

Systematic GIS-based landslide inventory as the first step for effective landslide-hazard management

Abstract The purpose of the so-called IFFI project (*Inventario dei Fenomeni Franosi in Italia*—Inventory of Landslides in Italy) and of many other related activities carried out by the *Centro Regionale per le Ricerche Territoriali e Geologiche* of ARPA Piemonte (*Agenzia Regionale per la Protezione Ambientale*—Regional Agency for Environmental Protection), is to map all the existing landslides in Piemonte (including both results of monitoring data and available historical data). ARPA carried out new systematic surveys using airphoto interpretation and created a specific alphanumeric geological information systems (GIS)-based database to store and process all the collected data. In order to obtain proper landslide-hazard zoning, it is necessary to provide a landslide inventory and to define the relationship between landslides and geological setting. A landslide inventory represents a fundamental base of knowledge, is a very basic tool for land planning, and strongly helps the local authorities in their decision making.

Keywords Landslide inventory · GIS · Data spreading · Hazard management

Introduction

In 1978, the *Regione Piemonte*, in northwest Italy (Fig. 1), created a *Servizio Geologico* (Geological Survey) in order to cope with problems deriving from landslides and flooding. In 2002, both structures and personnel of the survey were moved to ARPA Piemonte, *Agenzia Regionale per la Protezione Ambientale* (Regional Agency for Environmental Protection). The *Centro Regionale per le Ricerche Territoriali e Geologiche* of ARPA Piemonte is now in charge of collecting all possible information concerning landslides, the geomechanical characteristics of earths and rocks, and the management and development of the regional landslide-monitoring system. It is also responsible for:

- management of the geographical information system of ARPA Piemonte;
- definition of criteria useful to landslide-related hazard assessments;
- diffusion of information and knowledge concerning landslides and flooding.

A first systematic landslide inventory map (1:100,000) was produced for the regional territory in the 1980s with the aim of identifying the most critical and hazardous areas (about 9,000 landslides involving bedrock). In the 1990s, the geological information system (SIGeo) was powered by important data related to landslides through systematic analysis of historical and technical archives (last 150 years), including newspaper articles.

The IFFI project

In Italy, a specific law, the 183/1989 (*Norme per il riassetto organizzativo e funzionale della difesa del suolo*), requires a systematic preliminary

evaluation of natural hazards for proper land-use planning. This law created the *Autorità di Bacino* (Interregional Land Use Authorities), which, along with the regional administrations, is in charge of land-use definition in regard to natural phenomena, such as landslides and flooding. In 1997, the *Comitato dei Ministri per la Difesa del Suolo* (National Land Use Committee), on the basis of the law 183/89, promoted the IFFI project (Amanti et al. 2001) in order to provide a standard methodology for landslide classification (a national working group prepared the project guidelines) and to improve the state-of-knowledge of landslides in the whole of Italy. The IFFI project contributes to the production of a national homogeneous landslide information system in order to provide the base for better landslide-hazard evaluation. Since the existing data were scattered and heterogeneous, the guidelines defined a specific method for the collection and processing of the information, defining three levels of landslide knowledge, depending on the available information. The first level defines a basic landslide classification (shape, location, state of activity and type); the second level includes more detailed data from field surveys; the third includes data available from the pre-existing detailed studies. The use of a specific alphanumeric geological information systems (GIS)-based database allows storage, mapping and processing of the collected data.

In *Piemonte*, most of the activities were carried out directly by ARPA, which also coordinated the action of other agencies involved in the project (local administrations, National Research Council, and universities).



Fig. 1 Piemonte (red colour) is an area of about 25,400 km² located in the northwestern Italy. The Alpine mountain chain surrounds a part of the region with a length of more than 400 km and a width of 150–250 km. A wide hilly environment is present in the south-central part of the region

The project lasted for about 3 years (2002–2004) and involved 20 geologists (12 by ARPA) with good technical GIS skills. The IFFI Project provided a chance to systematically validate, standardize and improve the original data stored in many different formats, files and papers, and to update regional landslide knowledge. Furthermore, the project was an opportunity to exchange the data and strategies with other regional authorities.

Adopted methodology

A methodological approach, shared by several Italian national and regional authorities, based on conventional approaches was applied in order to obtain standardized and comparable results. First, we considered the great deal of geological information filed in regional and ARPA archives as a result of 30 years of landslide data collection. The adopted methodology started from the analysis of the existing alphanumeric and cartographic data. Afterwards, a detailed airphoto interpretation was carried out on the whole regional area in order to review the existing data and to collect the minimum required information (regarding location, size and shape, type of movement, state of activity and general movement direction) where these data were missing. Other detailed information (second and third level) came from the direct surveys in the field and from more detailed studies of the examined sites. Classification of landslides (type, activity, general features, etc.) was made referring to the international literature, and particularly to Varnes (1978). In order to simplify the cartographic representation of numerous and very small single phenomena that affected homogeneous areas, an additional term, which integrates the standard landslide movement classification of Varnes, was also introduced. With the term “areas affected by . . .” it was possible to classify easily the slope sectors affected by these widespread phenomena of instability. There are three types of affected areas: areas affected by seasonal widespread falls/topples, areas affected by shallow landslides/rapid flows, and areas affected by widespread sinkholes. All these areas are characterized by the association of numerous single phenomena triggered during a single heavy rain event, or by the seasonal repetition of single quite rapid and small movements.

Evaluation of state of activity is not an easy matter, for displacement data are rarely available, but it is important because it includes information about time evolution of the landslide. If geological surveys or instrumental data were available, we referred to the classification of Cruden and Varnes (1996). If displacement data were not available, the IFFI Project used a morphologic approach for the analysis of landslide features. In order to produce objective and standard data for the whole region, we devised a specific evaluation method that takes into account the following points (Fig. 2):

- Landslide movement type. The state of activity evaluation is different between rapid landslides and long-lived slow landslides;
- Morphological environment. Recognition of landslide movement landforms is linked to geological–climatic–anthropological features, as a result of the relationship between landslide evolution and morphologic changes due to natural and human action;
- Observation date. State of activity refers to the date of the survey, to the date of the airphotos or to the date of the available documentation used for the evaluation.

In order to obtain a high-quality geographic database, we developed a rigorous data-validation procedure. Some specific tools enable us to point out the topologic error in the geographic data and to check the reciprocal completeness of alphanumeric and geographic data and their logical relationship (such as wrong or missing information). All

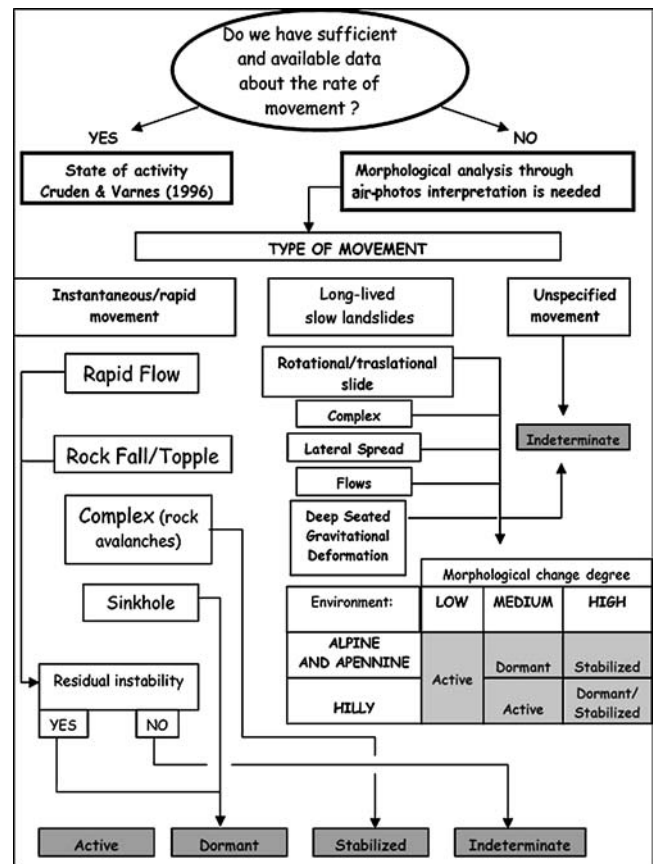


Fig. 2 This flow chart shows the methodology used by ARPA to define state of activity of landslides. If data about rate of movement were not available, the IFFI Project used a morphologic approach for analysis of landslide features. For long-lived slow landslides, the evolution of landslide surface features and morphologic changes are the key to define the state of activity. For rapid instantaneous landslides, such rock falls or shallow landslides, the state of activity is defined by means of an estimation of residual instability

data are periodically collected, stored and checked to yield a validated database.

Result analysis

The number of mapped landslides has grown considerably compared to the first regional inventory study (1:100,000 landslide mapping carried out for the entire regional territory in the 1980s). Today, on the bases of IFFI results, about 34,000 single phenomena have been identified and analysed.

The knowledge also increased in terms of data quality: the old 1:100,000 landslide mapping was simply cartographic description without distinction of landslide type (only an activity distinction was made). On the other hand, the new landslide inventory collected several relevant parameters in a specific database. About 300 out of 34,000 analysed landslides include detailed information (second and third level), such as activation date, landslide control, specific investigation, monitoring, detailed damage information, etc. (Table 1).

About 12% of the hilly and mountainous areas and 10% of the entire Piemonte territory are affected by landslides. IFFI mapped almost 600 deep-seated gravitational deformations (DSGD); more than 2,300 large complex landslides; 11,600 slides; over 6,800 rock falls and topples; 2,700 slow flows; 1,800 non-defined landslides and

Table 1 The table resume some of the detailed landslide information collected in a specific geo-database^a

Level	Data type	Number of data
1°	Damage	2,751
1°	Iconographic enclosure	892
1°	Bibliographic information	8,363
1°	Morphological element	Over 5,800
2°	Detailed damage information	615
2°	Triggering date	1235
2°	Geological information	461
3°	Structural countermeasures	229
3°	Specific investigation	519
3°	Hydrogeological information	121

^aData are stored in three different level of knowledge

8,000 shallow rapid flows/areas affected by shallow rapid flows (Figs. 3 and 4).

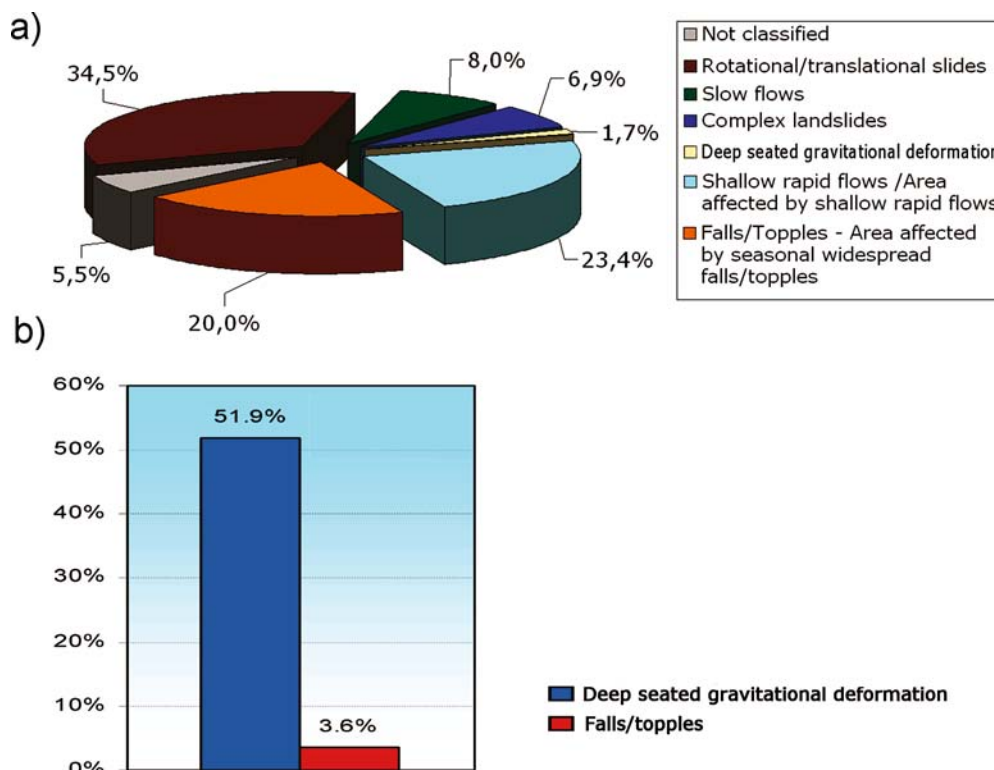
The study points out a definite zoning of the various landslide types linked to different geological settings. These different settings are the result of the interaction among different influencing factors: the litho-technical characteristics of the rocks, the different geo-structural settings and the climatic conditions and regimes (Fig. 5). The *alpine environment* of Piemonte with high slope gradients, low daily mean precipitation, and the presence of foliated and unfoliated rocks is characterized by the presence of rock falls/topples, large complex landslides and deep-seated gravitational deformation. The DSGD are not great in number, but, referring to areal distribution, they affect more than 8.4% of the *alpine environment*. The *prealpine environment*, with lower slope gradients (generally less than 30°), higher daily precipitation, vegetated slopes and widely distributed soil cover is mainly

affected by shallow landslides and rotational slides. The *Langhe Region of Piemonte* (Fig. 5) is characterized by asymmetrical valleys, with steep southeast-facing slopes and gentle northwest-facing slopes, and a monocline succession of marl and sand-stone layers. Owing to this particular structure, translational rock-block slides and shallow landslides make up the majority of the landslides. Over 20% of the *Langhe Region* is affected by landslides; about 55.5% are translational rock-block slides and 33.1% are shallow landslides. Finally, the hilly southeastern part of *Piemonte* (*Appennine/Torino hill environment*) is characterized by sedimentary clayey rock and occurrence of slow flow landslides. More than 7% of the *Appennine/Torino hill area* is affected by landslides; about 21.7% of these are flow landslides (Fig. 6).

Data dissemination

In order to overcome the drawbacks related to conventional paper maps (high costs and difficulty of updating), the results of the project, after final revision and validation, were disseminated by means of specific intranet–internet services with two different ways of access. The first one is restricted to the public administrations, through RUPAR (the Italian intranet service for public administrations); the second one has free access through the ARPA Web-GIS services (Fig. 7). The latter system also allows crossing IFFI data with other geographic information by simple use of a conventional Web browser. Periodic revisions of data will be scheduled in order to provide an up-to-date database. Data are provided by a detailed metadocumentation, based on European Standard, defined by Technical Committee CEN/TC 287 “Geographic Information”. Indeed, data are not significant without detailed information about their quality, source and use limitations. Metadata represent the added value of data, particularly when the data are processed. A correct data description allows optimum use of information and avoids improper use. Other data, such as general documentation, cartography, geological information and

Fig. 3 (a) This pie chart shows the percentages of landslide types in *Piemonte* in regard to total number of landslides. Percentages by areas are not an easy matter because of landslide superimpositioning, so, percentages refer to number of IFFI landslides. “Areas affected by . . .” are counted as singles phenomena. (b) Referring to statistics by areas, results change considerably: e.g. in the Alpine environment the deep-seated gravitational deformations are 4.7% referring to total number of landslides but 51.9% referring to total area affected by landslides. Falls and topples are 14.4% referring to total number of landslides but 3.6% referring to total area affected by landslides





Rock falls and topples

are very common in the alpine environment, particularly in massive rock units. Movement is very rapid to extremely rapid; it can involve roads, houses, and human activities. Often these landslides border the middle-lower part of deep seated gravitational deformations



Deep seated gravitational deformations

involve all of the principal geo-structural units of western alps, with a higher frequency in metamorphic schistose rock units. The upper part of the slopes exhibit a clear dislocation, characterized by ridge-top trenches with elongated depressions. The middle-lower parts of the slopes show a bulge morphology due to rock-mass dilatancy. Sometimes these phenomena could evolve into other types of landslides

Complex landslides

are equally distributed in the Alpine and Appennine environment. They are characterized by a low probability of evolving as catastrophic events, but can have very large direct and indirect impact on human infrastructures and environments.



Rotational/traslational slides

occur predominantly on surface of rupture or relatively thin zones of intense shear strain. These are the most common landslides in Piemonte. Translational slides are generally diffused in Prealpine and Appennine/Torino Hill, whereas translational slides are typical of the Langhe environment.



Shallow rapid flows

involve thin colluvium and are triggered by severe meteorological events. They are very common in the Prealpine and hilly environment. Despite the modest volumes involved, these landslides are very dangerous due to their velocities.



Slow flows

involve clayey materials with high plasticity. The distribution of velocities in the displacement mass resembles that of a viscous liquid. The movement is slow or extremely slow and can alternate between periods of acceleration and stoppage. Flows can remain active over very long periods, thus causing considerable damage to property and roads.

Fig. 4 Main type of landslides that affect Piemonte

Fig. 5 The chart shows the numerical distribution of landslide types subdivided by different geological–geomorphological environments in Piemonte

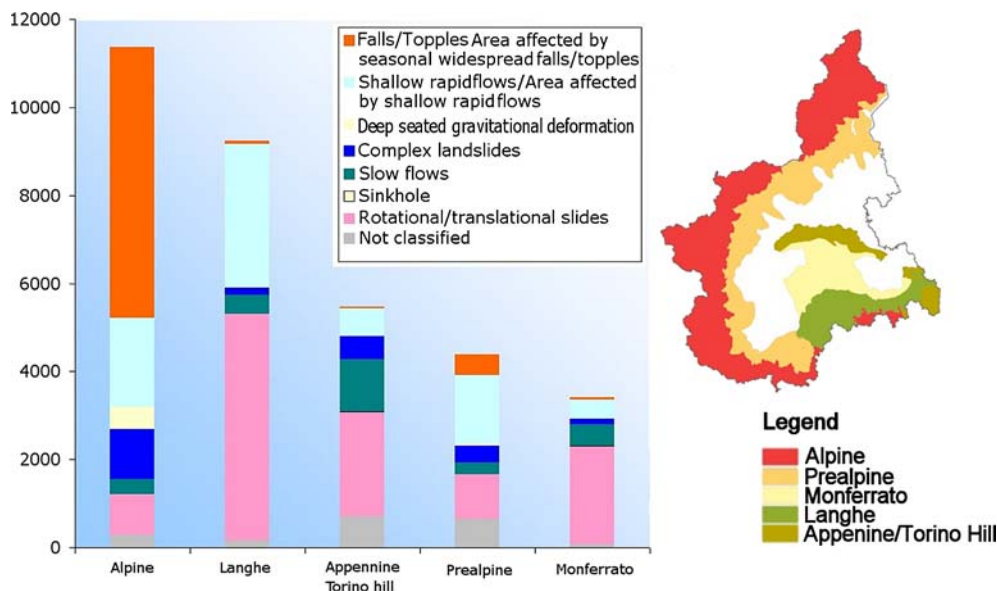


photo-video archives, are not available by net, but are available in ARPA Piemonte.

Documentation and methodological approaches to the understanding of phenomena, developed by ARPA, are made available through events, publication of conventional papers and maps and through internet services (Fig. 8). In this way, all potential users (professionals, public agencies, local authorities, etc.) can easily reach the available data. Data are cost free and available at the URL: <http://www.arpa.piemonte.it/>.

The use of datasets for effective land-use management

Proper land planning and risk management requires both an accurate analysis of natural phenomena at a regional scale and an in-depth knowledge of the evolving mechanisms, landslide type, frequency and spatial distribution of mass movements. The organization of data at different levels of investigation satisfies both needs: enough standardized information at regional level and a suitable level of detail on a limited number of more interesting phenomena. A GIS-based landslide inventory is a tool that allows effective analysis of this kind of data at several scales. Analysis on a regional scale allows some important considerations useful for hazard and risk evaluation. At medium scale, specific models for every kind of landslide can be applied in order to define a more effective hazard framework. At last, a detailed analysis on single phenomena is an important aid in managing short-term emergencies and satisfying specific demands of local government administrations.

The system described tries to provide a very simplified methodology to obtain a preliminary and qualitatively regional hazard framework. This methodology is based on basic landslide information (IFFI first level). In order to elaborate a landslide hazard map, it is necessary to assess the possible intensity of the natural phenomena, as well as the probability of occurrence of an event of any intensity (Prina et al. 2004). First, we grouped landslides into three different velocity classes on the basis of the type of movement. Then the class of velocity was crossed in a matrix form with their extensions to estimate the intensity (Fig. 9). Here the intensity means a measure of the destructive potential of a landslide based on a set of physical parameters, such as downslope velocity, thickness of the landslide debris,

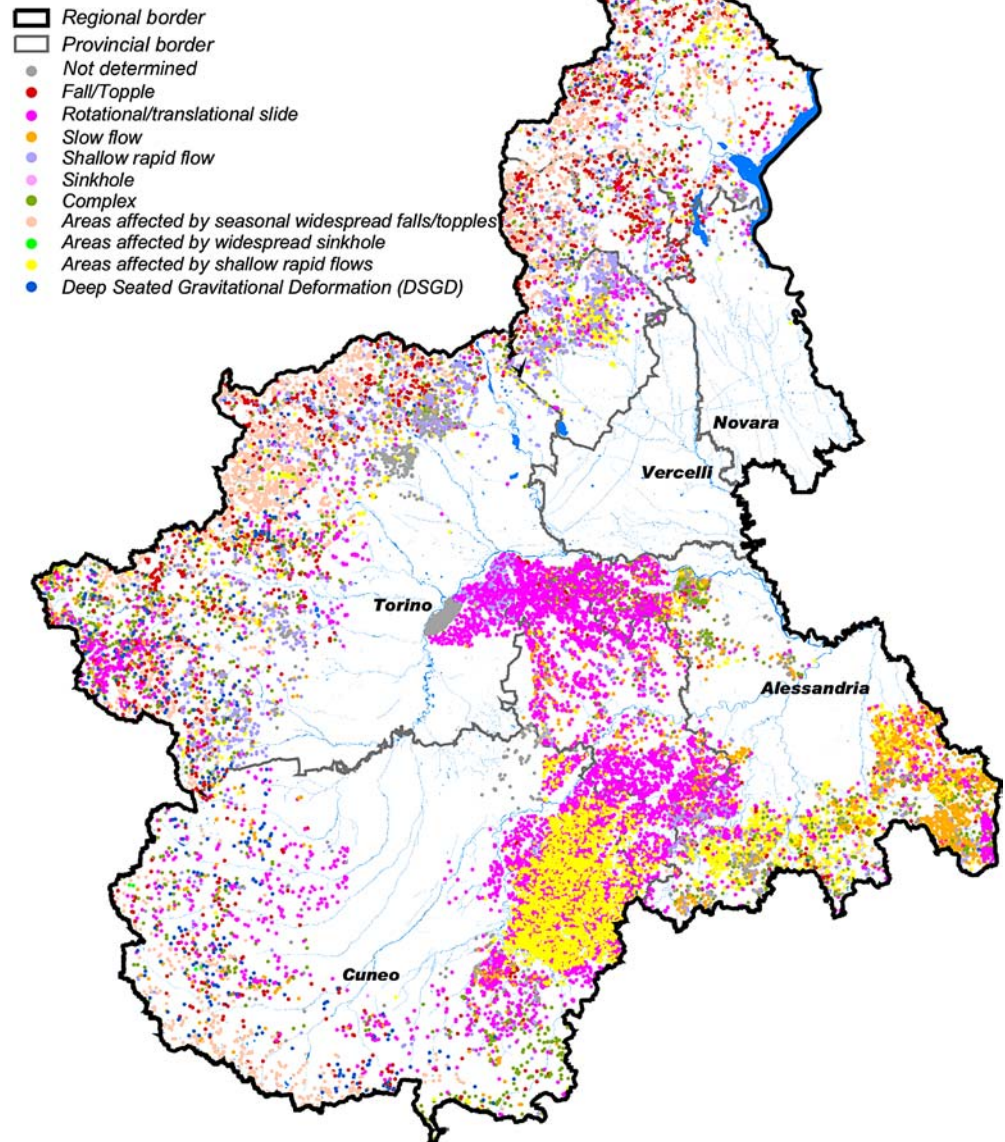
volume, energy and impact forces (Fell and Hartford 1997). Evaluation of the probability of occurrence at regional scale is a difficult matter. Note that here Probability of occurrence means the likelihood of a specific outcome, measured by the ratio of specific outcomes to the total number of possible outcomes (Fell and Hartford 1997). The state of the activity, as defined in the IFFI project, includes indirect information about the frequency of reactivation because a morphological criterion was used. For *long-lived slow landslides* (REGIONE PIEMONTE and SUPSI 2002), the evolution of landslide surface features and morphological changes are the key to defining the state of activity. For *rapid instantaneous landslides*, such *rock falls* or *shallow landslides*, the state of activity was defined by means of an estimation of residual instability and thus turned into a qualitative probability of occurrence. The intensity was eventually crossed with the probability of occurrence to define four different hazard levels (low, medium, high and very high).

It is important to remember that the framework of Fig. 10 has a purely indicative character, but it is useful in identifying areas for which a detailed survey is mandatory. ARPA Piemonte uses this simplified landslides hazard map, crossed with the element at risk coverage, to focus the attention to the more serious phenomena where close examination is needed. Note that here element at risk means the population, buildings and engineering works, economic activities, public services utilities and infrastructure in the area potentially affected by landslides (Fell and Hartford 1997).

A more detailed hazard analysis was made by ARPA Piemonte for specific types of landslides on restricted areas. Over an area in southern Piemonte, with a very high landslide density and strongly affected by the November 1994 heavy rains, ARPA Piemonte produced landslide hazard maps (at 1:50,000 scale) both for *translational rock-block slides* (Fig. 11) and *shallow landslides*. This study was aimed at increasing the reliability of the hazard evaluation methodologies and reducing the uncertainty related to both the choice of input parameters and to the variability of the measures. The study was focused on a 470 km² wide area affected by these two particular kinds of landslides. These movements occur in complex upper Miocene formations, including predominant marl, silt-marl and sandstone

Fig. 6 Spatial distribution of the 33,965 landslides in Piemonte analysed by means of the IFFI project. Due to scale of representation, landslides are represented by points

Simplified map of IFFI landslides



lithotypes in rhythmical sequences, characterised by a monoclinical layer with a small variability. These landslides are characterized by:

- high number of landslides triggered by a single rainstorm;
- high spatial concentration;
- long runouts.

The first step for both landslide types was to prepare a detailed landslide inventory, after which separate approaches were used for the two types of landslides. In order to make it easier to cope with very large datasets all data processing was implemented in a GIS environment. A statistical model (multivariate statistical techniques) has been adopted for the *translational rock-block slides*. The results obtained confirm the reliability of the predictive power of the multivariate analysis, which is able to evaluate the landslide hazard.

For *shallow landslides*, a simple model based on the Montgomery and Dietrich method (Montgomery and Dietrich 1994) was adopted. This model couples a steady-state hydrologic and an infinite-slope stability model. In this work, influence of soil type and land cover on slope stability was taken into account, considering parameters as a function of these land features (Campus et al. 2005).

For both the studies, the results of models agree quite well with the field observation related to November 1994 heavy rains. The first model, which refers to *translational rock-block slide*, is able to discriminate correctly more than 75.4% of analysed cell; the second one, which refers to *shallow landslides*, is able to discriminate about 70.9% of analysed cell (Bosco et al. 2005).

The resulting maps are now in printing and will be soon disposable to public agencies working in local land use planning.

Fig. 7 ARPA Piemonte provides much geographic data by means of Web-GIS services. This system allows access to data by simple use of a conventional Web browser. It is also possible to query data information and to cross data with other different geographic information

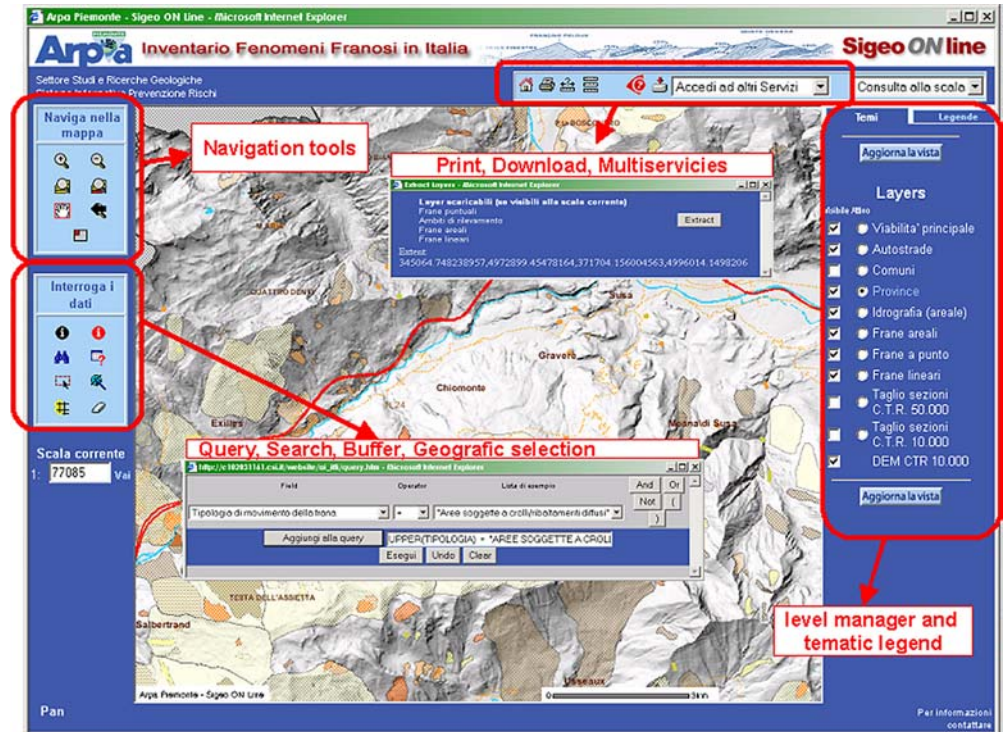


Fig. 8 Several types of information are available through Web-GIS Services, such as: meteorological radar, geologic maps, hydro-geological maps, geotechnical surveys, seismicity, avalanche information, and more. All of this information is part of ARPA Piemonte Sigeco



ARPA also carries out in-depth analysis on the more serious phenomena where detailed examination is needed. All over Piemonte several devices have been installed to monitor landslides that occur close to facilities or built-up areas. These systems were installed by public agencies and administrations and the regional government of Piemonte created an administrative unit to manage the landslide monitoring network. The network now includes about 300 monitored sites; each site includes an active or potential landslide that threatens buildings, roads, or urban areas and includes one or more

active instruments. Up to now, movement has been recorded at about 110 sites. The relevant figures concerning the network are summarized in Table 2.

The monitoring network is extensive (Fig. 12), i.e., it includes many sites with few, mostly conventional instruments (inclinometers, piezometers, extensometers, and topographic benchmarks).

The general goal is, in fact, to monitor many known landslides over large time spans rather than acquiring detailed information on

a limited number of phenomena. In this way, ARPA Piemonte can reinforce local authorities in general decisions and in the aftermath of major calamities. An example of the latter is the case of *Bognanco* (VB), where, after the heavy rains of October 2000, a landslide monitoring system (consisting of four inclinometers) proved its effectiveness in allowing 180 evacuated people to return to their homes in just 3 days (Fig. 13).

At a limited number of sites, where major landslides threaten large built-up areas or important structures, monitoring systems are more complex and include several types of instruments, with automated data recording and transmission. Such systems need to be locally managed, and are thus conducted jointly with local authorities. An example is the *Rosone* landslide (*Locana*, TO), where a complex landslide monitoring system will be connected to warning and evacuation procedures. It is quite important to stress that a monitoring network will never be exhaustive, for not all landslides can be monitored.

		Areal extension				Intensity					
		A1	A2	A3	A4	M1	M2	M3	M4		
Velocity	Very slow	M1	M1	M2	M3	Frequency	Low	P1	P1	P2	P3
	Slow	M1	M2	M3	M4		Medium	P1	P2	P3	P4
	Rapid	M2	M3	M4	M4		High	P2	P3	P4	P4

Fig. 9 Matrix representation of relation between velocity and areal extension used to define the landslide intensity and between frequency and intensity used to define a preliminary landslide hazard (P1: low, P2: medium, P3: high, P4: very high)

For instance, rapid shallow landslides affecting colluvium, such as soil slides/debris flows, although countless and dangerous, are not monitorable, for they are *instantaneous* landslides, in that they occur in a very short time (minutes) during single rainstorms.

Fig. 10 Preliminary regional hazard framework obtained by means of a simplified methodology. This map is purely indicative but it is a useful tool for identifying areas where close examination is needed (second or third level of knowledge)

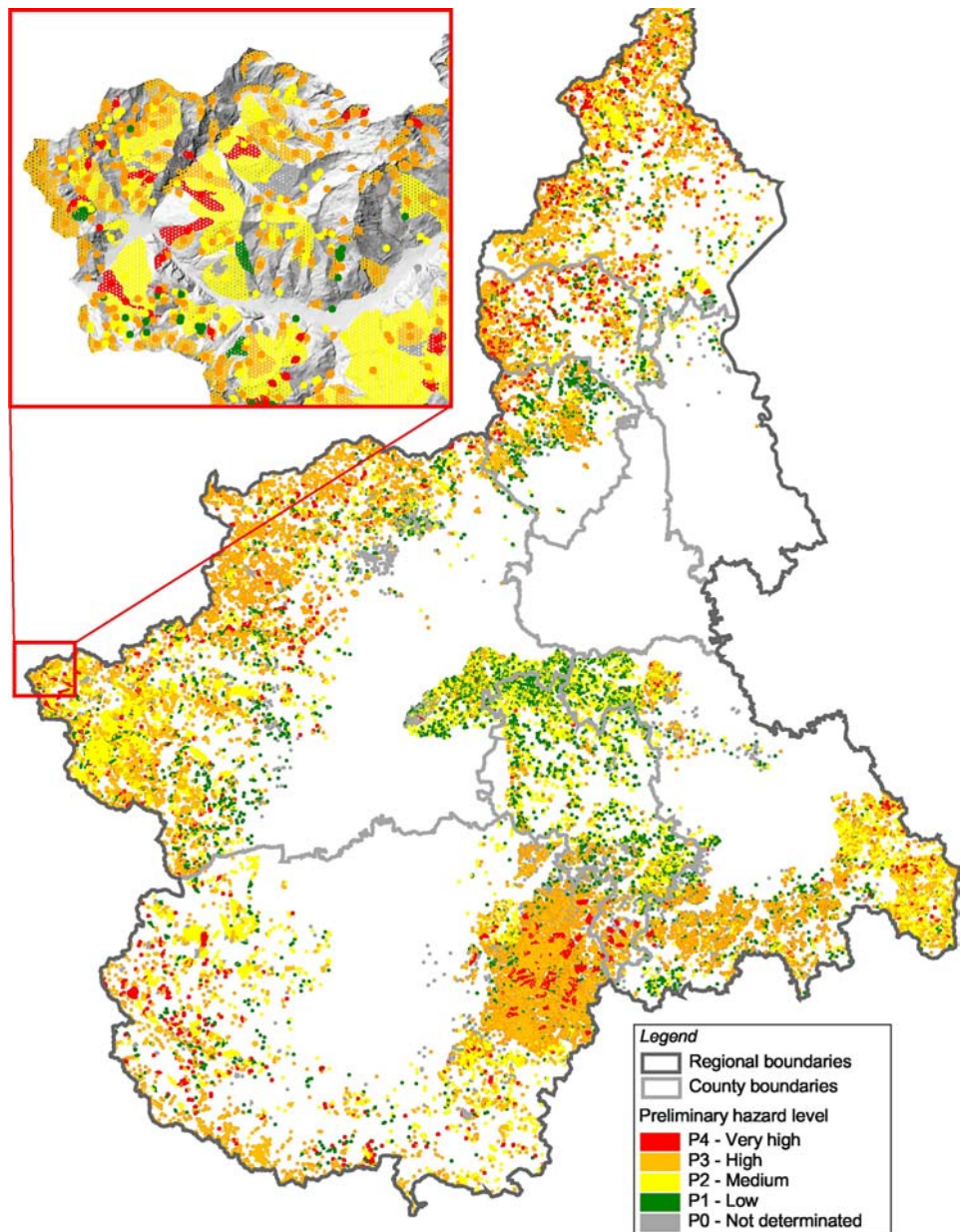
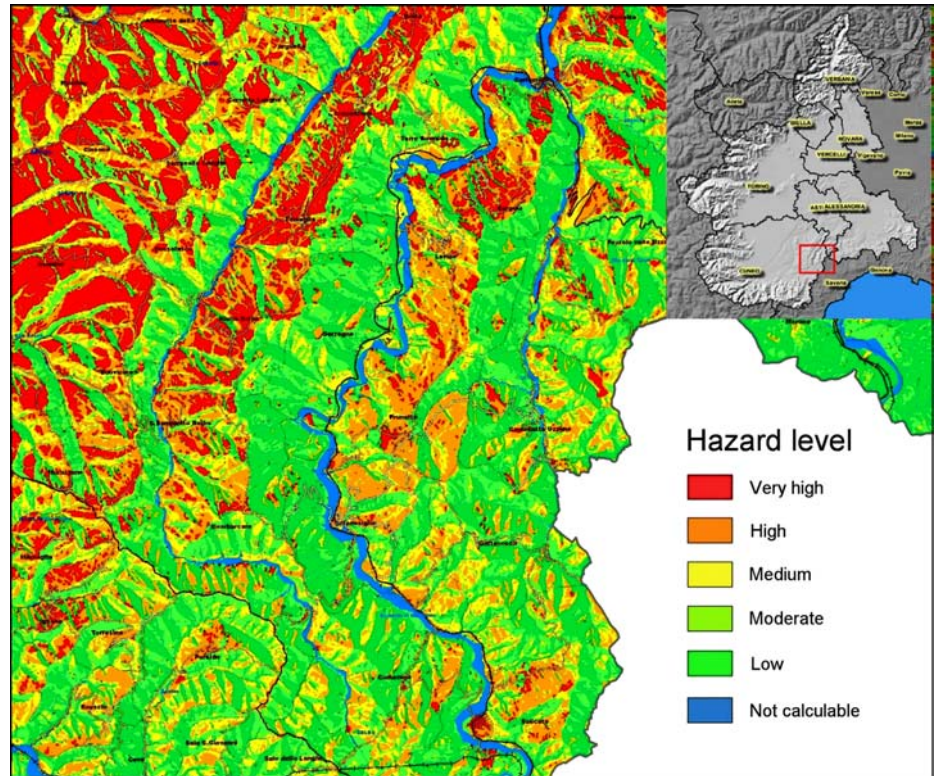


Fig. 11 1:50,000 landslide hazard map for translational rock-block slides



In order to manage the relevant amount of data from the monitoring system, ARPA Piemonte developed specific GIS-based software. The software is part of the package SIGeo, which also includes the landslide inventory and a geotechnical data bank.

Using the datasets in municipal urban planning and territorial management in the area of the Po River Basin

In order to integrate and standardize our datasets we made an effort to combine scientific landslide knowledge (developed by national and regional authorities) with applied information obtained from local governments. IFFI data were used to create and update local land-use planning. All information was furnished, with periodic updating, to professional geologists and public agencies working in local land-use planning. A specific protocol was established to allow data exchange from IFFI to geomorphological maps of local land-use planning and vice versa. Detailed information collected by professional geologists, after appropriate checks, integrates the IFFI dataset. A good agreement between local and regional landslide knowledge constitutes the

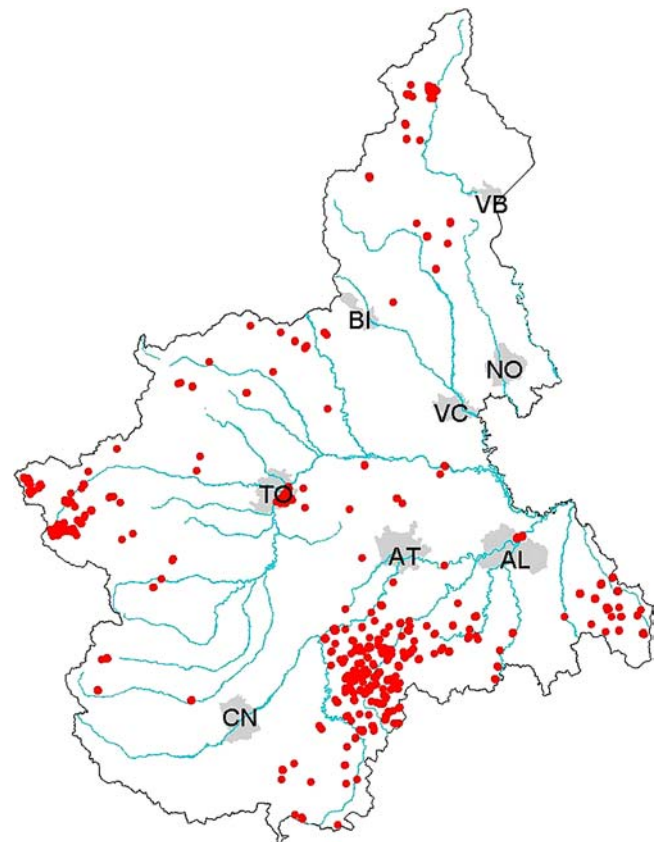


Fig. 12 Monitored landslides in Piemonte

Table 2 Monitored sites and type of instrumentation employed

Monitored sites	300
Inclinometers	650
Meters of inclinometer casing (m)	23,000
Frequency of manual measurements of inclinometers (n/a)	2 to 4
Piezometers	370
Wire extensometers, jointmeters (m)	120
Automated data recording units	120
<i>In situ</i> inclinometers with automated data recording and transmission	20
GSM data transmission units	35
Sites equipped for GPS survey	25
Sites equipped for conventional topographic survey	25

Fig. 13 Fixed points (red arrows) of the monitoring system that recorded movement in October 2000 on the Bognanco Landslide



Fig. 14 The Po River Basin (area 71,057 km²) in northern Italy



fundamental ingenuity for the integration of local and interregional planning.

According to state law 183/1999, the *Autorità di Bacino del Fiume Po*—AdBPo (Po River Basin Authority) supervises and coordinates territorial planning activities of the eight regions adjacent to the Po basin (Fig. 14). Execution of the Basin Plan Project, the main planning and implementation tool of the AdBPo, occurs through regular triennial reviews. Today, the current review phase aims to create an updated hydro-geological instability framework, which tries to integrate the research of the regional geological surveys with the information obtained by the geological maps of municipal urban planning.

The proposed methodology is based on the creation of systems to analyse data organized at various levels of detail. In line with this approach, ARPA Piemonte, as described previously, has launched a series of actions that, by employing GIS techniques, allows the identification of landslide hazards. The purpose of this process is to define various risk scenarios in order to be able to prioritise the structural countermeasures necessary for the mitigation of each risk.

Conclusions

ARPA Piemonte supports locals and regional authorities in hazard and risk management by means of several actions:

- definition and analysis of a landslide inventory at the regional scale;
- achievement, updating and maintenance of the GIS, geo-thematic cartography and working tools;
- realization of studies, research and experimentation to define new interpretative models for a detailed hazard analysis;
- diffusion of knowledge by means of internet services, events, publication of conventional papers and maps.

GIS technology is an essential tool in reaching these goals. A GIS-based landslide inventory allows collecting, management, analysis and dissemination of a large amount of data, widespread in the region. All of these actions, based on continuous scientific and technological research, with a strong multidisciplinary component and the involvement of local, regional, and interregional authorities, allows effective regional land-use planning and risk management.

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References

- Amanti M, Bertolini G, Ramasco M (2001) The Italian landslides inventory – IFFI Project. In: Jorge E, et al. (eds) Proceedings of III Panamerican Symposium on Landslides, Cartagena, Colombia, 29 July–3 August 2001, Sociedad Colombiana de Geotecnia, Bogotá, vol. 2, pp 841–846
- Bosco F, Campus S, Mensio L, Nicolò G, Tiranti D (2005) La previsione delle frane. In: Bovo S, Forlati F (eds), Dalla valutazione alla previsione dei rischi naturali, ARPA Piemonte, Torino, pp 196–214, ISBN 88-7479-082-1
- Campus S, Nicolò G, Rabuffetti D (2005) Le frane riguardanti la coltre superficiale. In: Bovo S, Forlati F (eds), Dalla valutazione alla previsione dei rischi naturali, ARPA Piemonte, Torino, pp 89–98, ISBN 88-7479-082-1
- Cruden DM, Varnes DJ (1996) Landslide types and processes. In: Turner AK, Schuster RL (eds), Landslides investigation and mitigation, Special Report 247. Transportation Research Board, National Research Council, Washington, pp 36–75
- Fell R, Hartford D (1997) Landslides risk management. In: Cruden DM, Fell R (eds), Proceedings of the International Workshop on Landslide Risk Assessment, Honolulu, Hawaii, USA, 19–21 February 1997, Rotterdam, Balkema
- Montgomery DR, Dietrich WE (1994) A physically based model for the topographic control of shallow landsliding. *Water Resources Res.* 30:1153–1171
- Prina E, Bonnard C, Vulliet L (2004) Vulnerability and risk assessment of mountain road crossing landslides. *Communication des laboratoires de mécanique des sols et des roches, Ecole polytechnique federale de Lausanne* 228:67–79
- REGIONE PIEMONTE, SUPSI (2002) Proposta di una metodologia inerente la mappatura e caratterizzazione dei processi di instabilità da sperimentarsi sui bacini dell'alto Toce e della Maggia. In: REGIONE PIEMONTE, SUPSI (eds), Progetto Interreg II Italia Svizzera 1994–99-Collegamento delle reti di rilevamento e condivisione delle esperienze e delle conoscenze per la gestione del rischio idrogeologico, pp 105–117
- Varnes DJ (1978) Slope movement types and processes. In: Krizek RJ, Schuster RL (eds), *Landslides: Analysis and Control*, Special report 176. Transportation Research Board, National Research Council, Washington, pp 11–33

A. Colombo · L. Lanteri · M. Ramasco (✉) · **C. Troisi**

Centro Regionale per le Ricerche Territoriali e Geologiche, ARPA Piemonte,
Torino, Italy
e-mail: manlio.ramasco@regione.piemonte.it
Tel.: +011-3163335
Fax: +011-3169340