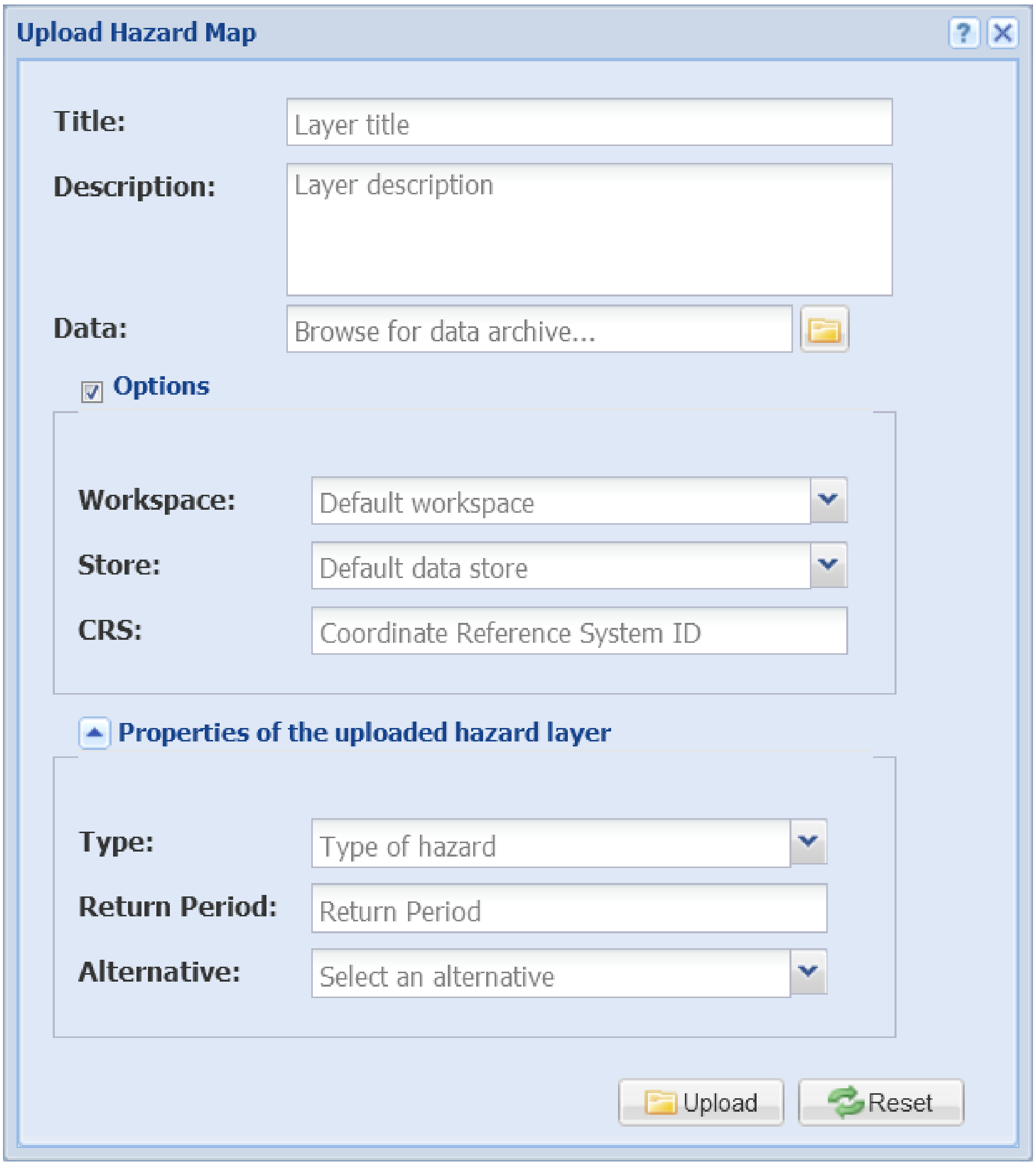

Figure S1. The import interface of the hazard component. The user can enter layer information such as name, description, hazard type, return period and the indication of whether the imported hazard map reflects the current situation or a possible future situation after the implementation of certain measures (for risk reduction module of the platform).

Figure S2. The interface of the vulnerability component with "data ranges" option. The user can enter vulnerability curve information such as name, description, hazard type, elements-at-risk type, vulnerability type (e.g., physical) and the indication of whether the vulnerability curve corresponds to the current situation or a possible future situation after implementing certain measures.

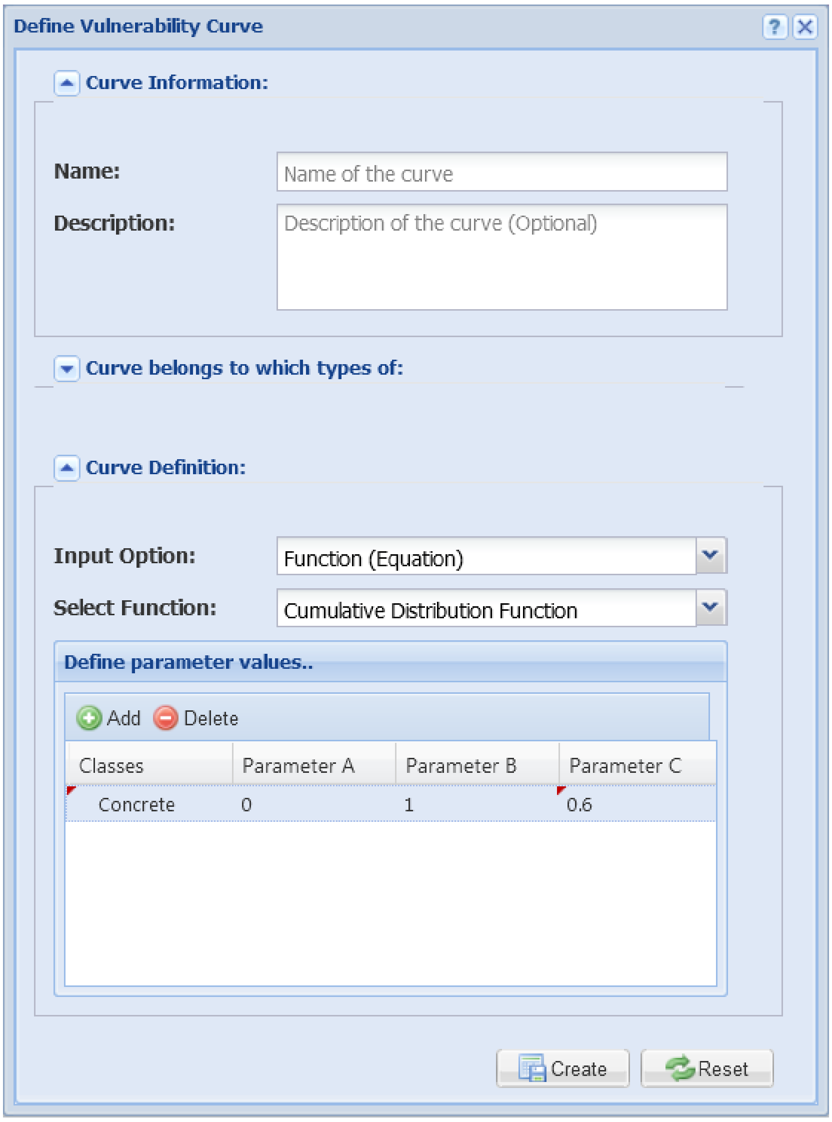

Figure S3. The interface of the vulnerability component with "CDF function" option. The user can enter basic vulnerability curve information as illustrated above, however, with the selection of input option as "function" instead of "data ranges". In the prototype, CDF is implemented and the user can give parameter values to generate the respective vulnerability curve (e.g., for different classes of a certain elements-at-risk).

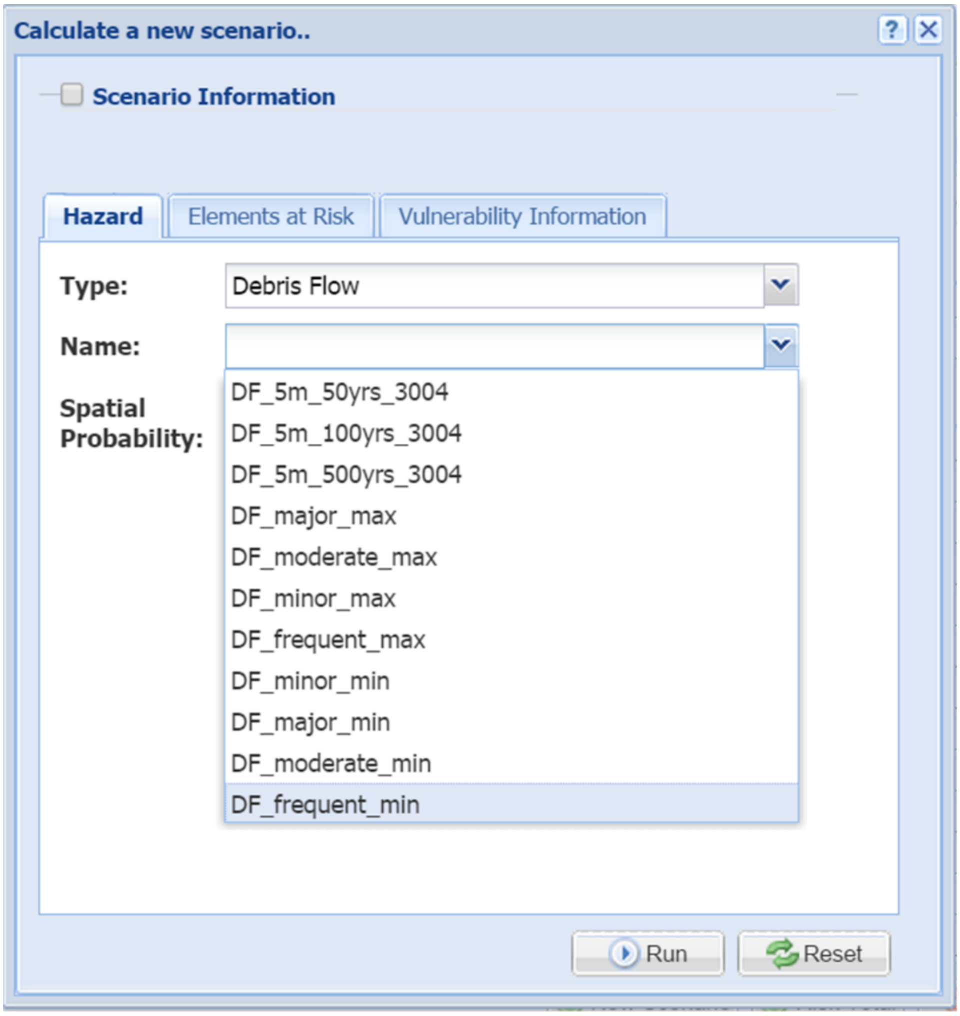

Figure S4. The interface of the loss component illustrating the selection of hazard input parameters for calculation of a loss scenario. The user can select an existing hazard map depending on the selected hazard type (e.g., debris flow). If available, its corresponding spatial probability information can be given, either in the form of map or input value (0 to 1).

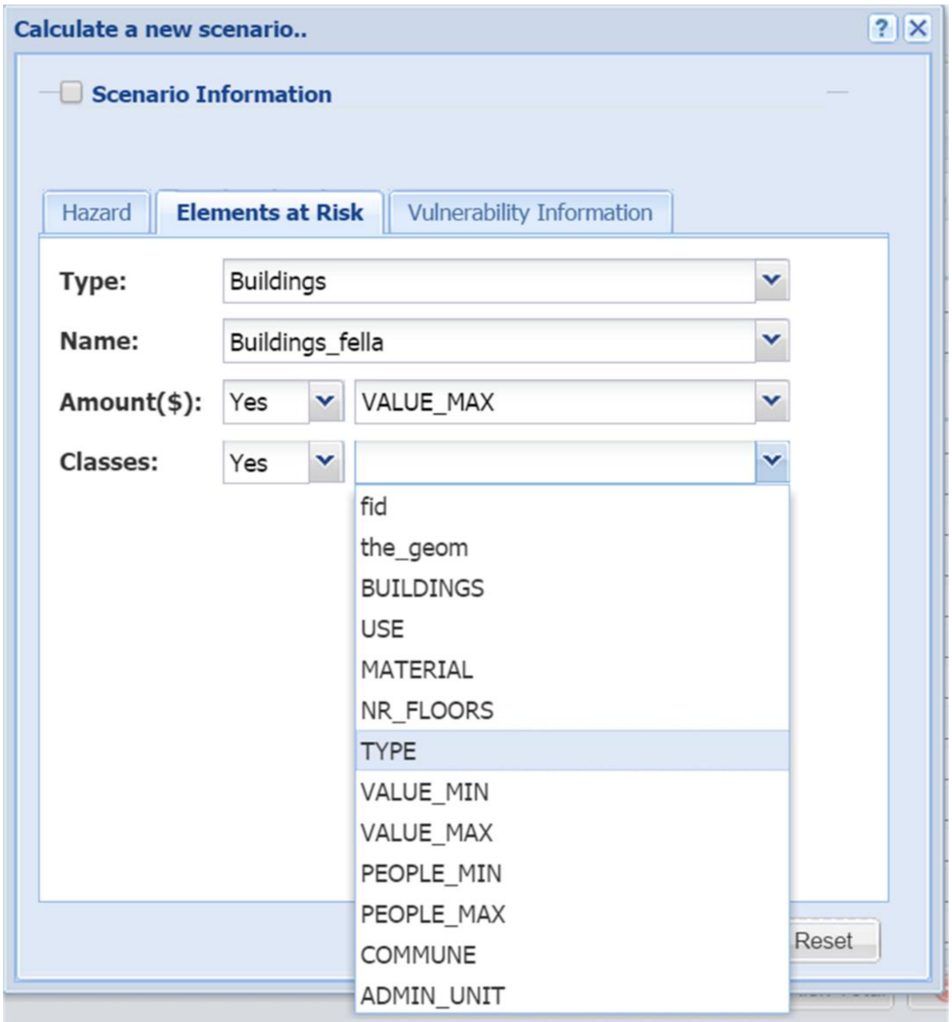

Figure S5. The interface of the loss component illustrating the selection of elements-at-risk input parameters for calculation of a loss scenario. The user can select an existing elements-at-risk map depending on the selected type (e.g., buildings). If available, the user can enter additional information such as amount (e.g., building value) and class (e.g., material type), by querying attribute information of the selected elements-at-risk layer.

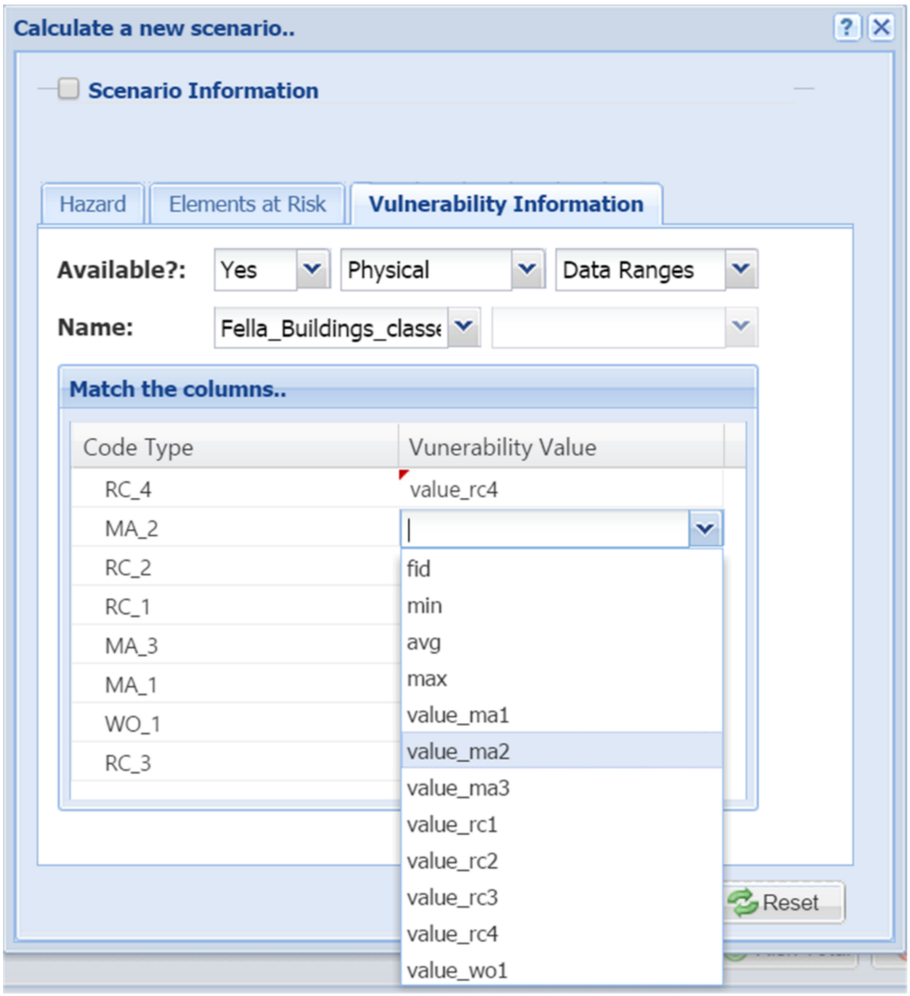

Figure S6. The interface of the loss component illustrating the selection of vulnerability input parameters for calculation of a loss scenario. If vulnerability information is available, the user can select the available information based on its data type (either data ranges or function). Then, the user can match the vulnerability data of the selected curve with existing classes (e.g., material types) of the selected elements-at-risk layer accordingly, to retrieve the corresponding vulnerability value of a certain level of intensity on each affected object.

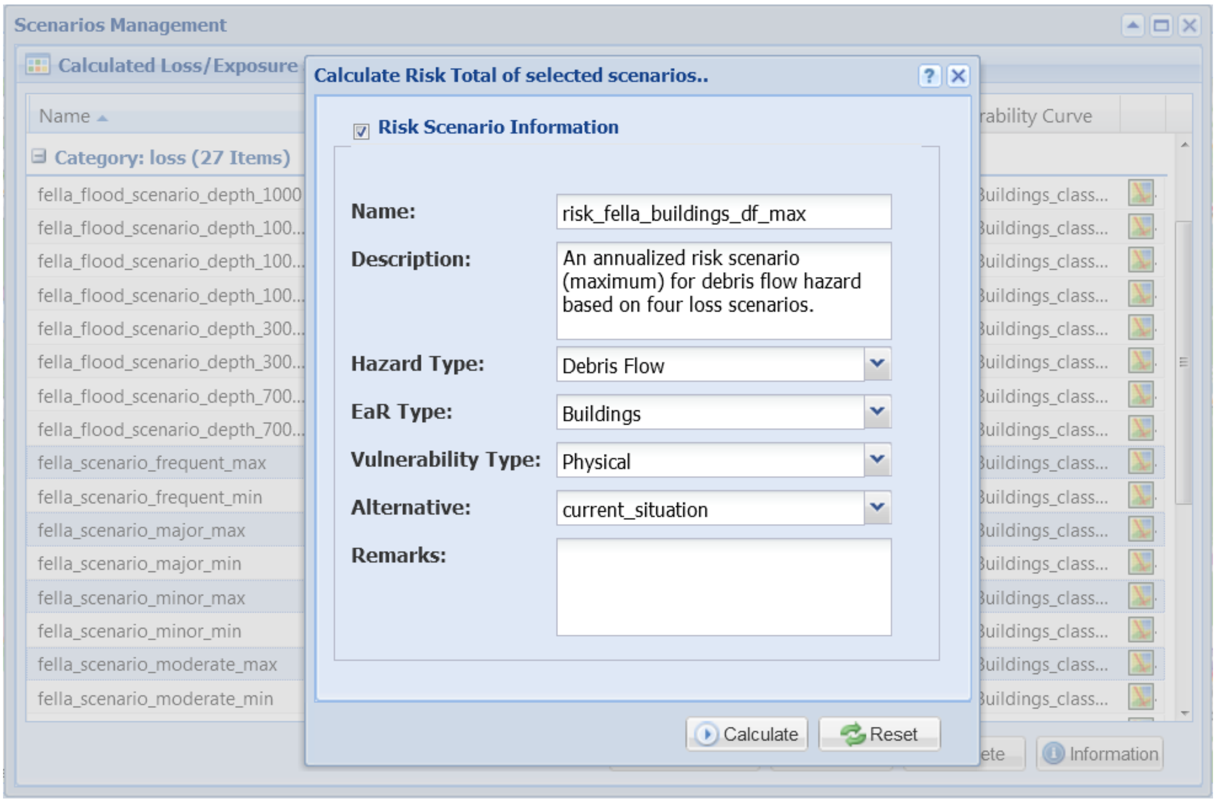

Figure S7. The interface of the risk component illustrating the selection of loss scenarios for calculation of an annualized risk scenario. At least three or more loss scenarios with different return periods are required, and the user can enter related information such as name, description, hazard, elements-at-risk and vulnerability type of the calculated risk scenario.

Appendix II: Supplementary materials (Chapter 5)

User Feedback Form

Name (optional)	
Profession	

Section 1: Mention in few words (or phrases) of your understanding on this platform.

____

____

Please use the following rating keys to answer the questions listed in the table.

(1) Extremely Bad (2) Bad (3) Fair (4) Good (5) Excellent

No.	Questions	Rating Key
1.	Do you find the platform useful?	
2.	Do you find the platform innovative?	
3.	Is the user interface of the platform clear and easy to follow?	
4.	Is the platform practical to use?	
5.	Rate the supporting ability of the platform in collaborative decision making.	

Section 2: In your opinion, which aspects of the platform should be improved and why?

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____

Section 3: Additional comments and suggestions (optional).

____

____

____

Thank you very much for your kind support in filling this feedback form. Please don't hesitate to contact Ms. Zar Chi AYE, Marie Curie fellow (CHANGES project) (email: zarchi.aye@unil.ch) for more detailed information about the development of the prototype or any other questions or comments you may have.

Appendix III: Supplementary materials (Chapter 6)

Role description sheet

Geologists

The main role of geologists is to identify the hazard. They take part in the creation of the hazard map. They are usually part of the authorities or consultancy agencies. Along with geo-engineers, they take part of the process to designing structural mitigation measures. They participate in the verification that those structures have a positive impact on the risk level.

Spatial planners

Planners are in charge of the spatial planning. They have to integrate the information related to natural hazards in their plans. At the communal level, spatial planning rules building authorizations. The spatial planning document related to natural hazards at local level is the hazard map. However, natural hazards are just one thing that planners have to take into account when they elaborate their strategies.

Environmental protection associations

The role of the environmental protection associations is mainly to verify that the implementation of mitigation measures does not harm the nature. Moreover, they make proposal on the re-naturalization of the area and the return of the river/streams to their original beds for example. They have the right to appeal against the building of any structure. They are present mainly at a regional level and their direct influence in the local community is limited, although it is relevant for the safety debate.

Mayor

The role of the mayor is to protect the population. The mayor is the main actor in term of decision making. Based on input given by experts, regional authorities and population, he/she must make choices regarding risk mitigation. His/her actions should prevent, using the suitable measures (structural or non-structural, and limit the damages caused by natural hazards. The mayor is elected. This means that he can be in a favourable (majority in the municipal council) or unfavourable (coalition or opposition in the municipal council) position. Therefore, his/her choices can be influenced by the political context as well as the population's opinions in the perspective to be re-elected.

Public representatives (community leaders)

Public representatives make the link between the population and the authorities. They have to make sure that the decisions of the later are beneficial for the first. They are concerned about the safety of the people and goods. Therefore, they are pushing the authorities to take actions. However, they have to pass along the concerns and complains related to the creation of mitigation measures. As mitigation measures are partially paid by public taxes, they can disagree with a budget. They can also disagree if the mitigation works have an important visual impact on the landscape.

Scenario sheet

Background

We will analyze the Cucco village, which is part of the Malborghetto-Valbruna municipality in North-Eastern Italy. This study area was affected by debris flows triggered by a severe rainfall event in August 2003. 14 houses were damaged because of the breaching of the existing mitigation barrier (Figure 1). After this event, new mitigation measures were placed by the Civil Protection. A small retention basin with a 10m depth retention dam was constructed, following by a channel leading to the downstream Fella River (Figure 2).

Figure 1. Debris flow event that occurred in Malborghetto-Cucco in August 2003 (Source: Civil Protection of FVG).

Figure 2. The new mitigation measure works after the 2003 event (Source: Google Earth).

This debris flow event is estimated to have a return period of 500 years according to the rainfall data analysis. The potential future debris flow scenario is modelled based on forward-prediction modelling with latest DEM data obtained in June, 2008 in order to identify remaining risk and assess the effects of existing mitigation measures in the area (Hussin et al., 2014). This study area is one of the case study areas of EU CHANGES project and the data used for this exercise are the research outcomes of the project (www.changes-itn.eu).

Stage 1: Identification of areas at risk (30 minutes)

Introduction

Within this first stage, we will identify where the areas at risk in Cucco village are. This can be done by overlaying two layers of given debris flow hazard and building footprints maps of Cucco and visualizing the areas being touched by debris flow as shown in Figure 3.

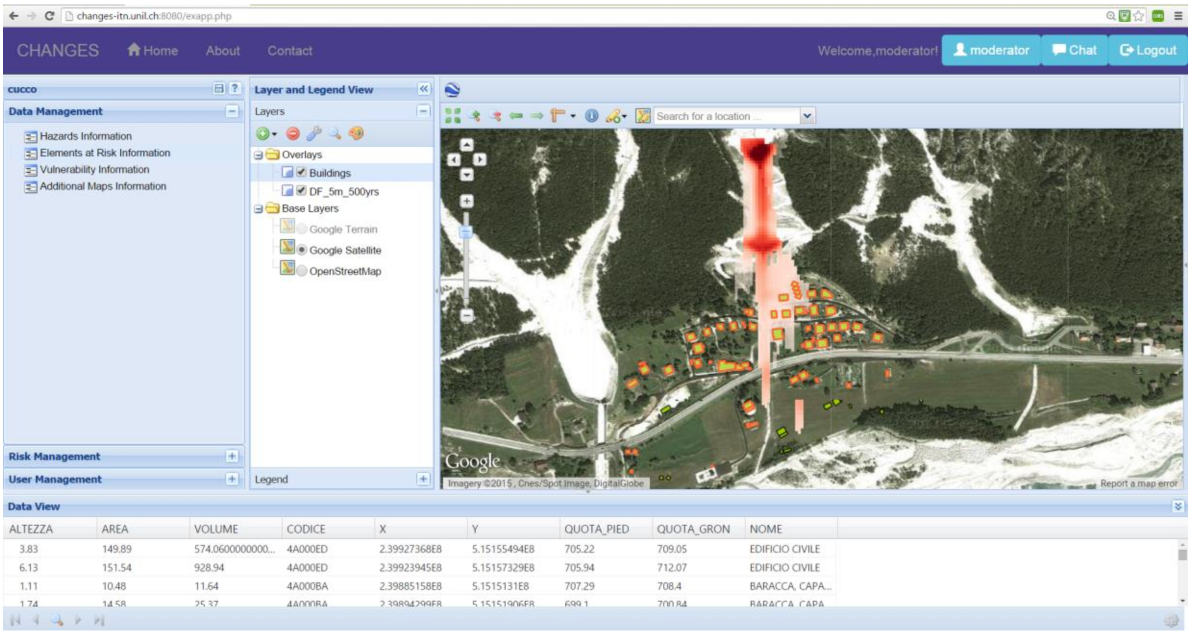
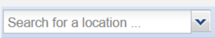


Figure 3. Overlay of debris flow and building maps of Cucco village.

Task

Your task is to visualize and identify the areas exposed to debris flow in the area. Follow the instructions below to achieve your task and please fill the given feedback form of this stage.

Instructions

1	Log-in to the platform: http://changes-itn.unil.ch:8080/main_login.php
2	Select the workspace "cucco"
3	Visualize the debris flow hazard and buildings maps.
4	Identify areas at risk
5	Explore the map interface and all of its tools • Location search box  • 3D Google Earth  • Legend and layer view panel (i.e. left of the map panel) • Data view panel (i.e. south of the map panel)

Stage 2: Formulation of alternative scenarios (45 minutes)

Introduction

After identifying the areas at risk in Cucco, the next step is to determine the possible mitigation measures to protect those areas at risk (Figure 4). Potential risks can be reduced based on the contributing factors such as hazard, vulnerability and exposure of elements-at-risk through the implementation of effective risk management strategies. Structural measures are defined as "any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard-resistance and resilience in structures or systems" (UNISDR, p. 28). Non-structural measures are "any measures not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education" (UNISDR, p. 28). Examples of structural mitigation measures include dams, slope stabilizations, hazard-resistant constructions, maintenance and planning of defense works and so on. Non-structural measures concern non-physical actions such as insurance, relocation, land planning early-warning systems and risk awareness training, etc.

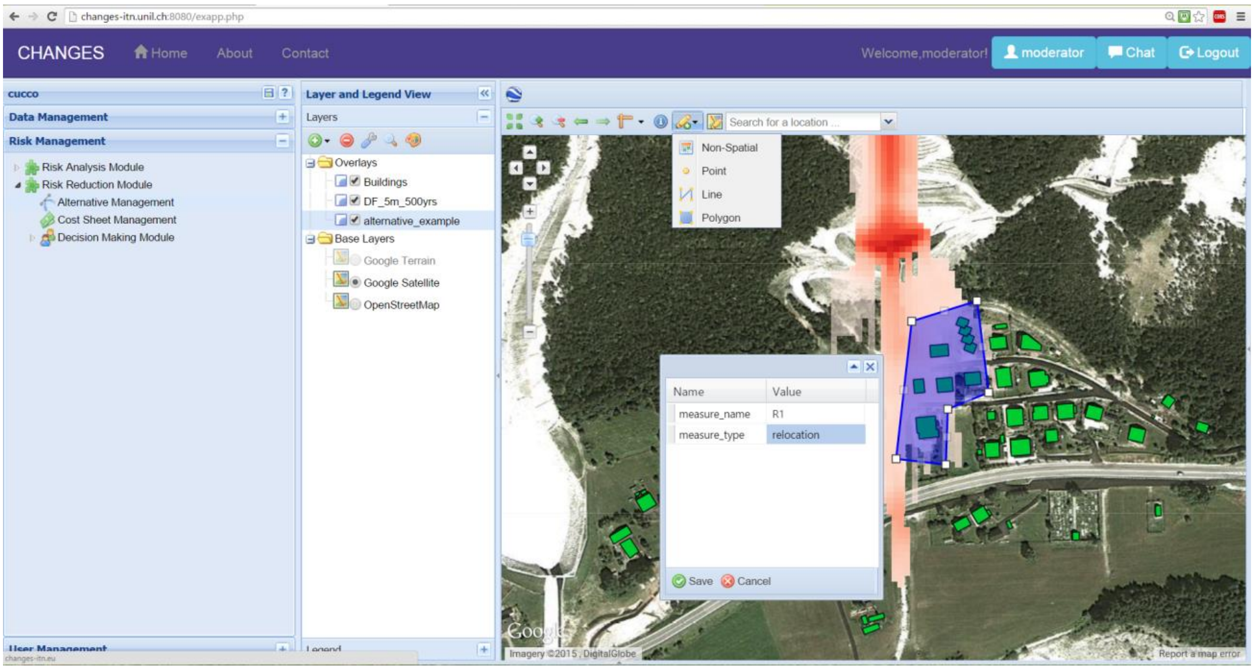


Figure 4. An example sketching of 'relocation' measure within an alternative scenario called 'alternative_example'.

Task

For this exercise, the class is divided in three expert groups as follows:

- Group 1 (Geologists)
- Group 2 (Spatial planners)
- Group 3 (Environmental Protection Associations)

The task of your group is to design your own alternative scenario of mitigation measures to reduce the risk in the area. A combination of measures is possible within an "alternative" scenario (both structural and/or non-structural measures). You can design your alternative scenario based on these following provided measures (but not limited to):

- Structural measures
    - Adjustments to the (design) of the existing structure
    - Structural adjustments to the houses
- Non-structural measures
    - Relocation of houses
    - Natural regeneration
    - Early warning system

Follow the below instructions to create your alternative scenario and please fill the given checkpoint feedback form for this stage.

Instructions

1	Log-in to the platform: http://changes-itn.unil.ch:8080/main_login.php
2	Select the workspace "cucco"
3	Add debris flow and buildings layers to the map.
4	Create your own alternative scenario by each group (for example: "alternative_1" for group 1). (*Hint:* Alternative Management of Risk Reduction module). There are three possible categories of scenario: • Only spatial (i.e. a scenario with mapping of measures) • Only non-spatial (i.e. a descriptive scenario without mapping of measures) • Both Please select 'Both' category for this exercise. Select the option 'Sketch'. Projection (EPSG: 3004). Bounding box information (minx: 13.42; miny: 46.5; maxx: 13.43; maxy: 46.51).
5	Add (sketch) the measures within your alternative scenario and fill in the attribute information (*Hint:* creation and editing feature tools of the map interface). The measures with geometry information (place, area, length…) can only be designed with the representation of points, lines and polygons. If you want to change the style of your alternative, please create a new style without changing the default style (Style Tool → Styles → Add).
6	Try out the chat functionality to interact with other groups. (*Hint:* The first group which initiated the chat needs to send the URL link to the other groups through email).

Stage 3: Selection of alternative scenarios (45 minutes)

Introduction

The alternatives proposed by different expert groups need to be evaluated and ranked in order to choose one alternative with all involved stakeholders. It is important to engage experts, decision makers and the community in the decision making process in order to achieve a sustainable and appropriate risk management. The decision making process can benefit from using Multi-Criteria Evaluation (MCE) methods. These methods consider different alternatives of a problem with the aim of addressing trade-offs between alternatives with inclusion of additional important criteria than the traditional cost-benefit analysis (Munda, 2004). It also allows to represent the different conflicting views of involved stakeholders and facilitate the decision making process (Kiker et al., 2005). In the prototype platform, Compromise Programming (CP) method (Zeleny, 1973; Simonovic, 2010) is used to calculate the ranking of alternative options. This method identifies alternatives which are the closest to the ideal solution by means of distance (measures of closeness). The alternative with the minimum distance value to the ideal situation is considered as the "best compromise solution".

The ranking procedure is conducted as followed. First, the criteria (Table 1) that will be used for the ranking are defined by experts (for this exercise, Pierrick Nicolet was our expert). In this exercise, five criteria are defined by a moderator (in real life an expert) to evaluate the performance of the alternatives proposed by each expert groups:

Table 1. Criteria that will be used to do the ranking.

	Name	***Description***
Criteria 1	Cost	The total cost of the alternative
Criteria 2	Efficiency (buildings)	The effectiveness of the alternative to the buildings
Criteria 3	Efficiency (persons)	The effectiveness of the alternative to the persons
Criteria 4	Local agreement	The agreement of the local population
Criteria 5	Land disruption	The lesser effects of the alternative on the nature

After defining the criteria, each of the alternative that will be compared in the ranking receive a value for each criterion. This is also done by an expert (again Pierrick in our case). There are three alternatives considered here (Table 2).

Table 2. Alternatives considered in this part of the exercise.

	Description
Alternative 1	A larger retention basin
Alternative 2	An Early warning system combined with structural adjustments to the houses
Alternative 3	Relocation of the population and natural regeneration

Table 3 (the performance matrix) shows the values that Pierrick assigned for each alternative and criterion. The assigned values depend on the types of criteria, however, they vary ranging from 1 (*Extremely Low)* to 9 (*Perfect)*.

Table 3. Performance matrix - Pierrick's criteria values for each alternative.

	Criteria 1	***Criteria 2***	***Criteria 3***	***Criteria 4***	***Criteria 5***
Alternative 1	4	7	5	5	3
Alternative 2	8	5	7	7	5
Alternative 3	2	9	9	3	9

Task

For this exercise, the class is divided in four stakeholder groups as follows:

- Group 1 (Public representatives)
- Group 2 (Mayor and municipality council)
- Group 3 (Geologists and spatial planners)
- Group 4 (Environmental Protection Associations)

The task of each group is do rank the alternatives by assigning weight to the criteria (Table 1). In other words, you have to decide depending on the role of your group, you have to classify the importance of the criteria for you (with a scale of 1: *the least important* to 5: *the most important* criteria). The output will be the ranking of the alternatives. If you play with the weights you will see that the ranking changes. When your group is satisfied with its ranking of alternative, you have to start a negotiation process with the other groups in order to achieve a final ranking of the alternatives on which every groups agree.

Follow the below instructions to achieve your task and please fill the given checkpoint feedback form for this stage.

Instructions

1	Log-in to the platform: http://changes-itn.unil.ch:8080/main_login.php (*Hint:* interface is different depending on your group role)
2	Select the workspace "cucco"
3	Observe the criteria and alternatives
4	Observe the performance evaluation matrix (Alternatives Vs Criteria)
5	Assign your weights to visualize the ranking outcomes of alternatives (*Hint:* double click in the weight grid to edit and click "Show Rank" button for visualization of the results)
6	Try changing weights to observe any changes in ranking outcomes of alternatives
7	Click "Save Results and Weights" when you are satisfied so that it will be saved in the system, and other groups can be able to visualize it

8 Observe the weights and ranking outcomes of yours in comparison with other groups

9 Negotiate using the chat function with the other groups to achieve a final agreement.

Final Feedback

- Filling of two feedback forms:
    - Exercise feedback
    - User Evaluation feedback
- Wrap-up discussion

References

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Kiker, G. A.; Bridges, T. S.; Varghese, A.; Seager, T. P.; Linkovjj, I. Application of multicriteria decision analysis in environmental decision making, *Integrated Environmental Assessment and Management* **2005**, 1, 105-108.

Munda, G. Social multi-criteria evaluation (SMCE): methodological foundations and operational consequences. *European Journal of Operational Research* **2004**, 158, 662 – 677.

Simonovic, S.P. Systems Approach to Management of Disasters: Methods and Applications. Wiley & Sons Inc.: New York, 2010.

United Nations International Strategy for Disaster Reduction (UNISDR). UNISDR Terminology on Disaster Risk Reduction, Geneva. http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf (accessed on 3 December 2014).

Zeleny, M. Compromise programming. In: Multiple Criteria Decision Making, J.L. Cochrane, M. Zeleny, Eds.; University of South Carolina Press, Columbia, South Carolina, 1973.

Feedback on the first stage

Name	
Major of master	
GIS experience	o Not at all o Little o Fair o Good o A lot

Where are the areas at risk?

____

____

____

____

Please use the following rating keys to answer the questions listed in the table.
(1) Not at all **(2)** Slightly **(3)** Moderately **(4)** Quite **(5)** Absolutely **(X)** I don't know

No.	**Questions**	**Rating Key**
1.	How easy was it to find the maps you needed to visualize?	
2.	How easy was it to find the layer and legend view panel?	
3.	How helpful is the location search box?	
4.	How helpful is the 3D Viewer for visualization of the area?	
5.	Overall, are you satisfied with the map interface and its tools?	

In your opinion, which aspects of this interface and visualization tools should be improved and why?

____

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____

Additional comments and suggestions (optional).

____

____

Feedback on the second stage

Role	

Explain why your alternative scenario should be considered as the most appropriate.

____

____

____

____

Please use the following rating keys to answer the questions listed in the table.

(1) Not at all **(2)** Slightly **(3)** Moderately **(4)** Quite **(5)** Absolutely **(X)** I don't know

No.	**Questions**	**Rating Key**
1.	How easy was it to create and visualize your alternative scenario?	
2.	How easy was it to sketch measures in the map interface?	
3.	How useful is the "create" and "editing" feature tools?	
4.	How useful would be if there was the possibility to add more attribute information of the measures?	
5.	How helpful would it be if a toolbox of mitigation measures was available?	
6.	Overall, are you satisfied with this part of the interface and its tools?	

In your opinion, which aspects of this interface should be improved and why?

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Additional comments and suggestions (optional).

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Feedback on the third stage

Role	

Comment on the results of your weights and ranking outcomes.

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Please use the following rating keys to answer the questions listed in the table.

(1) Not at all **(2)** Slightly **(3)** Moderately **(4)** Quite **(5)** Absolutely **(X)** I don't know

No.	Questions	Rating Key
1.	How easy was it to find criteria (and alternatives) information?	
2.	How easy was it to find evaluation (matrix) information?	
3.	How easy was it to understand information given by evaluation (matrix)?	
4.	How understandable is the weighting scale?	
5.	How user-friendly is the visualization interface of ranking outcome?	
6.	How helpful is the pie-chart visualization (criteria weights)?	
7.	How helpful is the bar-chart visualization (ranking of alternatives)?	
8.	How helpful is the comparison of ranking outcomes with other groups?	
9.	How transparent is the decision making process?	
10.	Overall, are you satisfied with this part of the interface and its tools?	

In your opinion, which aspects of this interface should be improved and why?

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Additional comments and suggestions (optional).

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Exercise Feedback

Name	
Role-playing experience	YES / NO

Explain in few words of what you learned from this exercise.

____

____

____

Please use the following rating keys to answer the questions listed in the table.

(1) Not at all **(2)** Slightly **(3)** Moderately **(4)** Quite **(5)** Absolutely

No.	**Questions**	**Rating Key**
1.	Is this exercise interesting?	
2.	Is this exercise useful for your learning and understanding?	
3.	Is this exercise helpful in understanding of how real world situation works?	
4.	Does this exercise stimulate your interests in risk management topic more?	
5.	Would you like to do further exercises involving interactive tools?	

In your opinion, which aspects of this exercise should be improved and why?

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Additional comments and suggestions (optional).

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User Evaluation Feedback

Name	

Explain in few words of the purpose of this prototype platform.

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Please use the following rating keys to answer the questions listed in the table.

(1) Not at all **(2)** Slightly **(3)** Moderately **(4)** Quite **(5)** Absolutely

No.	Questions	Rating Key
	Is this prototype platform …	
1.	… innovative?	
2.	… interactive?	
3.	… useful?	
4.	… practical?	
5.	… supportive as a decision support tool?	
6.	… easy to use?	
	How …	
7.	… useful is the left navigation panel to find the information needed?	
8.	… often the prototype have errors and need to refresh?	
9.	… successful is the prototype in performing its intended task?	
10.	… helpful is the chat functionality for interaction between users?	
11.	… are you satisfied with the prototype, in overall?	

In your opinion, which aspects of the prototype should be improved and why?

____

____

Additional comments and suggestions (optional).

Appendix IV: Background of the system

This application is a web-GIS based collaborative decision support application, running on different web browsers of desktop computers including Mozilla Firefox, Google Chrome and Internet Explorer. The purpose of this application is to assist risk managers and decision-making authorities in analysing the consequences of natural hazards such as floods, debris flows and landslides as well as in formulating and selecting of possible risk management measures collaboratively and interactively.

A prototype version of this web application is realized using open-source geospatial software solutions and technologies, backed up by Boundless framework and its client-side development environment. The open-source code of the developed prototype application is available and deposited in the repository: https://bitbucket.org/zaye/. The tutorial demonstration for various components of the application is available on YouTube at: https://www.youtube.com/playlist?list=PLGKCWCiTPytyK8Mniv9d2kebsHQBRQnU3. This prototype was mainly tested with Google Chrome on Windows and can be accessible at: http://changes-itn.unil.ch:8080/main_login.php through authorized user accounts. For this moment, the platform is accessible only within the local network of the University of Lausanne. Otherwise, it can be connected through the university's VPN network (https://crypto.unil.ch).

This documentation briefly presents a high-level overview, background architecture and data model design, available components (functions) and respective user interfaces of the prototype application. For the background concepts and methods applied in this application, please see the section 4.2 and section 5. 4 of Chapter 4 and 5 respectively.

System overview

The system is composed of the following modules:

Data Management: This module acts as an essential input to the risk analysis module. It includes three main components: hazards, elements-at-risk and vulnerability, to provide the necessary data for the calculation of loss and risk scenarios. Within this module, the user can upload hazard intensity (.tiff format) maps, elements-at-risk (.zip format including .shp file) maps and vulnerability (.csv, .xls and .txt formats), along with the relevant metadata information. For the vulnerability component, the user can also create the vulnerability curve directly in the system (e.g. a CDF function) by entering the specific input parameters of the function.

Risk Analysis: This module is one of the main modules of the application and results obtained from this module are applied in the decision-making process for formulation and selection of risk management alternatives, when the resultant risk level is not acceptable. It contains two main components: loss and risk. Within this module, the user can generate loss scenarios based on three types of input parameters (i.e. hazards, elements-at-risk and vulnerability). Then, a risk curve (with annualized risk) can be produced using these generated loss scenarios for different return periods of the hazard event.

Alternative Management: This module allows the user to formulate risk management alternatives (i.e. a combination of risk reduction measures), which are then used for the re-calculation of risk and decision-making process. Within this module, the user can propose (sketch) preliminary alternatives interactively in the map interface or can upload the alternative map (in .zip format including .shp file). For the calculation of new risk for each alternative, the user is required to provide new (updated) maps and information (i.e. hazards, elements-at-risk and vulnerability) within the data management module, and then, risk can be recalculated using new input information in the risk analysis module. These obtained results can then be applied in the decision analysis module for comparison of alternatives.

Decision Analysis: This multi-criteria evaluation module serves as an important module of the application. In this module, the results of risk analysis and alternative management modules are used to compare alternatives in terms of decision criteria such as social, economic and environmental criteria. Each participating user can indicate his/her preferences on the decision criteria. Based on the performance values (of alternatives against criteria) and preference information (of the criteria), a ranking of alternative is produced, allowing the user to choose the best compromise alternative.

User Management: This module allows an admin user to create and manage user accounts, binding to a certain working space (study area). Depending on the nature (role and responsibility) of different stakeholders in a certain study area, there are three levels of users:

- **Expert-L1**: This user has the same privileges as an admin user, except that he/she cannot access to the user management module. For example, representatives from one or different sectoral planning authorities.
- **Expert-L2**: This user has less privilege than the Expert-L1, with a read-only access to data management and risk analysis modules. His/her participation is enabled in

alternative management and decision analysis modules, however, with a certain access to certain functionalities. For example, spatial planners.

- **Decision-maker**: This user has the most limited privileges amongst all users, providing access to only a simple user interface of the system, mainly for the decision analysis module. The interface is simplified due to his/her limited technical capacity and level of GIS knowledge in using the system. For example, mayor of the municipality and public representatives.

System architecture

The architecture of the prototype is based on the three-tier client-server model (see the section 3.2.2 of Chapter 3), backed up by the Boundless (formerly OpenGeo) framework (Figure 1). Boundless provides a robust and flexible architecture with modular components for managing and publishing geospatial data, built on open-source geospatial software and standards. For the prototype implementation, only open-source components are specifically chosen due to its cost, flexibility and community support. The thin-client approach is applied so that only a browser is sufficient and no additional complex software is needed to install on the client side.

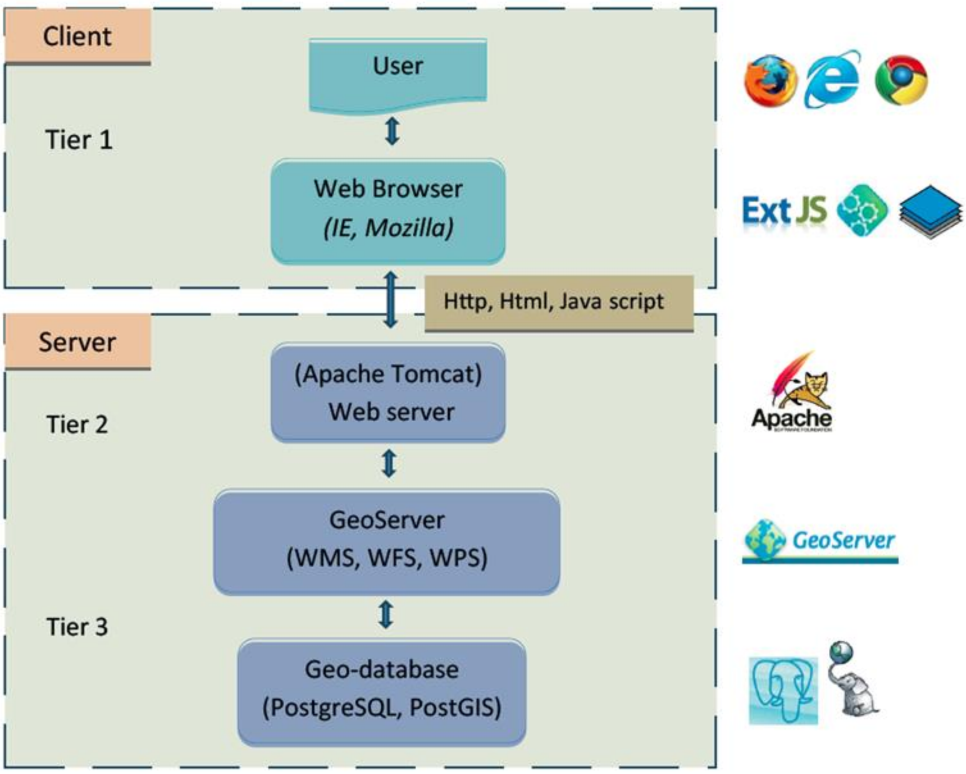

Figure 1. Architecture of the system (Source: taken from Chapter 3)

Including OGC standards like WMS, WFS and WCS, a number of open-source software solutions are integrated in different layers of the architecture:

- **Database**: PostgreSQL/PostGIS for storage and management of spatial and non-spatial data,
- **Application server**: GeoServer and GeoWebCache for publishing and caching map layers/titles, and
- **User Interface**: GeoExt and OpenLayers for building flexible user interfaces in the web browser.

Please refer to section 3.2.2 of Chapter 3 for more information about these applied open-source components and standards.

To build and deploy the prototype web platform, the Boundless SDK is used, which is a client-side development environment of OpenGeo suite. It offers the tools for creating JavaScript-based web applications with customizable components and data utility classes. Its GXP template is used to develop the prototype, which is configured to work with GeoExt, ExtJS 3.4 and OpenLayers 2. Bootstrap framework is also used for customized HTML and CSS templates of the application. Server-side and general-purpose scripting language such as PHP is used to connect to the database through SQL queries and perform necessary operations on the server-side. In order to programmatically configure GeoServer through its REST interface, PHP-cURL library is used. This is useful and important, especially in performing GeoServer operations such as creating a new workspace or adding an existing PostGIS table as a new feature type.

For the set-up of the development environment, we use Ubuntu 12.04.1 LTS server, running on a standard desktop-PC with Intel Core 2 Quad CPU Q9650 3GHz and 4GB RAM.

Data model

Within the system, it is designed that an admin user can create a workspace for each study area. Each workspace corresponds to a schema in the database, meaning all related data of a study area are stored accordingly in the specific schema of the database. The background data model of a schema is illustrated in Figure 2, in this case, a workspace called demo. This schema is created automatically (with default non-spatial tables) in the database upon the creation of a new workspace (study area) in the system. There are two main parts in the schema: the lower part represents data structure of the *data management* and *risk analysis* modules (see section

4.7 of Chapter 4 for further explanation) and the upper part represents the *alternative management* and *decision analysis* modules (see section 5.5.2 of Chapter 5 for further explanation). There are also additional tables:

- *cost* and *cost_values* to store associated cost data of a certain alternative,
- *users* to manage users in the workspace and
- *additionalmaps* to store associated data of additional maps such as administrative units and land use/cover maps.

This main data model (Figure 2) does not show spatial tables (i.e. no tables with geometry attributes). Because spatial tables are created dynamically in the database during the runtime upon the user's actions, i.e. when uploading a new building (vector) layer as an elements-at-risk object or creating a new alternative. For example, when a user creates a new alternative scenario to design risk reduction measures (with sketch option), in the system, this following sequence happens:

- a new table (e.g. alternative_1) is created with default attributes such as id, name, description and geometry to record the information of each sketched measure (feature),
- a new record is added in the *alternatives* table with its associated information such as id, name, description, category, option and mapping index to record the information of the newly created table (i.e. alternative_1 from the previous step).

The relationship between the dynamically created spatial table (i.e. alternative_1) and the default non-spatial *alternatives* table is made through an attribute called *mapping_index*, which stores the name of the dynamically created spatial table, in this case, alternative_1. Therefore, *alternatives* table is non-spatial and it only stores the information of all created alternative scenarios. The same approach applies to other tables such as *hazards*, *elements-at-risk* and *loss scenario*. The relations between these default non-spatial tables (i.e. *hazards*, *elements-at-risk*, *loss scenario* and *alternatives)* and dynamically created spatial tables (i.e. for example, *df_major_max_5px*, *buildings_fella*, *fella_scenario_major_max* and *alternative_1*) are illustrated in Figure 3. Note that attribute (column) names of some spatial tables (i.e. vector layers uploaded directly by users such as buildings and alternatives) could be different from the ones illustrated in Figure 3, depending on the user's uploaded data. While loss tables (such as *fella_scenario_major_max*) might have less attribute columns, according to the input choices of users in the application's loss interface (see section 4.2.2 of Chapter 4 for the workflow).

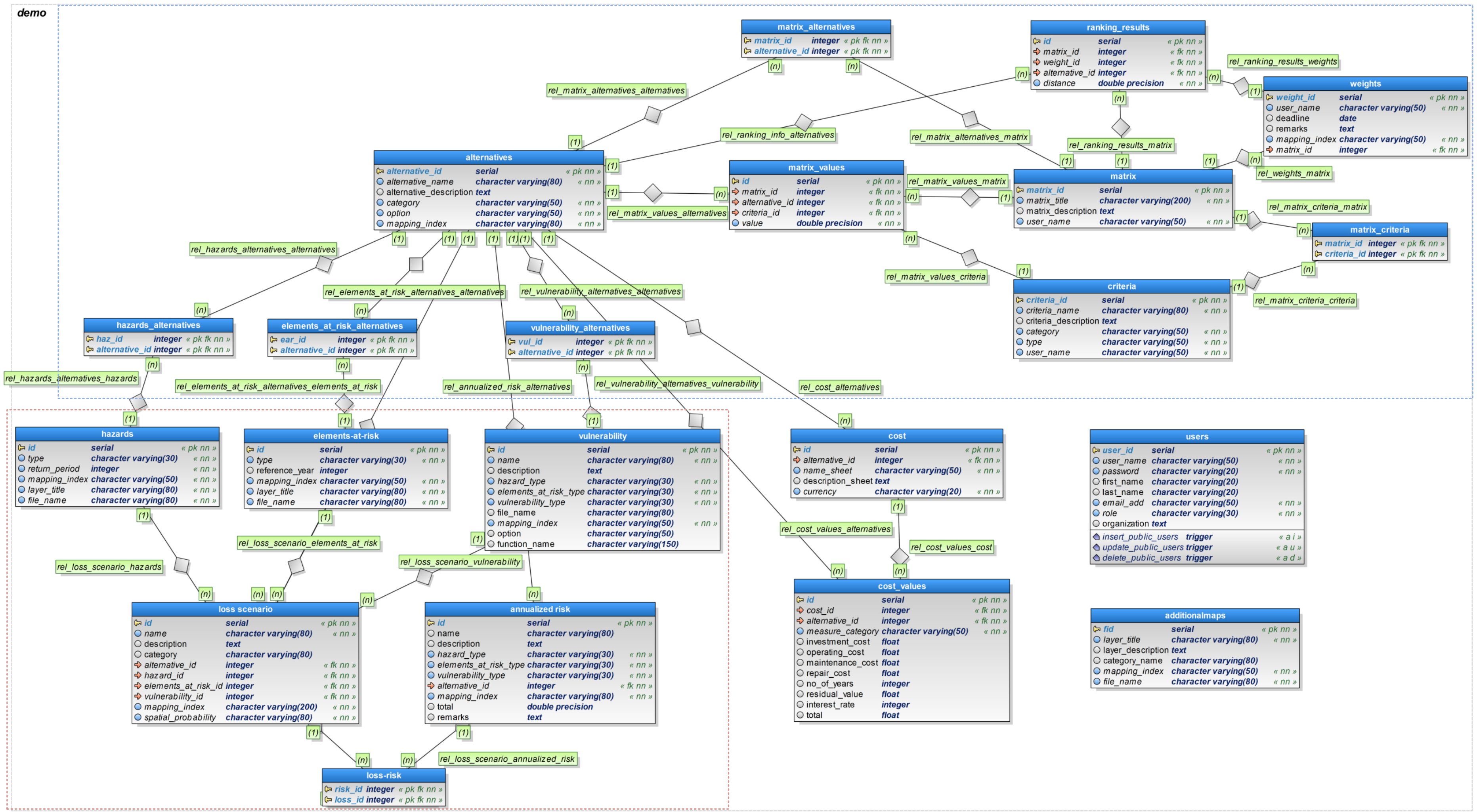

Figure 2. Global data model of the schema (in this case, demo). The lower (dotted line in pink colour) part of the model represents the background data structure of the data management and risk analysis modules (see 4.7 of Chapter 4), while the upper (dotted line in blue colour) part represents the alternative management and decision analysis modules (see 5.5.2 of Chapter 5).

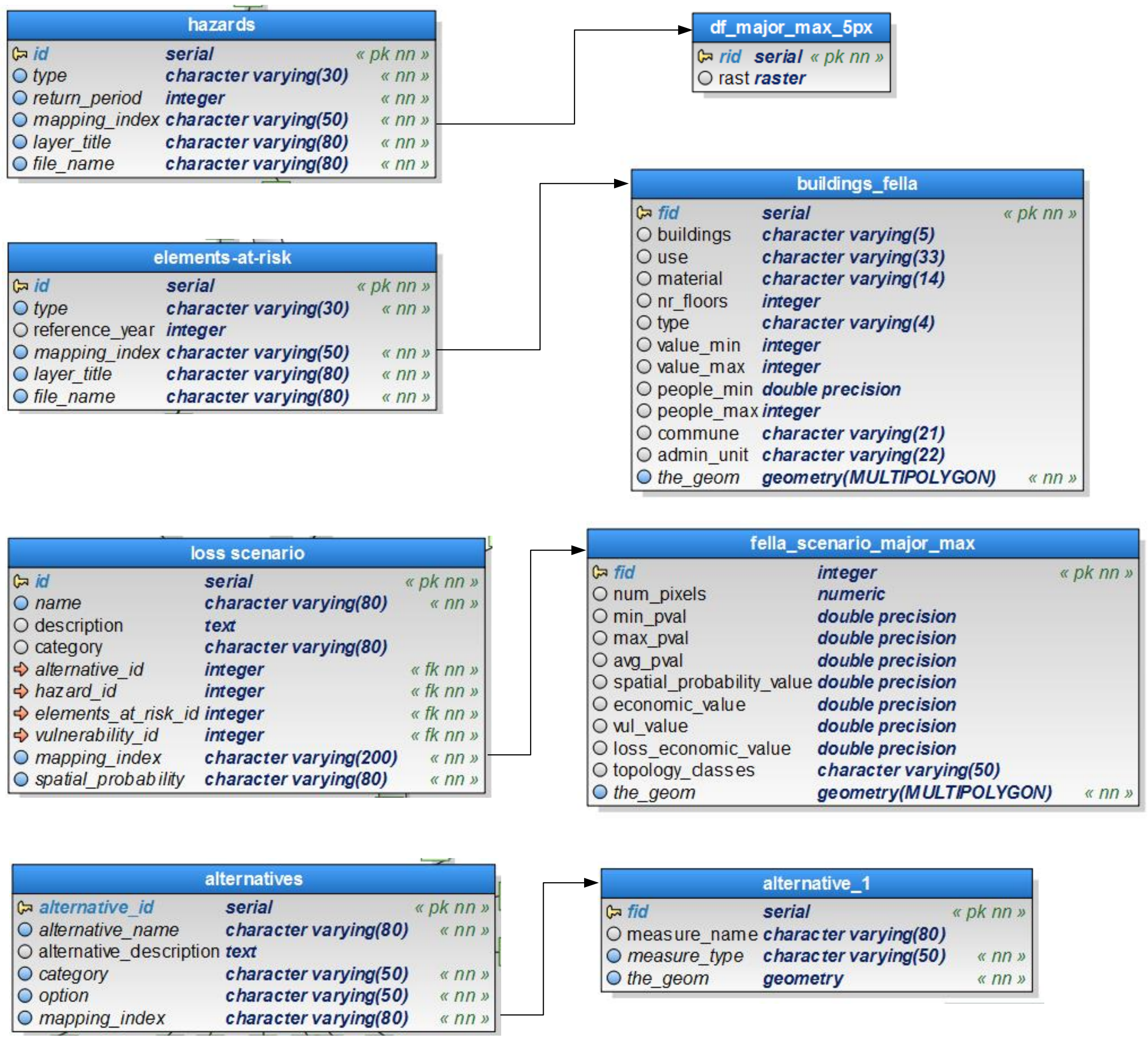

Figure 3. Illustration of relationships with dynamically created spatial tables in the data model (schema). The 'mapping_index' attributes of the main non-spatial tables (on the left) store names of the spatial tables (on the right) to create a link between them. For example, 'mapping_index' attribute of the 'alternatives' table stores the value 'alternative_1' to create a connection with the newly created alternative table.

Apart from the main schema (data model) of a workspace, there are also some important tables in the *public* schema of the database for managing users and workspaces in the system. Figure 4 shows the relationship between these tables. The *users* table stores all the users' information such as user name and password while the *workspace* table stores the information of all created workspaces in the system such as name, description and scale of the study area.

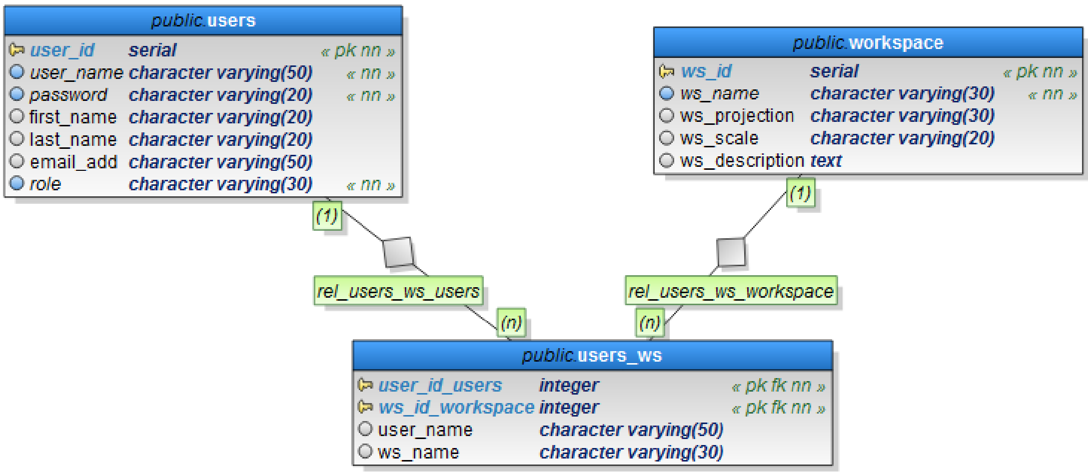

Figure 4. Data model of the public schema.

Functionality

This application is composed of different modules for user management, uploading and management of input data, risk analysis, formulation and selection of management alternatives. Figure 5 shows the main interface of the prototype web platform for the admin and expert users. The interface is divided into various panels: 1) *main navigation* panel on the left with access to three main components (i.e. data management, risk management and user management); 2) *map view* panel in the centre (with layer navigation and legend panel on the left) with basic tools for zooming, searching locations, styling, drawing and editing features of layers, etc.; and 3) *data view* panel in the bottom to show feature information of the respective (vector) map layers. The *data management* tab includes tools for the upload and visualization of raster and vector maps as well as for the creation of vulnerability curves, serving as essential input for risk analysis. The *risk management* tab contains tools for risk analysis, creation and selection of different risk reduction measures. The *user management* tab has a tool for creating, assigning and managing user accounts and roles.

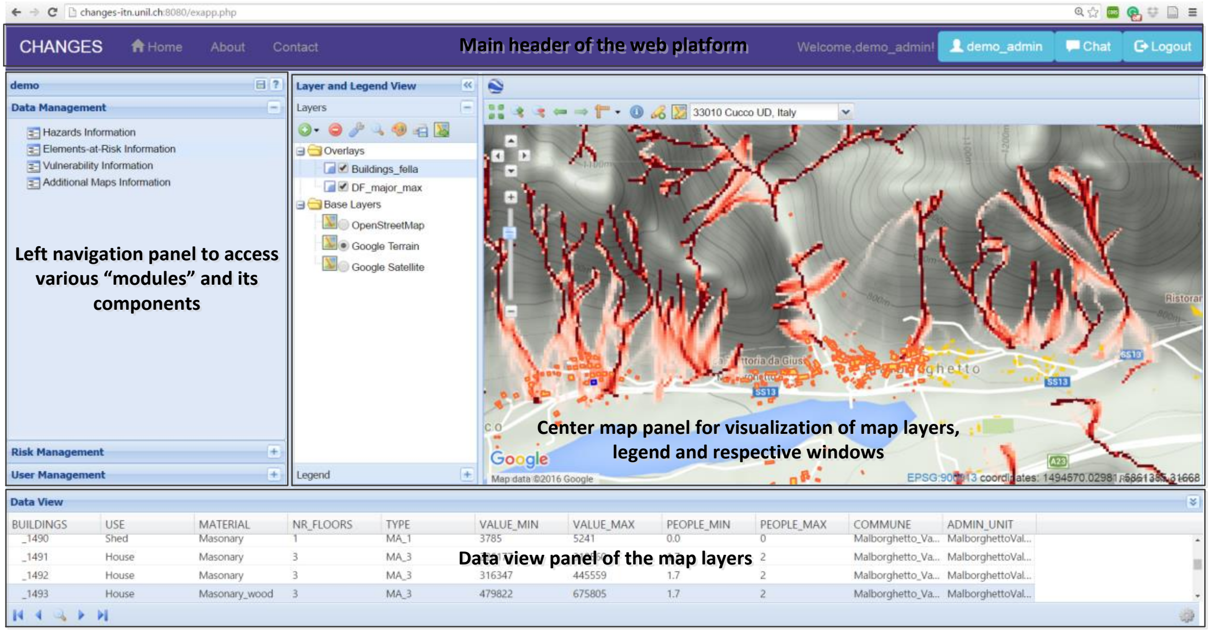

Figure 5. The main interface of the application for admin and expert users within a selected workspace called "demo"

The application also has a simple interface for decision-maker users, as illustrated in Figure 6, mainly for the selection of alternatives. It allows users:

- to visualize defined alternative and criteria,
- to assign weights (preferences) on the decision criteria,
- to visualize ranking information based on their assigned weights and
- to compare different rankings of alternatives for all participated users.

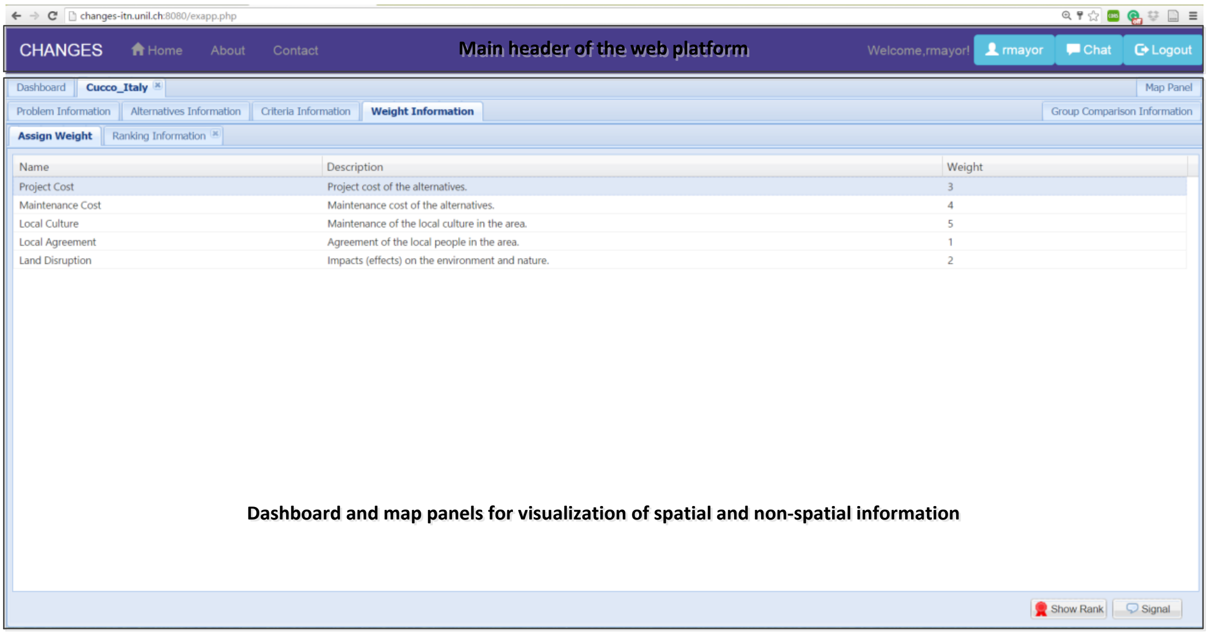

Figure 6. The simplified interface of the application for decision-makers users within a selected workspace called "demo"

The respective user interfaces of these functions can be further seen on YouTube through the following demonstration videos:

- Data management (https://youtu.be/FCScR_s5cbk),
- Risk analysis (https://youtu.be/pJc-K5zI85E),
- Alternative management (https://youtu.be/0c05LU0hbyQ) and
- Decision analysis (https://youtu.be/F1mmVw1sr3w).

Appendix V: Implementation of the system

In this section, snippets for some functionalities of the application are described, as an example, to have an idea of how the prototype development was carried out. For the complete coding of the whole prototype application, open-source code is available and deposited in the repository: https://bitbucket.org/zaye/.

Retrieving the list of available hazard layers

Figure 1 shows the user interface of the "Hazards" component, which allows users to: 1) view the list of all uploaded hazards; 2) add a certain hazard layer into the map for visualization; 3) update the associated layer information; and 4) add (upload) or delete a certain hazard layer to and from the system.

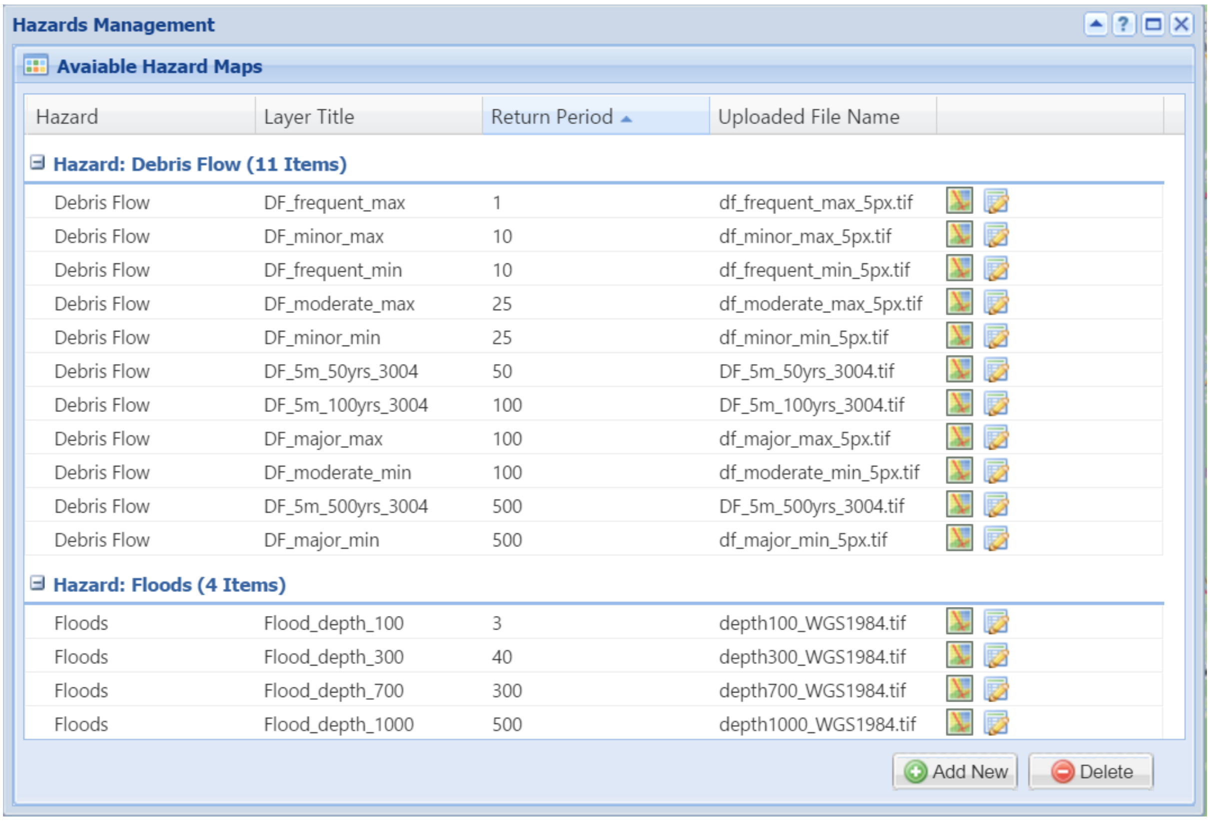

Figure 1. The user interface of a grid panel which shows the list of all uploaded hazard layers in a certain workspace.

The following JavaScript code (in ExtJS 3.4) is extracted to show how a data store (i.e. in this case, a grouping store) of the illustrated grid panel is configured to load/fetch records dynamically from the remote database through a PHP script.

```
### JavaScript code of the datastore
var xg = Ext.grid;
this.haz_store = new Ext.data.GroupingStore({
  url: 'hazardInfo.php',
  sortInfo:{field: 'return_period', direction: "ASC"},
```

```
  groupField:'haz_type',
  reader: new Ext.data.JsonReader({
    totalProperty : 'totalCount',
    root          : 'rows',
    successProperty: 'success',
    idProperty    : 'id',
    fields: [
       {name : 'haz_id', type : 'int'},
       {name : 'haz_type', type : 'String'},
       {name : 'layer_title', type : 'String'},
       {name : 'return_period', type : 'int'},
       {name : 'mapping_index', type : 'String'},
       {name : 'file_name', type : 'String'}
     ]
  })
});

this.haz_store.reload({
    params:
       {ws: workspace,
       task: 'load'}
});

### JavaScript code of the grid panel with the configured datastore
var hazGrid = new xg.GridPanel({
    id: 'hazGrid',
    store: this.haz_store,
    colModel: new Ext.grid.ColumnModel({
       columns: [
         {header: "Hazard", dataIndex: 'haz_type'},
         {header: "Hazard ID", dataIndex: 'haz_id', hidden: true},
         {header: "Layer Title", dataIndex: 'layer_title'},
         {header: "Return Period", dataIndex: 'return_period'},
         {header: "Mapping Index", dataIndex: 'mapping_index', hidden: true},
         {header: "Uploaded File Name", dataIndex: 'file_name'},
            {
              xtype: 'actioncolumn',
              items: [
              {
                 icon: 'src/gxp/theme/img/silk/map.png',
                 tooltip: 'Visualize the hazard map',
                 handler: function(grid, rowIndex, colIndex) {
                   // to load the layer into the map
                   // here comes the respective codes
                 }
              },
              {
                 icon: 'src/gxp/theme/img/silk/table_edit.png',
                 tooltip: 'Edit Data',
                 getClass: function(v, meta, rec) {
                     if( role == 'expert-L2') {
                          return 'x-hide-display';
                     }
                 },
                 handler: function(grid, rowIndex, colIndex) {
                   // to edit the layer information
                   // here comes the respective codes
                 }
              }]
            }
         ],
         defaults: {
             sortable: true,
             menuDisabled: false,
             width: 5
         }
    }),
    view: new Ext.grid.GroupingView({
       forceFit: true,
       groupTextTpl: '{text} ({[values.rs.length]} {[values.rs.length > 1 ? "Items" : "Item"]})'
    }),
    frame:true,
    width: 700,
    height: 450,
    title: 'Avaiable Hazard Maps',
    iconCls: 'icon-grid',
    fbar: ['->', {
       text:'Add New',
       iconCls: 'add',
       hidden: role == 'expert-L2' ? true : false,
       handler : function(){
         // to show a window to upload the raster map to GeoServer and database
        // here comes the respective codes
       },
       scope: this
      },{
```

```
        text:'Delete',
        iconCls: 'delete',
        hidden: role == 'expert-L2' ? true : false,
         handler: function(){
           // to delete the selected records from the database and GeoServer
           // here comes the respective codes
         }
    }]
});
```

The list of all hazard layers from the “hazards” table of a certain schema (workspace) in the database is retrieved using the following PHP script (extracted from the file hazardInfo.php).

```
### PHP code to retrieve data from the database
<?php
    $workspace = $_POST['ws'];
    $task = $_POST['task'];

    $dbconn=pg_connect("host=localhost port=5432 dbname=geoserver user=opengeo password=opengeo");
    if (!$dbconn){
        echo "An error occured.\n";
        exit;
        }

    if ($task == 'load') {
         $query = "SELECT haz_id, haz_type, layer_title, return_period, mapping_index, file_name FROM
         ".$workspace.".hazards";
        $arr=array();

        If (!$rs = pg_query($dbconn,$query)) {
            Echo '{success:false,message:'.json_encode(pg_last_error($dbconn)).'}';
        }
        else {
                while($obj = pg_fetch_object($rs)){
                $arr[] = $obj;
            }
            Echo '{success:true,rows:'.json_encode($arr).'}';
        }
    }
?>
```

Editing features of the vector layer

For editing of features in the application (Figure 2), we use an existing plugin called “FeatureEditor”, which is available as a part of the GXP template[4] and built upon OpenLayers, ExtJS and GeoExt. To use this plugin in the application, it can be figured as follows in the main “app.js” file of the application.

```
### Declare plugins to use
/**
 * Add all your dependencies here.
 *
 * @require plugins/FeatureManager.js
 * @require plugins/FeatureEditor.js
 * @require plugins/FeatureEditorForm.js
*/

### Add plugins in the tools section of the main viewer application
{
   ptype: "gxp_featuremanager",
   id: "manager",
   paging: true,
   maxFeatures: 500,
   autoSetLayer: true,
   autoLoadFeatures: true
}, {
   ptype: "gxp_featureeditor",
   featureManager: "manager",
   autoLoadFeature: true,
```

[4] See http://suite.opengeo.org/opengeo-docs/sdk-api/ and http://suite.opengeo.org/opengeo-docs/webapps/gxp/index.html for the application development with Boundless SDK GXP template

```
    snappingAgent: "snapping-agent",
    supportNoGeometry: false,
    splitButton: false,
    showSelectedOnly: false
}
```

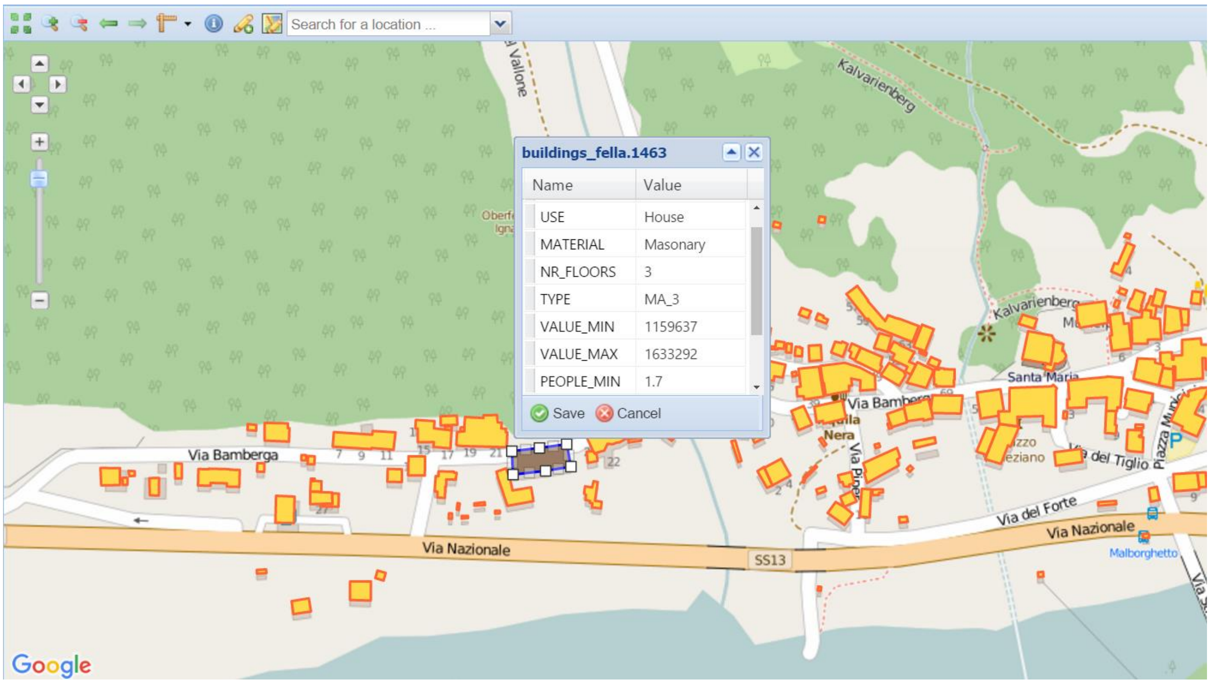

Figure 2. The user interface for editing of features in the vector layer (using FeatureEditor plugin).

Adding a PostGIS table with PHP/cURL

PHP with cURL functions are used for REST configuration of the GeoServer instance (see Figure 3.9 of Chapter 3[5]). For example, the following script adds a PostGIS table (i.e. in this case, a dynamically created alternative table by the user) to GeoServer as a new feature type, so that this layer can then be visualized in the web-GIS application through a WMS GetMap request.

```
### PHP code to publish the created PostGIS table to the GeoServer
// Initiate cURL session
$service = "http://localhost:8080/geoserver/"; // replace with your URL
$request = "rest/workspaces/".$workspace."/datastores/postgis/featuretypes"; // to add a new featuretype

$url = $service . $request;
$ch = curl_init($url);

// Optional settings for debugging
curl_setopt($ch, CURLOPT_RETURNTRANSFER, true); //option to return string
curl_setopt($ch, CURLOPT_VERBOSE, true);
curl_setopt($ch, CURLOPT_STDERR, $logfh); // logs curl messages

//Required POST request settings
curl_setopt($ch, CURLOPT_POST, True);
$passwordStr = "username:password"; // replace with your username:password of GeoServer
curl_setopt($ch, CURLOPT_USERPWD, $passwordStr);

//POST data
curl_setopt($ch, CURLOPT_HTTPHEADER, array("Content-type: application/xml"));
$xmlStr =
"<featureType><name>".$tab_name."</name><latLonBoundingBox><minx>".$minx."</minx><maxx>".$maxx."</maxx><min
y>".$miny."</miny><maxy>".$maxy."</maxy><crs>EPSG:4326</crs></latLonBoundingBox></featureType>";
curl_setopt($ch, CURLOPT_POSTFIELDS, $xmlStr);
```

[5] For REST configurations with cURL, see
http://docs.geoserver.org/latest/en/user/rest/examples/curl.html.

```
//POST return code
$successCode = 201;

// Execute the curl request
$buffer = curl_exec($ch);

// Check for errors and process results
$info = curl_getinfo($ch);
if ($info['http_code'] != $successCode) {
   $msgStr = "# Unsuccessful cURL request to ";
   $msgStr .= $url." [". $info['http_code']. "]\n";
   Echo '{success:false,message:'.json_encode($msgStr).'}';
} else {
   $msgStr = "# Successful cURL request to ".$url."\n";
   Echo '{success: true, mpIndex:'.json_encode($mapping_index).',message:"The sketch layer has been created
and added to the map. You can now start drawing the measures using CREATE and EDIT feature tools of the map
center panel!"}';
}

// free resources if curl handle will not be reused
curl_close($ch);
```

Appendix VI: Co-author publications

Article 1:

Prenger-Berninghoff, K., Cortes, V. J., Sprague, T., Aye, Z. C., Greiving, S., Głowacki, W., and Sterlacchini, S.: The connection between long-term and short-term risk management strategies for flood and landslide hazards: examples from land-use planning and emergency management in four European case studies, *Nat. Hazards Earth Syst. Sci*., 14, 3261-3278, doi:10.5194/nhess-14-3261-2014, 2014.

Article 2:

Olyazadeh, R., Aye, Z.C., Jaboyedoff, M. and Derron, M.-H.: Prototype of an open-source webGIS platform for rapid disaster impact assessment, *Journal of Spatial Information Research.*, doi: 10.1007/s41324-016-0017-y, 2016.

Article 3:

Cortes, V. J., Aye, Z.C., Frigerio, S., Bogaard, T., Pasuto, A., and Sterlacchini, S.: A web-GIS decision support framework for assisting technicians in evaluating check dams inspection reports (prepared for submission), 2016.

Nat. Hazards Earth Syst. Sci., 14, 3261–3278, 2014
www.nat-hazards-earth-syst-sci.net/14/3261/2014/
doi:10.5194/nhess-14-3261-2014

Natural Hazards and Earth System Sciences
Open Access

The connection between long-term and short-term risk management strategies for flood and landslide hazards: examples from land-use planning and emergency management in four European case studies

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Abstract. Adaptation to complex and unforeseen events requires enhancing the links between planning and preparedness phases to reduce future risks in the most efficient way. In this context, the legal–administrative and cultural context has to be taken into account. This is why four case study areas of the CHANGES[1] project (Nehoiu Valley in Romania, Ubaye Valley in France, Val Canale in Italy, and Wieprzówka catchment in Poland) serve as examples to highlight currently implemented risk management strategies for land-use planning and emergency preparedness. The focus is particularly on flood and landslide hazards. The strategies described in this paper were identified by means of exploratory and informal interviews in each study site. Results reveal that a dearth or, in very few cases, a weak link exists between spatial planners and emergency managers. Management strategies could benefit from formally intensifying coordination and cooperation between emergency services and spatial planning authorities. Moreover, limited financial funds urge for a more efficient use of resources and better coordination towards long-term activities. The research indicates potential benefits to establishing or, in some cases, strengthening this link through contextual changes, e.g., in organizational or administrative structures, that facilitate proper interaction between risk management and spatial planning. It also provides suggestions for further development in the form of information and decision support systems as a key connection point.

[1]Marie Curie ITN CHANGES – Changing Hydro-meteorological Risks as Analyzed by a New Generation of European Scientists

1 Introduction

According to global and European reports (EEA, 2010; UNISDR, 2011), in past decades the number of disasters caused by natural hazards has demonstrated an increasing trend fueled by changing contexts in socioeconomic, environmental and climatic patterns. Particularly in the target study areas of the CHANGES project[2] (Fig. 1), it is evident that damages have occurred in recent years due to extreme events resulting from hydrometeorological hazards. This is made apparent through examples such as the flash floods that struck in August 2005 in the catchment of the Targaniczanka stream (tributary of Wieprzówka River, Poland) that repeated in the spring of 2010. Evidence is further found in the French

[2]The CHANGES project specifically focuses on hydrometeorological hazards, in particular floods and landslides. All case study sites that were part of the project were selected because of (more or less regularly) appearing floods and landslides. This is the one characteristic that all case study sites have in common and supports the ability to make a cross-country comparison in light of these types of hazards.

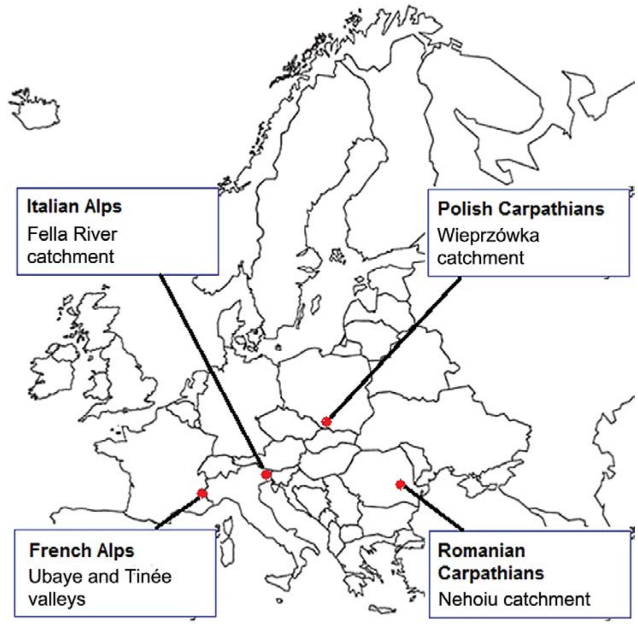

Figure 1. Location of study areas.

case study site through flood events caused by peak discharge of the Ubaye River in May 2008 (Barcelonnette Basin in Alpes-de-Haute-Provence) and in the Romanian case study with the flash flood event in 2005 that affected the Nehoiu Valley in Buzău County, which resulted in substantial economic damages. Finally, within the Italian case study, evidence is given through the intense flash flood event in the Fella Basin (Val Canale in the Friuli Venezia Giulia region) that occurred in August 2003 and caused hundreds of millions of Euros in damages and even human casualties. Since the CHANGES project deals with hydrometeorological hazards, this paper will examine, in particular, risk management strategies related to flood and landslide hazards.

Changing contexts in a long-term and short-term perspective should be managed within an integrated risk management framework that accounts for both temporary management strategies and permanent preventive measures to reduce the impact of natural hazard processes (Fuchs et al., 2012). Both long-term and short-term risk management strategies are equally important. An integrated or comprehensive risk management approach, however, calls for coordinating and weighing up different risk management options and then choosing the best combination of measures and practices available in order to achieve the most efficient strategy. For clarification, this paper considers a strategy to be a broader, more goal- or vision-based agenda. A policy is considered to be less broad and serves more as a guideline for action used to work towards achieving the strategy. Measures and practices are considered to be the actions actually employed following the guidance of the policies, which work towards the achievement of the main goal or strategy.

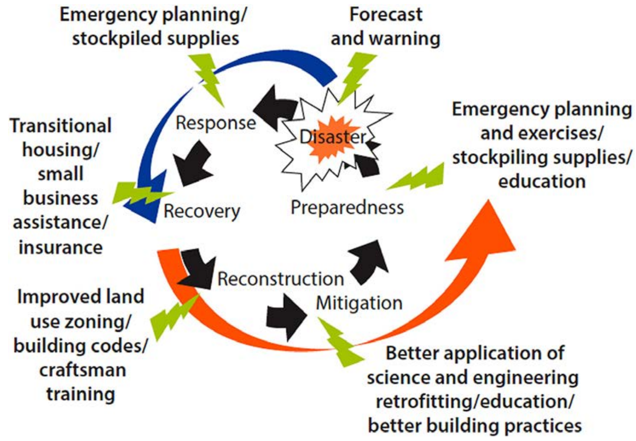

Figure 2. The phases of the disaster risk cycle (Jha et al., 2013).

Furthermore, an integrated approach suggests not only a combination of long-term and short-term measures but also the interaction between the actors involved towards policy agreements for the successful implementation of risk strategies. This has also been stressed by the European Commission, which underlines the requirement of "linking the actors involved in developing and implementing measures that can have significant impacts on disaster prevention" (European Communities, 2009, p. 6). Within this paper, short-term risk mitigation refers to emergency management (preparedness and response) measures aimed to minimize the impact of a disaster, to be prepared for a crisis situation and to be able to immediately respond. In contrast, examples for long-term measures include permanent technical (structural/nonstructural) measures as well as spatial planning, which is inherently a future-oriented activity that can implement long-term prevention measures (Fig. 2). The coordination of short-term and long-term management strategies is not an easy task, mainly due to the often existing void between crisis management and risk prevention (Neuvel and Zlatanova, 2006) or the disconnection of actors involved (Sapountzaki et al., 2011). It also often implies a conflict of objectives since, for instance, regulations related to regional planning and development include several other aims besides prevention of natural hazards (Holub and Fuchs, 2009). Moreover, the legal framework and the political–administrative system significantly determine how risk responses are designed and by which institutions they are implemented (Greiving and Fleischhauer, 2012). In addition, cultural beliefs play an important role how risks are perceived, evaluated and managed (Angignard et al., 2013).

When we refer to "coordination" we mean its most basic sense, i.e., information sharing and exchange. However, coordination towards long-term activities also requires cooperative efforts between actors involved. That is, by enhancing the interaction and sharing of resources between risk managers for the evaluation and selection of risk management strategies towards achieving a common goal (Himmelman, 2002).

In this paper, we consider the need for connections between long-term and short-term management strategies with a specific focus on spatial planning and emergency preparedness. This consideration was realized through analysis of a variation of different cultural contexts, including different legal and administrative settings within the four case study areas of the CHANGES project. The analysis was completed through data collected via stakeholder meetings and expert interviews. Stakeholder meetings were carried out to establish initial contacts. These meetings enabled collection of preliminary data from discussion and responses to a series of pre-prepared questions. Translation was provided by a native speaker during both this preliminary phase and the semi-structured expert interviews, which comprised the second phase. Expert interviews were attempted with one interview partner at a time; however, in some cases, interviews were held with two or more persons. During this phase, an interview guide was used and provided for a mixture of both closed and open-ended responses. Interviews were conducted with the following interview partners: decision makers in municipal offices (including mayors and local crisis management teams), volunteer and professional fire brigades, civil protection, regional and district level crisis management offices, spatial planners, and sectoral planners (e.g., representatives from water authorities, geological surveys, and environmental protection agencies). The highly valuable input from these interview partners in addition to supporting literature serves as the basis for the analysis of in-practice examples for spatial planning and emergency preparedness management and their existing and potential connections.

Section 2 gives a brief background of what is meant by risk management strategies within the research. Subsections are divided into a focus on spatial planning and emergency preparedness containing explanation and examples of these strategies within each of the case study sites. Section 3 provides the connection between spatial planning and emergency preparedness in the context of the case study sites, focusing explicitly on points for establishing and strengthening coordination for risk management strategies. Section 4 concludes the paper with final reflection on the key points for coordination and what remains to be investigated in further research.

2 State of the art of risk management strategies

Risk management strategies utilize and apply resources towards the ultimate goal of reducing disaster risks and the overall threats imposed by extreme events, thus achieving disaster risk reduction (DRR) (Paul, 2011). The efforts to achieve this goal are made throughout all phases of the disaster risk management (DRM) cycle (Fig. 3), which includes

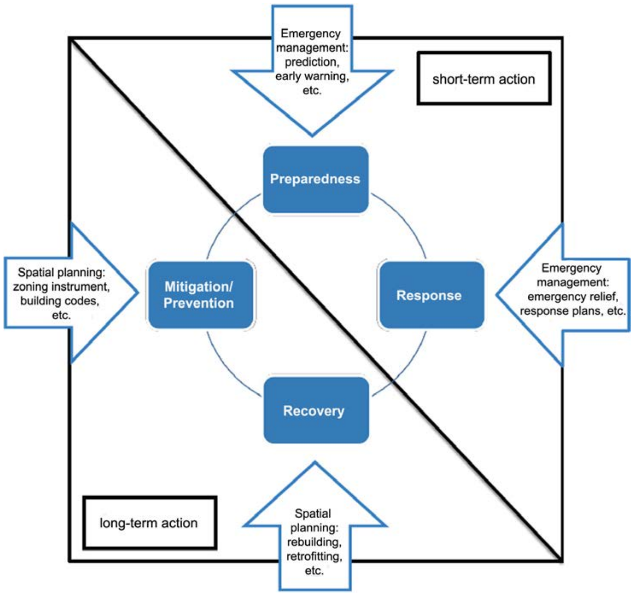

Figure 3. Short-term and long-term activities within the disaster management cycle.

the phases of prevention (often interchanged with mitigation in DRR research), preparedness, response and recovery (Jha et al., 2013). Within and across all phases at all administrative levels, DRM activities and processes are conducted for the design and implementation of strategies to improve the understanding of disaster risks; to reduce losses; and to control, avoid and transfer risks (IRGC, 2009; UN, 2009; IPCC, 2012). In this research, focus is placed on the first two phases of the DRM cycle, which are defined as follows based on Alexander (2002, p. 5):

- Prevention: actions taken and decisions made to reduce the threat (potential for tangible and intangible losses) of disaster consequences in the future, typically divided into structural and nonstructural measures.
- Preparation: given the preeminence of a threat, actions taken and decisions made to reduce the impact of the impending disaster.

The activities and processes conducted by emergency management and spatial planning practices constitute key components of DRM. Overlaps between these two components exist especially in terms of actions taken and decisions made within emergency preparedness (a part of overall emergency management) and regional and/or urban planning practices. In practice, the emphasis on what actions are taken and decisions made varies depending on the consideration for and importance placed on short-term and/or long-term strategies.

Often, and from what has been revealed from the CHANGES case study research, greater action and policy attention is given within phases that require a limited window of available time for decision making. These are namely the response and recovery phases as opposed to the prevention and preparation phases. This pattern applies also within the latter two phases, where often the more immediately required actions for preparedness are given greater attention than actions for prevention. Reasons for this emphasis within the case study findings vary including limited financial resources, inability to target preventive actions due to uncertainty of the location in which the hazard will occur (e.g., especially for flash flooding), interinstitutional conflicts regarding responsibilities and abilities to construct structural mitigation measures, among other reasons. This focus can lead to a common pattern of risk management strategies, which tends to be highly disaster reactive. In consequence, this pattern reduces the realization of measures for prevention and preparedness which dramatically diminish potential losses as compared to measures taken later in response and recovery phases, especially for long-term planning strategies (Pelling and Schipper, 2009; UNISDR, 2009; EEA, 2012). Nevertheless, some in-practice examples from case study analysis reveal that long-term-focused strategies are pursued, for example, where long-term land-use planning strategies are well enforced.

Risk management strategies for both emergency preparedness and spatial planning are dependent upon the "place" or national, regional and local context (e.g., including the institutional, social, geographic and physical characteristics) in which they are developed (Cutter et al., 2003). This context is especially important to consider, as one management practice in one case study is not necessarily suitable for application in another. Thus, taking a case study approach to understanding emergency preparedness and spatial planning at regional and local levels is crucial for consideration of the different case-specific contexts and the respective in-practice connections between these two components of DRM. For each case study presented in this paper, examples are provided which demonstrate the types of measures employed for both spatial planning and emergency preparedness, with focus on the importance of encouraging their connections in risk management strategies. The benefit of strengthening this connection is especially pertinent for the nature of the threats caused by multiple and sudden onset hazards such as flash floods and landslides, as dealt with in the CHANGES project. Therefore, the need for continuous adaptation to complex and unforeseen environments requires enhancing the links between planning and emergency preparedness while acknowledging the roles, needs and values of the involved parties (Comfort and Kapucu, 2006; Garcia and Fearnley, 2012). This integrated approach can have strong implications both in long-term and short-term perspectives to strengthen the resilience of a community before, during and after a disaster strikes.

The subsections following this section provide a brief elaboration on the roles of spatial planning and emergency preparedness practices within DRM strategies in general. The subsections then delve explicitly into the details of these strategies within each case study site. More precisely, the sections offer specific examples and results from the analysis of field site visits and commentary from interview partners in each case study, contributing to the understanding of these practices at a more local level.

2.1 Role of spatial planning for risk management

Spatial planning is undeniably one of the major contributors to DRR. By regulating the long-term usage of space, it can determine the distribution of people and development structures and decide on the location, the type and the intensity of a planned development. An appropriate allocation of the different land uses can thus influence exposures to natural hazards and minimize or prevent damages to life and property (Sutanta et al., 2010). Consequently, planners can either increase or decrease risk through decisions on how and where to build houses, infrastructure and facilities. They have certain instruments at hand, which clearly affect risk reduction activities, but their effectiveness depends to a certain extent from the national planning system they are embedded in. Although spatial planning in general has competences in all phases of the disaster risk cycle, its main competences lie in the prevention phase.

Within the prevention phase one can distinguish between structural and nonstructural mitigation measures. Especially in regard to nonstructural mitigation, spatial planning has notable competences, e.g., in terms of reducing the damage potential with zoning instruments that regulate future development. Its main characteristic or the main task of land-use planning instruments consists in guiding new development away from hazardous areas, i.e., leaving hazard-prone areas free of development, as well as determining and restricting future land uses. Non-structural measures also involve the relocation of existing developments into a safer area (Greiving, 2004). For an enforcement of restrictions of land use, hazard maps are needed which serve to display hazardous areas and thus help to designate areas with settlement restrictions in local land-use plans (Schmidt-Thomé, 2005; Greiving and Fleischhauer, 2006).

Concerning structural mitigation measures, at the local planning level, authorities can influence building permissions through their legally binding land-use plans. Building standards can be used that aim at specific regulations to protect settlements and infrastructure (Schmidt-Thomé, 2005). Spatial planning instruments ensure building code compliance and an efficient quality of construction (Sapountzaki et al., 2011). Such building standards can be traditional building codes, flood-proofing requirements, requirements regarding the retrofitting of existing buildings, etc. (Burby et al., 2000). Examples include the prohibition of a basement or the strengthening of the outside wall (Schmidt-Thomé, 2005).

In regard to reactive, short-term activities, the role of spatial planning is rather small (Schmidt-Thomé, 2005). However, it can still have a supporting role. For instance, it has to consider the needs and interests of emergency response units. The development of evacuation plans and the location of emergency shelters are always related to current and future urban development (Sapountzaki et al., 2011), which is why spatial planning has to ensure that any inhabited area or industrial facility is reachable in an appropriate time in case a disaster strikes. It also has to anticipate potential adverse impacts on roads and response stations and thus plan for an appropriate accessibility with different means of transport (Schmidt-Thomé, 2005; Greiving and Fleischhauer, 2006).

In the four case study sites of the CHANGES project, spatial planning as a risk prevention instrument is regarded with different degrees of importance. Whereas authorities in three sites (the French, Italian and Romanian study areas) rather rely on structural mitigation measures, authorities in the Polish case study site underline the essential role of nonstructural mitigation in the form of restrictive land-use planning.

In Poland, flood and landslide prevention is directly linked with local land-use planning. In the Polish study area, the Wieprzówka catchment in the Małopolska voivodeship, interviewed mayors highlighted the importance of nonstructural mitigation measures, whereas the number of structural mitigation measures in the municipalities concerned is negligible. Therefore, the main activities addressing risk reduction consist of regulatory zoning in terms of determining, restricting or prohibiting future uses and developments. The reason for a rather reserved implementation of structural mitigation measures can be the limited financial means which are not sufficient to stabilize all landslides and to protect all areas at risk, as stated by local authorities in Stryszawa municipality. It was also argued by public authorities in the municipality of Andrychów that implementing structural measures required a better identification and understanding of the areas at risk. However, the uncertainty about (a) which and how many areas are at risk and (b) what the probability of future events is results in a limited amount of structural mitigation measures. For instance, floods in this area occur suddenly and there is neither much time for preparation nor is it easy to predict which zones or places might be hit. Due to the difficulty in assigning the best places for structural measures, local authorities rely on land-use planning competences to reduce the risk. Another obstacle to implementing structural measures is the distribution of legal competencies. River banks are commonly known places where structural measures are needed. However, they are under the administration of separate authorities and local authorities are unable to do anything without an agreement with the responsible water board. As regards landslides, an online information system for landslide assessments called SOPO ("System Osłony Przeciwosuwiskowej") is currently under construction in the Polish Carpathians. The first available results give hope for better identification of areas at risk for urban planning purposes and simultaneously impose a task of formulating adequate land-use regulations.

The situation in the Italian Fella River catchment is different. After heavy rainfalls in 2003, which caused severe flooding and landslides, several mitigation works have been completed in the towns of Malborghetto and Ugovizza by the civil protection agency of the Friuli Venezia Giulia region as an immediate reaction to the disaster. Officials of Malborghetto explained that, due to the existing problem of continuous outmigration from the valley, structural measures were considered as an effective and necessary option to prevent both having to relocate people and having people leave. Furthermore, according to a representative of the river basin authority, 90 % of the events in the Fella River catchment occur at more predictable places or even at the same ones. This is why civil protection can more easily identify the most affected areas and better anticipate disasters. The authors conclude that the importance of spatial planning related risk management activities is rather low. Nonetheless, spatial planning can currently contribute in terms of prohibiting new construction in hazard-prone areas thanks to the so-called "Piano stralcio di assetto idrogeologico" (PAI), a legally binding plan providing one map each for hydrological, geomorphological and avalanche hazards. The PAI promotes a risk-reduction-oriented spatial planning by displaying areas exposed to hazards in four different levels (moderate, medium, elevated, highly elevated) (Fig. 4). In addition, the map for geomorphological hazards also shows the elements at risk, i.e., a parameter for vulnerability, and existing structural defence works. Contents and prescriptions of a PAI need to be considered in all planning documents, i.e., their provisions are legally binding for local authorities as well as for the private sector (Galderisi and Menoni, 2006). In the Fella catchment, the PAI has been adopted but not yet approved. Nonetheless, the current available version already has to be used in local spatial planning.

In the town of Nehoiu in Buzău County, Romania, the lack of funds is clearly the biggest problem. The insufficient budget immensely limits actions at the local level. Nonetheless the focus lies on structural mitigation measures, as dams and other built structures are considered to be most effective in the short term. In fact, several interview partners in the Nehoiu town offices indicated that there is no possibility to consider a long-term perspective because of the need to first try to manage short-term problems. Within this case study, the role of spatial planning in risk management is rather low and its use as a risk prevention tool is not fully taken into account. Planning decisions at the local level are often based on local knowledge and experiences, as commented by an urban planner in Nehoiu town. For instance, current planning practices merely prohibit construction in areas where the landslide risk is known or a landslide already exists. According to a representative of the local planning department, in areas where a potential risk of landslides exists, building permits are usually granted. Moreover, planners seem to judge existing risks differently. While earthquakes, for which information is available on a small scale, are regarded as rather serious threats, floods and landslides seem to be undervalued. Reasons can be existing structural mitigation measures like

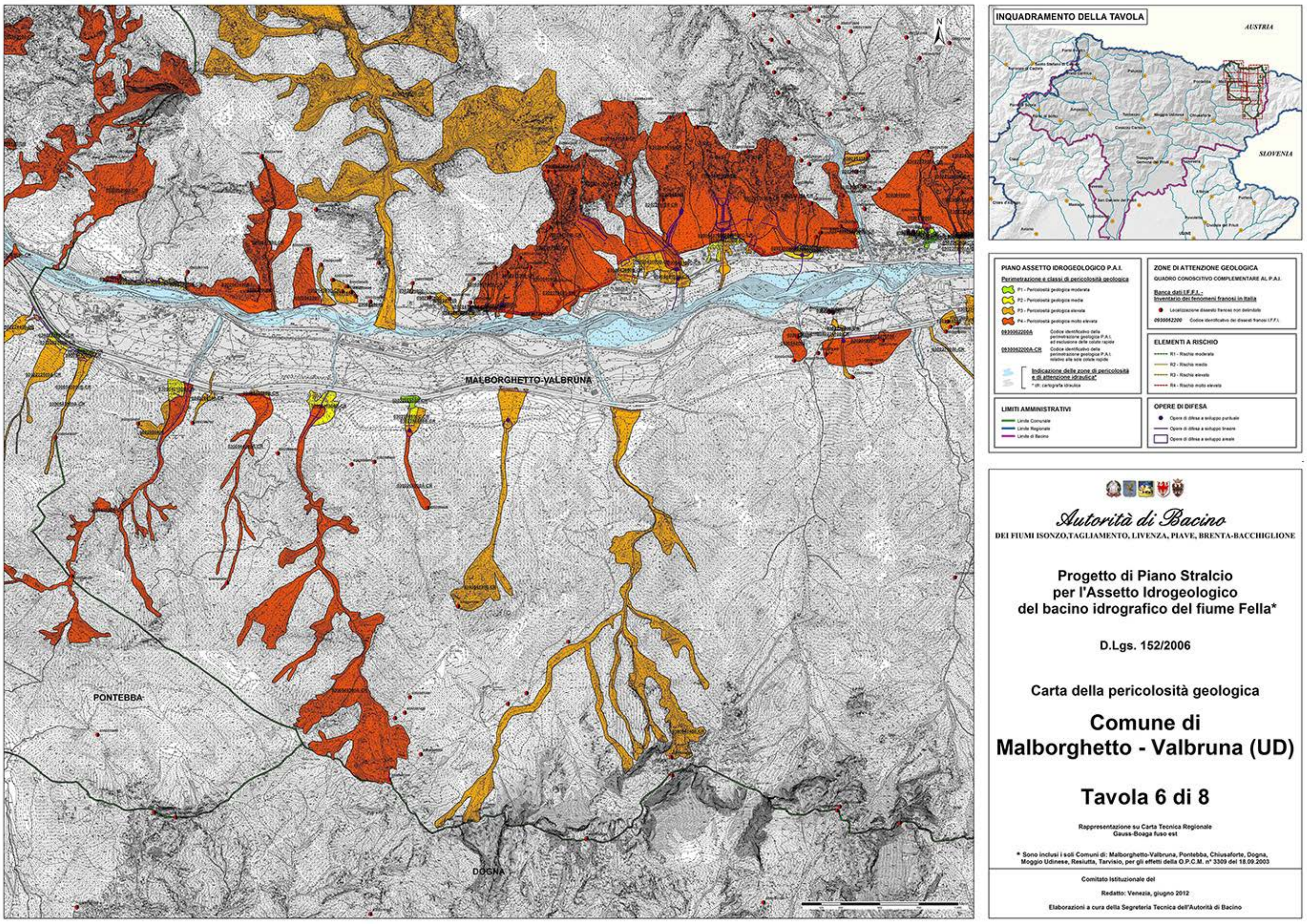

Figure 4. Geomorphological hazard map – PAI, commune of Malborghetto-Valbruna, Italy (Autorità di bacino dei fiumi dell'Alto Adriatico, 2012). The map comprises all types of mass movements: rapid flows, falls, topplings, surficial slides and rotational/translational slides. Red areas indicate a highly elevate geomorphological hazard, orange areas indicate high geomorphological hazard, yellow areas indicate medium geomorphological hazard, and violet lines and points indicate structural defense measures in development.

dams and dykes that cause a false sense of security. Illegal building also constitutes a problem and adds to an increasing risk. The purpose of regulatory zoning as a risk mitigation measure is known and its benefits are acknowledged; still, the commune is both limited in its actions in this regard and considers structural measures to be even more effective. Reasons for this approach may be the lack of hazard- and risk-related information that could be used in land-use planning (especially hazard and risk maps) as well as a lack of acceptance of the population for a more preventive planning approach, which influences current planning decisions and activities.

In regard to the importance of structural versus non-structural measures, the situation in Barcelonnette, a commune in the Ubaye Valley, is in a way similar to the one in the Fella River catchment. In general, structural measures are considered as very effective and practical. Since the commune is already quite densely populated and developed, the zoning option and the designation of retention areas do not seem to be feasible, at least not in regard to protecting already existing developments. Thus, structural measures like the elevation of a dyke have proved to work and are also accepted by the population. However, it has to be stressed that, in the year 1995, the French government implemented a very strong and influential risk prevention instrument which has essential effects for nondeveloped areas: the "Plan de Prévention des Risques Majeurs", PPR (Risk Prevention Plan)[3]. The PPR (Fig. 5) is an instrument designed for the prevention of any type of risk, including, among others, floods, landslides, rock falls, earthquakes and avalanches (European Communities, 2000; Mancebo, 2009), and determines where building is allowed (white zone), not allowed (red zone) or allowed under certain conditions following specific regulations (blue zone). The PPR is therefore

[3] France has a well-elaborated framework of natural hazard management due to the long tradition of hazard mapping and risk management instruments and the prevention of risks has always received great attention.

particularly important in terms of prohibiting new development in risky areas (red zone) or adapting building structures to present risks (blue zone). In order to protect existing structures such as the departmental road and houses along the Ubaye River, structural measures are necessary, however.

While in Italy and France comparably strong and separate prevention instruments provide for compulsory consideration of hazards or risks, respectively, in spatial planning, in Poland and Romania the obligation of taking hazards into account exists, but the realization differs. In the former two cases, maps with comparably clear delineations of the hazard or risk levels exist. In the latter two cases only information about the extent and the intensity of hazards is used. In the case of the Romanian site, decisions are often based entirely on local knowledge and experiences. Despite the compulsory use of spatial planning as a tool for risk prevention, it is not equally considered as effective as structural mitigation measures. However, there are opportunities for planning to be the more efficient strategy in the long run.

2.2 Role of prevention and preparedness for emergency management

Typically, activities for emergency management aim at safeguarding people and assets exposed to particular threats while incorporating the "organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps" (UNISDR, 2009, p. 13). Overall, emergency management requires fast or near-real-time provision and absorption of information for hazard and vulnerability identification. Communication is based upon the coordination of different organizations such as government agencies, local administrations, nongovernmental and volunteer forces (Comfort and Kapucu, 2006; De Leoni et al., 2007), in which local volunteers and crisis management teams are often the first responders (Fischer, 2008). Despite the short-term focus, emergency activities comprise all four stages of the DRM cycle (Lindell, 2013). Consequently, effective emergency management includes preventive actions that protect passively against casualties and damage at the time of hazard impact. Such extended management perspective represents a proactive resilience approach to strengthen the communities' capacity before, during and after a disaster strikes. This is opposed to a reactive resilience approach that focuses on emergency response to reduce casualties and damage when an event takes place (Adger et al., 2005).

By taking into account the imminent probability of the event and the limited time for decision making, activities for emergency management mainly rely on the implementation of emergency plans and early warning systems (Mens et al., 2008). The former define a chain of actions, actors and resources that are required in order to be better prepared and to better respond in case of specific risk scenarios (Piatyszek and Karagiannis, 2012). The latter encompass the monitoring and identification of triggering factors for hazard events, which may be citizen- and technically based (Garcia et al., 2013). The overall aim is the activation of warning messages for the implementation of either active or passive temporary measures that reduce vulnerability and risk consequences (Rogers and Tsirkunov, 2010; Verkade and Werner, 2011). Examples of active temporary measures are the operation of protection works like dams or the allocation of sandbags to increase the height of levees. Instead, examples of passive ones correspond to the reallocation of building furniture and appliances to higher floors or the evacuation to safe areas (Holub and Hübl, 2008).

However, in case of sudden-onset hazards such as flash floods and debris flows, time is a crucial restriction to activate warning messages and to support the implementation of emergency plans at the time of hazard impact. In this case early warning can only benefit people and movable objects and not stationary objects such as infrastructure (Hübl, 2000). In addition, long-term and short-term changes contribute considerably to the risk levels regarding the temporal and spatial distribution of buildings and people exposed (Aubrecht et al., 2013). Consequently, there is an imperative need to enhance communication and coordination activities beyond emergency response while accounting for the interaction between different actors involved in risk prevention and preparedness. This holds especially true for spatial planners and emergency managers if one considers their essential need to share common critical data, particularly for mountainous environments, where hazards often occur unexpectedly and rapidly.

When comparing the emergency management structures within the four case study areas of the CHANGES project, the mayor has the legal responsibility for disaster management at the municipality level. Regional and national levels provide support for lower tiers of emergency management. This support depends on the spatial extent and intensity of the event as well as the exhaustion of local resources for event management (Gaetani et al., 2008; Dworzecki, 2012). Moreover, competences of emergency management at the regional level integrate activities to promote risk prevention, monitoring and forecasting activities that respect the national principles. In the French site, such competences are based upon the "seven pillars of French prevention policy". These pillars include, among others, the understanding of phenomena, unexpected events and the risks they pose, monitoring and reducing vulnerability (MEEDDM, 2011). In Friuli Venezia Giulia, a functional center at the regional level supports local administrative levels for forecasting, warning, coordination of emergency plans and response. This center is structured according to the national legislations (law no. 225/1992, legislative decree no. 112/1998, law no. 401/2001 and law no. 100/2012) and further adapted according to regional legislations. In the Romanian site, emergency committees operate according to the government emergency ordinance 21/2004 for the implementation of national strategies

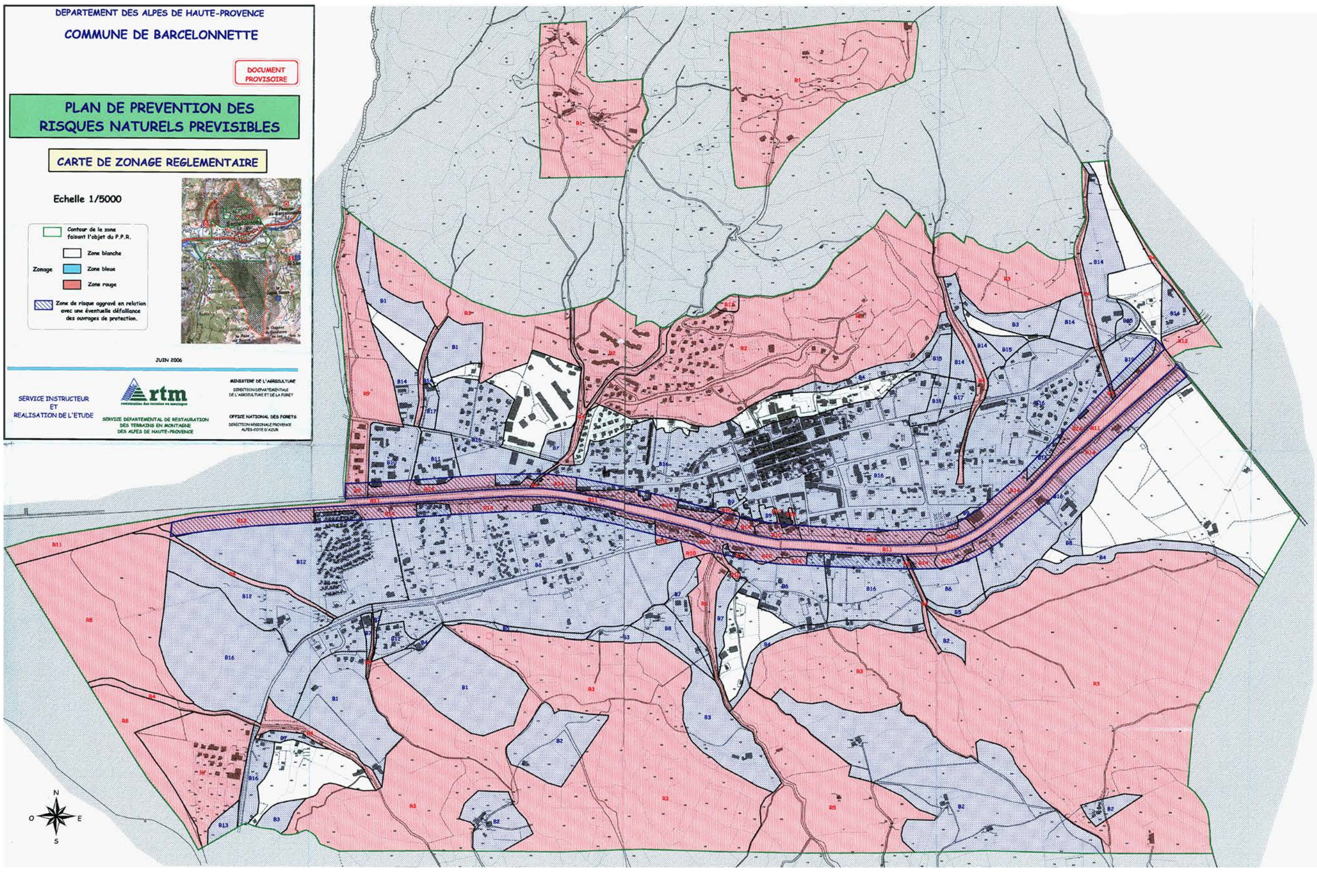

Figure 5. Plan de Prévention des Risques Naturels of Barcelonnette, France (RTM, 2006). Red areas indicate high risk, blue areas indicate medium risk and white areas indicate low or no risk. The three risk classes are based on a matrix comprising three hazard classes and four classes of potential consequences (exposed elements/vulnerability). The hazard comprises the probability of occurrence of an event, and the exposed elements can be defined as the entirety of persons, goods and infrastructures likely to be affected by a hazard.

at lower administrative levels into emergency plans and by planning exercises to maintain awareness and to inform citizens. For the Polish site, these competences for crisis response plans and programs are stipulated within the act of 26 April 2007 on crisis management (2007).

In addition to the above legal framework and with reference to preparedness activities, all case studies receive warning information from meteorological services. Overall, monitoring and warning systems are more specialized and automatic in the French and Italian sites as compared to the Polish and Romanian sites. Despite the differences, there is a common interest to develop early warning systems based on modeling approaches and triggering thresholds while incorporating local knowledge and citizen-based approaches. Such approaches are still technically based but give focus to the active engagement and communication with people exposed to risk (Basher, 2006).

Additionally, in all study sites, emergency plans are recognized as key instruments to support preparedness and response activities. In the French and Italian cases in particular, there are available platforms to manage and update emergency plans, whereas in the Polish site information systems are devoted to support crisis management. Moreover, the implemented systems support comprehensive databases to collect and share data on the occurrence and damages of flood and landslides. In contrast, in the Romanian site, regional (county level) emergency authorities acknowledged the need for developing a platform and tools to support their activities. Such integrated platforms could also support the scientific identification of dangerous areas by sharing and combining it with local knowledge on past hazard events.

In practice, the competences of emergency management for each study site are generally driven by the level of involvement of regional and local authorities in prevention and preparedness activities as opposed to response and recovery phases. In this regard, the interaction with private and volunteer organizations is considered as a relevant aspect to support proactive resilience approaches. The Italian site is an example of strong community involvement in volunteer activities. The Friuli Venezia Giulia model of volunteer activities follows a historical tradition of fire brigades that was enhanced after a devastating earthquake in 1976 (Bianchizza et al., 2011). For the Romanian site, different categories of stakeholders in Buzău County (e.g., the regional environmental protection agency as well as local and regional bodies of emergency management) identified the need to promote and adapt voluntary activities to the local context. In the Polish and French sites, the local-level involvement in emergency activities is limited to fire brigades that are the first responders in case of emergency.

The overall risk management focus also varies according to the distribution and coordination of funding as well as other types of financial means not only to support preparedness and response but also to promote instruments to prevent losses. In the Italian site, after the 2003 event, a large sum of approximately EUR 40 million was spent on remediation works in the form of restoration works and recovery from damages to affected infrastructures (both private and business structures), among others. Additionally, a large sum of money was spent on structural mitigation measures such as check dams and channels (Fig. 6). Consequently, large investments were made in prevention measures. However, in general, two-thirds of the annual costs of the Italian civil protection system (around EUR 1.7 billion) is used to refund payments accrued during previous disasters (Gaetani et al., 2008), i.e., for recovery. In the French site, it became apparent that attention is paid to both prevention and preparedness. One of the reasons may be that the French system for natural disaster indemnification combines the solidarity idea behind mutualization – related to an existing risk and through payment of premiums – with the national solidarity principle by guaranteeing indemnification granted by the state (Consorcio de Compensación de Seguros, 2008). Therefore, the state also has a financial interest to provide for the best prevention and preparedness possible in order to reduce and minimize potential damages before a disaster strikes. In contrast, in the Romanian site, the limited operative resources and lack of funds focus most efforts on the preparedness and response phase regardless of the importance of prevention activities, as recognized by interview partners. In the Polish site, the limited funds are distributed among the preparedness and response instruments that are in place (i.e., early warning and information systems for crisis management). In general and in looking beyond the scope of the case study findings, other preventive measures in addition to zoning regulations are rarely implemented at local level due to difficulties in ownership rights and distribution of responsibilities. As a result, municipal authorities must deal with the future risks arising in emergency situations rather than taking preventive actions in advance[4].

Section 2 focused on the role of spatial planning and emergency management for risk management in general and provided examples from the case study sites as well as an explanation for the respective focus of risk management strategies. The next section will highlight currently existing connections between the two. It will also provide reflections on how these links could even be further developed and strengthened.

[4]These results corroborate statements found in the literature and experiences made in other case-study-related research works (e.g., Fleischhauer et al., 2006; Sapountzaki et al., 2011).

Figure 6. Structural debris flow mitigation measures in Malborghetto-Valbruna, Italy.

3 Coordination of emergency preparedness and long-term spatial planning activities

As stated above, disaster risk management includes activities before, during and after a disaster occurs. At the same time a question that is often raised is whether the focus should be on pre-disaster measures in terms of risk prevention or on post-disaster measures, i.e., emergency response. Sapountzaki et al. (2011) argue that emergency planning often plays a larger role than prevention planning. This can be regarded as a concern as generally both should be considered equally important: the former because it primarily ensures the prevention or at least the reduction of adverse consequences from a disaster. Preventing a disaster in the first place should be the primary goal. However, the latter is just as essential because, due to the residual risk, a well-functioning emergency system is vital for any society (Neuvel and Zlatanova, 2006). Moreover, risk levels vary markedly on different temporal and spatial scales. On the one hand, this is due to long-term socioeconomic development that can be regarded as the basic goal. Therefore, permanent constructive mitigation measures and land-use regulations should be implemented. On the other hand, short-term fluctuations in the frequency and magnitude of events call for emergency plans and temporal measures such as immediate support and evacuation (Fuchs et al., 2012). Neuvel and Zlatanova (2006) further mention the need for investments that address both risk prevention and crisis response to make a society more resilient to disasters. However, this requires effective coordination not only among different disciplines and policy areas but also across all phases of the disaster risk cycle (European Communities, 2009) of all risk management approaches involved.

In this regard, attention has to be paid to the interlinkages between spatial planning and emergency management, especially within the prevention and preparedness phases. Neuvel and Zlatanova (2006) note that, although emergency management units and spatial planners work in different environments and time frames, they are concerned with similar safety issues. As mentioned above, spatial planning is involved in emergency management and vice versa. In spatial planning, integrated risk and hazard maps are essential to enable the inclusion of a DRR strategy into land-use plans (Sutanta et al., 2010). Disaster hot spot locations can be identified with the practical knowledge inputs of emergency managers, such as safety recommendations provided by fire departments (Neuvel and Van den Brink, 2009). The information obtained from emergency response units can provide more insight into useful risk reduction measures as well as what interests need to be considered if emergency management concerns are addressed (e.g., areas required for emergency response and spaces for shelter, evacuation routes, accessibility of residential and industrial areas by emergency response units in case of a disaster, allocation of response stations, etc.) (Greiving and Fleischhauer, 2006). At the same time, spatial planning authorities have information on planned development in hazard exposed areas as well as on vulnerable zones and elements, which should be communicated to emergency services for inclusion in the emergency management plan. In general, spatial information in the form of maps and models is appreciated by both entities, i.e., spatial planning and emergency management authorities. Accordingly, there are essential links between spatial planners and emergency managers to achieve better preparedness and response activities in risk management. Linking all actors within an integrated response strategy towards disasters throughout the whole disaster management cycle (Greiving et al., 2012) can be regarded as a key prerequisite for successful disaster reduction. Consequently, it is not only important to coordinate risk management activities at the same temporal scale but also to support cooperation between the different actors involved and promote the sharing of resources.

However, Sapountzaki et al. (2011) recognized that actors involved in risk management are hardly connected to each other. Young (2002) refers to this problem as the "problem of interplay". The problem of interplay constitutes a particularly crucial factor for the mitigation of spatial risks (Greiving and Fleischhauer, 2006). Institutions should not be regarded as individual arrangements but rather be seen as part of a wider network, since they interact with other arrangements both vertically and horizontally (Young, 2002). The existence of disconnected actors can partly stem from a historically fragmented administrative system. Often there are no linkages among the actors involved, which means that activities and information transfer run parallel and there is no real exchange (Greiving et al., 2012). In addition, funding is also often fragmented. As a result, the – mostly limited – resources are used in a rather ineffective and inefficient manner (Greiving et al., 2012), thus reducing key success factors. Neuvel and Zlatanova (2006) found that models and systems developed by emergency units are hardly used by spatial planning authorities. Moreover, spatial planning authorities use systems with information on the location of vulnerable assets, which can be of importance for emergency services. Whereas regional and local planners strongly focus on the location of urban development or safety measures for construction projects, emergency managers mainly focus on organizational aspects, such as surveillance, coordination, communication and logistics (Caragliano and Manca, 2007). Nevertheless, the physical characteristics of an area greatly influence the possibilities for emergency management. Therefore, alignment of information and actions among risk actors can increase the coherence of safety measures (Neuvel and Van den Brink, 2009). This potential alignment of emergency services and spatial planning has been examined in the CHANGES case study sites.

In France, risks are rather managed in a whole system. Procedures addressing risk assessment and management have become more integrated and tend to cover the whole disaster risk cycle. Interviews conducted in the Ubaye Valley provide the impression that risk prevention and emergency preparedness and response are considered equally important. What must be additionally considered is that the emergency system in France "has moved toward an integrated risk management policy partly to become a key element of local planning and local policies" (Renda-Tanali and Mancebo, 2010, p. 10). There are two examples of this which clearly demonstrate the positive approaches which should be further investigated in future research.

During the preparation or the revision of a "Plan Local d'Urbanisme" (PLU), the commune can consult the "Service Départemental d'Incendie et de Secours", SDIS (Departmental Fire and Rescue Service), which provides technical advice which addresses specific requirements attached to the project in question. These requirements concern prescriptions regarding minimum constraints for the accessibility of emergency services, the protection against fire risks and the consideration of major risks, including floods and forest fires. The prescriptions must be respected during the realization of future local planning projects within these zones. According to the first paragraph of article L.126.1, Code de l'Urbanisme (Urban Planning Code), the prescriptions of the SDIS rate as "servitudes" (easements) and shall be annexed to the regulations of the PLU.

In general, the mayor has responsibilities in all phases of risk management (see Fig. 3). There are several informative and regulatory instruments dedicated to natural risks. Besides the PPR as a regulatory instrument for risk prevention, mayors make use of a local document for emergency preparedness and response called "Plan Communal de Sauvegarde" (Communal Safeguard Plan, or PCS). The plan governs actions and measures to be taken during and after a disaster (Renda-Tanali and Mancebo, 2010). It intends to combine all local documents contributing to preventive information and the protection of people. According to article L731-3 of the Inner Security Code (Code de la sécurité intérieure) the PCS is only obligatory for communes that are endued with a PPR.

No direct link with local planning documents is found in the legislation, which means that the PCS does not – necessarily – take into account information included in a SCot ("Schéma de cohérence territoriale") or a PLU, nor does a PLU have to consider the contents of a PCS. In the French case study site of the CHANGES project, it was expressed by urban planners that the consideration of the PCS during the elaboration of a PLU is regarded as useful. Since the document integrates different kinds of information, it could be a valuable source of information for local planning practices. Conversely, knowledge about elements at risk (sensitive buildings and infrastructures exposed to hazards) is vital for the elaboration of a PCS (DDSC, 2009). However, according to the "Guide pratique d'élaboration" (Practical Guide for Elaboration) of the PCS, spatial planning documents do not constitute any of the sources mentioned to be consulted for information, although spatial planning usually disposes of this vulnerability-related information, "since such facts as the current distribution of population, the location of settlement areas, or technical infrastructure is basic information which is already needed for any kind of spatial planning activity" (Greiving, 2006, p. 186). In this context, linking the PCS and planning documents can be seen as an asset in aligning prevention, preparedness and response activities.

Consequently, potential linkages and possibilities for coordination between emergency management and spatial planning are apparent, but it seems that so far coordination only takes place in the form of technical advice provided from an emergency management authority towards local planning. It appears that no information is exchanged in the other direction, which means that a two-way communication process does not take place. There are, however, opportunities to establish such links, especially in the preparedness phase.

In many Italian regions the main actor in regard to emergency preparedness and response is the "Protezione Civile" (civil protection). In their review of the Italian national civil protection system, the OECD (2010, p. 11) concluded that "Italy has implemented a coherent, multi-risk approach to civil protection that fully integrates scientific research and technological expertise into a structured system for forecasting and early warning of natural disasters". The National Department of Civil Protection is a system coordinated by the prime minister and benefits from its position under direct authority of the Italian government (OECD, 2010). This shows the great importance that is attached to emergency response operations and recovery. Similarly, the observations and interviews from the CHANGES research allow one to reach the conclusion that risk management approaches seem to be very disaster reactive, especially in regard to funding. A great part of the governmental budget is dedicated towards emergency response and recovery activities (see Sect. 2.2).

Spatial planning as a tool for risk prevention has a less prominent role, and planning requirements for construction and buildings are often set aside (OECD, 2010). However, with the PAI (Piano stralcio di assetto idrogeologico) (see Sect. 2.1), Italy has quite a powerful risk prevention instrument in regard to planning activities. The problem is not the existing planning instruments themselves but a need for better implementation of prevention policies. Another prerequisite is the reinforcement of urban planning codes, e.g., through robust enforcement measures that may include thorough inspections, higher incentives for retrofitting and stronger penalties and efficient sanctions in the case of legal violations (OECD, 2010). In particular, illegal building is still a widespread problem throughout Italy – with the exception of the Valle d'Aosta region. In the year 2003 alone, 40 000 illegal buildings were constructed (Fiorillo et al., 2007). It is evident within the Italian case study that there is a stronger focus on emergency management as opposed to spatial planning. However, in considering how to move towards equilibrium, attention must be paid to the links between these two approaches.

It is noted by Galderisi and Menoni (2006, p. 103) that only "very few regional planning acts specify the links between general planning tools and civil protection tools". As a further problem these authors state that even though risk management instruments exist for all phases of the disaster cycle, they do not create an effective sequence of actions and coordination of activities[5]. Furthermore, the OECD (2010) highlighted that the NCPS (National Civil Protection Service) has no responsibilities in prevention policies and that it would be beneficial if the NCPS had more competencies related to these policies. After all, it is virtually assigned relevant capabilities and experiences in prevention strategies. Bignami's (2010) reflections lead in the same direction. He recognizes the need for a broader role for the modern civil protection by contributing to the determination of long-term choices. The author asserts this also for territorial structures, provided there is collaboration with authorities dedicated to land use, construction standards and the realization of public buildings. He continues to explain that a closer collaboration between spatial planners and civil protection services is needed in order to benefit planning practices.

In Friuli Venezia Giulia, there are geo-information systems to support exchange of information between civil protection and municipalities. Such platforms are particularly for the implementation of emergency plans (RiMaComm, 2013). In addition, there are initiatives to support exchange of information between civil protection and the regional technical services. The geo-information system SIDS (i.e.,

[5] A common pitfall, according to the UNHCR (2003, p. 12), is the fact that "everyone wants coordination, but no one wants to be coordinated". There are a couple of reasons why coordination efforts fail or why they are difficult to implement. Among others, this regards the problem that actors involved, their information and their processes are not necessarily always transparent or accessible for everyone (UNHCR, 2003). This problem also hints at the imperative to share information, make it generally accessible and provide for transparency in order to ensure a better understanding of the overall system everyone is part of.

Territorial Informative System for the Soil Defense) is currently used to share information regarding the database of hydraulic structures and protection works. It also allows the geological survey to validate hydrometeorological events that are reported to the civil protection agency. However, despite efforts to exchange information between regional services, there is limited coordination between authorities involved in civil protection and spatial planning. Current practices could maybe benefit from the common use of already existing systems, such as the SIDS. Expert interviews further revealed the fact that the civil protection agency of Friuli Venezia Giulia gives some specific opinions and guidelines to the municipalities regarding spatial planning but that the municipalities usually prepare the plan themselves, without consulting the civil protection agency. Municipalities are not obliged to ask the civil protection agency for advice but study the situation themselves. That means this link is neither formally nor legally stipulated. Furthermore, the municipalities generally have other studies at hand which they can make use of when elaborating land-use plans, which means that they have other sources than the civil protection agency. A representative of a fire department in Moggio Udinese (Province of Udine) criticized the missing coordination in the concrete case of a construction of a new bridge, which turned out to be too narrow for fire trucks. In short it was expressed that emergency planning is handled rather separately from spatial planning and that there is no real coordination, let alone cooperation.

Especially in light of the public debt crisis and government budget reductions, better coordination of activities and the best possible use of resources are required (OECD, 2010). There is an urgent need to identify the best option available. An example from this can be seen when looking at the many structural mitigation measures whose construction was considered most effective. However, at the same time, all these constructions were also very expensive. Bearing in mind that the study area is characterized by outmigration, such a costly investment might indeed be the most effective one at the time of decision making, but it might not be the most efficient one in the long run. One has to weigh immediate benefits with future development and long-lasting purposefulness. Therefore, by identifying parallel organizational areas of competence as well as opportunities for resource sharing, and also by comparing different alternatives, shrinking funds can be used more effectively.

In the Polish case study site, the main activities in regard to risk management seem to equally focus on regulatory zoning and emergency preparedness and response. In regard to the coordination of activities between spatial planning and emergency management, no according legal regulation exists. At the Sucha Beskidzka district office and professional fire brigade it was expressed that there is only a limited flow of information with planning authorities. Information is at most exchanged with sectoral planning authorities, e.g., about places where protective work is needed. This was also confirmed in interviews with urban planners, who state that generally there are very few connections with crisis management units.

In order to distribute the sparse financial means most efficiently, different risk reduction options should be weighed against each other in a cooperative approach, which currently appears to be difficult, as there does not even seem to be a strong level of coordination between different authorities involved in risk management. Furthermore the assignment of tasks and the allocation of responsibilities and property rights are sometimes difficult and questionable. The geo-information system ARCUS 2005 (Fig. 7) which is currently used to exchange information between local and regional administrative bodies involved in emergency management is a good example of vertical coordination, since it displays the availability of resources in case of a disaster, including emergency appliances and tools, as well as personal forces. It has been licensed to many administrative units in Poland, including the municipalities and districts in the Małopolska voivodeship. It is a software tool that is employed for emergency management purposes using elements of geographic information systems (GIS) and serves as a database. It allows for simultaneous illustration of all entities' resources and also prepares tables with data to be illustrated in the GIS application (Choryński, 2013). There is also a degree of horizontal exchange with different local authorities. However, this system is not being used by spatial planning authorities and consequently neither is the information it contains. Yet it was observed that such a system may be quite beneficial as a potential tool to exchange information. Recorded incidents and crisis situations related to natural hazards could help identify hot spot locations. Providing spatial planners access to such systems could be a good opportunity to enhance their information about the nature of hazardous establishments and particularly endangered areas in their municipality or the region. This information could then also be used by planning experts for the development of spatial plans. Conversely, spatial planning could provide information about vulnerable objects, which could be fed into the system. In the Polish case study site, similar to the Italian site, there is hardly any coordination or cooperation between emergency management units and spatial planning bodies. Additionally, there is also no formal obligation to establish such links and develop according processes.

In Buzău County in Romania, the interview partners explicitly acknowledged the importance of prevention. The problem again is the missing realization. It was stated in expert interviews at the Emergency Situation Inspectorate (ISU) that – based on statistical evidence – prevention is apparently 8 times less expensive in the long-term than emergency response and that prevention is even more important than recovery. Still, more investments are made in emergency response than in long-term risk prevention. However, concerning cooperation between planning and emergency entities, Buzău County provides some positive approaches. For

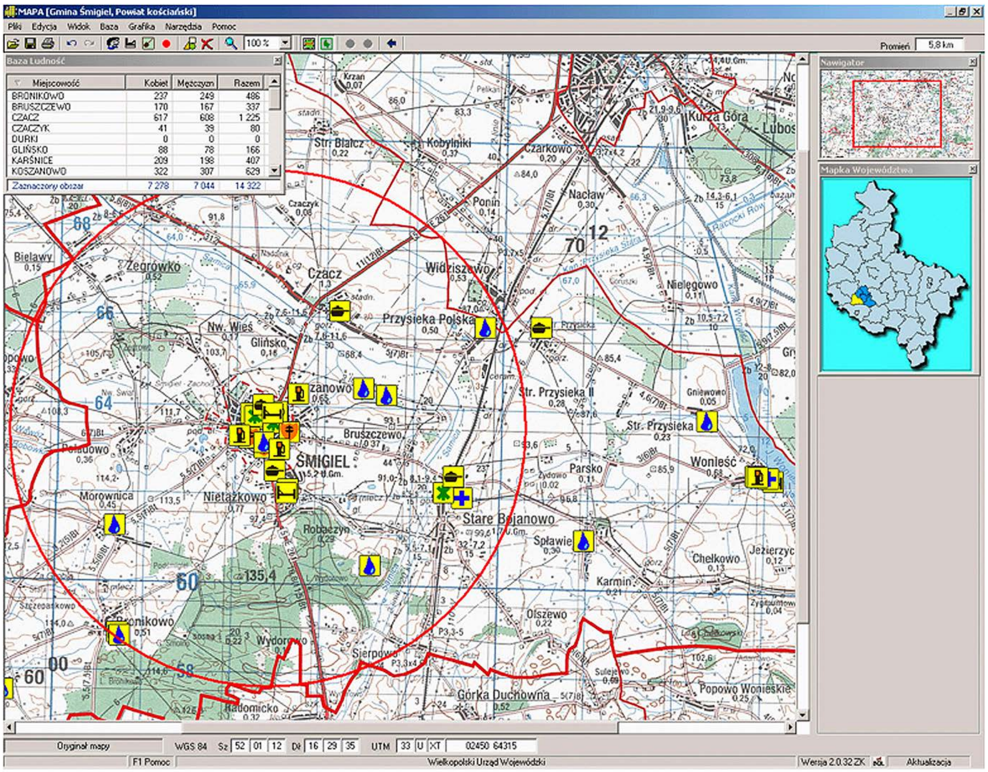

Figure 7. ARCUS 2005 system (Choryński, 2013). The map displays selected resources of the municipality marked with the flag, in this case the municipality of Smiegiel in the Wielkopolska (Greater Poland) region in Poland. This involves elements such as infrastructure, hospitals, pharmacies, volunteer fire brigade stations, petrol stations, accommodation, clinics and primary health care, etc.

instance, the ISU in Buzău is directly involved in urban planning. ISU officers give their opinion on local spatial plans and also check the plans. The legal basis of this type of coordination can be found in the law 350 of 6 July 2001 on spatial planning and urbanism, which states that urban planning documents must be approved by a so-called "Comisia tehnica de amenajare a teritoriului si de urbanism" (technical committee for spatial planning and urbanism), which, in order to improve the quality of decisions regarding local sustainable development, provides advice, technical expertise and consultancy (law 350 of 6 July 2001, article 37 (1)). ISU has a member within this technical committee who is responsible for checking the document and looking for specific issues related to mandatory protection against fire. That member may also signalize whether issues related to natural hazards (landslides, floods, earthquakes) are either missing from the documentation or are only partly or insufficiently addressed. Additionally, ISU elaborates a prevention plan based on the urban plan and integrates all different plans into the County Spatial Plan, among others the evacuation plan and the flood prevention plan. Hence, there seems to be a two-way information exchange between spatial planning and emergency services, which has also been confirmed in the interviews. Furthermore it has been expressed that, although a system for the management of emergency situations already exists, a platform is needed which involves several services, such as the spatial distribution of events, the modeling of probabilities, better visualizations and maps, etc. This would not only be helpful in terms of emergency management but also in terms of better long-term planning at the county level.

One of the effects that evolve from a lack of coordination between long-term and short-term risk management strategies is the fact that actors involved do not cooperate. Adverse consequences resulting from an inefficient choice can be minimized by implementing cost–benefit analyses or by underlining the need for comparing different alternatives and sharing common resources. Thus, duplication of measures and a misuse of funds can be reduced or even avoided. This might ensure investment in the implementation of what are the most effective measures, and therefore a more efficient use of funds (Fig. 8).

In this respect, the implementation of a web-based decision support platform, as being developed by the CHANGES project for instance, could help integrate all the available risk information and support the decision-making process in the selection and implementation of different alternatives with the most relevant actors involved in risk management. It is not within the scope of this paper to further describe the system developed within the CHANGES project. We will therefore hint at a forthcoming publication by Aye et al., which

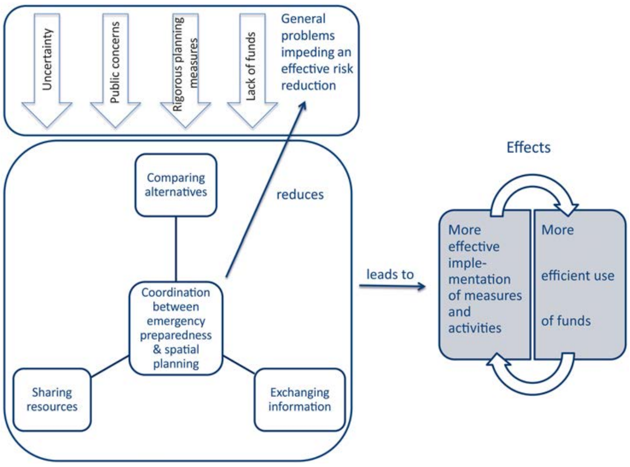

Figure 8. Effects of improved coordination between emergency preparedness and spatial planning actors and identified problems (uncertainty in natural hazard prediction, multitude and complexity of concerns of local authorities, rigorous spatial planning measures, lack of funds) impeding effective risk reduction, benefitting from improved coordination.

will focus on the web-based collaborative decision support platform and its potential use in the case study sites in more detail.

Neuvel and Zlatanova (2006), for instance, believe in the clear benefits of the use of effective open standard GIS systems. Those systems constitute an important instrument to support decision makers in both risk prevention and emergency response (Greene, 2002). How actors use each other's data can be made more efficient through the implementation of a common spatial information system. Such a system can link different actors involved and may ensure improved access to and exchange of information as well as better coordination of risk prevention and emergency response activities (Neuvel and Zlatanova, 2006).

While web-based support systems facilitate the exchange of information and promote effective decision making, they are merely a support tool that could be used to assist the decision-making process. There are, however, more important root causes which need to be addressed and solved in order to allow for better coordination and cooperation in general.

4 Conclusions

This paper has discussed the roles and competences of spatial planning and emergency management in risk reduction, while highlighting furthermore the fact that risk management activities of spatial planning and emergency management are interrelated and require sufficient coordination and cooperation. In this context, the examination of four case study sites revealed several issues that would be worth addressing in the future in order to strengthen or even improve the respective regions' and/or municipalities' risk reduction efforts. It would be interesting to examine whether the findings are also valid in the case of other extreme events. This could maybe be a possible next step for future studies.

In regard to existing coordination, it can be stated that there are a few positive examples of approaches in the case study sites that show links between spatial planning and emergency preparedness to a certain extent. These can be summarized as follows:

- In the Romanian case study, processes are institutionalized and have a formal, legal basis; coordination is facilitated through the comprehensive role of the ISU which encompasses both civil protection units and firefighting units and consolidates several competencies under one roof, but missing legal enforcement sometimes reduces the success of certain measures (especially in regard to land use decisions).
- In the French case study, already existing practices that try to link emergency management services and local planning (e.g., the responsible unit for emergency management gives an opinion on the content of spatial planning documents) could benefit from a more effective information exchange.
- In the Italian and Polish case studies there is almost no coordination or exchange of information between the two actors, which is why there is considerable merit in reconsidering formal communication processes and institutionalizing such processes.

Better exchange of information can be enabled through geo-informational systems that are shared by several bodies and entities and which allow access to risk-related information at a spatial and temporal scale (see Sect. 3). In many places, computer information systems, web platforms or other databases exist that are predominantly used for emergency related activities, while spatial planners have limited access or use their own systems (e.g., GIS software). User groups could be extended to enable sharing of common, critical data and information. The need for such a system was stressed in the Romanian case study in particular, since it is regarded as a major support. Further research should, however, still focus on testing and validating such prototype tools and systems in order to address the needs of the actors involved and adapt them to different contexts.

A few more general problems were additionally identified that impede an effective implementation of risk reduction strategies and which could benefit from better coordination between the actors involved (see Fig. 8):

- Uncertainty in natural hazard prediction issues inevitable challenges to decision makers (especially in the case of the Polish case site, where uncertainty inhibits structural measures): Coordination between long-term and short-term strategies is crucial for finding the most effective solution when there is uncertainty regarding hazard and exposure location, since coordinated activities help in finding the best alternative.

– Existence of various concerns at local level: Risk mitigation is one of many concerns public authorities have to deal with. Although mayors stated that prevention of risks is considered as crucial, problems such as touristic development, outmigration, economic development and progress usually also constitute main concerns. Effective coordination would be helpful in finding the most effective solution for the several urgent objectives, including risk mitigation, and would help in legitimizing the final decision.

– Rigorous spatial planning measures stand in the way of more development-oriented strategies: Certain spatial planning measures hinder development, which is why a focus on structural measures or a response-oriented system might be favored (e.g., in the Italian case, relocation of sites to less hazardous areas may intensify existing trends of outmigration and hinder touristic development). Consideration of all existing socioeconomic and environmental objectives may imply the need for compromising competing objectives. Therefore coordination between different actors and a coordinated decision-making process are required in order to align desired goals and existing restraints.

– A lack of funds limits risk prevention policies and requires a purposeful allocation of available financial means: Coordination is crucial in this case in order to choose the most efficient option possible, while cooperation supports the sharing of limited resources.

Solutions to these problems can be found in changes of existing structures (both administrative and legal). These are essential in (a) demanding more formal coordination (b) facilitating cooperation processes and (c) promoting legal enforcement. The latter is particularly important in cases where there is a lack of trust between public authorities and citizens. For example, in the Romanian case site there is a lack of acceptance by the population of a more preventive planning approach and a common cultural norm of breaching the spatial planning law. In this context an improved raising of awareness and the provision of risk information might be a clear asset as well. Such information could enhance awareness about the actual risk situation and avoid a false sense of security. This also holds true for the information or education of planners, who are dealing with planning-related risk prevention in the first place and therefore need to be able to effectively use and understand risk information and correctly value the risk situation.

In conclusion, it can be said that many improvements are still needed in order to create a risk management process in which long-term and short-term strategies are dealt with in a more comprehensive manner and by applying a cooperative approach.

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Prototype of an Open-Source Web-GIS platform for Rapid Disaster Impact Assessment

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Prototype of an Open-Source Web-GIS platform for Rapid Disaster Impact Assessment

ABSTRACT

Impacts of natural disasters have increased worldwide in the past decades. Earthquakes are one of the disasters that have been studied for real-time analysis and crisis management. Disaster-related losses have been examined by the damage extent of the houses, infrastructures, fatalities and injuries converted to financial losses. Web-GIS technologies provide a wide range of solutions to map these damages, analyze data and publish the results on the web. Open-source tools and data have been widely used today because they stay free and facilitate access to data especially significant in developing countries. This research presents a web-GIS prototype using open-source geo-spatial technologies such as Postgis, GeoServer, Geoexplorer and OpenStreetMap (OSM) to evaluate the rapid impact of naturally produced disasters like earthquake for the estimation of total damages. For this purpose, expert knowledge such as earthquake intensities and vulnerability inputs are imported into the system. Moreover, OSM data for building information are also extracted for the analysis and the loss of the damage is then rapidly estimated and visualized in the platform. This work is part of a project for catastrophe modeling based on open-source data and software. We hope that applying open-source data, techniques and solutions will decrease the time and efforts needed for rapid disaster and catastrophe management.

Keywords: Open-source, Web-GIS, Disaster Assessment, Earthquakes

1. INTRODUCTION

Generally, disaster crisis occurs due to a complete mixture of human actions and natural hazards that directly results in vital changes during a short period of time such as death, disease, displacement including damages to infrastructure and economic loss [1]. During the past decades, hazard events, namely as earthquakes, droughts, floods, storms and fires have produced significant loss of people, properties and environment. By understanding the past hazard events and anticipating of the future events, risk of disasters can be minimized. As a result, disaster assessment should be a repetitive and remaining process [2] including underlying causes, dynamic pressures and unsafe conditions and this refers to a relationship between disasters, hazards and vulnerability [3]. Different types of assessments are based on different types of disasters and available resources. The initial assessment needs to be carried out quickly and when more information is available, this can be improved [2].

During the past years, more than 1,100 dense earthquakes have occurred, causing more than 1,500,000 casualties and collapsing buildings of more than 90% [4]. Recently, available fundamental information immediately after an earthquake is its magnitude, depth and epicenter provided by U.S. Geological Survey (USGS) data. However, estimation of damage patterns are not an easy process and it requires more detailed on-site information [5]. Besides, hazard map production is a long process and includes a lot of efforts, and therefore, hazard maps cannot be available quickly and freely. Moreover, elements at risk and vulnerability information require an extensive and a massive database. In this regards, open data such as OpenStreetMap (OSM) and USGS data, including shake maps can be integrated directly in the web-GIS application and this will reduce the time and efforts needed for the analysis. These data will be used to estimate damage and loss of the event.

Web-GIS systems support disaster assessment of an earthquake immediately and facilitate the analysis. Unlike the desktop systems, web-GIS offers user authentication, more interactive communication, fast data visualization and no specific needs in terms of data transferring. The huge amount of building data can be added to the system over the internet once an online visualization and analysis can be completed quickly afterwards; however a desktop application like Quantum GIS (QGIS) requires data transfer from one system to another. On the other hand, web-GIS applications make it convenient for users to access from any location using Internet without any extra installation. Moreover, the main reason that there is a lack of web-GIS systems for disaster management is that risk and disaster analysis except hazard analysis typically are not complicated and they can be simply calculated in any desktop GIS however web-GIS systems assist all stakeholders to communicate with each other easier and produce and maintain a huge database that can be accessed from anywhere.

Web-GIS platforms, spatial data infrastructures, geo-visualization tools and GUI (Graphical User Interface) in the field of risk management have been applied in several related works (see [5], [6], [7], [8] and [9] among others). In addition, different GIS prototype systems (academic work [5] and commercial technologies [8], [10], [9] and [11]) have been proposed. Despite the variety of systems, there is no system which challenges the application of open data like OSM in planning of rapid disaster assessment, combined with loss and risk estimation based on available information through the application of a web-GIS platform.

In this work, web-GIS technologies play a fundamental role in both rapid disaster assessment and loss estimation mainly for earthquakes. This prototype application calculates loss of damage by importing data from OSM and adding other information such as earthquake intensity, vulnerability and the value of the buildings. The application is implemented based on the open source framework, namely OpenGeo (Boundless). OpenGeo includes of Postgis, GeoServer, and Geoexplorer.

Section 2 of this paper begins with the methodology for rapid disaster assessment and conceptual framework of the system. In section 3, the background architecture and implementation are proposed, and section 4 is devoted to describing the data which were used to test the application and discuss an initial result of the development. In the last part, the conclusion of this study and future works for the catastrophe management and modeling platform are reported.

2 The Conceptual Framework

The central goal of this study is to develop an integrated system for catastrophe management in case of earthquakes, focusing on rapid disaster impact assessment. The entire system plans to improve rapid assessment when there is a lack of information and data. The functions of the system are related to four main phases:

1. Hazard
2. Elements-at-risk
3. Vulnerability
4. Loss

Intensity can be defined as a major disturbance created by a disaster. Dealing with earthquakes, general information does not give an indication about the frequency. Generally, the hazard is stated in terms of the incidence rates of intensity values [12]. Additionally, vulnerability is the characteristics in terms of the ability to resist and improve the effect of a hazard [3]. Vulnerability functions are extremely hazard-related. For example, some buildings can be very vulnerable to earthquakes and less to other hazards like floods [12]. Likewise, the loss computation for events like earthquakes is problematic because of the lacking vulnerability information of buildings (objects at risk) or hazard intensity. Due to the uncertainties of this process, loss can be known as a probability distribution in the shaking area. This methodology contains modules that permit building information such as area and prices to be added for objects at risk (i), to estimate damage and loss, primarily using the shaking intensity ($I(x_i)$) at the location of the object (i) within the database. Using a probabilistic approach, the loss of the i^{th} object for one simulation is defined by:

$$Loss_i = P(0/1)_i \times fV_i(I(x_i, RND)) \times W_i \qquad (1)$$

P(0/1): Probability of an object i to be affected (yes or no) depending on the knowledge;
$fV_i()$: Vulnerability function of the considered object depending on the intensity I;
$I(x_i, RND)$:Intensity function depending on the location x_i and a random value RND [0-1];
W_i: Value of the objects at risk (mainly buildings).

The total loss is calculated as:

$$TL = \sum Loss_i \qquad (2)$$

Figure 1 (the loss assessment flowchart) allows the end users to visualize and understand an integrated rapid disaster assessment framework.

3. Implementation

The main features of the platform (Figure 2), contain: 1. Top panel that focuses on user management and documentation. The *user management* module is used for creating, assigning and managing user accounts and permissions. 2. Main panel that is divided to Map view, Layer view, Legend and Data view in a table format. The map view panel is located in the center with tools for zooming, searching locations, styling, drawing and editing features; and Data view panel is located in the south to visualize feature information about the particular (vector) layer on the map. The main features of the *loss calculation* module are added to the top bar of Map view for sketching a new shake map layer as well as for calculating loss.

The GIS system is designed to process multiple events with different magnitudes for different epicenters. Considering the spatial data stored in the geodatabase component, the system has been structured to obtain earthquake information such as magnitude, epicenter, intensity, and vulnerability and OSM data. Likely, it is possible to have a preliminary assessment of the damage. For this reason, the vulnerability data has been imported in terms of probabilistic percentage or damage function for different buildings.

3.1 Architecture

The geo-spatial analysis and visualization plays a fundamental role in disaster and post-event management. For this purpose, the geospatial technologies have been combined into the architecture as a geo-visualization interface. The information and maps are stored and managed within a spatial database, therefore, it is possible to visualize and request data through a map viewer using Open Geospatial Consortium (OGC) web services and

GeoServer. The designed global architect (Figure 3) is implemented by using free open source software (FOSS) as a client-server architecture (Three-tier architecture). The platform consists of the three main layers including client, server and database layer. Followings are the main components:

1. Geo-database (PostgreSQL and Postgis)
2. Geographic user interface including map interface (ExtJS, OpenLayers and Geoexplorer)
3. Open-source server for sharing/publishing of geo-spatial data (GeoServer)
4. User management with SQL [13]
5. Data analysis and processing with PHP

The user sends a login request to the Apache web server using the user interface of the web browser. The request passes through the PHP to SQL server and login is succeeded upon validation. Afterwards, the requests to the GeoServer are handled (e.g. in case of layer query, visualization of different layers, etc.). The data are analyzed and processed on the server side and sent back to the client side through HTML pages. Lastly, the results are displayed in the forms of maps and tables using OpenLayers and OGC web services in Geoexplorer that is the main view of the platform.

3.2 Procedures

The disaster assessment method includes four main phases (Table 1). Once the user enters into the system, the first phase is to provide the information about earthquake, importantly epicenter, depth and magnitude. Then, the expert can update the intensity of each earthquake by uploading a shape (.SHP) file or drawing on the map canvas in the platform that can be added directly to database for further analysis(Phase 1 in table 1). Next, OSM data are uploaded to the system as a SHP file layer. This data are generated in Quantum GIS (QGIS) and imported into the system. OSM data are not a complete set of building data, therefore, Postgis can help to complete all buildings to overlay to the desired area and form to polygons by using different functions such as ST_Overlaps, ST_MakePolygon, ST_Union, etc (Phase 2 in table 1).

Before moving into the calculation phase, vulnerability information is required to be linked to the building data. These data are derived from a table in CSV file mentioning the type of the building and damage probability. Similarly, it can be defined by the probability of the damage area (Phase 3 in table 1). The value of each building is being calculated and added to the system for the final phase (area is multiplied to price per square meter). Consequently, the user can select an earthquake layer, a building layer and vulnerability type after naming the calculation process (Phase 4 in table 1). As a result, the loss is computed in overall as well as for every building. Besides, the computed loss can be visualized as a map layer in the system. These procedures are the basic steps in the existing system, however, it is planned to enhance more detailed data and information on how the system can simulate and estimate intensity and vulnerability information for an improved analysis.

3.3 Data Model and GeoServer

Geodatabase is designed to integrate and incorporate geo-spatial data delivered as an input to the system, including the data linked to earthquake (e.g., magnitude, epicenter and intensity) and specific data connected to the area of interest (such as building information, OSM data and vulnerability tables). The FOSS technologies chosen to develop this component were PostgreSQL and Postgis.

The GeoServer component, in connection with Geodatabase (Postgis), is provided to process spatial analysis and visualization. This module delivers a complete and up-to-date description of the different layers including earthquake intensity layer, building layer and maps of expected financial loss in that area. Consequently, the results are stored and visualized through GeoServer and OGC services such as Web Map Service (WMS) and Web Feature Service (WFS).

4. Study Data and Results

As an example, the 2015 Nepal earthquake, which is the largest earthquake to occur during the last 50 years in this country, is applied to this study [14]. In April 2015, a massive earthquake of 7.8 M occurred in Nepal as a result of faulting between the India plate and Eurasia plate. At least 8,702 people were killed, 22,493 injured [15], 500,717 buildings were destroyed and 269,190 damaged in this earthquake and during the M 7.3 aftershock on May 12, 2016 [16]. Nepal is one of the countries in the world with the lowest GDPs and the main source of economy is agriculture and tourism. Reports indicate that the losses caused by this recent earthquake could considerably set back the economy of Nepal [17]. Figure 4 displays the location of the recent earthquake and the aftershocks in Nepal [18]. The shake map of data for earthquake of 7.8 M was imported into the system by drawing the area in a polygon format. These data can also be downloaded from USGS website as different formats such as vector or raster [19]. Figure 5 indicates the shaking intensity caused by the 7.8 M Nepal earthquake [17]. And figure 6 demonstrates the buildings that are overlaid with the central administrative unit. An approximated shake intensity map was sketched into the system by an expert and the building layer of the country was uploaded as a SHP file to the system [20]. The building information is a huge file, hence we decided to limit the study to a specific administrative unit of Nepal that was most affected by the earthquake called as Central unit. The map of administrative units for Nepal was downloaded as a vector layer [21].

After adding all the layer maps, the update of the building information needed to be updated. The price per square meter in [year] in Nepal was estimated between 350 to 615 US dollars [22]. By having the area of each building in the database, the price of each house could be roughly estimated. Finally, the loss of each building and overall loss for the whole region were calculated. Table 2 indicates the total number of houses that were exposed in the event as well as the overall loss. This is the preliminary result of the system based on open data and expert knowledge. Therefore, authors do not recommend others to use this result. According to the government, the earthquake destroyed 160,786 houses and more than 3 million houses were damaged [23]. The result of this study shows that 3.1 million houses were exposed to the earthquake and 124,000 of the houses were exposed to the higher risk or in the absence of other information, the maximum loss shows that 124 000 buildings were destroyed.

5. Conclusion

This work presented the prototype development of an open-source web-GIS platform, which aims to help various experts dealing with rapid disaster impact assessment in the case of natural hazards especially earthquakes. Even though different tools were developed in this field, their practice is restricted due to the complex design of the systems, flexibility and usability. Unlike existing complex systems, the conceptual framework is based on a simple and generic approach, allowing the experts to interactively work through a web-GIS mapping interface and facilitating the analysis by using open-source data such as OpenStreetMap and USGS data. Due to its flexible and generic structure, it can be applicable not only in a certain study area (we proposed recent earthquake in Nepal) but also in any other regions by just uploading data through the server and adding expert knowledge.

There are many challenges in developing a web-GIS system and the most important ones are lack of information and data. In order to utilize GIS and other geo-Spatial technologies, a variety of spatial data are required. The elements-at-risk information is critical for disaster impact assessment and in this study, OSM data are used. Though these data are not a complete set, they provide a basic set of information and then more information can be added based on expert and local knowledge of the study area. Besides, the estimation of loss by using open data (e.g., OSM, USGS, Numbeo and GADM database) do not involve extensive collection and can be performed rapidly with a modest budget. The more accurate loss estimation requires an extensive inventory at additional cost to the end user and can be employed in future works. In addition, stories of the house, lifelines like water supply and transportations were not considered in this study and will be applied in further stages of this system. This paper presented the initial implementation and the background framework of a web-GIS system for rapid impact assessment and demonstrated a preliminary result of the case study area in Central Nepal for the recent earthquake on April 2015 while several aspects of the platform could be improved better for applying in real practice to fulfill the lack of information, the user requirements and skilled knowledge of the earthquake experts.

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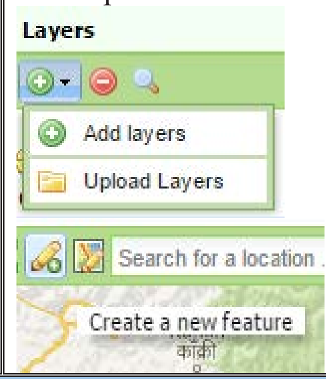
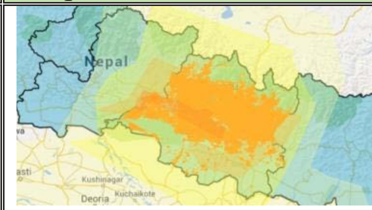
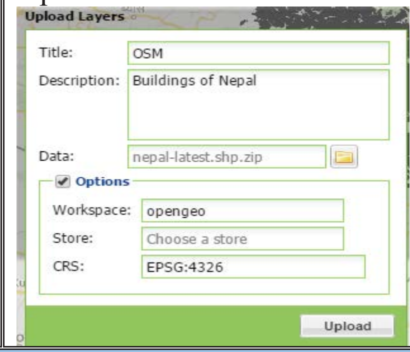
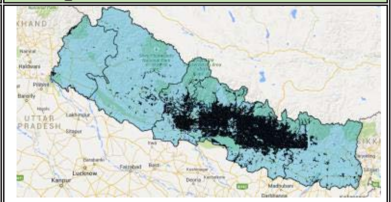
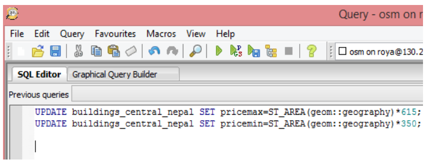
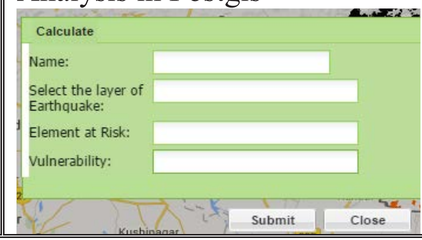
Table of Figures:

Table 1: The main steps of the loss calculation in the platform

<table>
<tr><td colspan="3">Phase 1: Earthquake data</td></tr>
<tr><td>Input Data</td><td>Tools</td><td>Output</td></tr>
<tr><td>1. Shake Map
2. Earthquake information</td><td>Upload SHP file or sketch

</td><td>

Earthquake map</td></tr>
<tr><td colspan="3">Phase 2: Building data</td></tr>
<tr><td>Input Data</td><td>Tools</td><td>Output</td></tr>
<tr><td>1. OSM buildings
2. Administrative Units</td><td>Upload SHP file

</td><td>
Buildings map</td></tr>
<tr><td colspan="3">Phase 3: Vulnerability data</td></tr>
<tr><td>Input Data</td><td>Tools</td><td>Output</td></tr>
<tr><td>1. Value of buildings
2. Damage probability in the affected area</td><td>CSV file or table


Analysis in Postgis</td><td>
<table>
<tr><th>gid</th><th>type</th><th>damage</th><th>pricemin</th><th>pricemax</th></tr>
<tr><td>161860</td><td></td><td>60</td><td>13100.2296213...</td><td>22758.8734946...</td></tr>
<tr><td>161861</td><td></td><td>60</td><td>15914.6448023...</td><td>27648.3235972...</td></tr>
<tr><td>161862</td><td></td><td>60</td><td>15605.2189669...</td><td>27110.7617645...</td></tr>
<tr><td>161863</td><td></td><td>60</td><td>7612.35806502...</td><td>13224.8593502...</td></tr>
<tr><td>161864</td><td></td><td>60</td><td>20762.8670500...</td><td>36071.0825869...</td></tr>
</table>
Vulnerability table</td></tr>
<tr><td colspan="3">Phase 4: Loss estimation</td></tr>
<tr><td>Input Data</td><td>Tools</td><td>Output</td></tr>
<tr><td>1. Earthquake layer
2. Buildings layer
3. Vulnerability</td><td>Analysis in Postgis

</td><td>

Loss map</td></tr>
</table>

Table 2: Overall Loss for different intensity layers of the shake map

Intensity Zones	Number of Houses exposed in the area	Loss Price: Minimum cost per square meter 350 $	Loss Price: Maximum cost per square meter 615 $
VIII	124 000	2.1	3.6
VII	957 000	12.2	21.3
V and VI	2 000 000	13.3	23.3
Overall	3 100 000	27.6 Billions	48.2 Billions

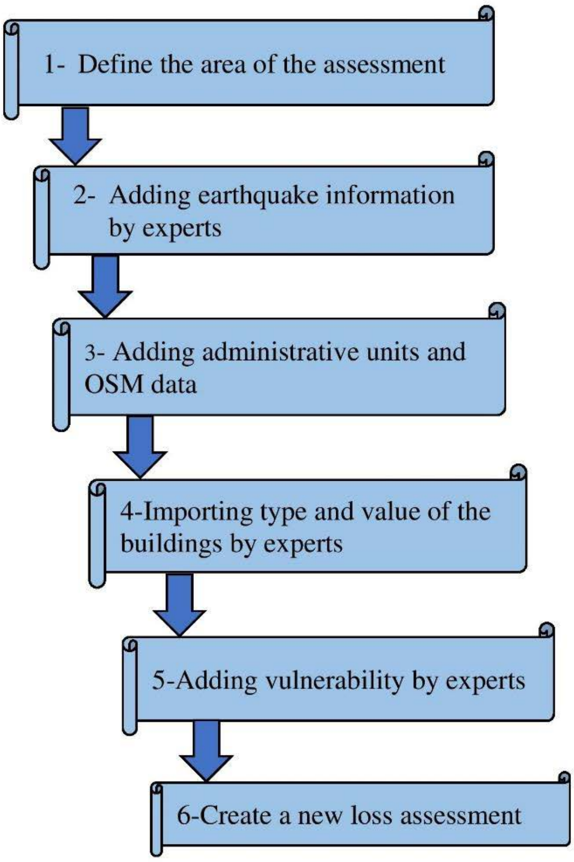


Figure 1 The loss assessment process

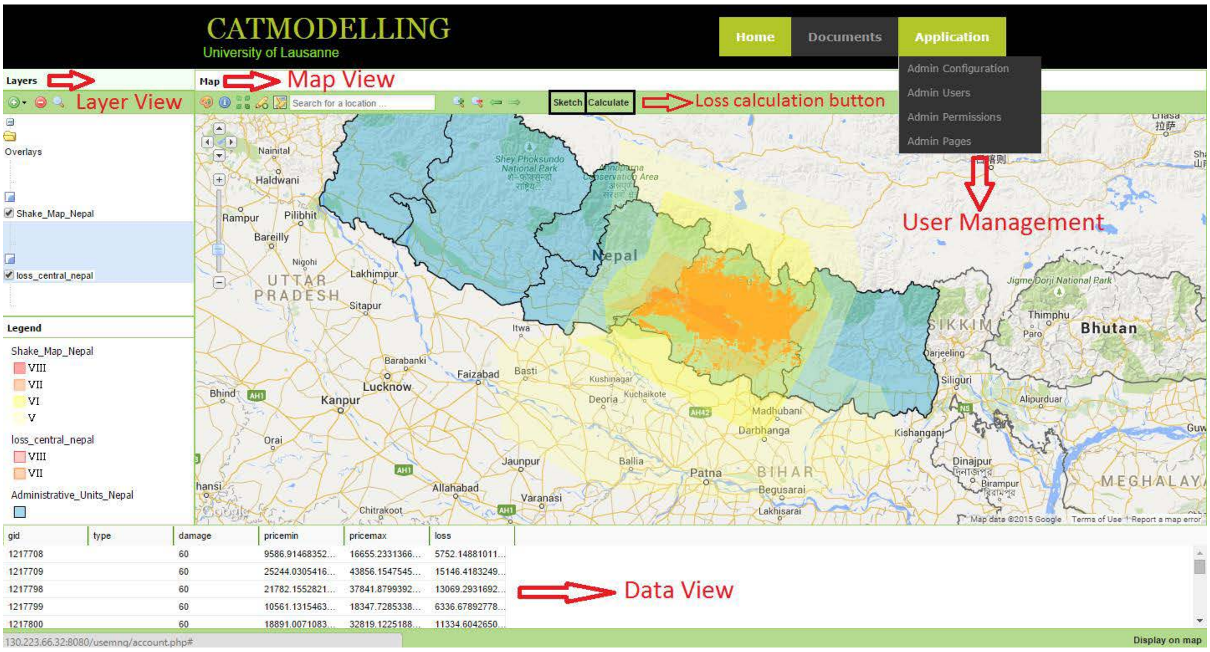


Figure 2 The main interface of the web platform with admin privilege

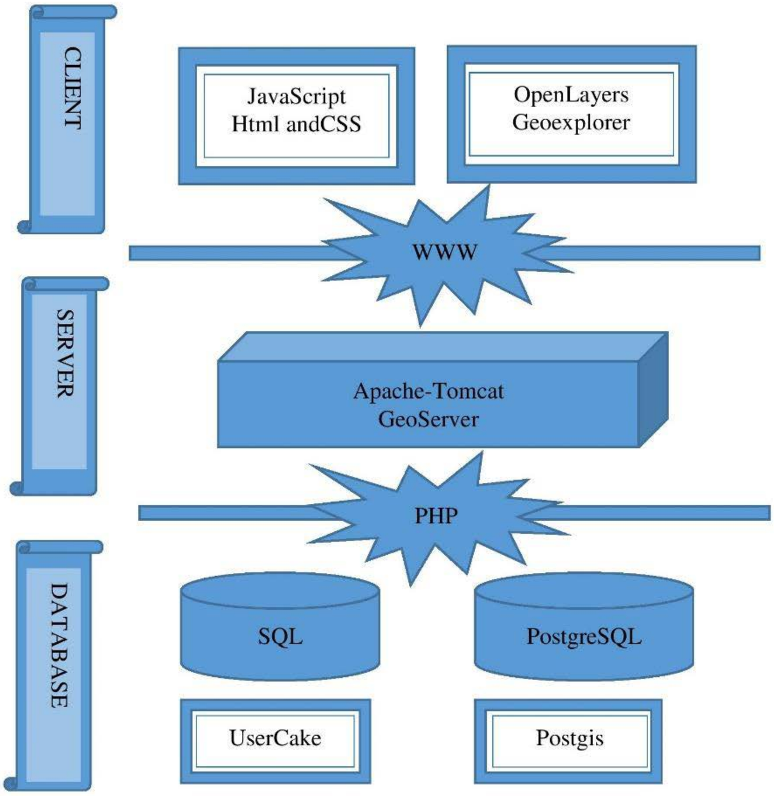


Figure 3 Architecture of the Web-GIS platform

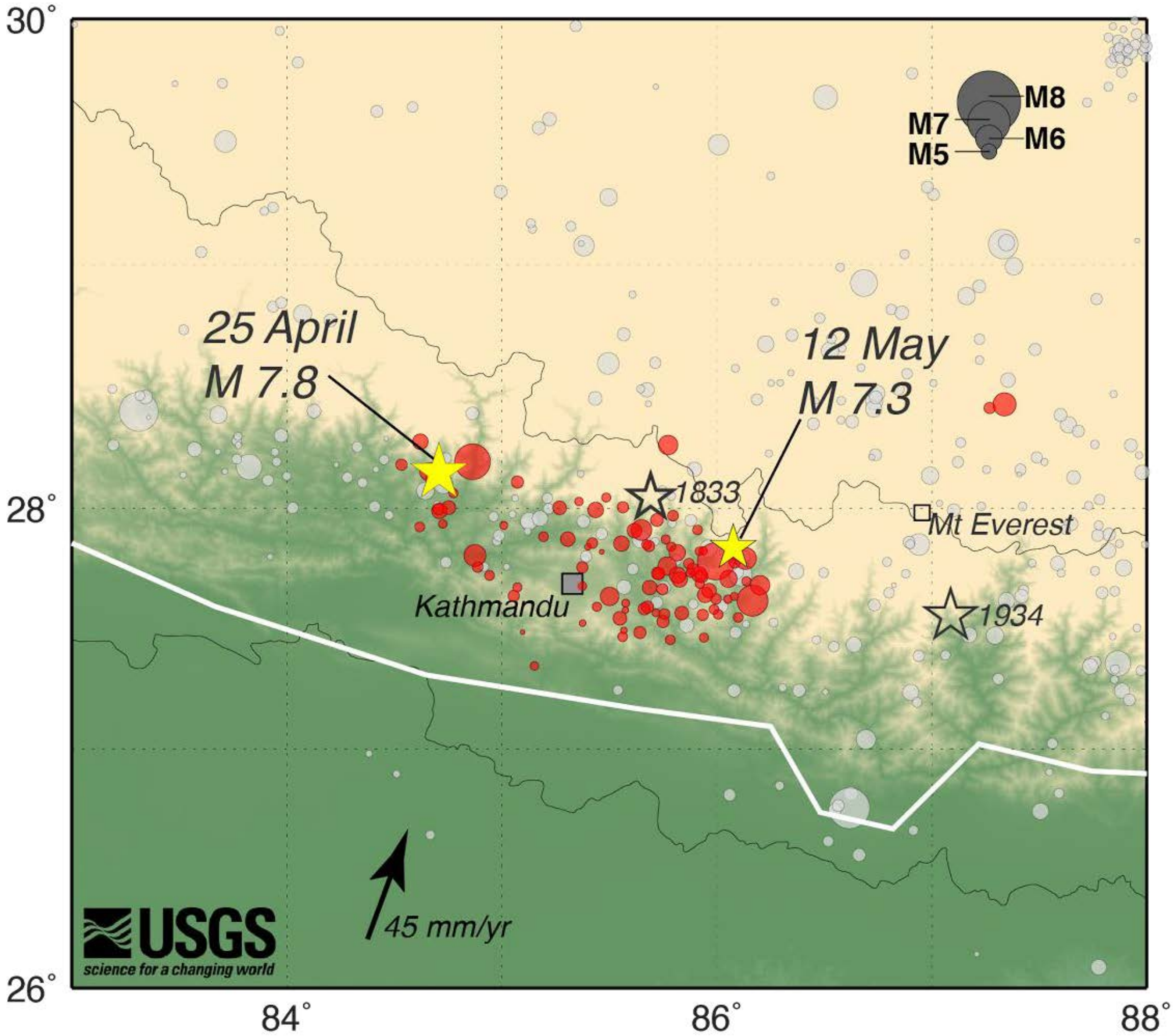


Figure 4 Magnitude 7.8 Earthquake in Nepal & Aftershocks (Source: [17])

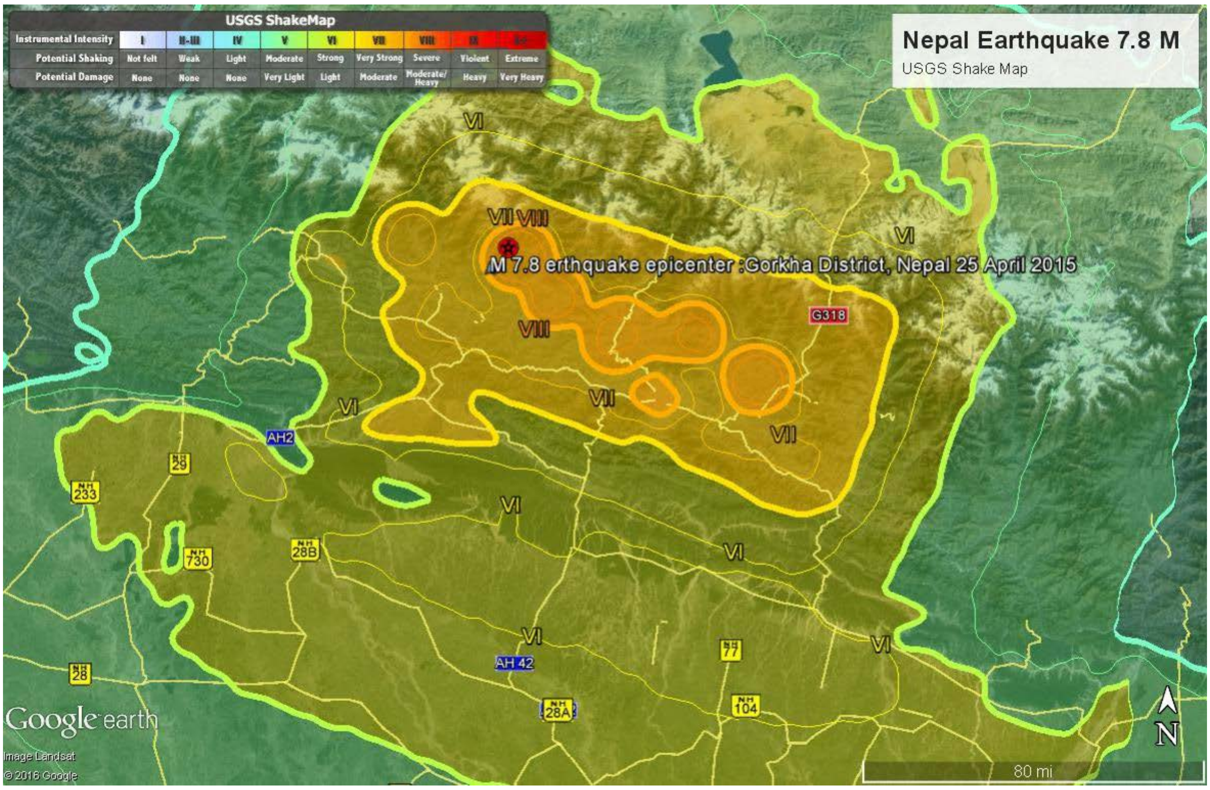


Figure 5 Shaking intensity map of Earthquake 7.8 M (Source of Data: [17])

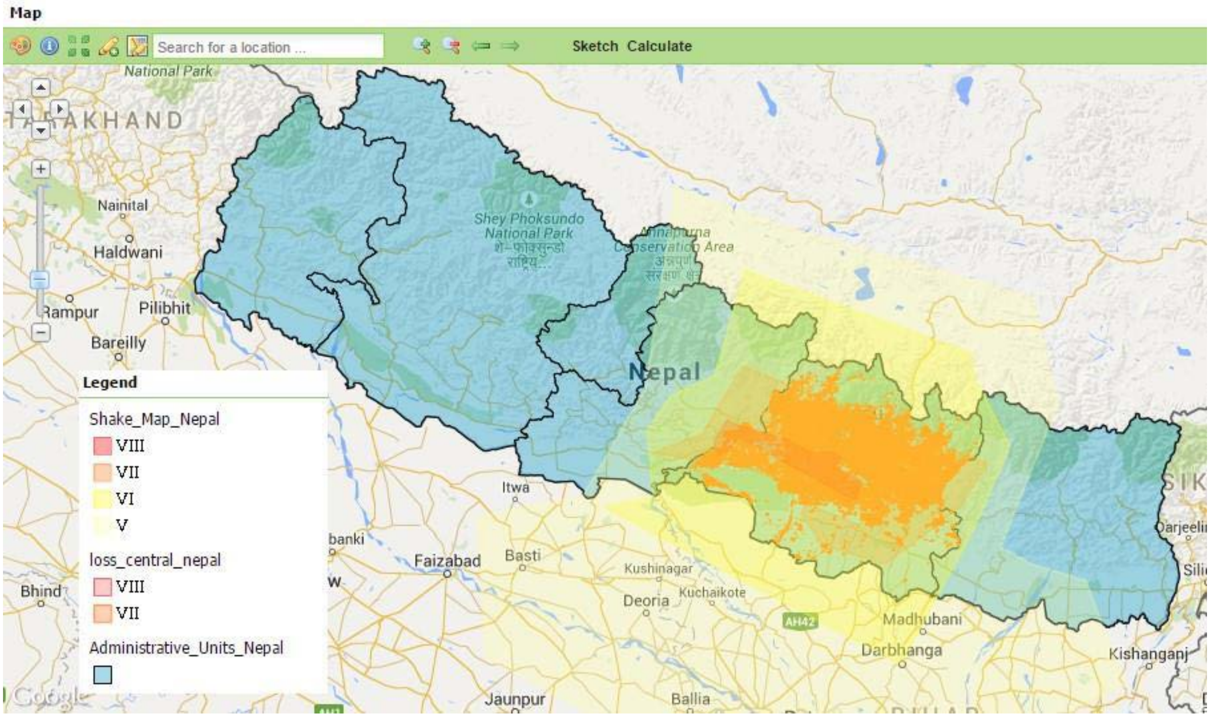


Figure 6 Overlay of buildings with central administrative unit in the map view of the system

A Web-GIS decision support framework for assisting technicians in evaluating check dams inspection reports

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Abstract

This paper presents a decision support framework to assist technicians, responsible for the inspection and maintenance of protection works, in a first-level inspection to evaluate the functional conditions of check dams. We followed a user-centred design approach by engaging technicians in the Fella basin (north-eastern Italian Alps) since early design stages. First-level inspections can be carried out by regular technicians or skilled volunteers to identify possible degradations in the status of the structure itself or surrounding area. Technicians-in-charge evaluate the functional status of inspected check dams based on available reports. Therefore, the conceptual design of our decision support framework incorporates four modules for managing the inspection reports: 1) Registered users, 2) Inspection planning, 3) Available reports, 4) Evaluation of reports. The framework was developed on a web-GIS platform using Opengeo Suite. In this paper, we show the full implementation of the evaluation module for the evaluation of check dam inspection reports. Feedback from potential users was collected during a testing workshop organized in the study area. Participants perceived the evaluation module as useful and innovative and highlighted aspects to refine its capabilities. The conceptual design of the decision support framework can be further adapted to evaluate inspections reports of other type of hydraulic structures.

Keywords: decision support, web-GIS application, user-centred design, functional status, hydraulic structures

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1. Introduction

Decisions about inspection and maintenance planning of mitigation structures against debris flows such as check dams are usually under the responsibility of specialized technical agencies. Thereby, Technicians-in-charge decide about the functional status of such structures based on tier-level inspections (Rudolf-Miklau & Suda, 2013). Tier-level inspections start with a prescreening level, hereafter referred as first-level inspections. Technicians-in-charge generally assign inspectors to fill in reports and take pictures as complementary data to the inspection. More frequent or larger coverage of inspection campaigns can be possible by involving skilled volunteers in support of regular inspector technicians. However, using visual inspections requires systematic evaluation procedures to support maintenance decisions about the inspected structures (Dirksen et al., 2013). Moreover, the use of such inspections for proactive inspection and maintenance strategies require efforts for coordination and collaboration between the different management organizations (Prenger-Berninghoff et al., 2014; Watson, 2004) that may benefit from the use of the collected data.

The use of web Geographic Information Systems (GISs) and decision support systems (DSSs) has become increasingly prevalent for the management of environmental resources and related hydraulic structures (Matthies et al., 2007). The increasing availability of open-source data, web-based applications and geospatial technologies (e.g. Botts et al., 2008) has simplified the exchange, processing and visualization of geospatial information that is relevant for decision-making (e.g. Chang & Park, 2004; Frigerio et al., 2014; Gkatzoflias et al., 2013; Turconi et al., 2014). One of the advantages of web-based applications is it makes information interoperable between management organizations (e.g. Awad et al., 2009), which has increased the preference of web-based over desktop-based applications (e.g. Nogueras-Iso et al., 2005). Web applications further facilitate the use of a variety of data sources and technologies following standard formats for data collection and processing (Horsburgh et al., 2011). Moreover, a growing community of open-source research has facilitated the application of web-GIS technologies into the development of decision support frameworks, for example in the field of natural hazards and water management (Aye et al., 2015b, 2016; Delipetrev et al., 2014; Stefanovic et al., 2015).

Despite potential advantages of DSSs and web-GIS applications, differences in expectations and expertise level of the variety of intended users have created a gap between design and use (Bhargava et al., 2007). Laitenberger & Dreyer (1998) stated that users tend to use a system according to the extent they believe it is useful to perform their activities and the system is appropriate for the context of use. Díez & McIntosh (2009) suggest that factors influencing the use and usefulness of DSSs include users participation and perception of the system, user computer experience, quality in use, top management support and training or support to adopt the system.

McIntosh et al. (2011) summarise the challenges for developing DSSs into engagement, adoption, cost and technology, testing and validation. Thereby, engagement challenges require having strategies according to available resources to work collaboratively with users since early stages of the development. Adoption challenges require starting with simple implementations, developing tools incrementally and having a strategy to facilitate the future adoption of the designed application. Cost and technology challenges require re-using software components to overcome up-front development and ensuring funding for the long-term maintenance. Finally, testing and validation challenges are not only about using the designed application but also about analysing the support capabilities, for example in decision-making.

To address design challenges, user-centered design approaches (UCD) are being widely considered in software engineering (McIntosh et al., 2011; Wallach & Scholz, 2012). UCD originates from the usability aspects of designing software user interfaces (Gould & Lewis, 1985). Therefore, ISO/IEC. 9241-14 (1998) standards define usability by the extent to which a designed product can be used to achieve specified goals in a context of use (effectiveness), optimizing the resources expended (effectivity) and generating a positive attitude towards the use of the product (satisfaction). An extended view of usability can be the quality in use of a designed product for its intended purpose (Bevan, 1999). In so doing, UCD aims at better understanding usefulness, usability and appropriateness requirements by engaging users since early design stages (van Velsen et al., 2008). In this paper, we present a prototype of a decision support framework for assisting technicians in evaluating check dam inspection reports. We evaluate the usefulness of such framework following a UCD approach as implemented in a pilot study area.

2. User requirements for the evaluation of first-level inspections

The Fella basin, located in the northeastern Italian Alps of Friuli Venezia Giulia Region (FVG), was chosen as pilot study area due to the existing collaborations between potential users and scientists. After severe floods and landslides occurred in 2003, Civil Protection of FVG implemented several mitigation measures such as check dams as an immediate reaction to the disaster (Prenger-Berninghoff et al., 2014). In addition, for planned inspection and proactive maintenance of implemented works, Civil Protection suggested skilled volunteers in support of technicians to carry out first-level inspections in the Fella basin. Consequently, technicians-in-charge required systematic inspection procedures to use volunteers reports for decision making on check dams maintenance.

Preliminary research included a data-collection exercise with technicians and volunteers to better understand the context of use and issues about the quality of first-level inspections Cortes Arevalo et al. (2014). We focused on the inspection of check dams due to its relevance, number and often remote location in the mountain basin of the pilot study area. Potential decision-makers are technicians who are in-charge of planning inspection and maintenance of mitigation works. In our study, skilled volunteers are mainly Civil Protection volunteers from the municipalities of the pilot study area. Such volunteers traditionally received the training on formative, informative and safety procedures Protezione Civille della Regione FVG (2009) and were further interested in supporting inspection campaigns.

Technicians-in-charge further required the decision support for getting an indication from collected reports about the functional level of inspected structures. Therefore, a decision support framework for systematically evaluating reports became an important prerequisite for increasing frequency and amount of inspections with the support of skilled volunteers. **Figure 1** and **Table 1** illustrate the modules we proposed for such framework: 1) Registered users, 2) Inspection planning, 3) Available reports, 4) Evaluation of reports. The workflow-input information to the framework are inspection reports that are collected either by skilled volunteers or regular technicians to be systematically evaluated by technicians-in-charge. The workflow-outputs are functional levels (e.g. best, medium, worst), each corresponding to a course of action.

Table 1: Modules comprising the decision support framework

Module	Capabilities	Implementation stage
Registered Users	• Login of technicians-in-charge. • Explore the database of available inspectors among technicians and skilled volunteers.	Mock-up interface
Inspection planning	• Create and assign an inspection plan to an inspector. • Select maximum number of structures to inspect (e.g. 10) according to available structures and technician-in-charge. • Define a period to carry out the inspection plan.	Mock-up interface
Available Reports	• Submit first-level inspection reports. • Visualize available reports of structures inspected for each section of the form: i) Inspector ii) Structure to inspect iii) Inspection conditions iv) Functional conditions A) Damage level, B) Obstruction level and C) Erosion level v) Human infrastructure vi) Synthesis advice	Mock-up interface
Evaluation of reports	• Systematic aggregation of first-level inspection reports into indices representing the structure status. • Categorizing the indices into functional levels according to rules defined by technicians.	Core functionalities

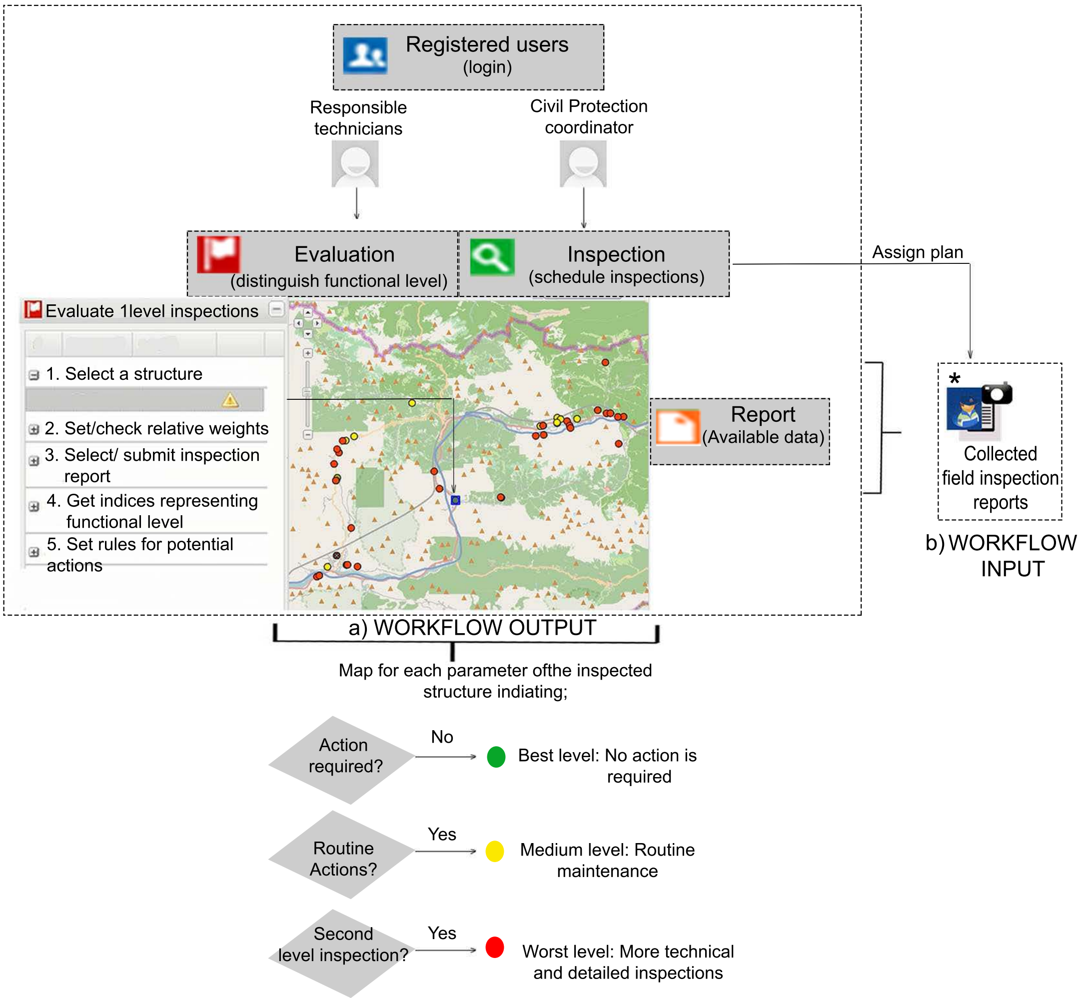

Figure 1: Workflow describing the input and output information for the decision support framework. *Volunteer icon (Civil Protection of FVG region, Italy)

3. Conceptual design and system architecture of the Web-GIS platform

The conceptual design tracked a modular architecture consisting of four modules (**Figure 1**), each of them providing a group of capabilities for the framework. We focused on the evaluation module as a proof-of-concept for using inspection reports in decision-making. Registered users, inspection planning and available
85 reports were implemented as a mock up interface within the web-GIS platform for illustrating the conceptual design.

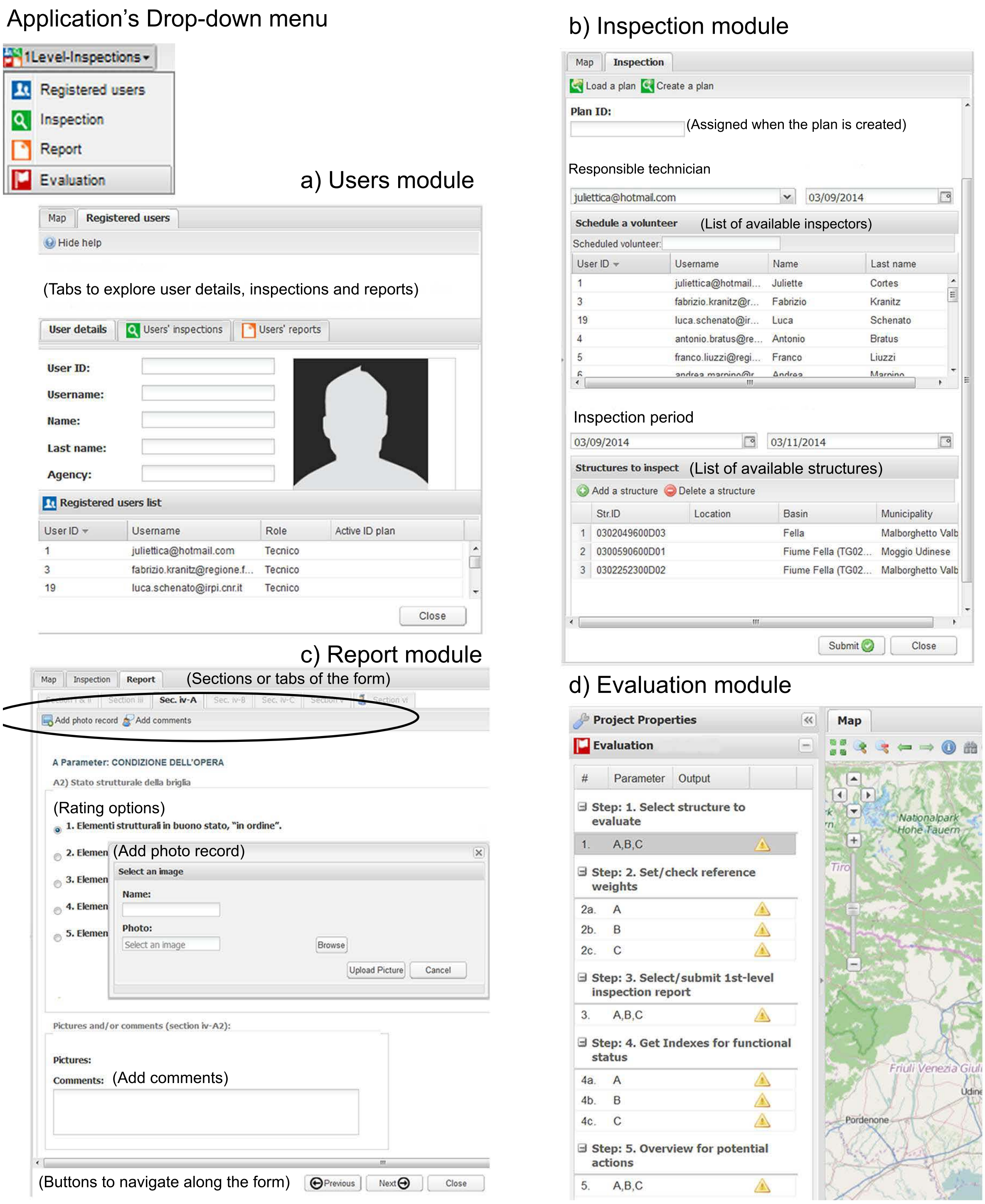

Figure 2: Conceptual design for a) registered users, b) inspection planning, c) available reports and d) Evaluation of reports

3.1. Conceptual design

Table 1 summarizes the modules comprising the conceptual design. The first module (Registered users) accounts for capabilities to explore user details, inspections and reports (**Figure 2a**). The second module (inspection planning) considers capabilities for creating inspection plans (**Figure 2b**). The third module (available reports) accounts for capabilities to submit or load reports in the database (**Figure 2c**). The report module comprises a sub-tab for each section in the form. It accounts for capabilities to report using rating options, add comments and photo records. The last module (evaluation of reports) focuses on the responses of the inspection form to get an indication of the functional status, which are represented by the three parameters referred in **Table 1**. Responses of other sections are only available as background information for the inspection. The module implements a step-wise approach (**Figure 2d**) to aggregate the reports of inspected structures into indices that are further categorized as functional levels, each corresponding to a course of action. Component sections and figures in the inspection form were adapted from existing procedures in FVG (Servizio Forestale FVG, 2002) and neighbouring regions (Provincia Autonoma di Bolzano, 2006).

3.2. System architecture of the Web-GIS platform

The platform uses a typical multi-tier client-server architecture of web-based applications (**Figure 3**). State of the art applications integrating decision support and geospatial capabilities have system architecture that often comprises a back-end tier including the relational database, a middle tier for managing geospatial data and a front-end tier for managing specialized services and other software components of the user interface (Aye et al., 2015a; Delipetrev et al., 2014). In the client or front-end-side, visualization functions and requests to the server side are provided through the user interface (browser). According to Zhao et al. (2012), basic data processing can be performed in the client-side to minimize requests to the server and improve user interactions. Instead, complex processing and submission/retrieval should be carried out in the server-side. In this work, data processing (i.e. evaluation of collected reports) is mainly in the client-side as proof of concept of the core-capabilities for decision support.

The implementation is based on the Boundless (OpenGeo Suite) framework. **Figure 3** illustrates the system architecture that is running on Debian as operating system and Tomcat 7 as web-server. Data storage is done through the database management system (DBMS) and application server. On the server-side, OpenGeo Suite allows interoperability between Tomcat server and the DBMS. The DBMS comprises the relational tables to store first-level inspection reports and GIS data. **Figure A.1** in **Appendix A** illustrates the conceptual design of the data model. A Geoserver instance is deployed in the server as part of middle tier to connect the geo-spatial components of the database with the web-GIS user interface. In the client-side, we use the software development kit (SDK and GXP template) of OpenGeo Suite, which also includes plug-ins and mapping tools to explore the geospatial data. SDK deploys the mapping application that can be extended and customized from the GXP template using JavaScript libraries such as ExtJs, GeoExt and

OpenLayers. The possibility to develop such customized plugins facilitates the re-use of available mapping tools and functionalities (Aye et al., 2015b).

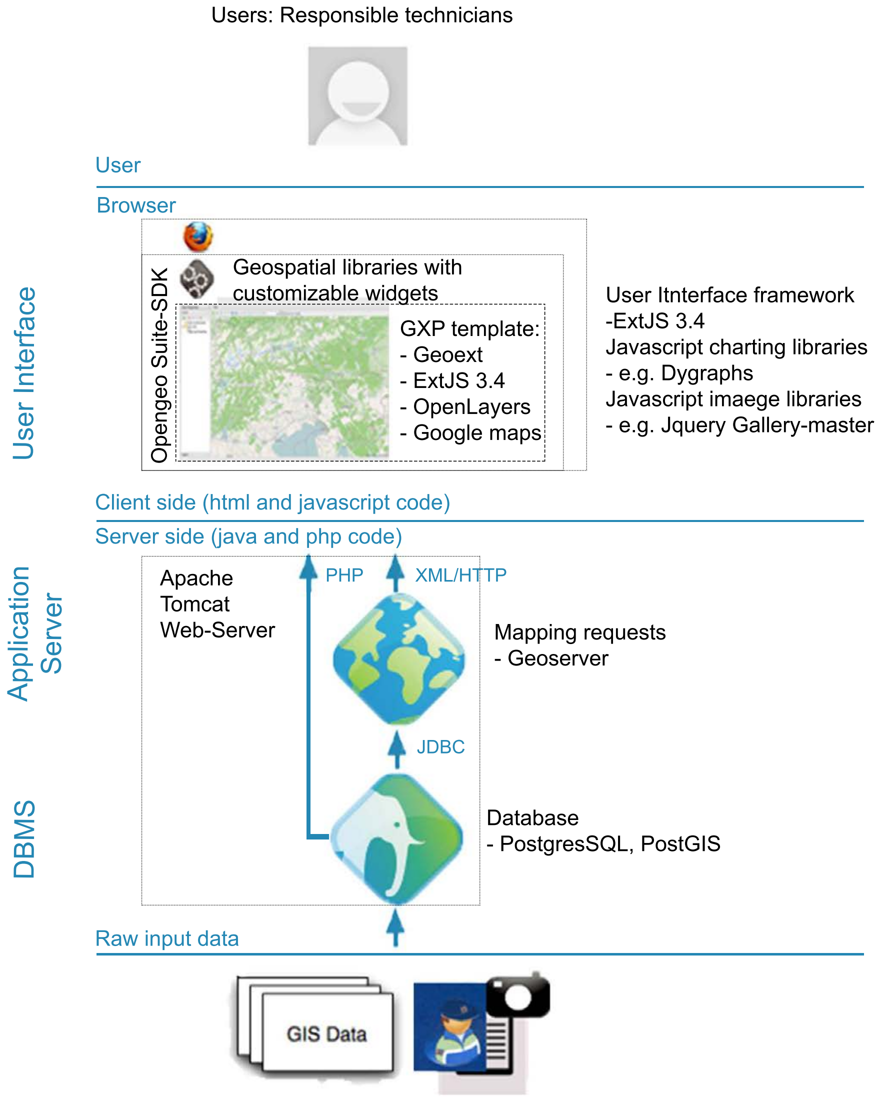

Figure 3: System architecture of the web-GIS platform based on Opengeo Suite. *Volunteer icon (Civil Protection of FVG region, Italy)

The user interface uses JavaScript libraries and open source projects for creating charts and data visualizations (e.g. Dygraphs) as well as providing photo gallery capabilities (e.g. JQuery Gallery master). ExtJs 3.4 provided options to create and update temporary stores in the client-side (browser). The logic behind the user interface includes the model and knowledge base implementation (**Figure 3**), which at this development stage demonstrates the evaluation module. Although a strict Model-View-Controller (MVC) architecture is not fully supported in ExtJS 3.4, the scripts coded follows the MVC pattern to support its migration and to facilitate further development stages. **Figure 4** presents the components of the MVC paradigm: Model (data stores), View (outputs) and Controllers (Functions) which is being increasingly supported in web technologies (Mikkonen & Taivalsaari, 2007).

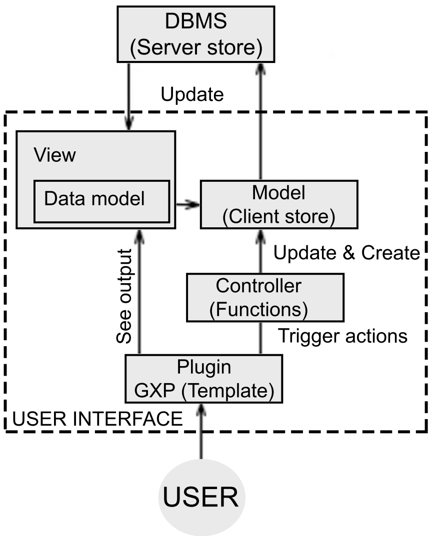

Figure 4: MVC components and illustration of the local client and server stores (adapted from Sencha, 2014)

After login to the platform, technicians-in-charge (users) can access the modules (**Figure 5**) through a plug-in the top toolbar of the view. The four modules of the framework are available in a drop down menu and are deployed in the central tab-panel next to the map tab. The right tab-panel deployed the help content and subtabs of the modules sharing the map-view for mapping interaction. Left tab-panel provided an overview of the users selections on each module. User interaction triggers actions and/or displays outputs to follow the steps of the evaluation module.

4. Conceptual design and system architecture of the Web-GIS platform

The decision support framework starts when registered users such as technicians of Civil Protection or technicians-in-charge for the management of mitigation works login to access the web-GIS platform. Registered users should assign a functional level to available inspection reports that are collected either in a paper-based form (as carried out in this study) or through a complementary mobile application to be designed as future research. The evaluation module comprises a method to aggregate available inspection reports into indices that are further categorized in a functional level based on rules defined by technicians.

To that end, the evaluation module includes five steps that technicians should go through once an inspection report has been filled in for a given check dam. The inspection form is based on linguistic rating scales mainly to report about three parameters indicating the functional status. Those parameters are: A) Damage level, B) Obstruction level and C) Erosion level. Each parameter is inspected by means of four

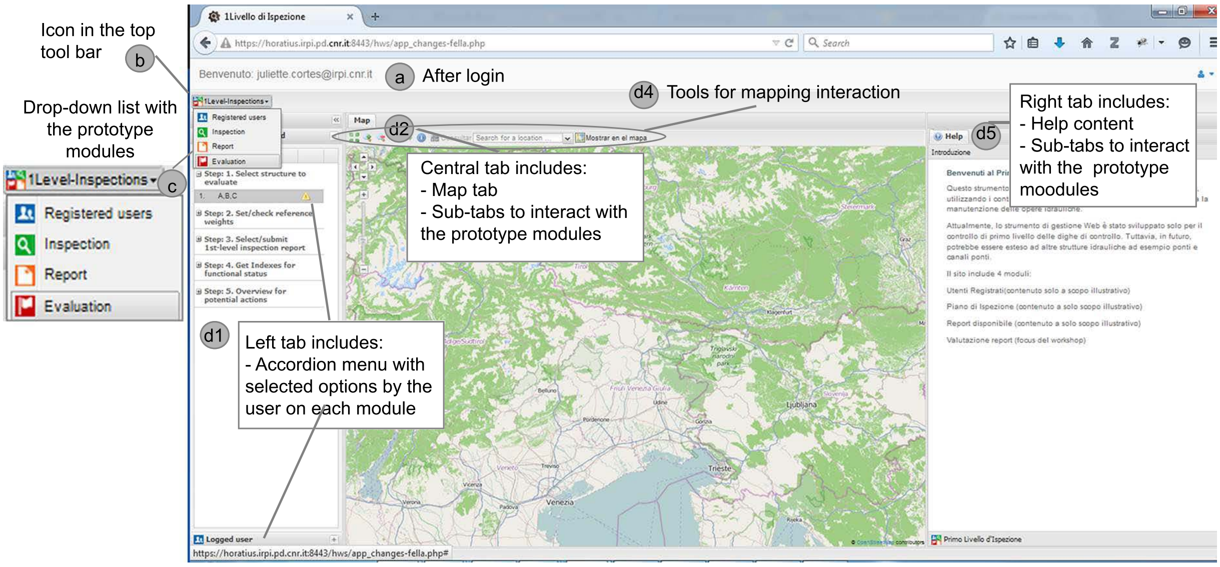

Figure 5: Web-GIS platform interface indicating a) Registered user; b) Decision support prototype; c) Drop down list to access the modules; d) Content in the left, central and right tab-panel. The central tab-panel includes the tools for mapping interaction

sub-questions, which were agreed with technicians-in-charge (Cortes Arevalo et al., 2014). When reported ratings become available, the evaluation module systematically aggregates them into indices at parameter level by means of multi-criteria Technique for Order of Preference by Similarity to Ideal Solutions (TOPSIS) method with fuzzy inputs (Chen & Hwang, 1992).

In addition, the module provides options to allow users formulating rules for categorizing the aggregated indices in one of the three levels, each corresponding to a course of action. The highest functional level (green) corresponds to no required actions. The medium level (yellow) denotes the need for a routine maintenance or additional information to validate functional level. Finally, the lowest level (red) indicates that a second level inspection or a more detailed engineering procedure is required before making the decision about the maintenance. In Cortes Arevalo et al. (2016) further details about the methodology behind this module are provided. Screenshots of an example report, hereafter listed, illustrates all steps through the platform interaction.

4.1. Select a structure to evaluate (check dam)

Figure 6 illustrates the database of structures (spatial layers) and available information about their properties, dimensions and photo record as presented in the right tab-panel. When available, inspectors can also visualize the images from photo records or previous inspections, which can be filtered according to the inspection ID (i.e. a unique identifier of the inspection report). The functional level is the actual field to be updated after getting the output of the evaluation module. For illustration purposes, **Figure 6**

also highlights the location of the pilot study area with the location of check dams inspected during the workshop.

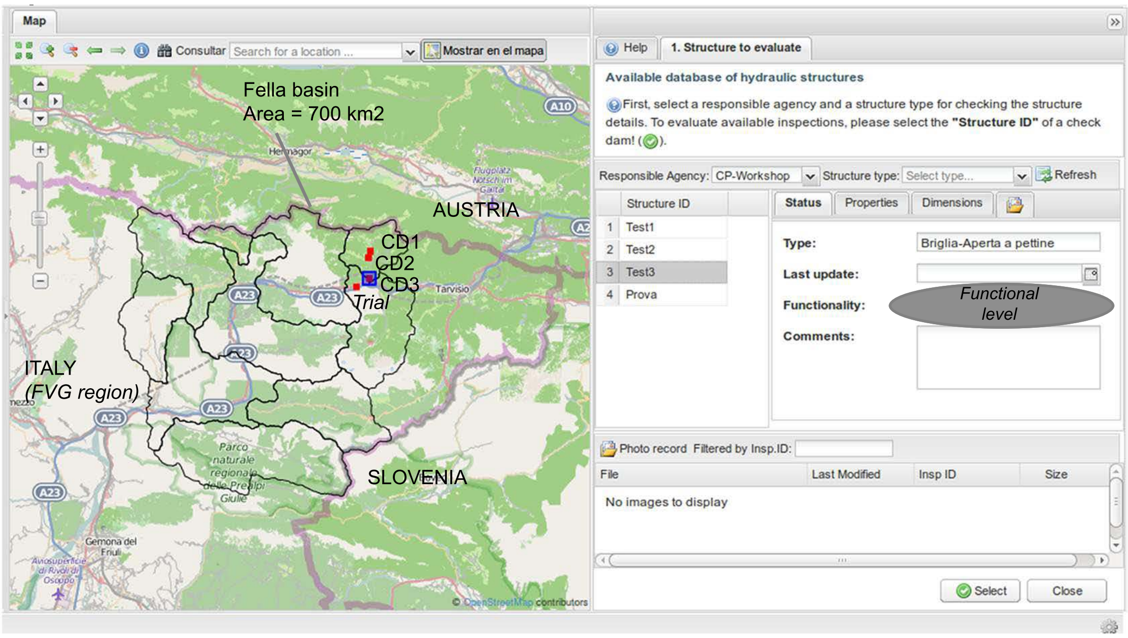

Figure 6: a) Exploring available databases of structures and b) Selecting one of the structures (CD) inspected in the workshop to continue with next steps. The layer of the study area location was added to the figure for illustration purposes

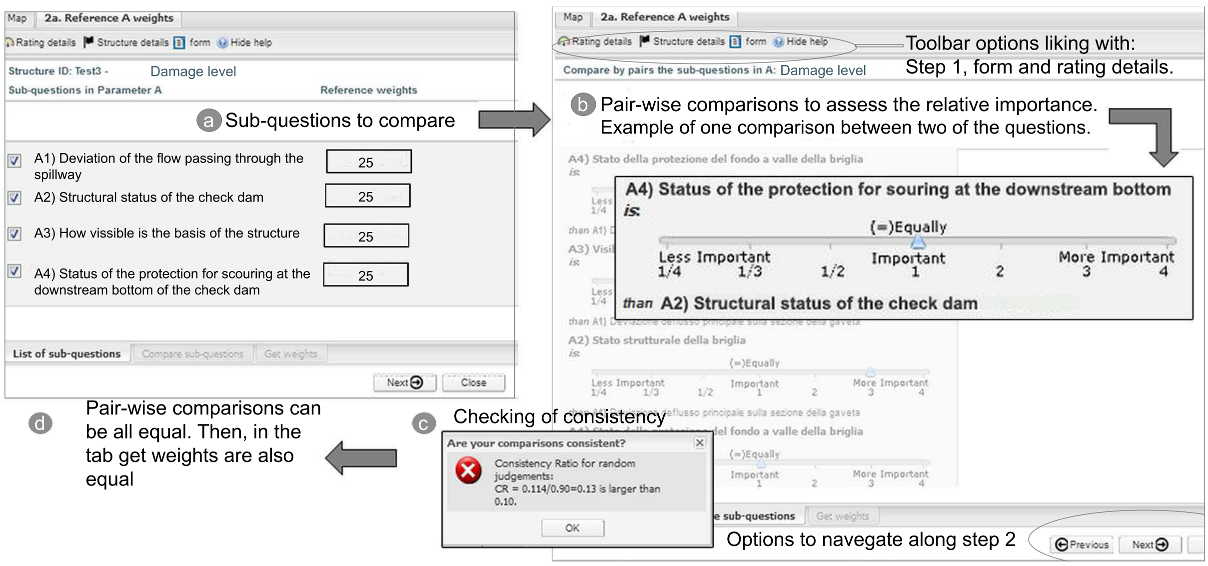

Figure 7: Setting reference weights for the index calculation at parameter level. User sets weights by interacting with tabs: a) Sub-questions to compare b) compare sub-questions c) check of the consistency of comparisons and d) get weights

4.2. Reference weights

For a selected structure, for example check dam 3 (CD3 in **Figure 6**), options are given so that users can compare the relative importance of sub-questions at parameter level (**Figure 7a**). **Figure 7b** illustrates the pairwise comparisons of sub-questions in A) parameter Damage level using the Analytic Hierarchy Process (AHP) method (Saaty, 1987). The AHP method allows checking the consistency of a comparison (**Figure 7c**). By doing the comparisons, technicians can derive the weights that will be used in the aggregation of reported ratings (**Figure 7d**). Weights should be set for sub-questions on each A, B and C parameter. Technicians can base their comparisons, for example, on the design criteria when building the structure. For the evaluation workshop, the relative importance was set equal for all questions to evaluate the outcomes of the module based on the quality of input reports (Cortes Arevalo et al., 2016).

4.3. Select/submit first-level inspection report

A mock up report coming from the inspection module was automatically listed to access the evaluation module (**Figure 8**). At the current development stage, users should select that report to type the data collected from the paper-based form directly into the user interface of the next step (**Figure 9**). The connection to the DBMS, based on specific requests of users, will be matter of a future development to load available reports that will be systematically evaluated in the following steps.

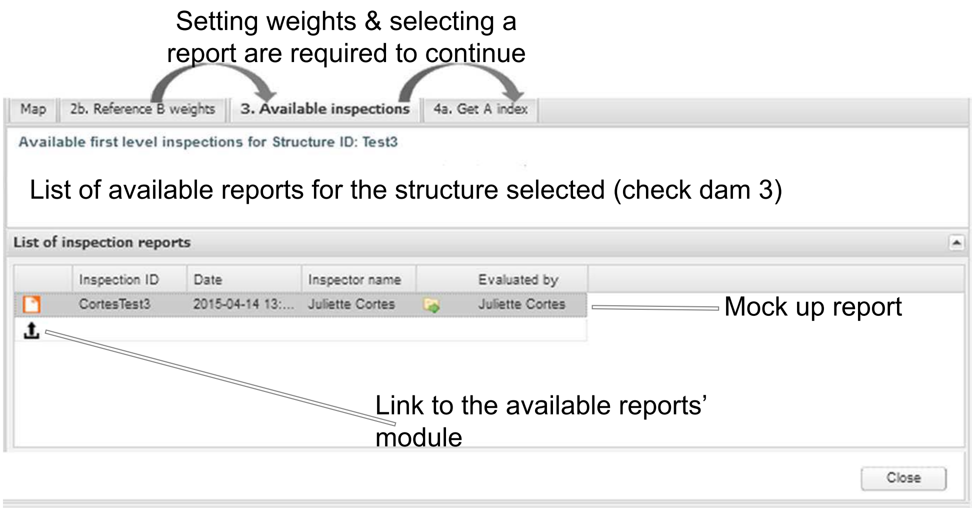

Figure 8: Selecting between available first-level inspect reports to evaluate

4.4. Derive indices

By interacting with this step, users can first aggregate the reported ratings into three indices at parameter level (**Figure 9a**). Indices are calculated by means of the TOPSIS multi-criteria method with fuzzy terms (Chen & Hwang, 1992). The fuzzy terms are the ratings reported for the structure inspected. The equal weights defined in Section 4.2. are used for aggregating the ratings into indices. A completeness ratio is calculated to highlight when participants report unspecified conditions.

Then, users can use the plot in **Figure 9b** to compare the reported ratings (bars in the plot) against the reference best and worst possible conditions (upper and lower lines in the plot). To go to the advised action, users should finally set rules to define a status of the structure that is acceptable. For example, to be assigned in the worst level (red), the aggregated index for the report has to be smaller than an acceptable minimum index and has to be larger or equal than the worst acceptable rating condition. The rules (acceptable index and worst rating) were fixed for the testing workshop but can still be modified by the user. **Figure 9** presents the evaluation for an example report of parameter A (Damage level). The same process is repeated for all parameters.

4.5. Overview of potential actions

The last step gives an overview of the outputs and functional level assigned for parameter A, B and C (**Figure 10**). The green color indicates that, according to the reported ratings, the structure was at the best functional level and no action needs to be carried out. The medium level (yellow) indicates that one of the expert-based rules was not true and additional information needs to be considered coming from photo records or previous inspection reports. The worst level (red) indicates that the structure may have been at the worst functional level and thus, a second level inspection needs to be carried out towards maintenance planning.

5. Workshop and feedback of the evaluation module (use case)

To introduce the web-GIS application and obtain feedback about the usefulness of the evaluation module, a workshop was organized in the study area with ten participants. Participants comprised of four technicians of FGV that had participated in the user requirement stage (Section 2). Six newcomers participated: a mixed group of two technicians of FVG, two technicians of neighboring regions and two last-year students of geosciences.

During the first day, attendants carried out individual inspections for three check dams in the Fella basin (**Figure 6**) that were collected in a paper-based format. The field inspections were carried out to use real data for using the module. The first-day program (inspection session) was finalized with the introduction of the decision support framework. During the second day, participants interacted with the evaluation module by using one of the reports collected during the inspection session. At the end, feedback was collected in a questionnaire form.

Participants rated their levels of agreement with statements in the feedback questionnaire using a Likert rating scale from -3 (full disagreement) to +3 (full agreement); which is a scale used for getting indication about users attitudes (e.g. Arciniegas et al., 2013; Inman et al., 2011). When preferred, participants provided

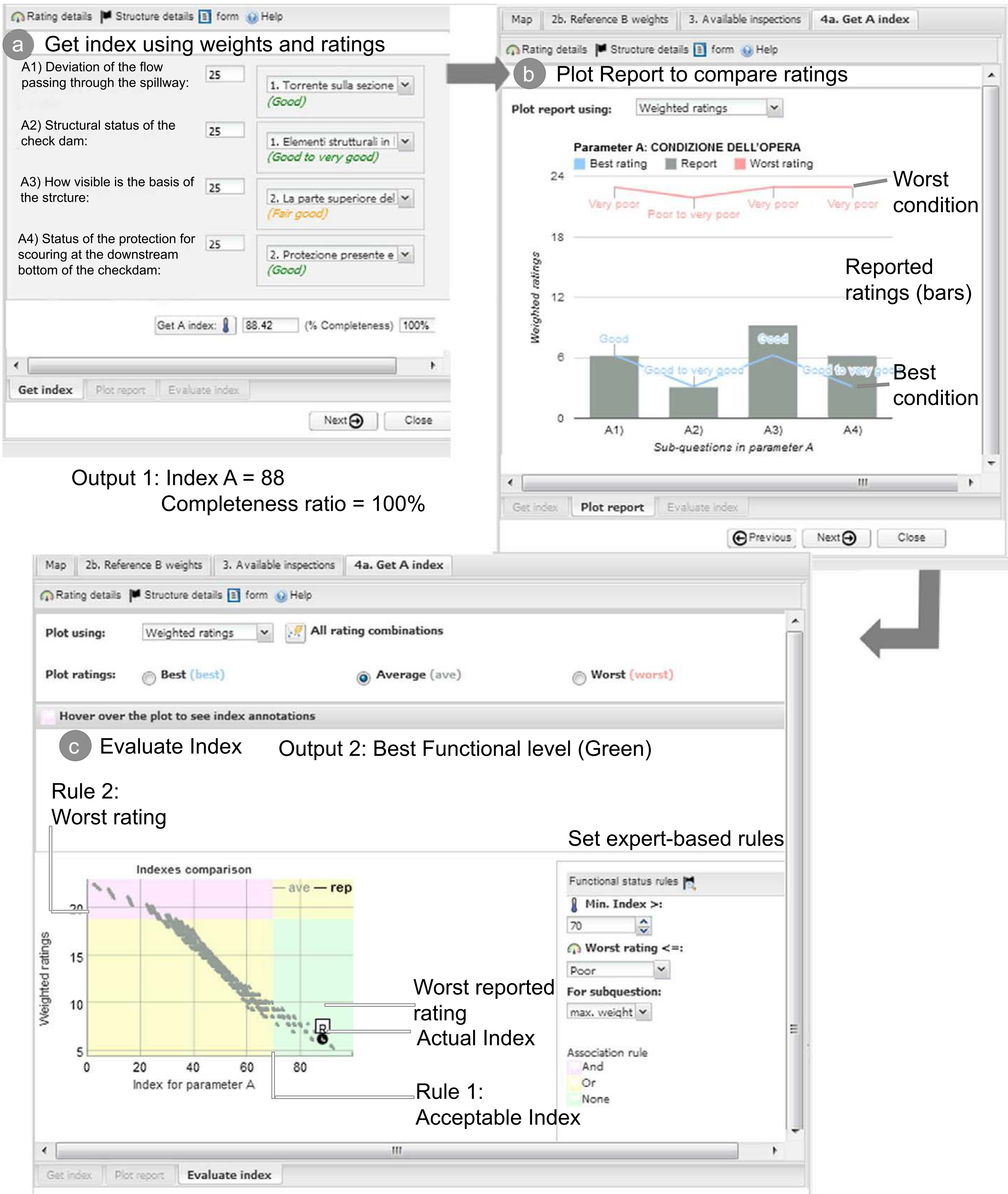

Figure 9: Outputs from the evaluation module: a) Index and a completeness ratio indicating the reported ratings. b) Report plot to compare ratings with reference conditions. c) Functional category of the parameter according to expert-based rules

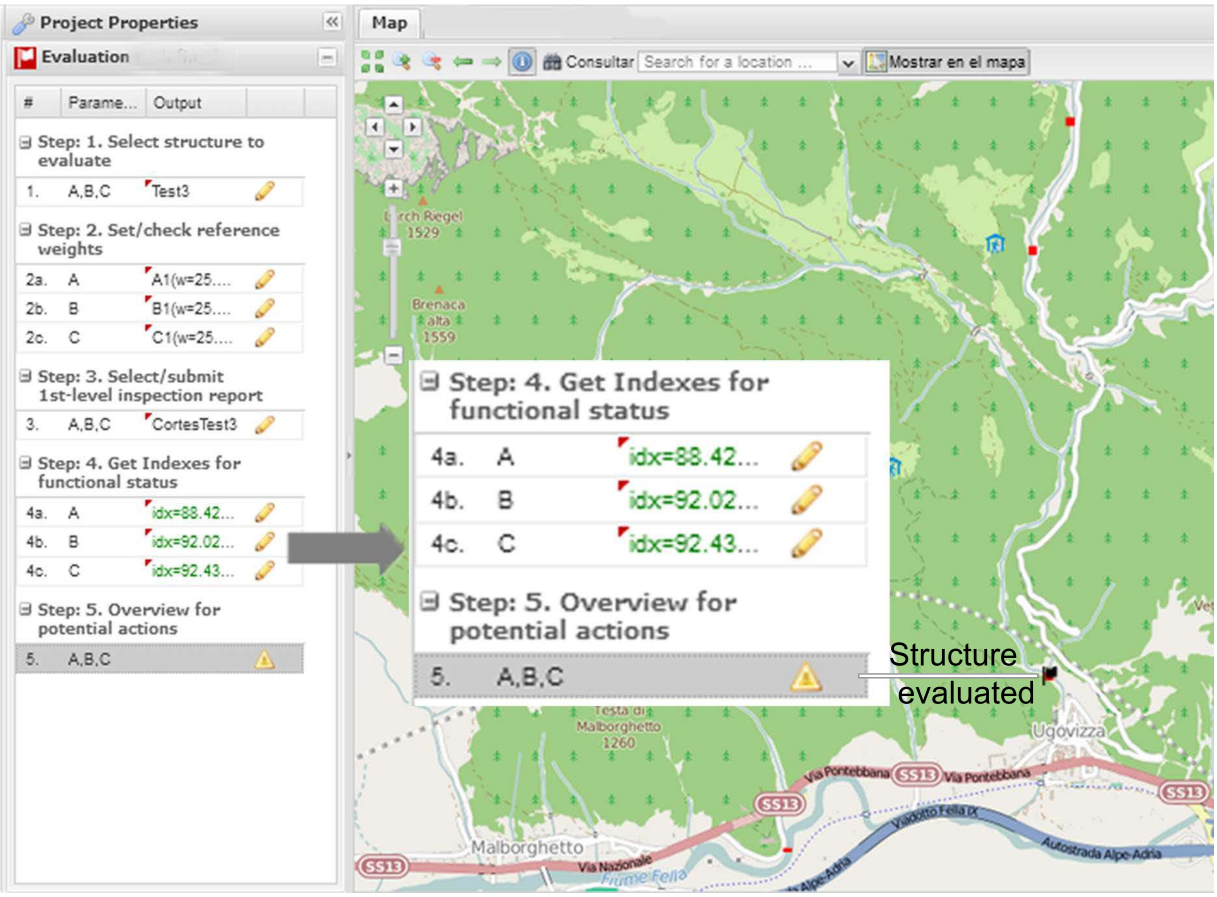

Figure 10: Overview of the derived indices and functional level for each parameter

comments to explain their judgments. Participants rated the following statements about the usefulness of the evaluation module for one of the check dam inspections that they carried out themselves (**Figure 11a**):

a) In the Get Index tab, the completeness ratio is a useful indicator for the quality of volunteers ratings

b) In the Plot report tab, the calculated indices (e.g. 70) for parameters A, B and C are useful and informative to support decision advice

c) In Plot report tab, the plot is useful and informative to understand the weighted- aggregation of rating scores into indexes for parameters A, B and C

d) The comparison plot for different combinations of rating options is clear enough to support your decision advice for the part A, B and C

e) In the evaluate index tab, the level assigned to the structure for parameters A, B and C, as indicated with the red, yellow, green color represents my preferences for the decision advice

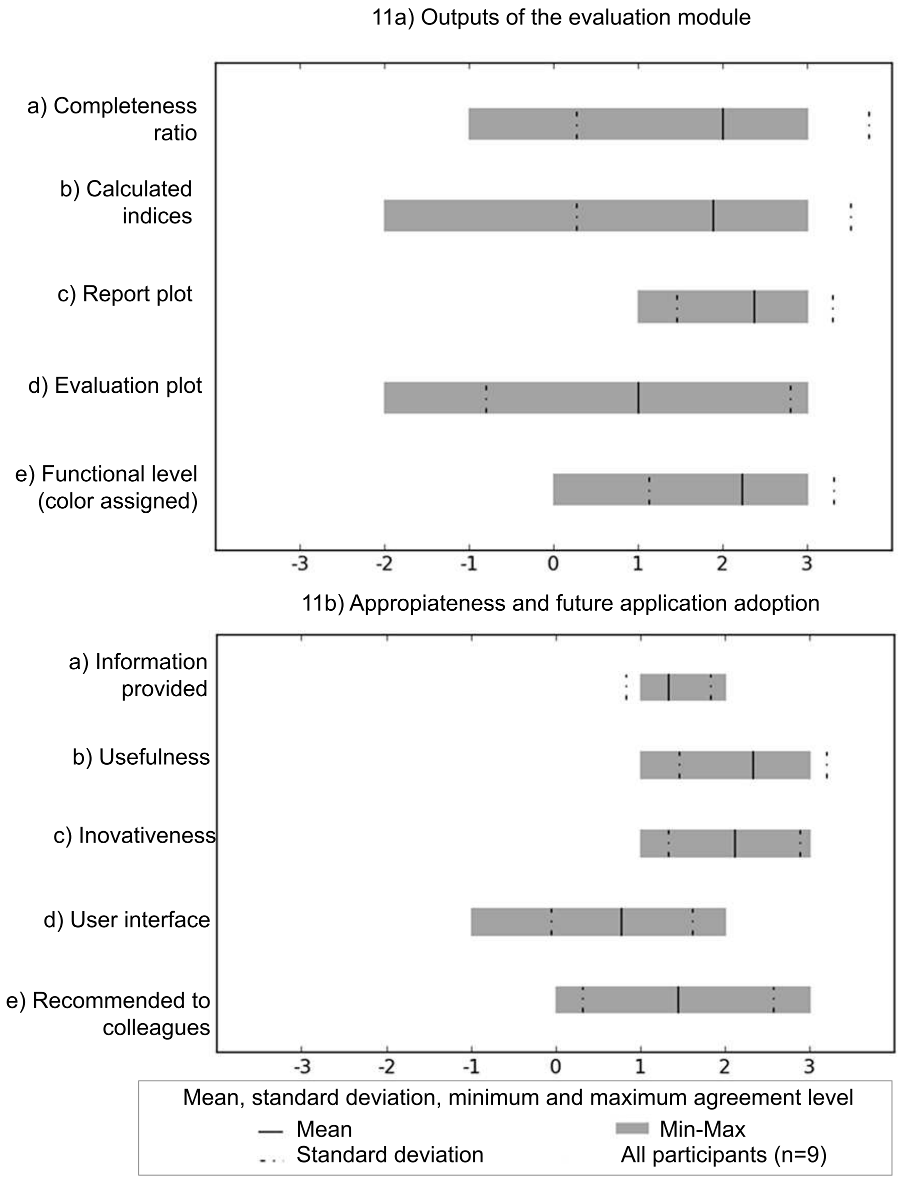

Figure 11: Agreement level about the outputs of the evaluation module, the usefulness and appropriateness for future application adoption. The difference in participants number is because one participant did not fill in the feedback form

We also asked participants about the appropriateness of the decision support module and future application adoption. To that end, participants rated their agreement to the following statements (**Figure 11b**):

a) The information provided is sufficient to follow each step (evaluation module)

b) The web-management application is useful

c) The web-management application is innovative

d) The user interface is clear and easy to follow

e) I would recommend my colleagues to use the evaluation module to support the interpretation of volunteer inspections

We finally ask them about additional comments or capabilities to the module. According to **Figure 11a**, the most appreciated aspect of the evaluation module was the report plot and the possibility to define a functional level based on expert-based rules. Although the evaluation module was considered useful and innovative (**Figure 11b**), participants found some features not straightforward to understand, e.g., the completeness ratio, calculated indices and evaluation plot. That is probably due to lack of documentation beforehand to the testing session and the needs for improvement in the user interface. In **Table 2**, we list the comments that participants provided to refine the prototype. A full implementation of the system together with users manual will allow for a more extensive evaluation of the platform.

Table 2: Overview of participants comments for refining the evaluation module

Aspects to improve	Participants comments
Information provided	• Clarify the instructions to interact with the different steps, special attention to the explanation about the weights
User interface	• The user interface is not clear enough yet • The user interface may benefit from the support of professionals
Appropriateness	• It is a nice idea • The evaluation of the indexes (weights) should be optional and it should be located at the end of each step. As default the weights should be equal and modified only for a choice about the priority of the intervention (second level inspection) • The weights should be adjusted when the questions are not to be compiled
Future application adoption	• To test the outcome of the evaluation module, it would be useful to have the statistical analysis of the different structure types • To make a more comprehensible and simple interface. Maybe with a step-by-step tutorial to help technicians that will be in charge of using the program • To give feedback to volunteers that will compile the form

6. Discussion and conclusions

This study proposed a decision support framework implemented into a web-GIS platform to assist technicians in managing first-level inspections reports about protective structures in the mountain basin of the pilot study area. At the current development stage, we introduce an evaluation module to test how to get an indication of the functional status of check dams based on the field reports. Following a UCD approach, the outcomes of the user requirement stage lead to the conceptual design, implementation and usage of the decision support framework. Therefore, collaborations with responsible technicians of the FVG Region, local municipalities as well as other stakeholders were important not only to understand user requirements but also to evaluate its first implementation.

The module architecture of the Web-GIS platform facilitated the development of the core-capabilities for decision support and the conceptual design of the complementary modules. The system architecture was developed using GXP library backed up by OpenGeo Suite SDK, which facilitate the re-use of available mapping tools and extension of functionalities. The interfaces scripts were coded based on the logical MVC that will support and facilitate the upgrading of the platform to a more recent version following such logic.

To test the functionalities of the platform, a proof-of-concept evaluation module was implemented. The testing workshop focused on users perception about the usefulness for decision support. The weighing procedure to aggregate questions in the inspection reports was met with scepticism (Section 4.2). The pair-wise comparisons included the Consistency Ratio (CR) that were proposed by Saaty (1987) as indication of the consistency of comparisons (**Figure 7c**). Such ratio should be used only to warn users about inconsistencies but not to limit the experts choices. Moreover, weighted aggregation should be used with caution because can change the outputs considerably especially if inspectors err by overestimating or underestimating defects (Cortes Arevalo et al., 2016). Participants suggested that the weighting option should be optional and located at the end of the evaluation process. For a more extensive evaluation of the platform, participants also required the evaluation of inspection reports from a larger number of structures to support statistical analysis of the module outcomes.

This is an initial prototype for the development of a full-scale system later on by transferring knowledge, theory and concept behind this decision support framework. Workshops to evaluate a full-scale system will require longer interaction with the Web-GIS platform focusing on a comprehensive evaluation of usability (Bastien, 2010; Hornbk, 2006). Thereby, qualitative evaluation methods (e.g. questionnaires) can be further combined with quantitative indications (e.g. data log analysis) to explain user interaction van Velsen et al. (2008). Future developments will consist of a full implementation of all the modules of the platform (**Table 1**) that could be further extended to other type of hydraulic structures, for example culverts. Consideration should also be given to include into the web-GIS platform a crosschecking feature to compare the outputs of the evaluation module with complementary information, such as photo record of the inspection and previous reports for the same structure. In addition, the overview of derived indices (**Figure 10**) should be provided for all check dams reports that were evaluated. Further options should consider sorting the structures according to the functional level of all three parameters and visualizing in the map the functional level assigned for each parameter. Future research may also consider a mobile application to extend the capabilities of the report module into a portable device to support data-collection and to provide feedback to inspectors.

To conclude, the web-GIS decision support framework consists of a systematic procedure for the evaluation of first-level inspection reports that facilitates the use of inspections collected by skilled volunteers or technicians. The platform can be further developed as a tool to support coordinated and collaborative efforts between different management organizations involved in preparedness and prevention with interest in inspection and maintenance planning. For example, that is the case of Civil Protection, technical agencies and basin authorities in FVG. Thereby, the framework can also complement spatial data infrastructures that centralize relevant information about the inspected structures and other preventive works or hydraulic structures besides check dams.

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Appendix A.

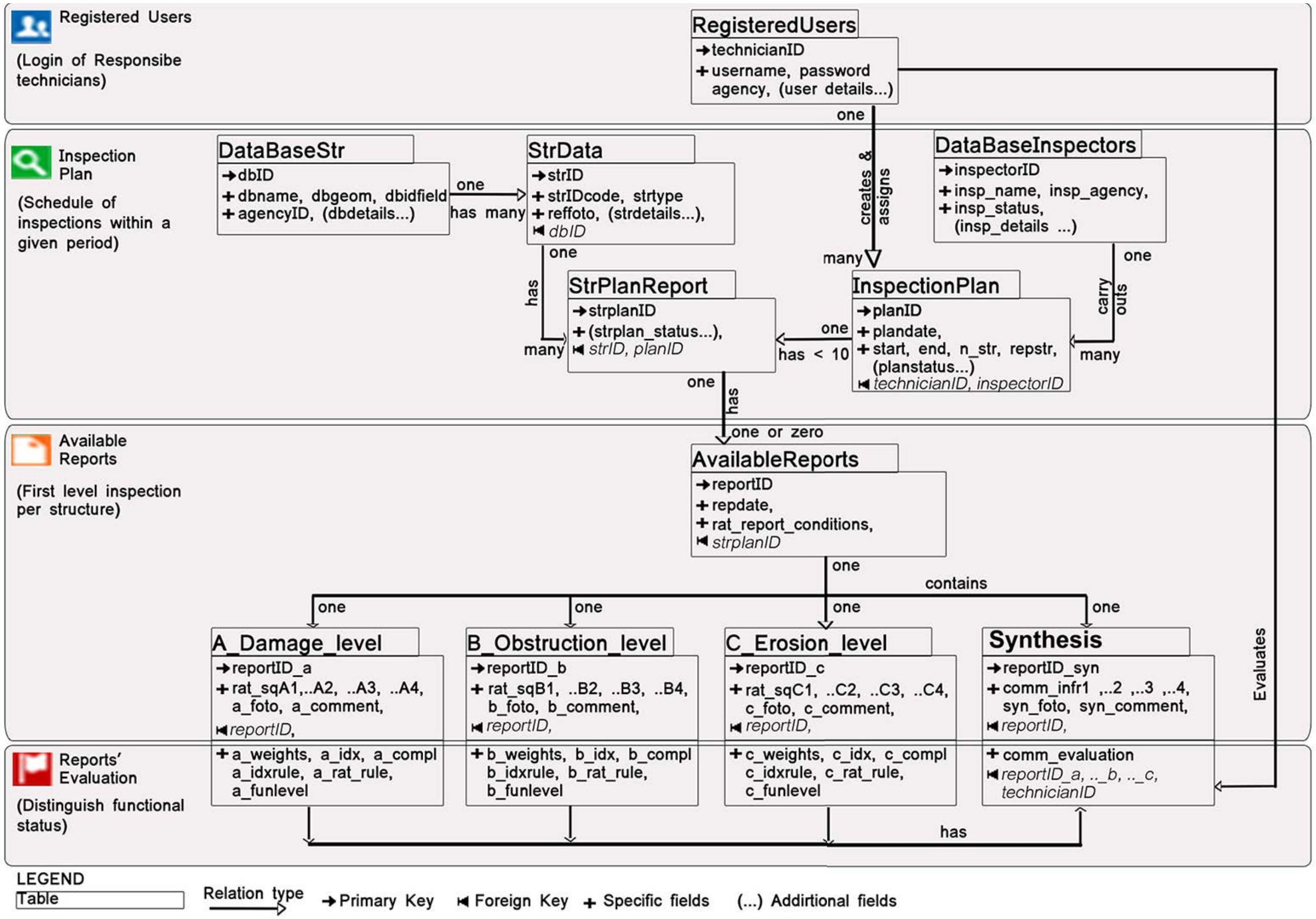

Figure A.1: Conceptual design of the data model behind the web-based application

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