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A collaborative (web-GIS) framework based on empirical data collected from three case studies in Europe for risk management of hydro-meteorological hazards

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ABSTRACT

This paper presents a collaborative framework of an interactive web-GIS platform integrated with a multi-criteria evaluation tool. The platform aims 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 the case study areas of the CHANGES[3] 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 paper 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 indicate 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.

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" ([27], 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 [12,15]. These interactions may evolve throughout the different stages of a decision-making process [26,35,7]. 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

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the decision-making process. Borrowing from Scharpf ([41], 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 ([5], 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 [16]. Regardless of either a temporary or permanent period of implementation, measures can be categorized into structural and non-structural as well as passive and active measures [22,25]. According to [22], structural measures distinguish physical engineering from more organizational and institutional measures. Active measures attempt to alter hazard characteristics to reduce consequences. In contrast, passive measures are based on the separation of elements at risk from the hazard itself. 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 [24]. 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. [6], 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 [30]. 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 [39]. DSSs generally go beyond the need of centralizing all necessary information while assisting in the interpretation of available knowledge, formulation, and evaluation of choices [37]. Such systems can thereby assist problem analysis without taking over the decision maker's responsibility for their choices and actions [21]. 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 [14] and can facilitate the contribution and integration of the needs of potential users, evaluation and potential improvement of the support system itself [31].

In this study, we proposed a collaborative decision support framework for the management of hydro-meteorological risks, integrating an interactive web-GIS interface with a MCE tool. The aim was 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 of the CHANGES project: the Małopolska Voivodeship of Poland, Buzău County of Romania and the Friuli-Venezia-Giulia region of Italy (as shown in Fig. 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 platform was developed based on these preliminary empirical inputs and then presented to the stakeholders for feedback during the dissemination meetings of the CHANGES project.

The structure of this paper is organized as follows. Section 2 introduces the need for collaborative decision-making and interactions. Section 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 4 describes the proposed collaborative decision-making framework. Section 5 presents the feedback collected for the prototype in the different study areas and discusses how it could support and enhance collaboration and exchange activities between the participating actors. Finally, we conclude this paper by discussing the presented framework and its potential for in-practice implementation along with relevant aspects for platform improvement.

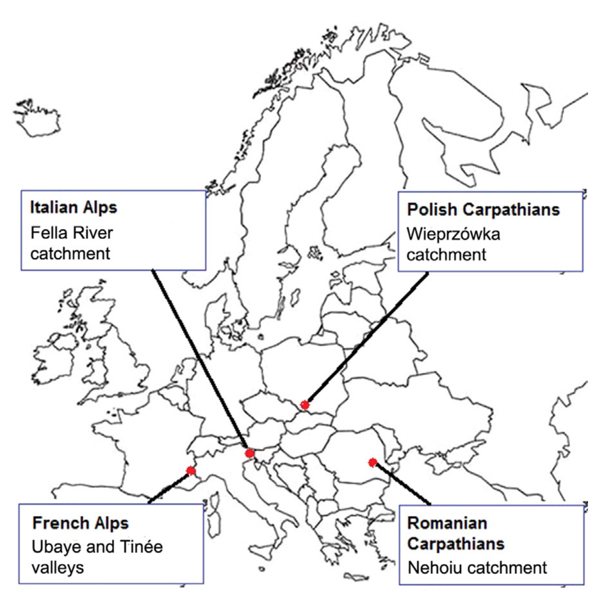

Fig. 1. All case study sites of the CHANGES project (Source: [34]).

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 [10]. 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 [17,20]. 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 [47]. This has also been stressed by the European Commission [13], 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[4] 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 [19,40]. 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.

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 CHANGES 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 analyzed 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-meteorological hazards (Fig. 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 paper.

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

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

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 Defense 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.

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.[5] This also holds true for 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 [8]. 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 [33,40,9] and thereby the sharing and dissemination of information is communicated quickly and more effectively [46].

Regarding the existing platforms and tools observed in the case study sites, in *Poland*, there is an application [2] 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 [34]. For the *Romanian* case study, a main operational platform called "Information Management system for Emergency Situations" (Sistemul de Management Informaţional pentru Situaţii 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 Defense. 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 [36].

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 above-mentioned 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.

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 provide the collaborative decisions itself. The framework of this platform 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 and 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, it is also

[5] For further information within this focus, it is recommended to consult the authors' previous work in Prenger-Berninghoff et al. [34].

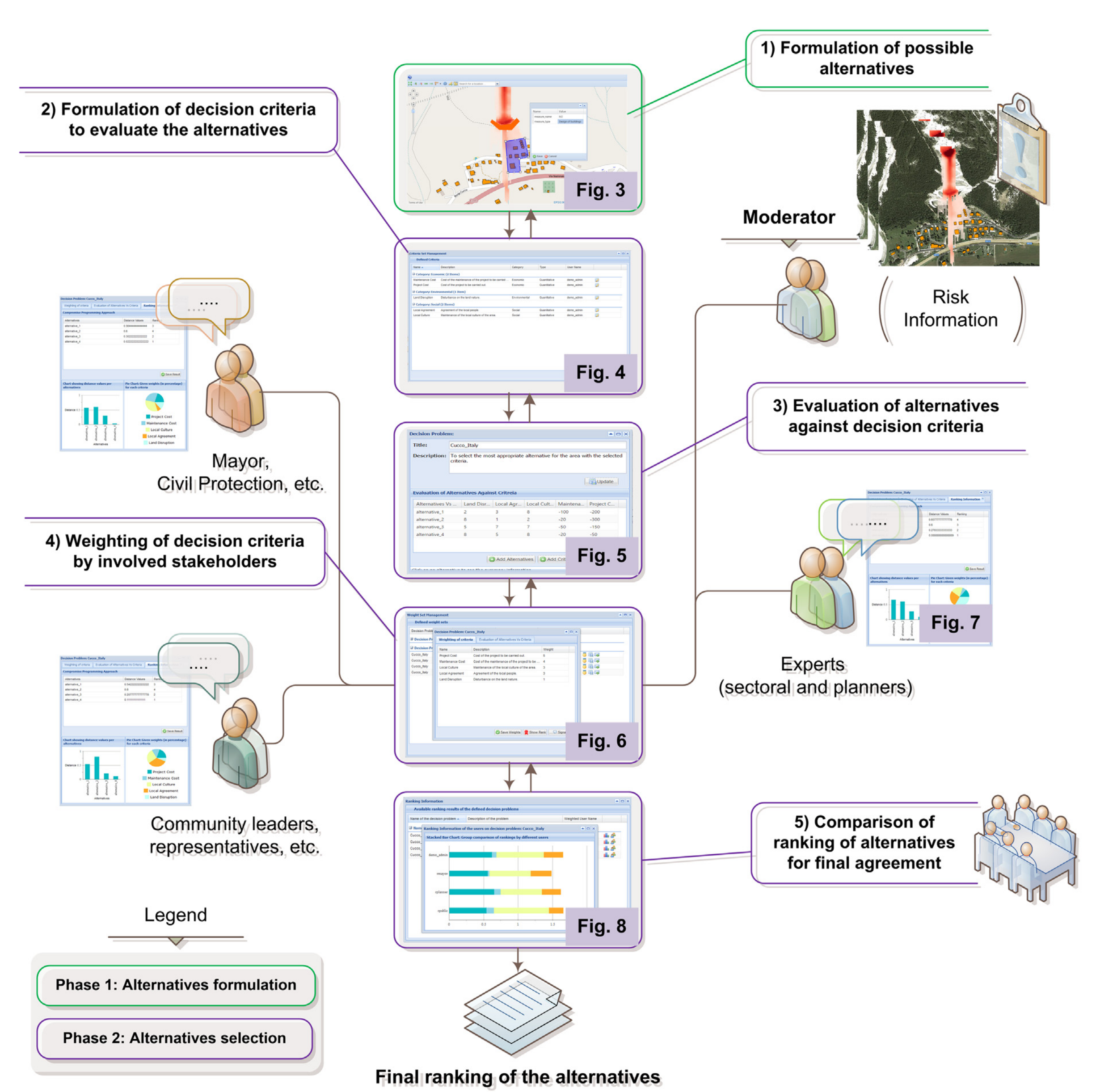

Fig. 2. Framework of the collaborative web-GIS prototype platform. Steps 1–5 are demonstrated with sequential figs. 3–8, which are identified by number as a reference to their place in the general workflow of the framework. Only the user groups involved in Step 4 are illustrated in this figure. The detailed interaction of who is involved in which steps is explained in Table 1.

possible to calculate potential losses and damages of affected elements if data required for risk assessment is available for the considered study area [3]. Based on this available (or calculated) risk information, 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 expertize 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 [28,29]. 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 [42]. Based on a typical structure of the decision-making process [15,26,35,7], the workflow of the platform is composed of the following steps (Fig. 2):

- *First phase:*

1. Formulation of preliminary risk management alternatives;

- *Second phase:*

1. Formulation of objectives in terms of decision criteria;
2. Evaluation of risk management alternatives against decision criteria;

Table 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 among other expert users to act as a moderator of the decision-making process.	Representatives of an institution with capacity to moderate the collaborative process.	Step 1, 2, 3, 4 and 5.
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.	Step 1, 2 and 3. Step 4 and 5 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.	Step 4 and 5. Step 1 and 2 for necessary adjustments within the iterative process of defining alternatives and criteria.

3. Weighting of decision criteria by involved stakeholders and
4. Comparison of ranking of alternatives to support final agreement.

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 1 summarizes these types of users and their interactions according to the different steps of Fig. 2. The workflow with user interactions can undergo multiple iterations until a specific ranking of options is achieved for final agreement.

4.1. 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 expertize and preferences for risk management can interactively propose measures. Fig. 3 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. Additional measures (structural or non-structural) can also be mapped and proposed through a similar procedure, and are grouped as an "alternative". This research uses the understanding provided by Holub and Hubl [22] (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' [32]. Table 2 describes an example list of potential measures grouped into management alternatives.

4.2. 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. In this context, we used "decision criteria" to convey information about relevant impacts of management alternatives. According to Meyer et al. [30], criteria should be measurable in quantitative or qualitative terms and meaningful to the decision makers. 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.

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. 4).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.

4.3. 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). Only expert users are allowed to modify the performance values depending on their roles and expertize 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.

4.4. 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 favorable 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

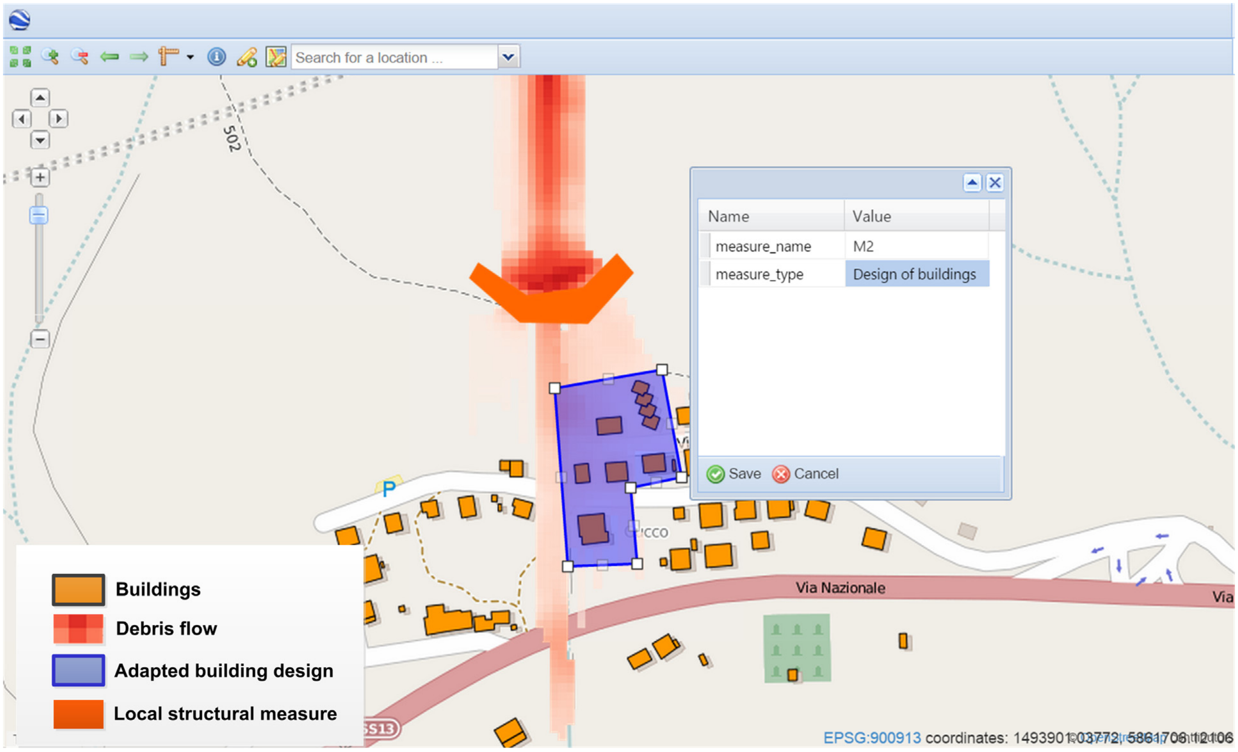

Fig. 3. An example proposition of risk reduction measures by an expert user through a sketching tool of the prototype platform.

Table 2
Example of potential measures grouped into management alternatives (based on [22,32])

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.	

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. 6). 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 MCE techniques. The ranking of alternatives is based on weighted aggregation methods 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 [44]. MCE can be categorized into three main groups of techniques: outranking, multi-attribute utility and mathematical programming techniques [18]. In the prototype, we implemented the Compromise Programming (CP) method, one of the mathematical programming techniques, to identify alternatives which are closest to the ideal one by distance values. The ideal solution is based on the best or worst value of each criterion depending on the criteria type (cost or benefit). This method supports the selection of an optimum solution assuming that decision makers seek a solution which is as close as possible to the ideal one [38]. The CP method is a popular decision-making approach because of its simplicity, transparency and flexible adaptation to various settings, and has been recommended for application to disaster risk management problems [43]. The combination of Step 3 and Step 4 produces the individual ranking of preferred alternatives which are recommended for implementation.

4.5. 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. 7). The comparison of ranking information resulting from other decision maker users can also be visualized (Fig. 8) in the

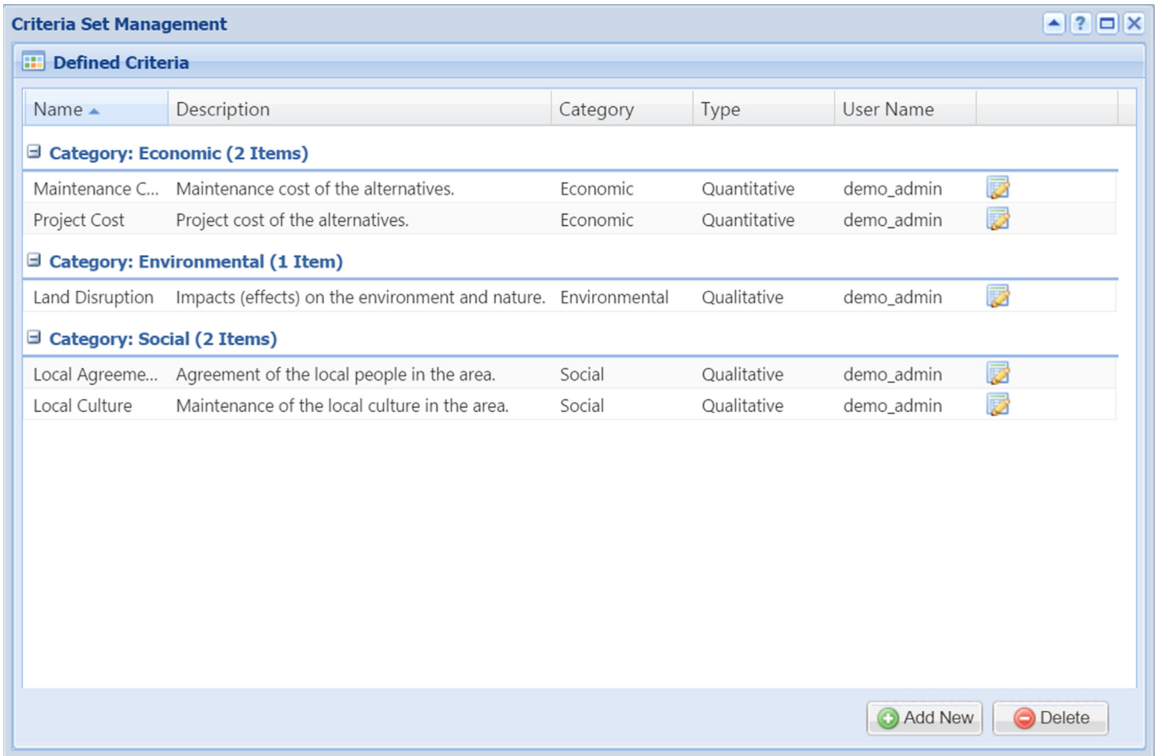

Fig. 4. An example list of defined criteria (both qualitative and quantitative) in the prototype platform.

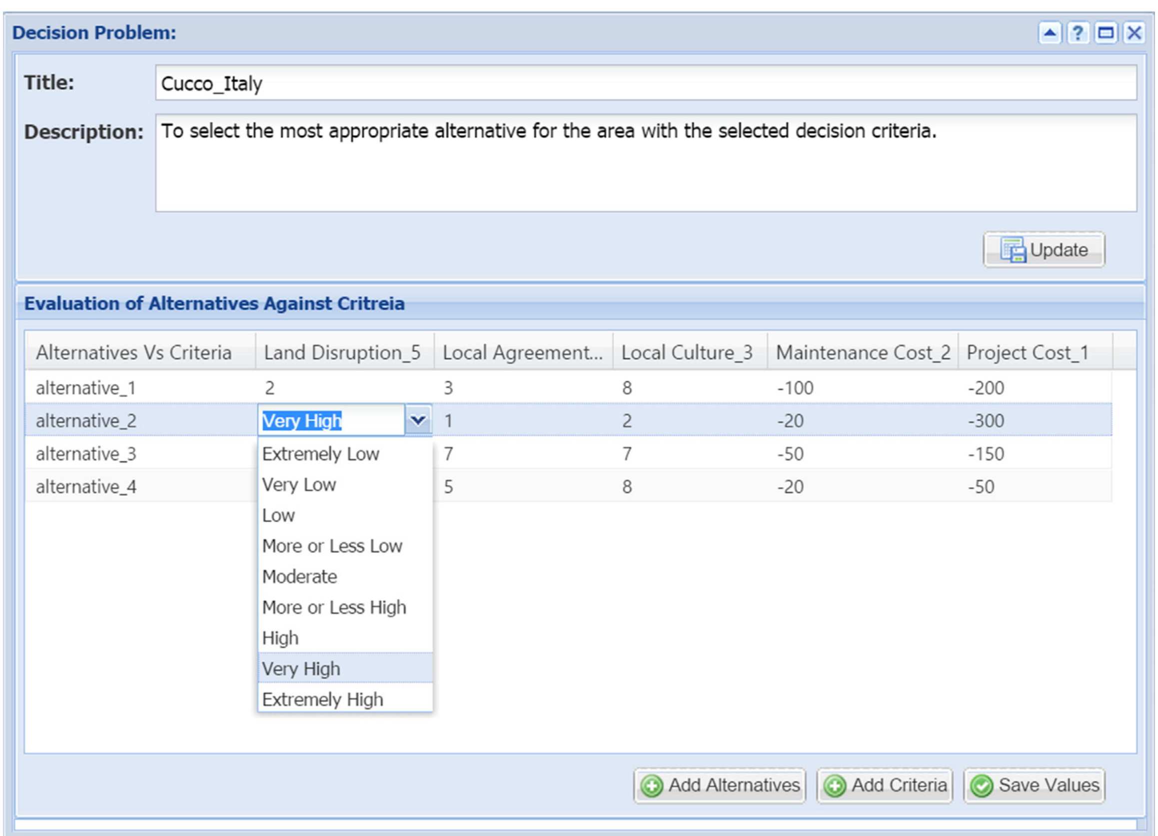

Fig. 5. An example evaluation matrix of the defined decision problem in the prototype platform.

platform for the purpose of negotiation to achieve a final agreeable outcome of alternatives and a visible expression and communication of different preferences. 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

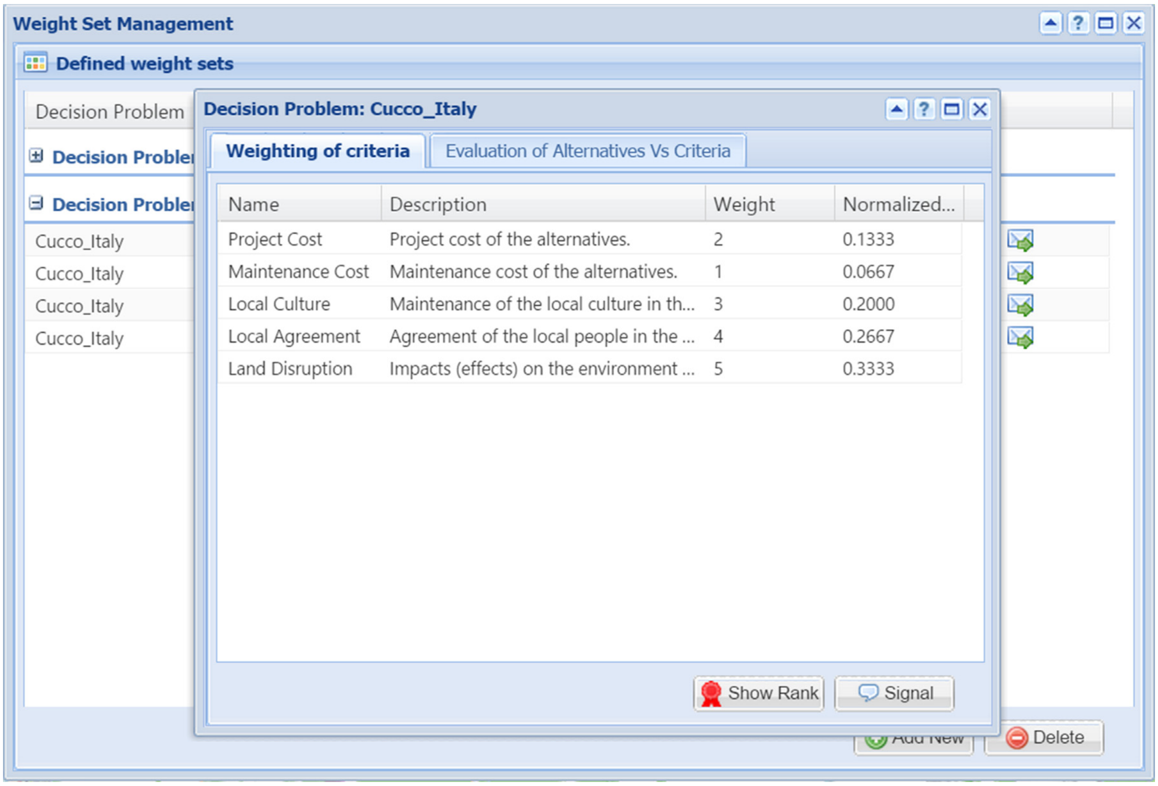

Fig. 6. An example of the weighting process of the participating user in the prototype platform, in which the land disruption criterion is highly weighted by the user (with a weight of 33%).

platform. Additionally, other services like instant chatting and audio (voice) communication are also integrated into the prototype to facilitate interactions in the decision-making process when participants are in different locations.

5. 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 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 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. 9 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.

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 3 highlights the main points extracted from the feedback of stakeholders based on the first two sections of the feedback

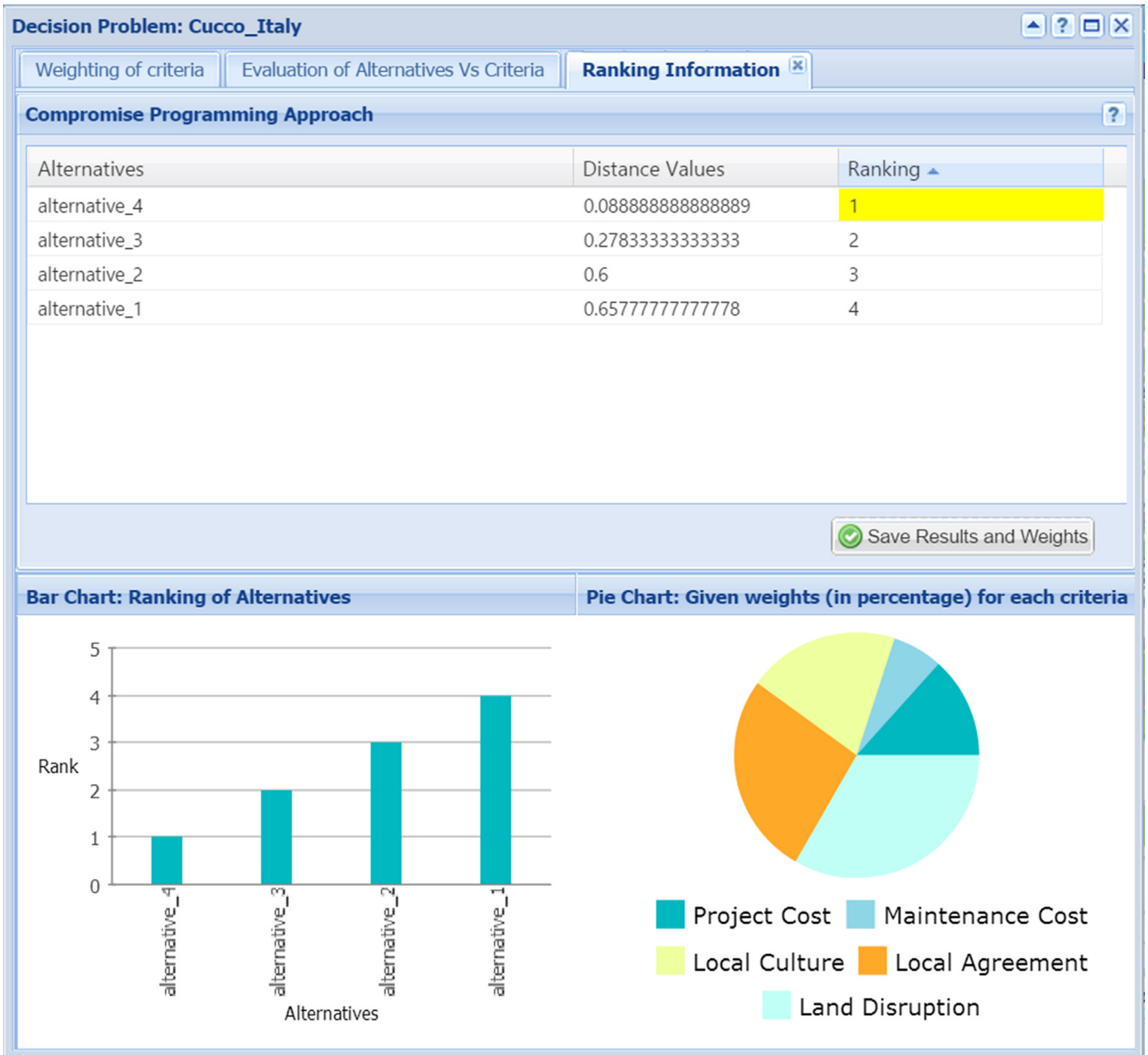

Fig. 7. Visualization of own ranking result (based on the given weights in Fig. 6) in the prototype platform. The upper grid and lower left bar chart represent the ranking order of alternatives (i.e. in this case, alternative 4 is ranked first). The right lower pie chart represents the given weights (%) of a participating user for defined criteria.

form and provides insights on the strengths and weaknesses of the platform and its potential improvements.

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

- the integration of cost-benefit analysis and interactive spatial query tool to further analyze and evaluate the consequences of the natural hazard events (for integration in the next version);
- 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.

6. Discussion and conclusion

In this paper, 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 [11] 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

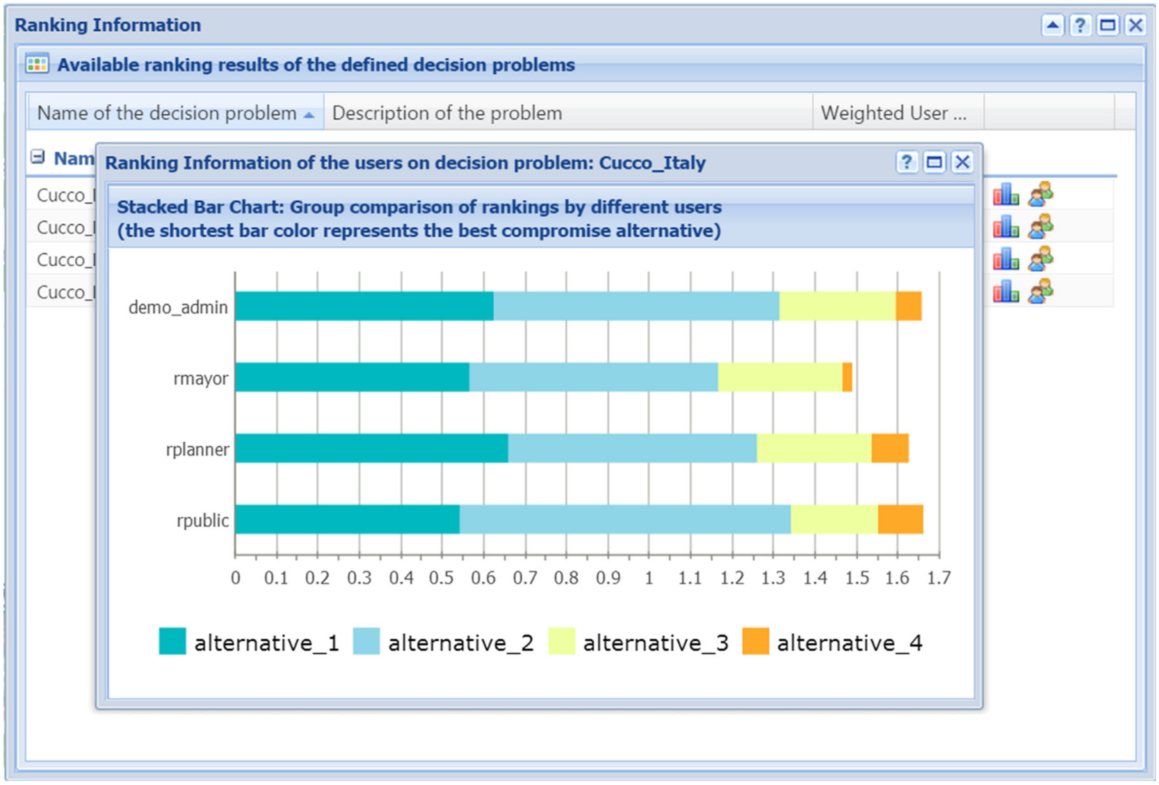

Fig. 8. Comparison of individual ranking results in the prototype platform, where the alternative with the shortest bar portion (distance value) is considered as the best solution (i.e. in this case, alternative 4 for all participating users).

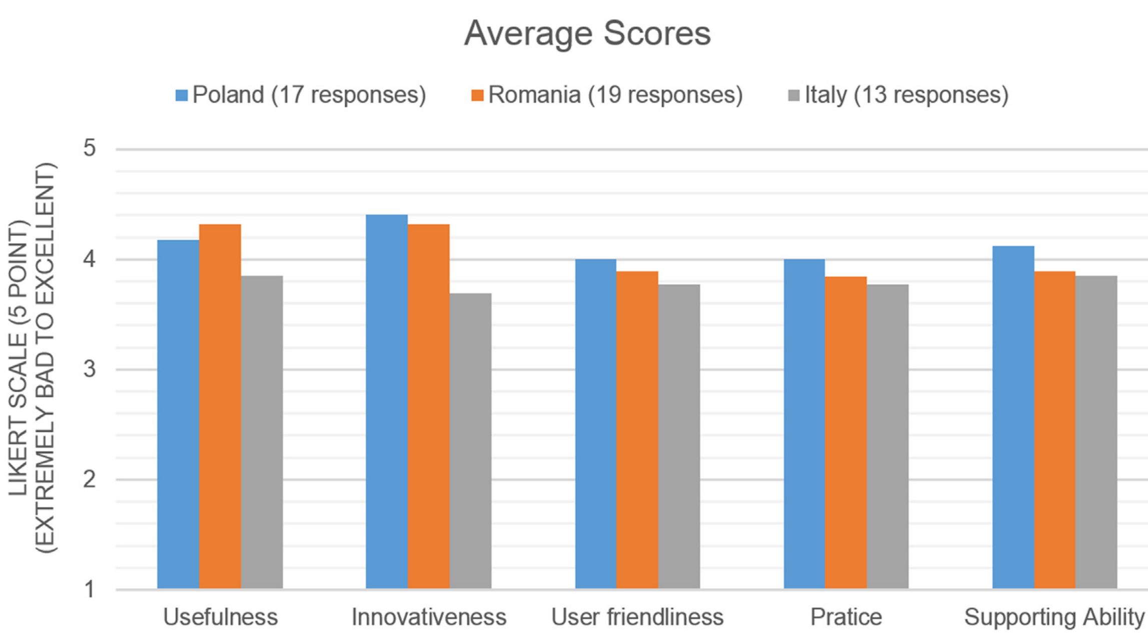

Fig. 9. Collected feedback (section 1) based on a 5-point Likert scale (of Extremely Bad to Excellent).

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 [1]. 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,

Table 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 analyze 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.

validation of the platform through interactive real-time exercises and integration of additional supportive tools in the platform. These provided crucial topics for current and 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 before the actual test cases in the study areas [4]. 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 [23]. 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 [45]. 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.

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