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GIS TECHNIQUES AND DECISION SUPPORT SYSTEM TO REDUCE LANDSLIDE RISK: THE CASE STUDY OF CORVARA IN BADIA, NORTHERN ITALY

ABSTRACT: CAVALLIN A., STERLACCHINI S., FRIGERIO I. & FRIGERIO S., *GIS techniques and Decision Support System to reduce landslide risk: the case of study of Corvara in Badia, northern Italy*. (IT ISSN 0391-9838, 2011).

Landslide hazard assessment aims at profiling the prospective damaging events and identifying the potentially affected areas to reduce risk. This means that procedures for the management of emergency situations can be effectively set up in advance.

Where and when a potentially damaging event will occur is one of the most important topics of discussion in the scientific community. As a matter of fact, landslide area will contribute to identify the vulnerable elements potentially affected by the event of a given magnitude and the degree of physical damage and the economic loss. Knowledge of the area and the time of occurrence, related to the triggering factors, permits to apply in advance an «early warning» system and related procedures to manage the crisis phase, according to Civil Protection Authorities and the laws in force. An example of the proposed methodology is presented; it exploits GIS techniques, Decision Support System, and mobile technologies to reduce landslide risk in the Corvara in Badia test site.

KEY WORDS: GIS, Landslide risk, Decision Support System, Northern Italy.

INTRODUCTION

Landslides caused enormous casualties and severe economic losses in mountainous regions worldwide and in the future landslide risk is bound to increase (USGS, 2006) in relation to human growth and development (Bonachea & *alii*, 2006). Global warming is generally expected to augment both the magnitude and the frequency of extreme precipitation events, which may lead to more intense and frequent land sliding (IPCC, 2007). It is therefore necessary to reduce the landslide risk preventing mass movements, which always involves systematic and rigorous processes of stabilizing or «managing» the slopes (Fell & Hartford, 1997). Since this is seldom sufficiently recognized (Guzzetti, 2000), new and more effective methodologies need to be developed to increase the characterization of landslide risk and to enable rational decisions on the allocation of funds for the management of landslide risk.

The relevance of many losses may depend on the time interval considered: in the short term, casualties, homelessness and damage to buildings, infrastructure and equipment may indeed be the primary concern. In the long term, however, economic loss and social disruption may be of greater importance. Mitigation measures for future landslide events are becoming increasingly common in municipal planning and development activities, especially where disasters occurred in the past. Preparedness and response planning mainly focuses on short-term contingency measures (to be applied during an emergency) whereas mitigation planning involves long-term control of land use, building quality and other impact-reducing measures for dangerous events (Sterlacchini & *alii*, 2007).

A preventive risk analysis is fundamental for setting up proper preparedness and response planning procedures. In achieving this aim, the degree of risk deriving from the expected magnitude of an event and its probable consequences, should be mapped and evaluated in systematic and quantitative way.

RISK ANALYSIS

Landslide risk can be defined in accordance with the definitions developed by the Office of the United Nations'

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Disaster Relief Coordinator (UNDRO, 1979). The schematic relationships between hazard, vulnerability and value (Cavallin & *alii*, 1994; Cavallin & Marchetti, 1995) are represented in figure 1. Hazard assessment must be developed as part of land analysis to define susceptible areas to landsliding and identify the magnitude and the run-out of the event. This permits the identification of vulnerable elements potentially affected, their value and associated risk (Glade, 2003; Greiving & Mayer, 2009).

This analysis can be performed by integrating different methodologies, aimed to manage the critical hydro-geological events, using available GIS tools (Dikau & *alii*, 1996; Carrara & *alii*, 1991; 1995), Decision Support System (DSS), and mobile technology. Moreover, the methodologies have to be set up and tested for different environmental system, characterized by different levels of hydro-geological hazards and risks. In addition, the complexity of the social and economic contexts must be included to verify their practical applicability with respect to the laws in force at a national, regional and local level. Moreover, each methodology has to be accepted and recognized by the Authorities (public administrators, economic planners, lawmakers, people responsible for civil protection, relief and emergency services) and by the general public as well, as useful tool for an integrated management of risk.

A methodological approach to the management of landslide hazard and risk begins with the assessment of landslide susceptibility and hazard to geographically identify, map and characterize specific hazard scenarios (i.e., synthetic cartographic mapping of possible hazardous events). This is done on the basis of statistical and deterministic models, historical records, expert knowledge, and the set of laws in force, at a national, regional and local scale. This step has to be followed by a detailed inventory (e.g., 1:5,000 scale) of vulnerable elements, such as people, assets, infrastructure, activities, public and private services. This is to provide an understanding of the possible physical effects on the elements exposed due to the impact of a potentially destructive event (Sterlacchini & *alii*, 2007).

This kind of approach should support local decision makers in assessing the nature and magnitude of the expected losses. The knowledge of the prospective physical effects and economic consequences will help to properly allocate financial resources for prevention and mitigation measures and to decide on how to manage assets in the aftermath of critical hydro-geological events.

SOME UNCERTAINTIES

There are some crucial items that can undermine the consistency of the framework mentioned above. They are related to the real possibility of providing answers to the following questions:

- Where and when will landslides occur?
- How large will landslides be?
- How fast and how far will landslides move?
- What areas will landslides affect and damage?
- How frequently have landslides occurred in the past in a given area?

All these questions are connected to the level of knowledge about predisposing and triggering factors (fig. 2) which are certainly influenced by Global Change effects (IPCC, 2007) in terms of an increase in the temperature and the intensity of precipitation.

As a matter of fact, increase in temperature will decrease the stability of the slopes in mountain areas, due to the melting of glaciers and permafrost (Dramis & *alii*, 1995; Gruber & *alii* 2004; Chiarle & *alii* 2007); therefore, landslide susceptibility will raise as well. Also the triggering factors are bound to undergo variations with the increase in precipitation intensities. For these reasons, the

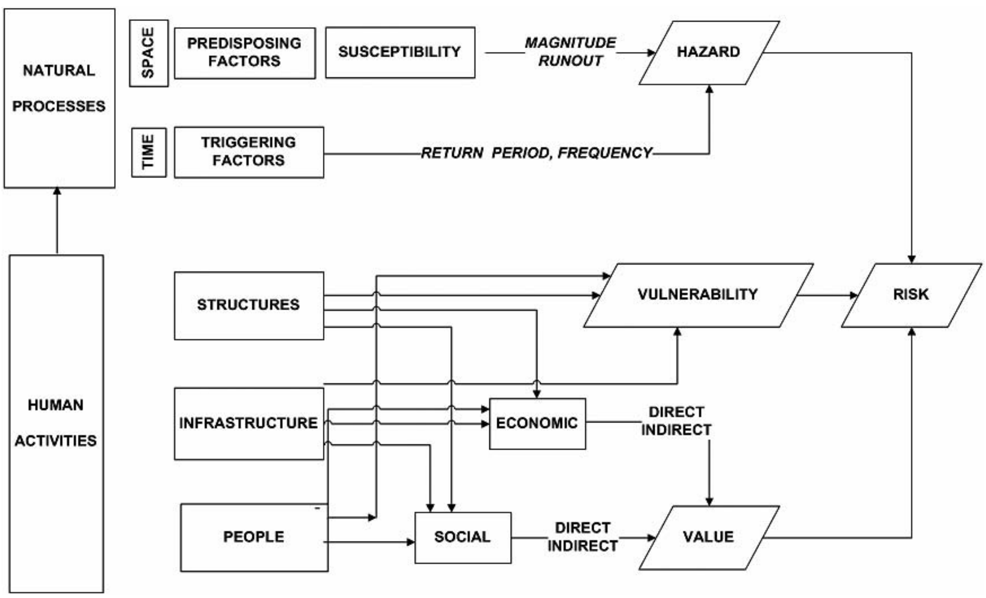


FIG. 1 - The scheme shows the relationships between natural processes, which can produce hazard, and the involved human activities. If these are vulnerable and have a social and/or economic value there is a risk (modified after Cavallin & Marchetti, 1995).

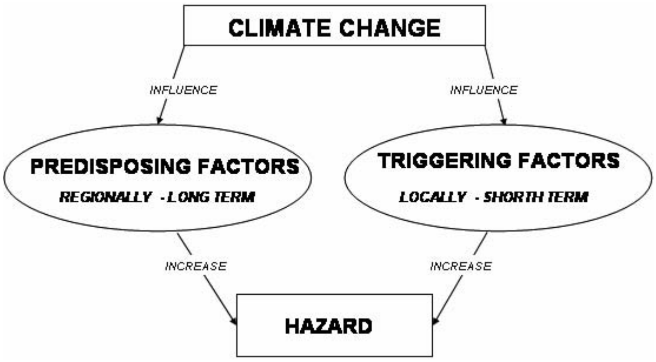


FIG. 2 - Scheme of how Climate Change can increase Hazard.

convergence of triggering factors and predisposing factors will lead to an increase of the frequency and intensity of mass movements in high-relief areas.

The prospective economic losses, in terms of direct and indirect damage, should undergo to an accurate assessment. However, it is difficult to assess direct losses due to the lack of information related to the magnitude of the event, on the one hand, and the structural characteristics of vulnerable elements, on the other hand. At the same time, it seems a very complex task also the evaluation of indirect consequences. One reason may be ascribed to the high number of variables to be considered in the analysis, related to today's social and economic trends of the study area and to the prospective ones, by which future losses may be addressed.

The increase in world's population and the higher wellbeing enjoyed will result in higher hazard levels and greater vulnerability of the elements exposed to risk, as shown in figure 3. Such situation will imply greater use of the land, due to the expansion of dwellings and services in support of human activities. The same will be for the infrastructure and for the communication network. The higher wellbeing requires the provision of infrastructure dedicated to tourism and entertainment. In essence, all this development will increase the value of the elements that may be affected by landslides, and raise the consequent risk as well.

Such a background makes critical he possibility to act on the vulnerable elements and their value by measures targeted to land planning and to the emergency management.

Planning interventions are directed to prevention by identifying areas susceptible to mass movements. This activity must take into account also the changes in the land use from human one to «natural» one, especially in the case related to abandoned mountain areas. In fact the areas previously adapted to human use when they are abandoned became unstable.

For risk reduction, what is feasible and necessary is the development of a forecasting system in case of extreme events. The target is to identify the hazardous areas where to apply procedures and actions which permit real time interventions on vulnerable elements to reduce the risk.

Planning can be applied at two different space and time scale: one is based on prevention with long term interventions on structures and infrastructure, which will reduce the physical vulnerability; the other is based on the prediction of the hazardous areas, involved by extreme events, in which generate actions, supported by emergency procedures, a Decision Support System and mobile technology, to reduce the social value. This is shown in the diagram of figure 4.

THE CORVARA IN BADIA CASE STUDY

In this study, landslide hazard and risk analysis was performed over the entire territory of Corvara in Badia. This mountain municipality is located in the central sector of Dolomites of the southeastern Italian Alps, in the Au-

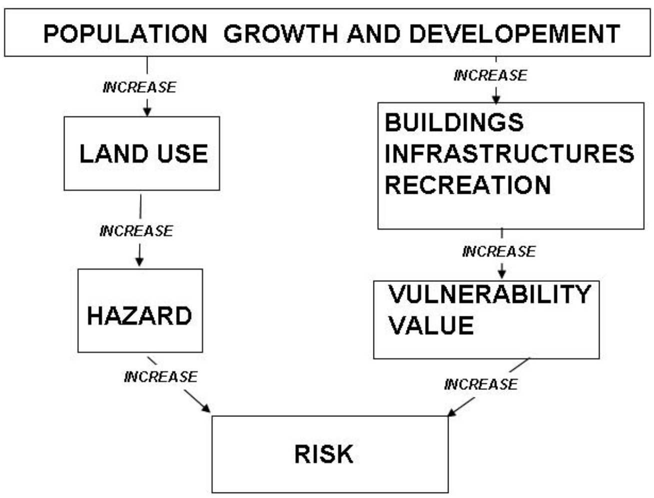


FIG. 3 - Flow diagram of how population growth and development lead to increase in risk.

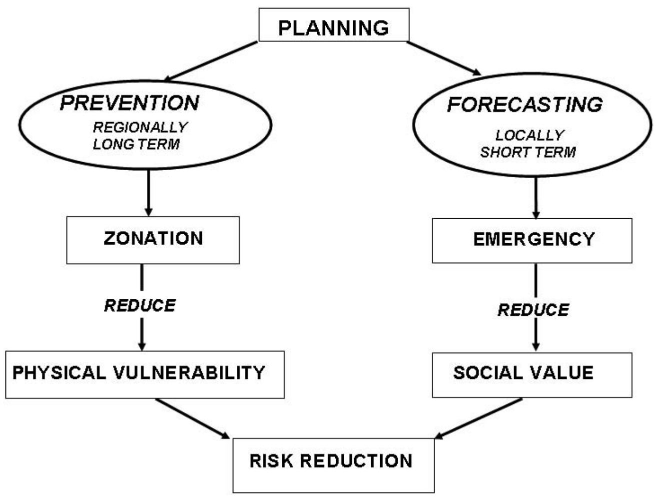


FIG. 4 - Interconnection of hazard assessment and mitigation strategies for risk reduction.

tonomous Province of Bolzano. At first, landslide hazard scenarios, related to the event occurrence probability were constructed. After the scenarios were provided, the identification of the potential vulnerable elements, the assessment of the expected physical effects, and the analysis of social and economic characteristics of the study area permitted to define the potential risk scenarios (Sterlacchini & *alii*, 2007). Subsequently, a procedure aimed at preparing and coordinating Civil Protection Plans was set up and put into practice The study was performed at a local scale (1:5,000).

Methodology

On the basis of data availability (Epoch, 1994; Newtech, 1998; Gets, 2001; Alarm, 2004; Mountain Risk, 2007; Corsini & *alii*, 1998, 1999, 2001; Panizza & *alii*, 2002; Soldati & *alii*, 2004) and the laws in force in the study area, landslide hazard scenarios were obtained through a qualitative or semi-quantitative methodology developed by Heinimann & *alii*, 1998 and 1999 (see also Raetzo & *alii*, 2002) and called «the Swiss Method». It takes into consideration aspects such as landslide magnitude and frequency. In that way, the entire municipality of Corvara in Badia was classified into homogeneous hazard domains.

Then, a detailed analysis was made of the vulnerable elements in the study area. It was aimed at assessing the likely physical effects on the elements exposed caused by the impact of potentially destructive events. The following elements at risks were identified and inventoried:

1. Infrastructure: roads, gas pipelines, power lines, water lines, penstocks, sewers, and skiing facilities;
2. Buildings: uses (residential, commercial, tourism, etc.), structural characteristics, number of floors, surface areas, volumes, numbers of residents, and occupancy rates. Market values, insured values, and construction costs were also obtained from insurance companies and building contractors.

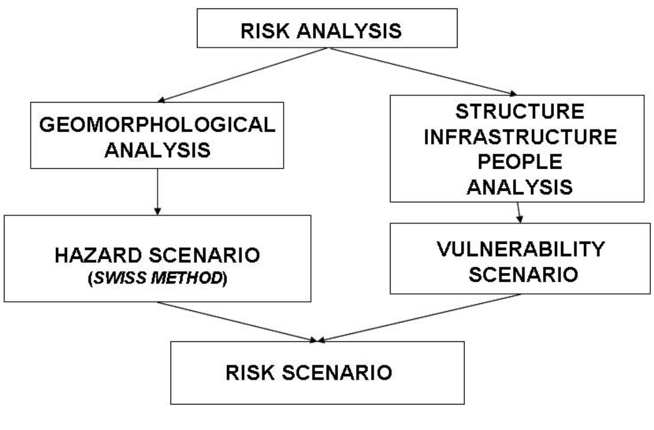


FIG. 5 - The scheme shows how it is possible to define the Risk scenario. Geomorphological analysis permits to produce the hazard scenario, while an analysis of the structural and infrastructural elements, which can be involved by the hazard, permits to produce the Risk scenario (modified after Sterlacchini & *alii*, 2007).

After that, qualitative risk scenarios were constructed combining hazard with the expected degree of physical effects on the buildings and infrastructures. Four risk classes were generated, each providing some general information on possible consequences. In the last step, contingency plans were prepared to be managed by PETer® (The Protection and Emergency TERritorial plans).

Risk evaluation

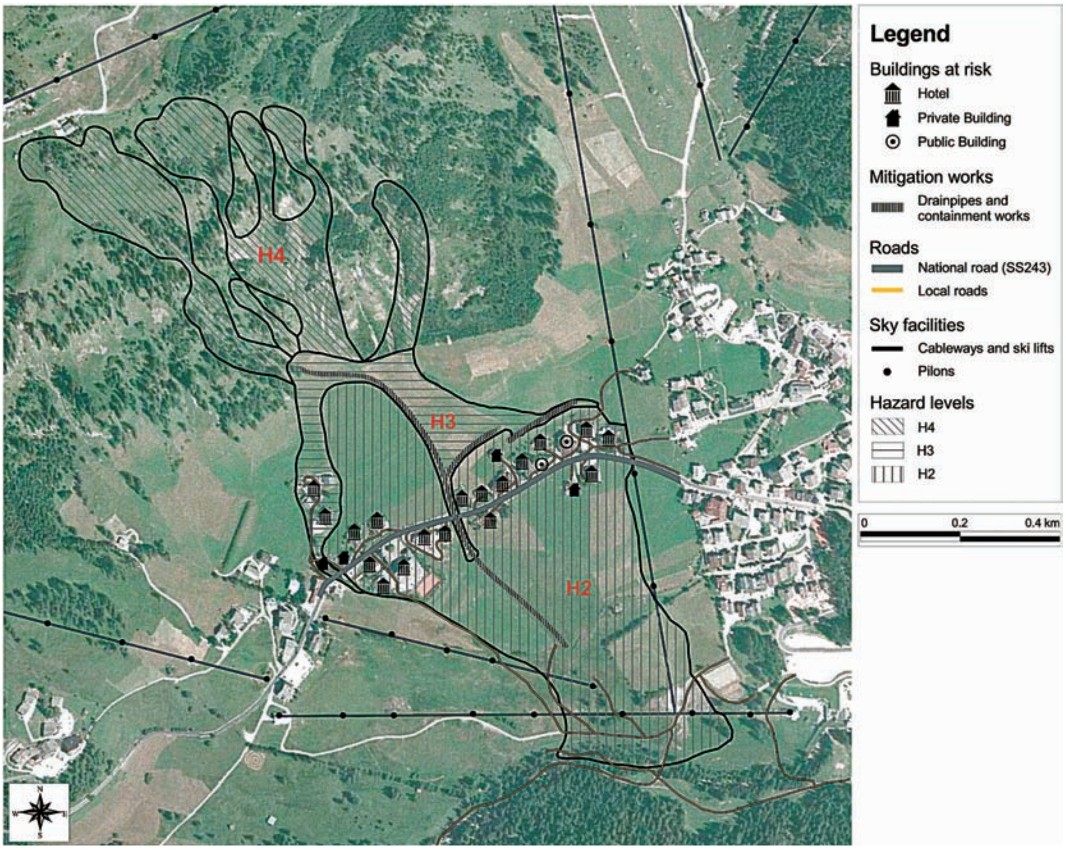
Let us consider, as an example, some results from the Plan Pezziè study area (an administrative division of the municipality). Plan Pezziè is affected by dormant low thickness earth-debris flows; the large number of debris cones mapped in the area is a clear indicator of an important gravitational activity over long periods. According to «the Swiss Method» (Heinimann, 1999), available data, and expert opinion, the landslides source area (107496 m^2) has a hazard level equal to H4 (maximum level). On the contrary, the landslide depositional area (618349 m^2) was characterised by two different hazard levels: H3 and H2. The level H2 is related with the fact that the area has been partially sheltered from debris-flows by man-made mitigation/protection structures.

A heuristic qualitative scale was used to express vulnerability, considering the physical effects on built-up areas and infrastructures, as shown in the hazard scenario of figure 6 (Sterlacchini & *alii*, 2007). The damage was estimated for each type of element at risk. None of those elements at risk is located in the source area, level H4, where structural damage would be expected. In such hazard level the potential event may lead to a rapid destruction of buildings and infrastructures; people are at risk of injury both inside and outside the buildings. Functional damage should be expected in the upper part of the depositional area, level H3, but no structural damage is expected there as long as the construction type has been adapted to the present conditions; people are at risk of injury outside the buildings. Functional/aesthetic damage is possible at the lower part of the depositional area, level H2; people are at a low risk of injury only outside the buildings. This area is mainly an alerting domain, where people should be notified of risk likelihood.

Finally, the risk levels were obtained combining information from hazard and vulnerability estimations, as shown in the risk scenario of figure 7. The risk can be qualitatively described as follow:

– Very low risk: this concerns all sectors without elements at risk, irrespective of the hazard levels.
– Low risk: in the lower part of the depositional area, where the location of local roads and skiing facilities made them safe from severe damage.
– Moderate risk: in areas characterised by elements at risk (16 hotels, 3 private houses, and 2 public buildings) in hazardous areas (class H2).
– High risk: in the westernmost sector of the scenario (class H3) where, in spite of the presence of mitigation/protection structures, local experts suggested that the area is not as safe as the previous one. In this domain two hotels and a private house are at risk.

FIG. 6 - Plan Pezziè hazard scenario (modified from Sterlacchini & *alii*, 2007). Hazard levels range from H4 to H2 moving from the source to the depositional area.



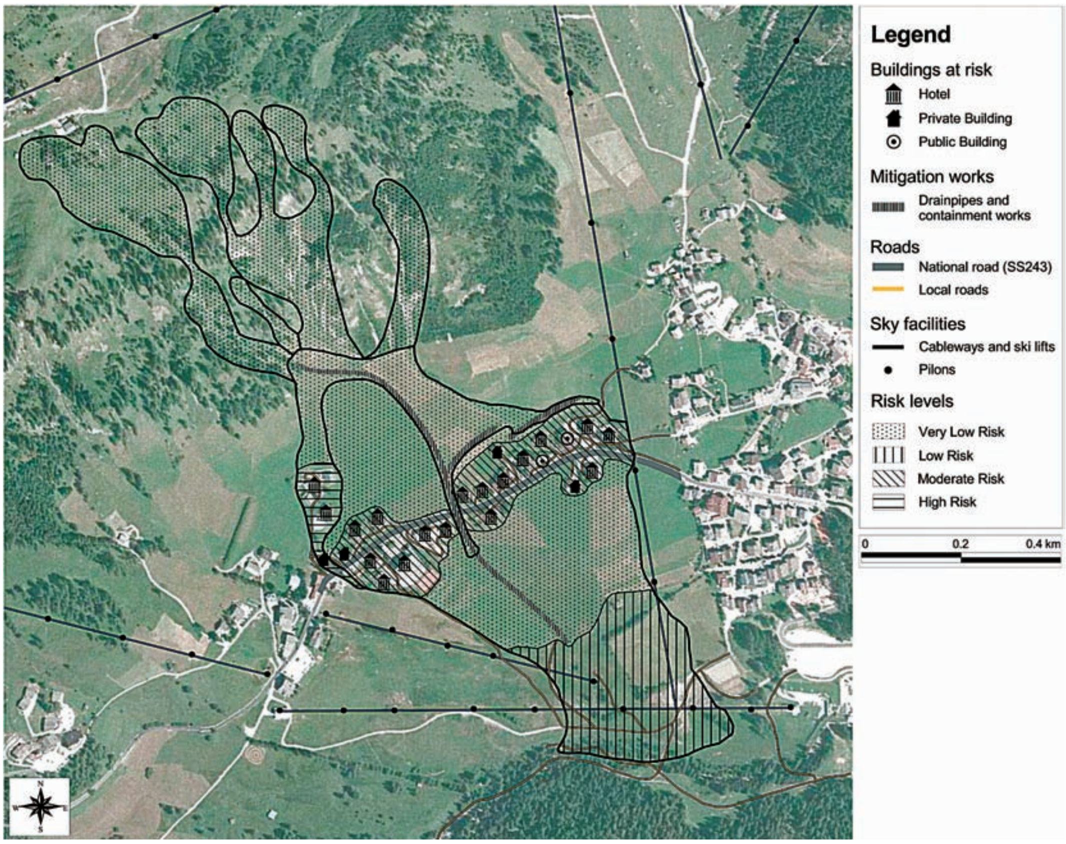


FIG. 7 - Plan Pezziè risk scenario (modified from Sterlacchini & *alii*, 2007). Risk levels range from «Very Low Risk» to «High Risk».

Risk reduction

A contingency plan was set up and tested in the study area (STERLACCHINI & FRIGERIO, 2010), through the integration of GIS tools (for storing, managing, analysing and representing geographical data), Decision Support System (DSS), and Information and Communication Technology (ICT). All that was for defining and controlling the decisional processes in terms of:

- procedures to be executed sequentially (according to the laws in force);
- people responsible for each procedure;
- instructions to be followed;
- documents to be drawn up;
- resources for coping with each phase of the emergency;
- tools for communicating/transferring the procedures to people in charge of taking actions.

A contribution by Corvara in Badia and Colfosco fire brigades and technical staff was the basic issue for the database set up, able to manage dynamically all of the structures, resources and people in charge involved in emergency management. A full-blown integrated solution by Geographic Information System, Decision Support System and Information and Communication Technology (object-oriented but clearly user-friendly to avoid any gap between final stakeholders and scientific support) offers a smart solution to tackle critical changeability and worsening conditions in emergency (fig. 8). The feedback to a critical situation is performed by direct action in the field (a Civil Protection Plan or a workflow cannot substitute first aid acts, evacuations, assistance over the affected area or supervision of buildings while stability appraisal is carried out); a chain of advice, orders, reminders and direct links can be a correct guide to face an emergency, also if it can never be completely adapted to the dynamic nature of a disaster event. For this reason the dynamism and resilience of a management system could be a well arranged solution for critical situation. A relational database was created and all information (georeferenced or not) was organized in specific graphic interface (logic criteria and Civil Protection Official Protocol «Mercurio», 1985), following different aims: to offer quick form for information query and spatial data management (editing, exporting, upgrading), to avoid data redundancy and unnecessary loss of time (particularly dangerous a in critical phase), and to consider every kind of spatial and attributive relationship involved.

A switched network system allows a separate management of every potential entity involved: the structures available for civil protection were gathered as first in Plan Pezziè area following typology and usefulness concepts. Buildings

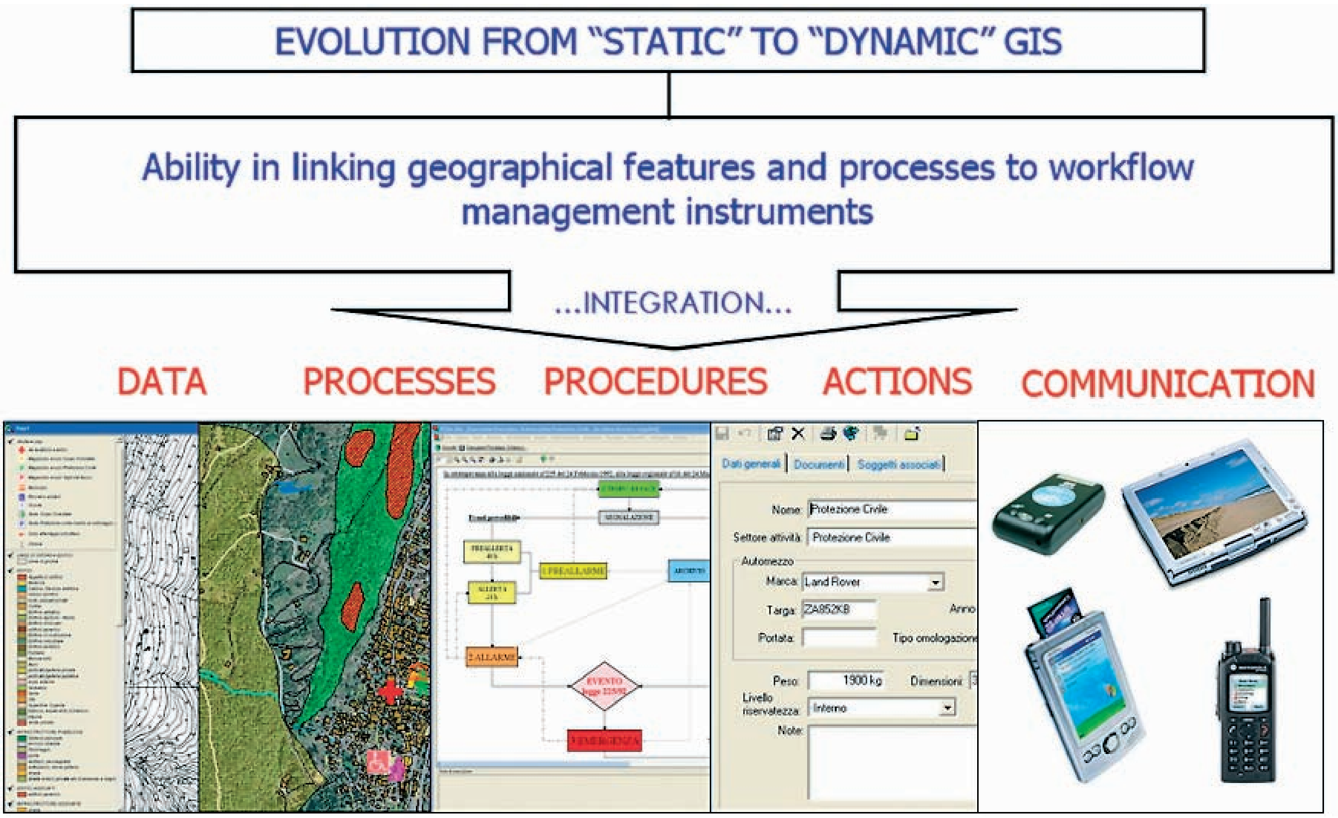


FIG. 8 - The phases of a real-time crisis management that can be accomplished effectively by the integration of GIS tools, Decision Support System, and Information and Communication Technology.

were split for use: residential, industrial, commercial and touristic like vulnerable elements or potential accommodation facilities; infrastructure was considered for type and capacity (roads, power lines, pipelines, water lines, telephone system, sewers and ski facilities). Different structures (primary and nursery school, municipality rooms) were identified and georeferenced with all information available, for a total accommodation capacity of 550 people.

To achieve a resources catalogue, the available features were tailored to the activity pattern: within Corvara in Badia municipality, a dataset about means of transport and mechanical staff was performed (every available resources by the Corvara in Badia and Colfosco fire brigades were updated and organized).

Inside the framework, an electronic address book was integrated with all entities involved, to have every time people in charge (Mayor, fire brigades, volunteers, technicians, staff) for an emergency step, to avoid misunderstanding and slowness in communication (fig. 9). All fire brigades contacts within Corvara in Badia and Colfosco were already managed with personal info, phone numbers and availability.

A Decision Support System (DSS) is the way to create a workflow of action, instruction and correct approach to the emergency management. Correct sequence of rules, logic purpose, law in force reminders and people in charge highlighting for every step-of-action define the best way to effort the emergency support.

Sequences of blocks, connectors, icons, and coloured styles take care of every information involved, training the stakeholder to a correct use of resources and structures involved. This flow of information was previously tested and actually planned for the study area, offering guide lines for Civil Protection Plan and digital informatics support to emergency management. At the end, this kind of solution is able to increase the resilience and efficiency of the system, especially in chaotic and not clear situation, to reduce sensitively time of first aid and improve the quality of direct support.

CONCLUDING REMARKS

Since landslide risk is generally increasing worldwide and the costs it generates will be even more unsustainable in the future, it becomes mandatory to develop risk management strategies (Greiving & Mayer, 2009; Mountain Risks, 2007). These must be applied to reduce the hazard and/or the vulnerability and/or the value of the elements exposed to risk. Such strategies depend on the area involved (regional to local extension), on the cost of the prevention measures, and on the time of application.

Interventions on the predisposing factors could reduce the hazard levels but with likely high costs, and with lengthy and sometimes inefficient results. Also the triggering factors are bound to increase the hazard, especially if they are connected with or induced by climate change.

Mitigation strategies must be better focused on vulnerability of the structures and infrastructure that can be affected by mass movements. According to the proposed methodology, it is possible to produce hazard and risk scenarios in which phenomena can be identified and charac-

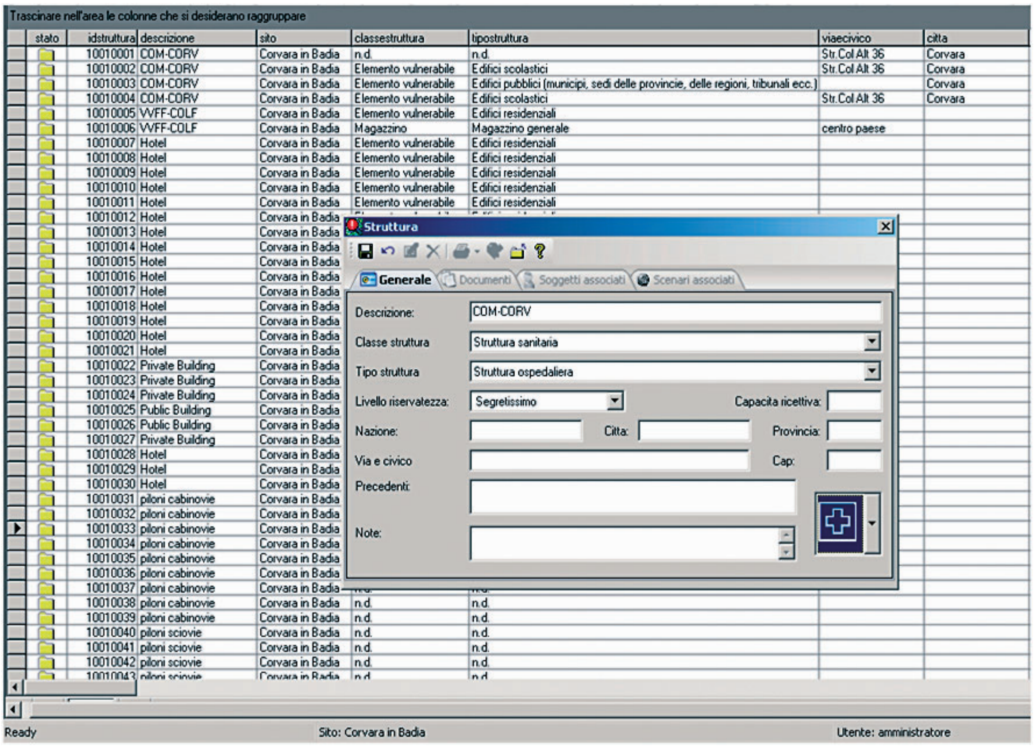


FIG. 9 - List of structures really available to cope with emergency in Corvara in Badia Municipality.

terised in advance. The hazardous areas and the vulnerable elements can be assessed and prevention plans can be designed and set up in advance.

GIS techniques and Decision Support System allow to design and set up prevention plans in advance, in relation to specific hazards. Anyway, local and regional planning is the only tool that is really available for a meaningful reduction in landslide risk.

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