Landslides (2006) 3:311–321
DOI 10.1007/s10346-006-0059-7
Received: 25 October 2005
Accepted: 11 September 2006
Published online: 10 November 2006

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UNESCO World Heritage sites in Italy affected by geological problems, specifically landslide and flood hazard

Abstract A National Research Council, Research Institute for Hydrogeological Protection (IRPI) study on Italian monuments included in the UNESCO World Heritage List has revealed that many are affected by geological, geomorphological, and engineering geological problems. These monuments are static entities set in an environment that often manifests highly dynamic processes. As part of the efforts to protect sites of cultural and natural heritage, this study has applied a preliminary and empirical Geographical Information System-based method developed to characterize the environmental hazards at the sites where the monuments are located. Because the study of hydrogeological degradation falls within the province of IRPI, this hazard zoning focuses on river and mountain slope dynamics specifically concerning landslides and floods.

Keywords UNESCO World Heritage · Italy · Hazard · Landslides · Floods

Introduction

Increased concern for the preservation of our cultural and natural heritage coincides with the importance such monuments hold for resources for culture, tourism, and the economy. Some architectural monuments have a high artistic and cultural value, but they are immobile entities set in an environment subject to natural dynamic processes and rapid changes in urban development and landscape evolution. Protecting damaged monuments from natural instability and against increasing pressure from anthropic activities has therefore become vital.

To this end, the International Association of Engineering Geology set up Commission 16 concerning "Engineering geology and protection of ancient monuments and archeological sites". The aim of Commission 16 is to survey the UNESCO World Heritage affected by natural and geological problems. The survey was conducted using a data collection form containing information on the historical and cultural background of the monumental site, its engineering geological conditions and related problems, a description of the survey and protection measures undertaken, the reasons why UNESCO listed the monument, the studies performed so far and accessible in the bibliography, along with photographs and drawings of the site.

The census for the Italian sites on the UNESCO list was carried out by the CNR-IRPI, Turin (National Research Council–Research Institute for Hydrogeological Protection, http://www.iaeg.it/commbeni.htm). The 39 listed monuments distributed across the country comprise cultural, archeological, and natural sites, including natural parks. After data collection and creation of a dedicated database, an analysis of the data showed that about 70% of the monuments are affected by geological problems (Fig. 1a). However, this finding should be examined in conjunction with the fact that Italy, although relatively small in area, presents nearly the entire range of natural risks, including earthquakes, landslides, volcanoes, floods, coastal erosion, and subsidence.

In Italy, hydrogeological risk represents a hazard that ranks second only to earthquakes in terms of casualties and infrastructural damage. The major geological problems for the Italian cultural heritage concerns floods and landslides, whereas subsidence, volcanic eruptions, and earthquakes play a secondary role (Fig. 1b).

Starting from these considerations, this study was directed at developing an empirical method to determine hazard zoning of phenomena resulting from slope and fluvial dynamics. To do this, hazard was defined as the "probability of occurrence of a potentially damaging phenomenon within a given time period and area" (UN-DHA-IDNR 1992). Specifically, the method can offer a preliminary valuable aid for identifying which areas may be involved in hydrogeological degradation and for determining the degree of hazard a cultural monument may be exposed to.

This study may be considered a methodological starting point for more comprehensive research on cultural heritage and its protection. CNR-IRPI, Turin, is also involved in studies on specific archeological sites and monuments in Italy and abroad, including monitoring activity by employing advanced technologies.

Methodology

The chief phenomena of hydrogeological degradation are inherent to slope dynamics and water course that manifest as landslides and floods, respectively, thus presenting diverse phenomena for which different study approaches are needed. Methods for defining hazard zoning will therefore start from different data sets and take different approaches.

In both instances, this study will illustrate the method and how it was applied in two case studies. To analyze slope dynamics, a geosite in Val Germanasca, a small valley in the western Alps, was selected; for river dynamics, a cultural heritage site from the UNESCO list, the village of Crespi d'Adda, Lombardy, central northern Italy, was studied.

A landslide can be defined as the movement of a mass of rock, debris, or earth down a slope. Landslides can have several causes, including geological, morphological, physical, and human, but only one trigger (Cruden and Varnes 1996). The most common natural landslide triggers include intense rainfall, rapid snowmelt, water-level change, volcanic eruption, earthquake shaking, and so forth.

As with the predictability of most floods, the predictability of landslides is extremely difficult, whereas a spatial definition of hazard is feasible. In this approach, various methods have been proposed and developed. The main examples for determining hazard zoning may refer to a method based on landslide inventory

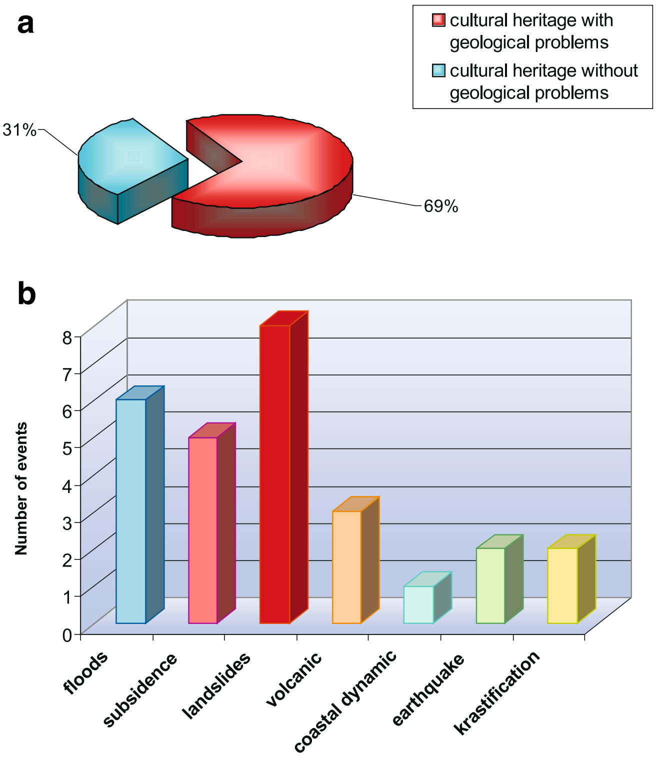

Fig. 1 **a** Graphic representation of Italian cultural heritage monuments included in the UNESCO World Heritage List and affected by geological problems. Many of these monuments are exposed to risk. **b** Graphic representation of the major geological problems affecting the listed Italian monuments. Floods and landslides are the most common problems

or heuristic, statistic, or deterministic approaches (Soeters and Van Westen 1996).

An ideal hazard zoning map of slope instability should include information about spatial-temporal probability, type, intensity, velocity of the phenomenon, run-out distance, and limit of retreat of the moving mass (Hartlén and Viberg 1988). Predicting landslide hazard for areas currently subject to mass movements is based on the assumption that the most dangerous phenomena that occurred in the past will provide reliable information for predicting future events (Dai et al. 2002; Soeters and Van Westen 1996). With the method illustrated in this study, a preliminary Geographical Information System (GIS)-based landslide susceptibility map was created from an inventory of landslide phenomena and other geological and geomorphological parameters that may directly influence the landslide (Guzzetti et al. 1999; Lan et al. 2004).

The landslide inventory can be created either by starting from a historical study or from an aerial photogrammetric analysis. The historic documents generally furnish information about the frequency of the phenomena, the location of the site/area, and a description of the phenomena and associated damage. The aerial photogrammetric analysis, together with field observations, permits localization of the landslide, information on the type of movement, the state of activity, and its distribution. To this end, other categories of predisposing factors need to be taken into account: lithology of the material involved, geomorphological information, land use, slope gradient, exposure, and elevation.

Each predisposing factor was assigned a specific weight in relation to an area's landslide susceptibility (Lan et al. 2004). The weight was assigned in relation to the different effect the factors had on an environmental setting. In the example considered, slope, technical rock properties (based on geology), and morphology are the factors with the greatest effect on slope stability (Carrara et al. 1978). The weights can be expressed in percentages. Each predisposing factor was also subdivided into different classes according to various characteristics (Lan et al. 2004). For example, the slope values were grouped into five classes of 10°. In line with evidence from the literature, a rating was assigned to each class identified within each parameter (Anbalagan 1992; Turrini and Visintainer 1998). The ratings have values within a range from 1 to 5.

With GIS, landslide location and inventory data are electronically entered and stored. On the other hand, the SDA application allows data rasterization of each parameter according to the weight and the assigned ratings. This empirical method will permit the creation of a distribution map of landslide susceptibility while considering the spatial distribution of the probability an event will occur.

Floods are critical processes connected with fluvial dynamics and river systems (Bull 1988). A flood may be viewed as a river in a state of crisis triggered by intense precipitation lasting several days and covering a wide area. During a flood, river bed morphology is altered as erosion and deposition move alluvial deposits and modify the channel's horizontal and longitudinal profiles. The terrain is generally saturated, and vast areas of stagnant water may be observed from 5 to 6 days after the paroxysmal phase has passed (Luino 2005). Usually, the floodwaters leave abundant sandy–silty sediment ranging in thickness from several decimeters to 1 m, with horizontal or inclined stratification (Costa 1988). Destroyed or damaged defense works may also cause damage to the cities and people they were designed to protect (Richards 1982). The definition of hazard given above emphasizes our need to know the frequency with which paroxysmal events happen, their intensity, and the segment of the area that may be affected. It follows, therefore, that the method implies two starting points: a geomorphological approach and a historic research.

The geomorphological approach is directed specifically at identifying flood-prone areas. Such areas may be grouped in a tiered classification system by comparing their past and present geomorphological aspects (Maraga and Turitto 1998). Geomorphological study takes the basic notion that during a flood the water will invariably occupy the entire hydrosystem, where both the deposition (median and lateral bars) and the erosion forms (terraces), depending on their height, represent the natural morphological boundary of flood propagation. Hence, the first step is to identify the morphological aspect of a flooded area, which may be defined as the flooded zone (Maraga and Turitto 1998). The next step is to combine it with a geomorphological analysis of the active and abandoned fluvial forms that control flood water propagation. Furthermore, man-made structures are additional elements that may direct flood water propagation. Consequently, the interaction between the fluvial hydrosystem's morphological forms and the man-made structures within it may sometimes heighten the extent of the flood and its effect on the territory (Barbero et al. 2005).

A further step in identifying the flooded zone and its changes over time is an analysis of the spatial-temporal distribution of the deposition and erosion forms and their correct geographical location. In temporal analysis, the forms are dated on a timeline because a water course develops on a millenary scale beyond the dimension of a human timescale. For this reason, the evolution of a water course and its related forms can be reconstructed over a period spanning at least 100–150 years on average. Setting the limits to a time period depends on the information available, whereas the data for a temporal location of channel adjustments may be deduced from maps (Agence del'eau RMC 1998). Cartographic information may be integrated with aerial photographic analysis and field observation, wherein the latter is possible only for studying recent changes (McEwen 1989).

In spatial analysis, the information from maps and photographs is georectified. In this way, all the data are rectified to a single geographical coordinate system, which in turn, allows an exact geographical location with historic maps. With georectification, it is also possible to overcome the problem of having variously scaled maps and photographs.

After georectification, the data and the information are entered into a GIS so that different geomorphological data with their spatial-temporal locations can be retrieved. The chief morphological elements obtained from different maps (e.g., evolution of the main channel, sandy–gravelly bars, fluvial islands, river terraces, and elements defining the flood plain) yield a historical reconstruction of the changes to the flooded zone (Caroni et al. 1990; Maraga 1990; Govi and Turitto 1994).

This geomorphological approach is combined with an in-depth historic study of the main flood events that affected the study area because the intensity and frequency of the flood events were reconstructed before planialtrimetric variations could be reliably interpreted (McEwen 1989). Hence, the historic study may be carried out on two levels. The first is a direct analysis of the main flood events based on a set of dates of the events and a description of the type of phenomenon and related damage. This will give a preliminary picture of the frequency of the main flood events. At the other level, the analysis starts from a chronological sequence of flood events to reconstruct flow discharge and hydrometric levels for each flood. This produces a rough value of the intensity of the event. The data stored in a GIS are then combined to define hazard zoning classes of increasing order.

The two methods described above were applied to two case studies.

Case studies

Scopriminiera and the Germanasca Valley

Since the 17th century, the territory between the Val Pellice and the Val Chisone, including the Val Germanasca, in the central western Alps was an area of high-quality talcum mining that accounts for nearly all its domestic production. In previous centuries, mining in the Germanasca Valley was carried out by small companies, usually family-run businesses that explored single veins and quarried throughout the entire production zone. Only over the last century did systematic exploration and quarrying achieve a scale that permitted not only extraction but also transportation and processing of the raw material. Currently, several abandoned mines penetrate the right valley slope (Lollino et al. 2004). To prevent the loss of this singular testimony to an industry that provided the local population with a livelihood for over 200 years, the Mountain Communities of the Chisone and Germanasca Valleys implemented a conservation and development project. The miners' work was historically documented, and the abandoned mining infrastructures were appropriately restored to create *Scopriminiera* (Discover the Mines), a tourist attraction unique to the area, which in fact may be considered a geosite (Fig. 2).

The Germanasca Valley is a typical Alpine valley on the hydrographic right slope of the Val Chisone. It measures about 197 km^2 in area. Geologically, the valley is incised in the heart of the Pennidic Dominion, where outcrop units belong to the Piedmon-

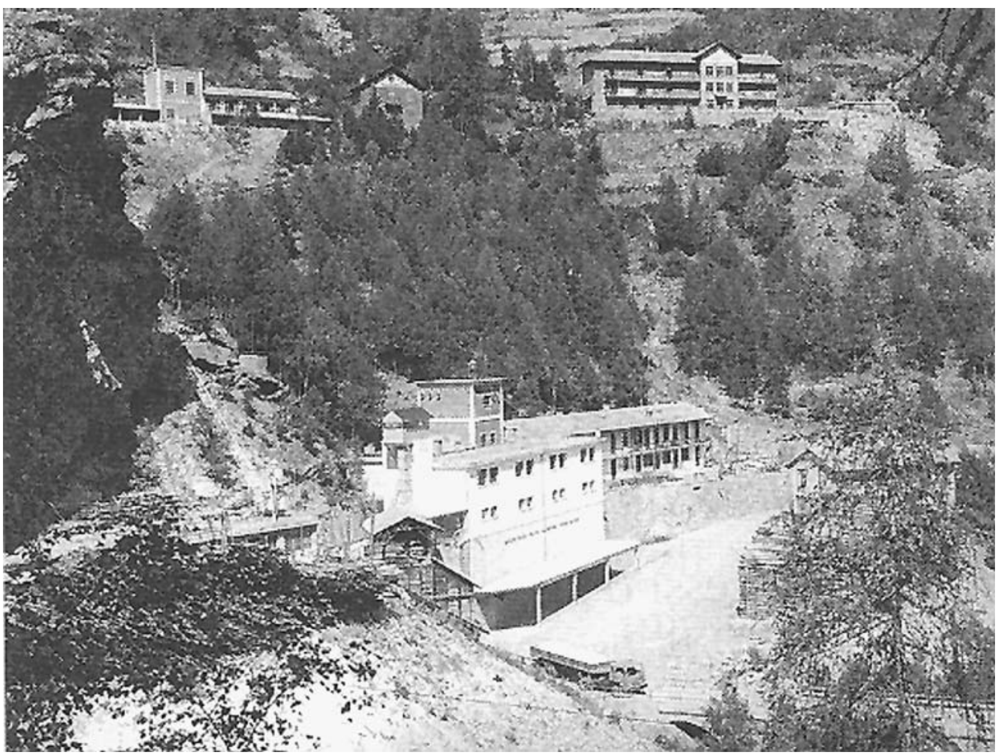

Fig. 2 Historic view of the Gianna Mine. In the foreground is the machinery for talcum processing outside the mine

tese Zone (micashists and calceshists) and crystalline massifs of the Dora Maira and the Ambin (orthogneiss, gneiss, and metabasites), with their corresponding sediment cover (Borghi et al. 1984; Deville et al. 1992). The morphogenetic processes modeling the relief are principally due to the now almost completely obliterated glacial-snow action, the action of water courses and of gravity, which are preponderant for the most recent modifications occurring on a human timescale (Nigrelli 2004).

The valley is characterized by certain heterogeneity of gravitational phenomena. The characteristic geomorphological context in which the area develops, slope steepness, and its geology are among the chief reasons for the concentration of such phenomena in this area (30% of the study area). A geomorphological analysis of the available data showed that most of the valley is characterized by extensive deep-seated gravitational deformations, partially reactivated (complex landslides), falls, primarily in the upper valleys and along rocky slopes flanking the roads, small rock/debris slides, and minor flows concentrated chiefly in stream incisions.

The geosite *Scopriminiera*, formed by the Paola and Gianna mines, lies inside a slope affected by slides, complex landslides in deep-seated gravitational slope deformation, and minor rock fall phenomena (Figs. 3 and 4; Lollino et al. 2004). As mentioned above, predicting landslide hazard depends on many factors, including time and spatial prediction, estimated movement velocity, quantity of material mobilized, and so forth.

The method applied to this case included a spatial prediction of hazard zoning with the aid of GIS data analysis. To correctly apply this method, one should keep in mind the principal factors that can influence an area's instability and to what degree each factor contributes to movement along the slope. Generally, the factors that will predominantly influence an area's predisposition to landslides are slope gradient, lithology of outcrops (i.e., rocks and surface deposits), land use, slope aspect, and the presence or absence of geomorphological instability. In addition to these geological, geomorphological, and spatial data is a series of information derived from historical data on activation/reactivation of movements that have occurred over at least the past two centuries. Historical information includes a description of phenomena that come into contact with or are inherent to zones where human intervention is active. These predisposing factors are related to the documented landslide phenomena in the area: slides and complex landslides (slides and flows). Each predisposing factor bears a certain weight on the spatial predisposition of a landslide. Geomorphological instabilities, type of lithology or outcropping lithology, and slope gradient are all factors that carry a greater weight than slope aspect or land use. Because rock falls marginally affect the geosite, differences in rock position and structure were not considered as they are beyond the scale of this study.

Moreover, a further distinction in classes needs to be operated between the elements characterizing each predisposing factor. In line with evidence from the literature (Anbalagan 1992) and according to the geosite setting, a rating was assigned to each class identified within each parameter. Slope steepness and aspect were obtained directly from a digital elevation model (DEM) within the basin of the Germanasca Valley. The DEM with a 50×50 grid was provided by the Region of Piemonte. Slope steepness was then subdivided into classes, wherein a steep slope was assigned a greater rating than the flat zone. However, slope rating is no simple undertaking; so to work with objective data, the first step was to calculate the percentage of a landslide area for each class. Proportional ratings were assigned to the values that were found to be characteristic for the study area. The geological data were derived from both the Italian Geological Map (scale 1:100,000) and other detailed maps (Borghi et al. 1984). For the geological factors, a different rating was assigned to each lithology characterizing the basin, according to which its effect on predisposition toward landsliding would be greater or lesser (Anbalagan 1992). Geomorphological instabilities and existing landslides derived from the field survey and photointerpretation analysis were distinguished by type of movement, and specifically on the basis of the state of documented activity. Land use analysis was conducted using an existing photointerpretation study (Comunità Montana delle Valli

Fig. 3 Frontal view of a slide phenomenon affected the slope near the *Scopriminiera*. The slide partially reactivated during the October 2000 event (*red line*)

Fig. 4 Rock fall near the *Scopriminiera* site. The access road to the site is immediately below the fall

Chisone and Germanasca, unpublished data). The data were analyzed and grouped according to vegetation class morphology.

GIS offered a valuable aid in data set-up, analysis, and spatial processing. The analysis led to the creation of a preliminary landslide susceptibility map of the area in question. In a feedback analysis step, the map was compared with the collected historical data to obtain the landslide susceptibility map. The analysis showed that different sectors could be classified into medium to highly elevated hazard zones subdivided into five classes (Fig. 5). Both the right and left slopes of the main valley showed a predisposition to landslides.

An additional consideration is that the minor falls are surface phenomena that do not directly influence the geosite because it is a subterranean mine, but they may negatively influence the

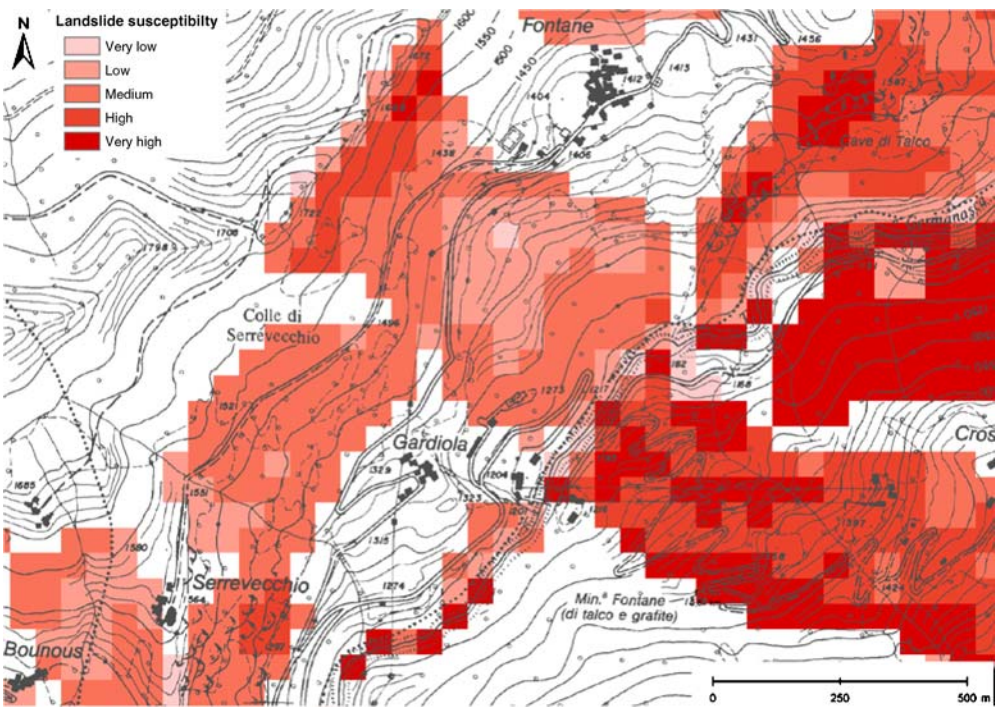

Fig. 5 Landslide susceptibility map of the *Scopriminiera* site. Increasing *red shading* indicates higher hazard classes

Fig. 6 Panoramic view of the village (photo by Andrea Raffin on http://www.globopix.net)

hazardousness of access roads to the site (tourism at indirect risk). Slide phenomena or complex landslides may involve greater thicknesses of material and thus directly influence the geosite's stability (tourism at direct risk).

The village of Crespi d'Adda

Crespi d'Adda is a fascinating example of a workmen's village in Italy. A model of the ideal city, the village was designed as a self-contained microcosm where the life of the workmen, their families, and the entire community centered around and functioned in harmonious order with factory production plans (Bonfanti and Colombo 1991). The village and factory were built by the Crespi family, owners of the textile mill, on the banks of the Adda River in 1878, during Italy's first wave of industrialization. The intent was to give workers a cottage with a garden and to provide them with all necessary services: church, school, hospital, community center, theater, and public baths (Figs. 6 and 7). Crespi d'Adda was included in the UNESCO World Heritage List in 1995 as an extraordinary example of a workmen's village, one of the most complete and best preserved sites in southern Europe (Cortesi 1995).

The surrounding environment is also particular. The village is located on a floodplain bordered to the south by the confluence of two rivers, the Brembo and the Adda, to the north by a high scarp

Fig. 7 The workers' houses (photo by Andrea Raffin on http://www.globopix.net)

known as the *Fossato Bergamasco*. The northern tip of the peninsula at the confluence of the two rivers, known as the *Isola Bergamasca*, is where the village was built. Before Italian unification in 1861, the *Fossato Bergamasco* formed the political boundary between the Duchy of Milan and the Republic of Venice (Bonfanti and Colombo 1991).

Besides being subject to active morphogenetic processes, the area was also heavily developed and the natural environment drastically modified. For example, levees and man-made channels regulate the Adda's course and its bed was exploited by sediment mining (Gelati and Martinis 1978). Geologically, the area displays four relatively uniform lithological units characterized by polygenic gravels and diffuse sands or irregularly interspersed with lentils and layers of various thickness. The gravels are mainly made up of crystalline and metamorphic elements associated with sedimentary rocks. They present a good degree of classification, rounding is elevated, whereas sphericity is medium high. The variable course grain sands yield an abundant matrix, locally constituting lenticular bodies (1 m) and sometimes giving way to clay silts. These well-stratified sediments give way to multiple orders of river terraces rising 5–70 m from the current bed and separated from one another by smaller well-demarcated scarps between 2 m and 20–30 m high. Crespi Village was built on an elevated terrace 10 m above the current bed and is separated from the bed below by a slope from 2 to 8 m high (Gelati and Martinis 1978).

The morphology of the confluence area shows that since 1833 there were at least three orders of terraces of different heights. Behind the village, the main embankment dividing the high from the low plain is about 30 m high. The other terraces, which are lower (<10 m) and border the course of the Brembo, date back before 1830 and so are not accessible from maps. The maps selected

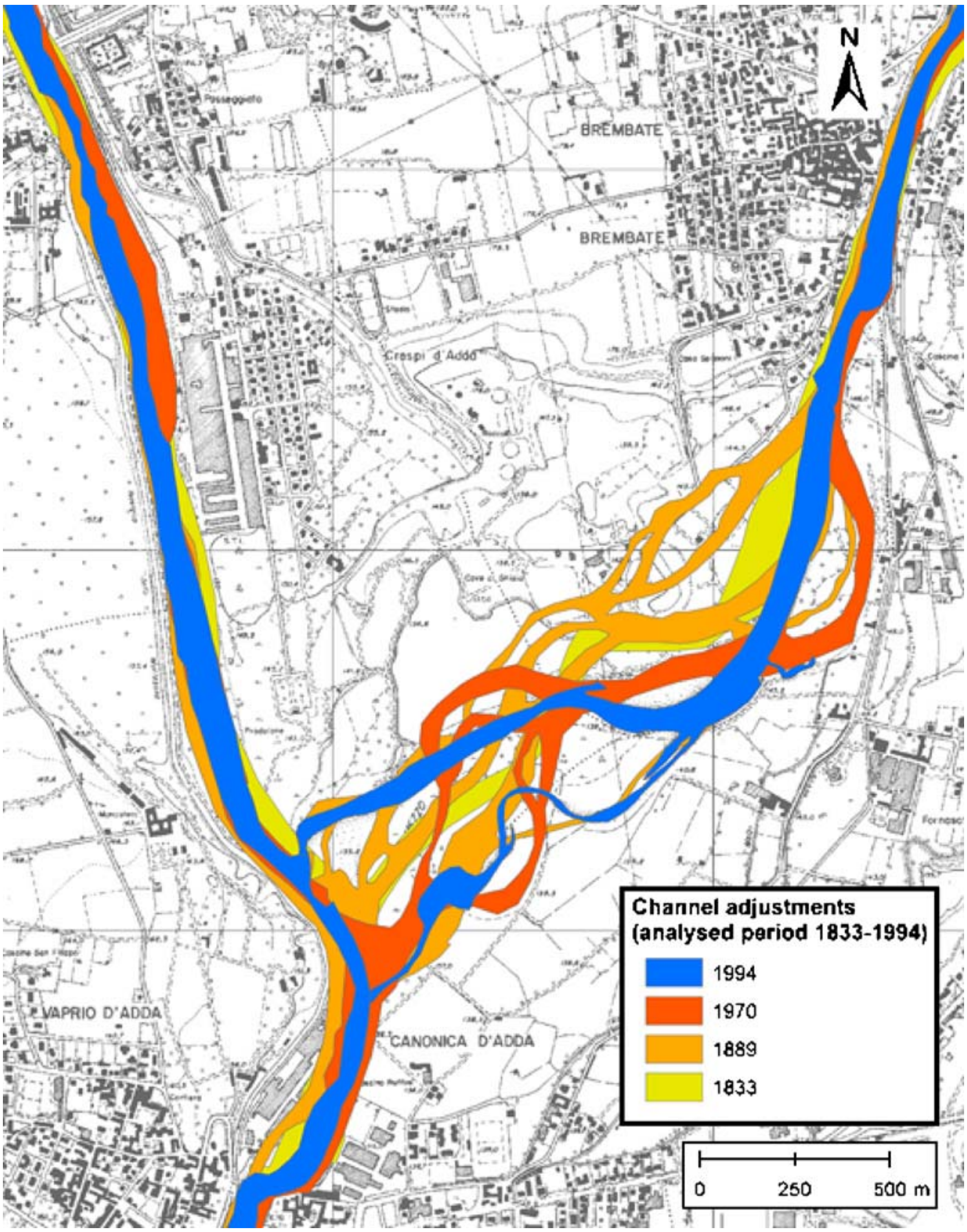

Fig. 8 Morphological changes in the beds of the Adda and Brembo rivers at their confluence (1833–1994)

cover a period of over 150 years (1833–1994), including the Royal Map of Lombardy–Veneto (1833; scale 1:86,400), the maps of the Military Geographical Institute (1889, 1956, and 1971; scale 1:25,000), and the Regional Map (1994; scale 1:10,000). The terrace of the upper plain, whose height (30 m) was estimated from the map, has remained unchanged over time, unlike the smaller terraces, which present appreciable planimetrical variations. A systematic distribution of the maps, which allows verification of river bed modifications at generally uniform intervals of time, indicated an adjustment in the course of the Brembo in the confluence areas from a multichanneled interconnected drainage to a single channel system (Fig. 8). On initial analysis, this progressive simplification of the main channel is explicable due to an increased in human impact on the territory resulting from the construction of engineering works (e.g., regulation weirs and levees) that led to a gradual down-channeling of the river bed. This is particularly evident along the entire course of the Adda from evidence dating to an era before the village was built. For a correct preliminary hazard zoning as applied in this study, a wider area was taken to analyze not only the active channel but also the main deposition (median and lateral bars) and erosional forms (terraces). The latter constituted a good morphological description of the flood-plain area also in relation to their height. The morphology of the erosional forms, combined with that of the

Table 1 The main flood events involving the Adda and Brembo rivers

Date	River	Hydrometric level/discharge	Annotation/reference
1230/10/17	Brembo		"Terrible flood" [2]
1239	Brembo		[2]
1404	Adda		[1]
1493/08/31	Brembo		[2]
1523/06	Brembo		[2]
1646/06/18–19	Brembo		[2]
1679	Adda		[1]
1783	Brembo		[2]
1793	Brembo		[2]
1810/10/27	Adda		[4]
1812/10/20	Adda		Bridge destroyed [4]
1821/11	Brembo		[1]
1829/09/20–24	Adda		Flooding in Cassano [4]
1830	Brembo		[2]
1834/09/27–28	Adda–Brembo		[2], [4]
1842/09/27–28	Brembo		[2]
1851/08/08	Brembo		[2]
1851/10/03	Adda–Brembo	3.20 m (Lodi)	[2], [4]
1868/10/04–06	Adda	4.73 m (Pizzighettone), 900 m^3 /s	[3], [4]
1882/09/16–21	Adda–Brembo	4.73 m (Pizzighettone)	Flooding at the Adda–Brembo confluence; major damage [2], [3]
1886/11/13	Brembo		Flood, bridge damaged [2]
1888/09	Adda–Brembo		Flooding [2], [3], [4]
1892/10/14	Brembo	7.00 m (P. Briolo)	[3]
1896/10/21–25	Adda–Brembo	4.06 m (Pizzighettone)	Flooding at the Adda–Brembo confluence [3]
1906	Adda–Brembo		[4]
1907/10	Adda		[4]
1926/05/18	Adda	3.67 m (Pizzighettone), 1,110 m^3 /s	[3], [4]
1928/11/02–03	Adda–Brembo	4.40 m, 1,460 m^3 /s (Pizzighettone); 8.00 m, 1,580 m^3 /s (P. Briolo)	Floods [3], [4]
1934/08/23–24	Brembo	2.80 m (P. Briolo)	[3]
1951/11/12	Adda–Brembo	4.62 m (Pizzighettone); 4.96 m (P. Briolo)	[3], [4]
1953/08/22	Brembo	908 m^3 /s (P. Briolo)	[3]
1957/06/25	Adda	2.23 m (Pizzighettone)	[3]
1960/09/19	Adda	3.47 m (Pizzighettone)	[3]
1963/08/19	Adda–Brembo	531 m^3 /s (Lavello); 218 m^3 /s (P. Briolo)	Flood in the Lodi area [3]
1966/11/06	Adda–Brembo	3.39 m (Pizzighettone), 1,300 m^3 /s	[3], [4]
1968/11/05	Adda–Brembo	2.54 m (Pizzighettone); 4.46 m, 485 m^3 /s (P. Briolo)	[3], [4]
1976/10/04–06	Adda–Brembo	5,20 m, 898 m^3 /s (Pizzighettone)	Intense flood [3], [4]
1976/10/12–13	Adda		[3], [4]
1976/11/03/04	Adda		[3], [4]
1980/08/24	Brembo	1.04 m (P. Briolo)	[3]
1981/05/26–28	Adda–Brembo	4.20 m (Lavello); 3.20 m (P. Briolo)	Flood at the Adda–Po confluence [3]
1981/09/27	Brembo	5.00 m (P. Briolo)	[3]
1987/07/18–19	Adda–Brembo	3.26 m (P. Briolo); 5.21 m, 918 m^3 /s (Lavello)	Widespread damage [3], [4]

Whenever possible, the hydrometric level and the discharge of the floods are given. *[1]* Chiesa (unpublished data), *[2]* Cappellini and Terzi (1988), *[3]* Govi et al. (1994), *[4]* Tropeano et al. (1999)

depositional forms, allowed the determination of a preliminary hazard zoning.

Based on the method described above, cartographic analysis was not comprehensive enough to produce a complete hazard zoning, so that the analysis had to be conducted at a higher level comprising documentation and reconstruction of the main historic events. The study of the events involving the two rivers (Table 1) started with a bibliographic search for a number of events from a specific period of time (Cappellini and Terzi 1988; Chiesa, unpublished data; Tropeano et al. 1999; Govi et al. 1994). The amount of documentation discovered on very old floods (e.g., 1230) emphasizes the wealth of information available. For the purposes of this method, however, it was much more useful to study floods over the past two centuries because these are the ones which have greater and more accurate detailed information. Of particular interest were the floods of 1882, 1892 (the recorded hydrometric level was 7 m upstream from the confluence of the two rivers), and 1896 that damaged mainly cultivated land, river crossings, and dwellings. During the 20th century, the frequency of flood events was quite regular. Major floods were recorded in 1928 (hydrometric level was 8 m along the Brembo upstream from the confluence, with a discharge of 1580 m^3/s), 1951, and 1987. In the last case, 18–19 July 1987, the Adda overflowed in its banks, flooding various areas and the *Isola Bergamansca* (Bendotti et al. 1987), and it was the last time in which a flood involved the two rivers causing enormous damage. The cause of such an intense phenomenon may be referred to an intense rainfall and high temperatures (freezing level above 4,000 m), two factors that probably contributed significantly to the release of abundant water into the local streams (Azzola 1989). A discharge and/or hydrometric level can often be associated with

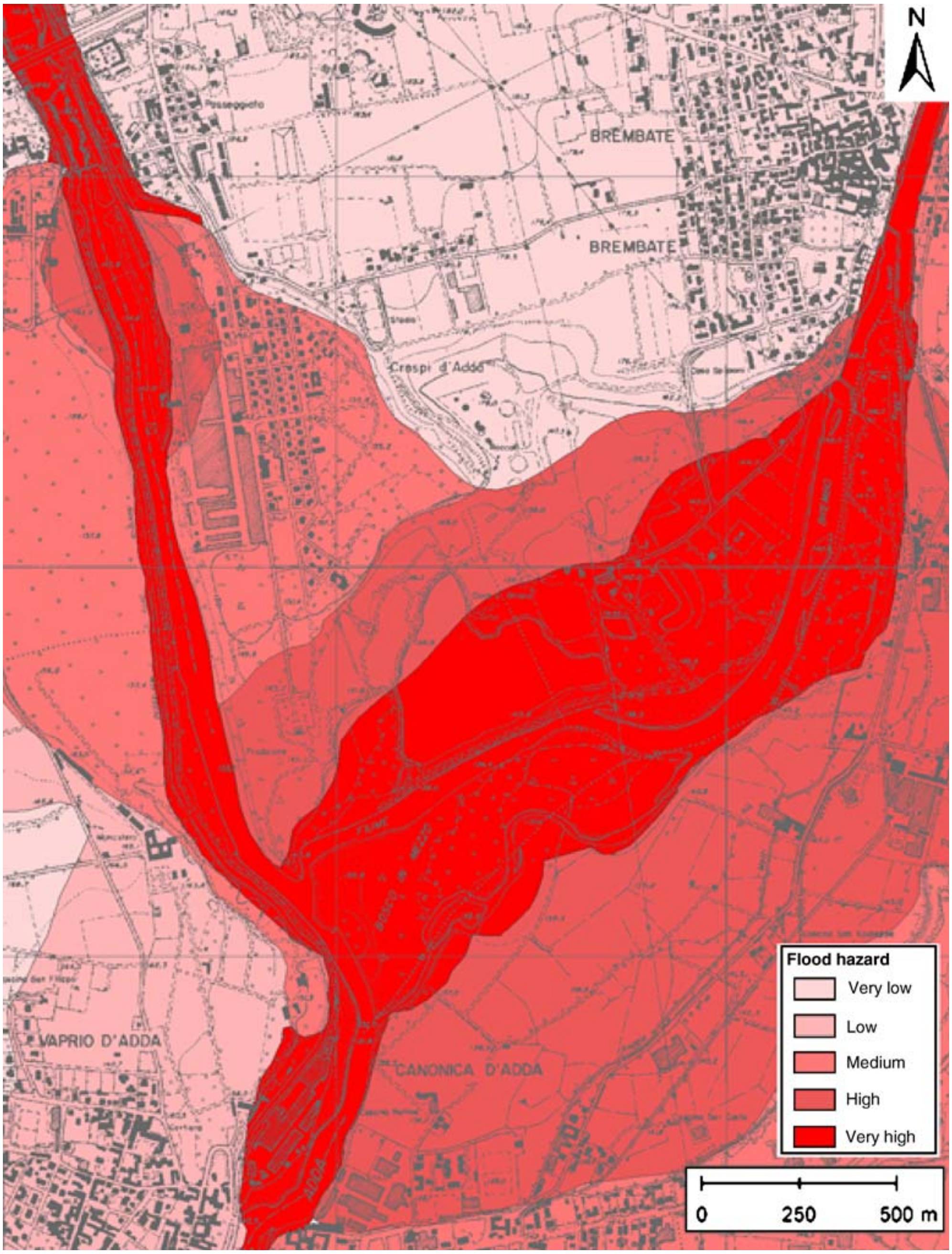

Fig. 9 Hazard zoning map of the confluence of the Brembo and Adda rivers. Increasing *red shading* indicates higher hazard classes

a specific historical date for each flood (Table 1). However, because such figures in themselves are difficult to contextualize in a study area, they need to be combined with photographic interpretation analysis to evaluate the distribution of discharges along a river's hydrosystem. In this case, an analysis of the confluence zone after the events of 1953 and 1987 enabled us to see that the worst affected areas were actually slightly further downstream from Crespi Village near the towns of Canonica and Vaprio d'Adda.

Spatial analysis of these data produced a hazard zoning of the study area divided into five classes (Fig. 9), which showed that the main part of Crespi, except for the cemetery and the area slightly downstream from the Trezzo d'Adda bridge, was built in a middle-to-moderate hazard zone, despite its location at the confluence of two rivers. This should not lead one to surmise, however, that the monument was built and set in an environment completely uninfluenced by the morphodynamic action of the morphological processes.

Conclusion

This analysis does not address all the issues related to the protection and preservation of cultural heritage set in a geologic–geomorphologic context exposed to a certain degree of hazard. To determine what constitutes a risk for an area, it is important to know not only the hazard of the environmental context in which the monument is located but also the vulnerability of the monument, which, because it belongs to cultural heritage, is probably very high.

This model is empirical; even so, it may lead to positive results for the sites analyzed. A bibliographic review of the literature shows that many methods employ complex data processing systems (i.e., neural network analysis, fuzzy relations, statistical analysis, etc.) or were developed to survey portions of extensive areas, making them less applicable to the study of specific zones like those of some UNESCO sites. With the method illustrated above, preliminary zoning of a natural context can be carried out in reference to the degree of hazard a setting manifests and then, based on hazard assessment, monitoring interventions or protection measures can be undertaken to make the site and the area surrounding around it safe.

Analysis of the study areas led to final considerations that differed slightly from those initially entertained. In the case of Crespi d'Adda, at first review of the survey forms, the site appeared to be set within a context of high hazard. In a later analysis, however, the conditions did not appear to be a cause for concern, despite the presence of a morphological agent that could trigger high-intensity phenomena and pose a risk for the monument. In contrast, in the case of the Germanasca Valley, the elevated hazard conditions in which the monument is set, which were known before the work had been started, remain and require further study. In general, the empirical method provides positive results for flood hazard; in the case of studying landslides it requires better contextualization and analysis of the geological and morphological characteristics.

These considerations underscore the need for territorial monitoring to ensure that information is regularly updated, processed, and analyzed to review the definition of hazard related to an area's natural dynamics. It is important to remember how the dynamics of an environment, the natural evolution of the phenomena, and the increasing human pressure on the environment all interact with one another.

Acknowledgements

The study was carried out within the framework of a research contract with MURST (Ministry of Universities, Scientific and Technological Research). We wish to thank the Comunità Montana Valli Chisone and Germanasca for providing some environmental shape files. Lastly, we would like to thank the two anonymous referees and Mrs. Maia Ibsen for their helpful comments and suggestions.

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