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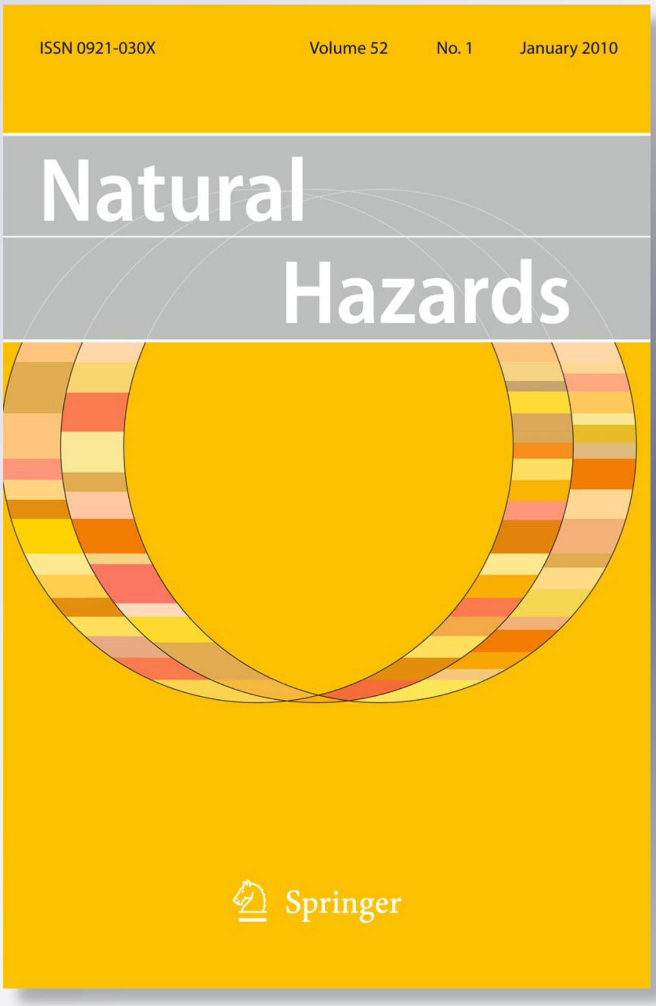

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ORIGINAL PAPER

Database of geo-hydrological disasters for civil protection purposes

Jan Blahut · Ilaria Poretti · Mattia De Amicis · Simone Sterlacchini

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Abstract This paper presents the results of a research concerning available historical information about natural hazards (landslides and floods) and consequent disasters in the Consortium of Mountain Municipalities of Valtellina di Tirano, in Northern Italy. A geo-referenced database, collecting information till 2008, was designed with the aim of using available data of historical events for hazard estimation and the definition of risk scenarios as a basis for Civil Protection planning and emergency management purposes. This database and related statistics about landslides and floods are shown, and a brief overview of historical disasters caused by natural hazards in the study area is presented. A case study showing how useful the database can be to define a simple but realistic scenario is described. Information availability and reliability is discussed and possible uncertainties are underlined. The study shows that collecting and making use of historical information for the definition of hypothetical scenarios and the evaluation of territorial threats is a fundamental source of knowledge to deal with future emergencies.

Keywords Disaster database · Civil protection · Risk scenarios · Landslides · Floods · Valtellina · Italy

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1 Introduction

Geo-hydrological phenomena that may cause disasters are, unfortunately, part of people's lives and experience in mountain areas, such as the Alps. They sometimes cause casualties and/or significant economic, social and environmental damage. Considering only the landslides, as an example, the annual economic loss for the whole Italy is estimated between 1 and 2 billion USD (UNU 2006). This amount is also reached in USA or India, but they have a larger area and different population density (USA) or different socio-economic settings (India). Moreover, in young mountain areas, and particularly in the Alps, concentration of geo-hydrological instability events is much higher than in other parts of the country (Reichenbach et al. 1998). This situation of widespread geomorphological hazard has led to a policy of risk management centred on prevision, prevention and mitigation of the impacts. This approach requires a preliminary intensive study of the natural phenomena that can affect the territory, i.e. the identification and characterisation of the hazard, and subsequently the outline of expected events and possible effects on the elements at risk, i.e. people, buildings, infrastructure, environment, social and economic systems. According to Italian legislation, this is the responsibility of Civil Protection.

Hazard and risk identification is the first step within an integrated natural risk management framework (Australian Geomechanics Society 2000). Firstly, classification of phenomena is made and expected magnitude and frequency is assessed together with possible outcomes of the hazard. Advanced numerical models are usually used for this purpose. However, they are not very useful in cases where no historical information is available for calibration of hazard scenarios. As a consequence, historical information is a fundamental basis for hazard and risk scenario preparation, and it should be assembled in an accurate and precise database, related to dangerous events and their causal factors.

The delimitation and characterisation of scenarios is crucial to organise possible preparedness and response activities when facing a disaster (Alexander 2000, 2002). According to regional regulations, a scenario is a detailed verbal and cartographic description of an expected event and its possible effects on the territory and human's lives (Regione Lombardia 2007). Problems arise as scenarios are hardly definable in a rigorous way (Drabek and Hoetmer 1991). Main difficulties concern the identification of spatial and temporal occurrence and magnitude of hazardous processes. Numerical modelling of physical processes allows to obtain detailed quantitative data on expected magnitude, but it often requires too much time, detailed data and resources, so simpler approaches are sometimes desirable for immediate applications. Looking further on emergency management, e.g. for long-term planning of resources allocation, risk hot-spots have to be identified, and this requires again to take into account the historical components. Moreover, historical knowledge of instability processes, relative hazards and effects, as detailed as possible on the territory under analysis, makes both authorities and the community more aware of problems that natural dynamics could cause.

Databases of past events are a very useful tool for the purposes abovementioned, as they give an idea of possible affected areas, expected magnitude of events, their frequency and possible impacts on vulnerable elements. These databases generally contain geographical, numerical and alphanumerical information in various digital formats, including vector and raster maps, terrestrial, aerial and satellite imagery, time series, tabular data, texts and documents (Couture and Guzzetti 2004).

The principal aim of the study is to realise, organise and populate a geo-database of past harmful landslide and flood events that affected an area located in the Consortium of Mountain Municipalities of Valtellina di Tirano (Central Italian Alps) and to show how the information gathered can be utilised to define useful and realistic local risk scenarios for Civil Protection purposes, without resorting to numerical models. The structure and contents of the database are briefly presented, together with preliminary statistics and trends. An application to a study case is described, and availability of data is discussed together with their reliability. Although this study is focused on the Valtellina di Tirano study area, the methodological scheme here proposed can be used in other regional studies.

2 Study area

The study was carried out in the territory of the Consortium of Mountain Municipalities of Valtellina di Tirano (Comunità Montana Valtellina di Tirano) that lies in the middle part of Valtellina (Fig. 1), an Alpine valley located in the Central Italian Alps (Lombardy Region, Northern Italy). The main valley has a transversal U-shaped profile derived from Quaternary glacial activity. The Adda River, the fourth longest Italian river, flows through the axis of the valley. The orientation of the valley, W–E in the lower part and SW–NE in the middle part, is controlled by the tectonic setting, as the valley is superimposed on a regional fault, the Insubric Line/Periadriatic Fault, which sharply separates the properly called Alps (Austroalpine, Penninic and Helvetic nappes) to the north, from the Variscan basement of Southern Alps to the south. The bedrock is mainly

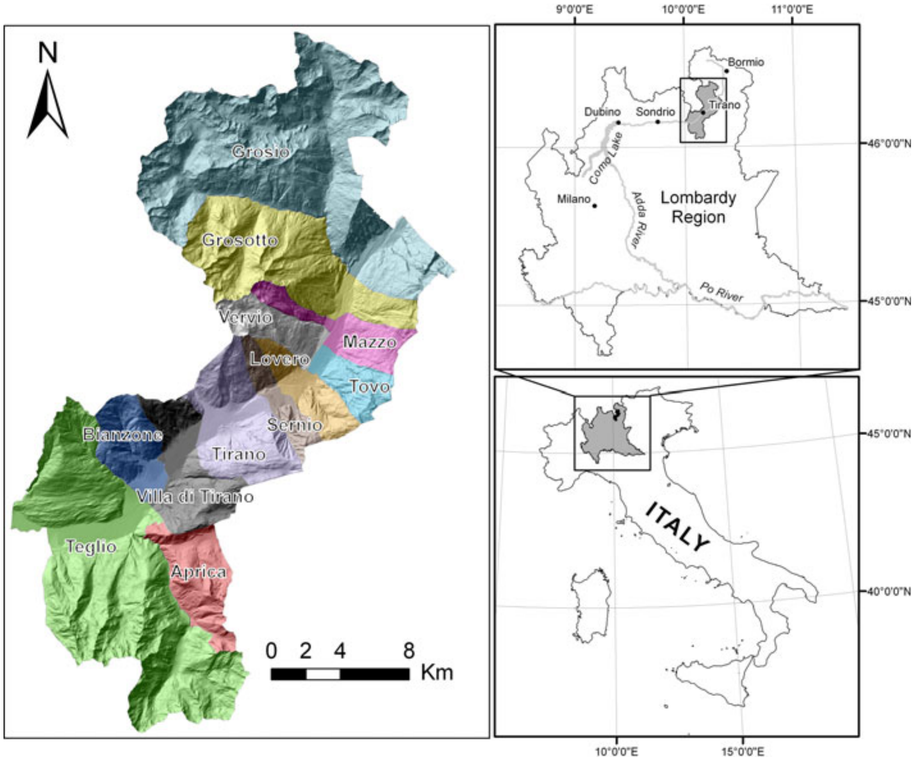


Fig. 1 Location of the study area showing the twelve municipalities of the Consortium of Mountain Municipalities of Valtellina di Tirano

composed of metamorphic rocks and intrusive rock units, with subordinate sedimentary rocks and cataclastic and mylonitic zones, due to the proximity of the tectonic lineament. The lower parts of the valley flanks are covered with glacial, fluvio-glacial and colluvial deposits of variable thickness. Artificially terraced areas are also present, with deposits usually ranging from 0.5 to 2.5 m (Crosta et al. 2003). Alluvial fans at the end of tributary valleys join the flanks to the plain of the Adda River; they are from 250 m up to 3 km wide.

Valtellina is mainly a tourist area, but it also has an important agricultural vocation, since it produces high quality grapes and apples. Vineyards and apple trees are implanted both on the valley bottom and on the northern flanks, which are terraced and retained by dry-stone walls.

In Valtellina, landslides and floods have repeatedly caused damage of different type and magnitude, sometimes implying the destruction of houses and properties. One of the primary causes of such instability lies in the tectonic and post-glacial (Holocene) conditions of the valley, supplying loose material and implying mass movements after deglaciation. Another significant cause is poor environmental management, mainly involving deforestation, mismanagement of water resources and overdevelopment of settlements and route ways, as reported by Alexander (1988).

More in detail, Valtellina di Tirano is an area of about 450 km^2 subdivided among 12 municipalities, with a population of about 29,000 inhabitants prevalently settled along the valley floor. The national road S.S. 38 crosses the whole area running almost parallel to the Adda River. It is the only route connecting the Como Lake to the municipality of Bormio, one of the main summer and winter tourist resorts in Lombardy.

Since ancient times, various damaging natural processes have affected the territory of the Mountain Consortium. They mainly include mass movements, such as rock falls, muddy-debris flows (according to the definition of Luino et al. 2008), translational and rotational landslides and deep-seated gravitational slope deformations due to the proximity of the major fault system. Floods are also quite frequent, both on the main valley bottom and in tributary valleys.

3 Overview of historical damaging events

A brief overview of past damaging events in Valtellina is presented based on available historical sources, i.e. books, chronicles, journals, newspapers and reports. It is worth emphasising that in most cases, the identification of process type (landslide, flood and torrential process) is quite confused in old chronicles and news. Damaging events were often defined as 'acts of God' or unnatural phenomena, without a clear description of mechanisms of action or triggering factors.

The history of natural disasters in Valtellina began when the first population established in the region. During antique times people were settled mainly on the slopes over the main valley floor, probably as a result of an ancient knowledge about flooding that was creating insalubrious zones. On the other hand, these settlements had to suffer from landslides. However, no information was found about floods or landslides in old chronicles till 1338. The first historical information comes from the area of Montagna in Valtellina, just a few kilometres east from Sondrio, the capital of the province: 'one Thursday afternoon in August 1338 after a tremendous hailstorm followed by intensive rainfall, several large landslides occurred, causing seven victims' (De Bernardi 1987).

In the period 1400–1800, there are many references: for example, F. A. Chiesa (1752 in Franceschi 1912) reports about a huge flood of the Adda River in 1404, which formed a large lake and made difficult to reach the upper part of the valley. Other information about landslides comes from the 16th to 18th centuries: they happened in 1520 in Castione (Parravicini 1612 in Franceschi 1912), in 1535 or 1538 in Ardenno (Damiani 1898 in Franceschi 1912), in 1600 in Boalzo (Damiani 1898 in Franceschi 1912) and in 1755 in Mazzo (De Bernardi 1987). Important floods occurred in 1550, 1678 and 1750 in the lower part of the valley (Chiesa 1752 and Morselli 1859 in Franceschi 1912). In 1792, events very similar to those which happened in 1987 were reported (De Bernardi 1987).

In the 19th century, information about disasters becomes more exhaustive, starting with the detailed description of the Sernio landslide in 1807 by Ferranti (1814). Processes are better identified, e.g. snow avalanches, torrential processes, landslides and floods are recognised (De Castro 1885 in Franceschi 1912). More information about damage and morphological effects is also available, e.g. on 14th August 1851 in Valmaggiore, a landslide caused 6 victims, destroyed houses and raised the river bed of about 9 m, and in July 1852 in Berbenno and Polaggia, 1 million of Lire of damage (which corresponds to about 2 millions of EUR in today's currency) was caused by torrential processes (Franceschi 1912). Remarkable damage occurred also in 1829, 1834, 1844, 1855, 1885 and 1888 when, after intense rainfalls, the Adda valley was flooded by the tributary torrents of Tartano, Mallero and Madrasco (De Bernardi 1987). Many instability processes in minor rivers were recorded: in Boalzo torrent (1820, 1821, 1871 and 1882), Rezzalasco torrent (1864), Ron torrent (1880, 1882) and Bitto torrent (1890). Landslides were reported in Bianzone in 1891, and in Grosotto in 1894 (De Bernardi 1987).

Data in the 20th century tend to be much more consistent than in the past. From the information gathered, it can be observed that very often landslides and floods acted conjointly, with a cause-effect correlation. Floods were generally accompanied by abundant transport of debris coming from tributary valleys; this load of material often caused the obstruction or the aggradation of riverbeds, both on alluvial fans and plain, inducing overflows. In the meantime, many landslides were triggered by river bank erosion.

The largest documented disasters in Valtellina di Tirano happened in 1983 and 1987. The 1983 events are described in the case study section of this paper (see Sect. 4.5). In summer 1987, after a long rainfall period, the entire valley was affected by floods and many landslides were triggered (Luino 2005). A total of 25,000 people were evacuated, and 53 casualties were recorded all over the region (Magistretti 2002). On the 28th July, the well-known Val Pola rock avalanche caused 27 victims (Costa 1991; Crosta et al. 2004). Valtellina di Tirano suffered the consequences of diffused shallow landslides and muddy-debris flows and the Poschiavino River's flood (Giacomelli 1987; Guzzetti et al. 1994).

Other major events occurred at the end of 20th century. From 14–17th November 2000, prolonged and intense rainfalls triggered about 260 shallow landslides in Valtellina, mostly concentrated on vine-terraced slopes. The highest landslide density in Valtellina di Tirano was observed around Bianzone, with 49 landslides per km^2, and near Tirano, with 26.8 landslides per km^2 (Crosta et al. 2003).

The most recent large disaster occurred in November 2002, when several shallow landslides and soil-slips occurred mainly on terraced areas. The events, which affected the whole Valtellina, caused two casualties, and the overall damage was estimated in 500 millions of EUR (Aleotti et al. 2004). A muddy-debris flow occurred in Tresenda (municipality of Teglio) on November 22nd, causing damage to roads and properties (Di Trapani 2009, personal communication).

4 Database

4.1 Available information sources

4.1.1 *Official databases*

Official sources of information about past landslides and floods in the study area are provided by national and regional authorities or research institutes, as listed below:

- National AVI Database: a Bibliographical and Archive Inventory of Landslides and Floods in Italy (CNR-GNDCI: Guzzetti et al. 1994);
- Regional Database of Landslides of the Lombardy Region (Regione Lombardia 2002);
- GeoIFFI Database: National Landslide Geographic Inventory Database for Lombardy Region (GeoIFFI 2006), set up in the framework of the National IFFI Project (IFFI 1997);
- SCAI Project: Study on the Unstable Inhabited Areas of the Sondrio Province (CNR-GNDCI: Agostoni et al. 1997);
- PAI Project: Hydrogeological Plan of the Po River Basin (Po Basin Authority: PAI 2001);
- Geological reports for the municipalities of the study area, required by legislation to support land-use planning.

The AVI Database has 80 records within the study area; among them, 26 have the complete date (day, month and year), while 39 only have the year of occurrence. At the moment, the database is covering the period from 1918 to 2000, but an updating is expected.

The Regional Database contains 501 records for the study area; among them, 61 have the complete date, while 450 report only the year of occurrence. This database covers the period from 1600 to 2000.

Two main problems arise analysing these two sources. The former is related to the location of events. Both databases have coordinates associated to the events, but they are represented as points. In some cases, these points are located in scars, sometimes in transport or deposition areas, while in other cases, they only refer to the locality where the events occurred. Areal extent is never outlined, even if in some cases, it can be approximately deduced by analysing information on the magnitude of the events (area, average length and width). The latter is related to the classification of these harmful events. As most of the primary sources for the databases are local chronicles and news written by non-experts, the correct type of phenomena is often misunderstood (e.g. a debris flow might be reported as a flood).

The GeoIFFI database is a vector database of landslides. In the study area, landslide scarps are represented by 5,547 points: for 1,200 of these, the entire body has been represented by a polygon. Landslides were mapped as polygons in cases when the landslide body was visible on aerial photographs (taken from 1954–55 to 2001), which were the primary source of information for this database (GeoIFFI 2006). In addition, rock fall prone areas are mapped, as well as alluvial fans. In this geo-referenced database, it is generally possible to identify source, spreading and depositional areas. Unfortunately, the temporal information is not provided, unless available from complementary historical sources. Referring to this database, only well-known events, that could be associated to the date of occurrence and that are described also by other historical sources, were considered.

The SCAI database has very detailed cartographic and descriptive information. It also provides information on geologic and geomorphological causes of failure. Unfortunately, it is limited to events occurred until 1996 and affecting urbanised areas. Only 14 records are available for the study area.

The PAI database is quite scarce, but it has the advantage of highlighting the most critical sites from a geo-hydrological hazard point of view.

In the geological reports for the municipalities, some basic information is provided about the main historical events that affected their territory.

4.1.2 Other sources

Publications, useful for the implementation of the historical database, were also examined. They have been mostly produced during the last 20 years by the Geo-hydrological Protection Research Institute (CNR-IRPI of Turin) and the National Group for Defence against Hydrogeological Catastrophes (CNR-GNDCI) of the National Research Council (Guida et al. 1979; CNR-GNDCI 1983; Govi et al. 1996; Cardinali et al. 1998; Tropeano et al. 1999, 2006; Fioraso 2000). A book describing the 1987 flood and landslide events was also produced by the Bank of Sondrio (Giacomelli 1987). The information gathered covers mostly the second half of the 20th century, but only text information is usually available. A very valuable source is the Bibliographical Research for a Catalogue on Landslides and Floods in Valtellina compiled by Govi and Turitto (1994). Some photographs and videos have also been collected and analysed.

4.2 Database structure

The database is supported by a Relational DataBase Management System (RDBMS) implemented in MS Access (Fig. 2) with an associated geographical representation. Each recorded event has an ID code (key-field) to be used for joining operations among tables to get extensive information. A summarising table was also produced in XLS format to allow performing some basic statistical analyses. Even though first historical records are from the 15th century, geo-referencing of the events was possible from 1600. A clear description of the place of occurrence of earlier events was not available.

The initial phase of the process consisted in combining information from the official databases. As a result, 489 records of damaging events, reported from 1600 up to 2001, were compiled and checked in order to avoid redundancies. However, each database was compiled for different purposes and at different scale. This affected the spatial resolution

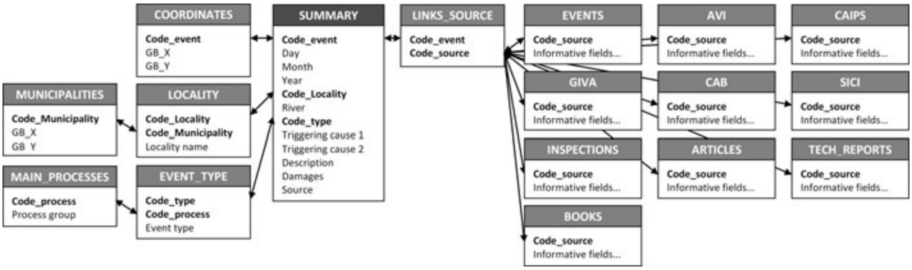


Fig. 2 Scheme of the constructed relational database. Links between the main data fields and sources are presented

consistency of our database: in some cases, the exact location of the event was provided (as a point or a polygon), while in other cases, only the approximate location (locality, stream/mountain name, municipality, etc.) was reported. In order to normalise the location of the events, geo-referenced points were used as the common basic spatial information. However, it has to be pointed out that these points do not always refer to the same part of the process: they might represent the initiation area, the transport area or the impact/deposition area, and in some cases, this distinction was not very clear. Additional text information about location was also stored.

Afterwards, other sources such as publications, chronicles, local newspapers, technical reports and information from the municipalities were examined. As a result, 126 records were added to our database. Two drawbacks arose regarding the information provided by the oldest sources: uncertainties in the recognition of process typology and vague location of events. The first problem is probably caused by the lack of specific scientific knowledge about natural hazards during past times, and probably also by a tendency to overestimate the phenomena, while the second inconvenience is mainly due to lack of coordinates, imprecise definition of affected areas or use of old place names. Moreover, in historical sources, the main attention is usually posed on damage and effects, more than on processes.

4.3 Database contents

The final database contains 615 records located in the territory of the Mountain Consortium of Municipalities of Valtellina di Tirano, covering the period from 1600 till 2008. A minor part of them (20%) have complete date (day, month and year), and half of them (58%) have at least the year of occurrence, while temporal information is not available for the remaining events (42%). Obviously, the number of dated events increases for the last centuries, when more information sources are available (see also Salvati et al. 2009; Tropeano and Turconi 2004); however, there are still some information gaps even during the 20th century, mainly during World War II and the post-war period. As a result, the apparent increase of frequency of the harmful events can be related mainly to better recording techniques than to other causes (Fig. 3).

Five main types of instability processes have been identified: floods (14%), muddy-debris flows (9%), rock falls (30%), other types of landslides (37%) and combined events

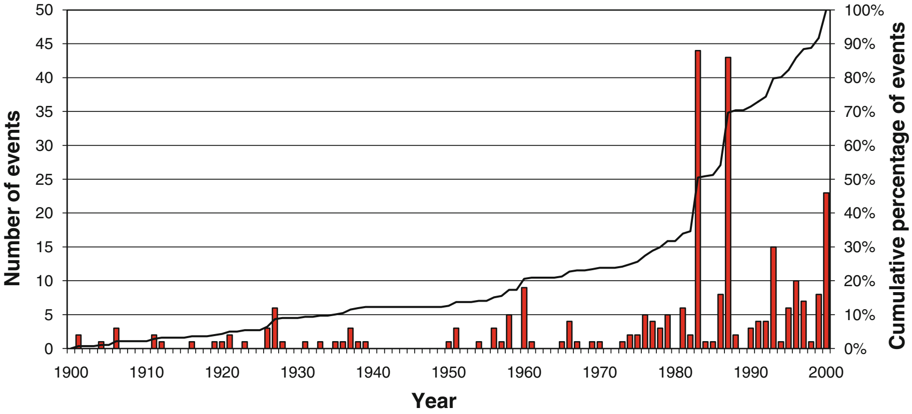


Fig. 3 Distribution of dated geo-hydrological events in the database during the 20th century

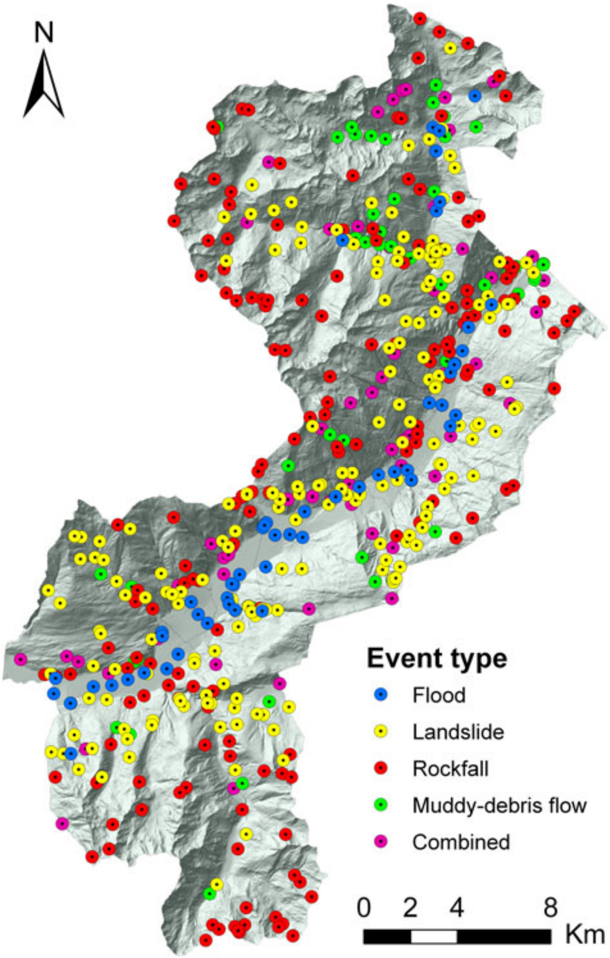
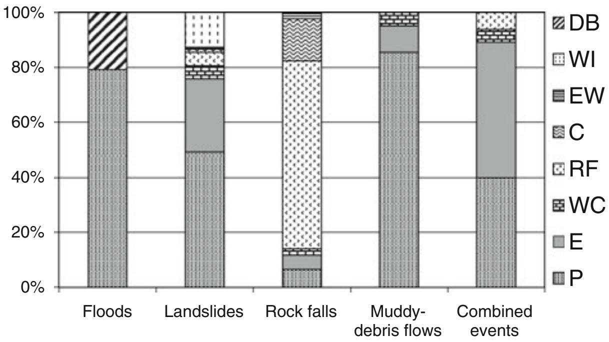


Fig. 4 Distribution of database events over the territory of Valtellina di Tirano

(11%). A more generalised subdivision of these processes is presented in the following paragraphs (see Sects. 4.3.1, 4.3.2 and 4.3.3). It is interesting to notice that all flood events have temporal information, with at least the indication of the year, while most of the rock falls are not dated. This could be caused by the fact that floods are usually described by station measurements of water level or discharge always associated to a date; moreover, inhabited areas are usually located close to water courses. On the other hand, rock falls often occur far from inhabited areas and affect a limited area and their magnitude, and temporal occurrence estimation is not always possible. For the other processes, the distribution between dated/undated events is more balanced.

Recorded events are distributed over the whole territory (Fig. 4). However, many differences exist according to the process type distribution. Floods are mostly located on the bottom of the main valley floor (Adda River floods and inundations); landslides and combined events are mainly recorded in the neighbourhood of the main valley, where most of the people live. Muddy-debris flow records are located mostly in the tributary valleys: phenomena start at high altitudes and reach the bottom of main valley floors. Many of them

Fig. 5 Triggering causes associated to the main five hazardous processes *DB* dike breaks, *WI* water infiltrations, *EW* excavation works, *C* cryoclastism, *RF* rock fracturing, *WC* (dry stone) walls collapse, *E* erosion, *P* precipitation



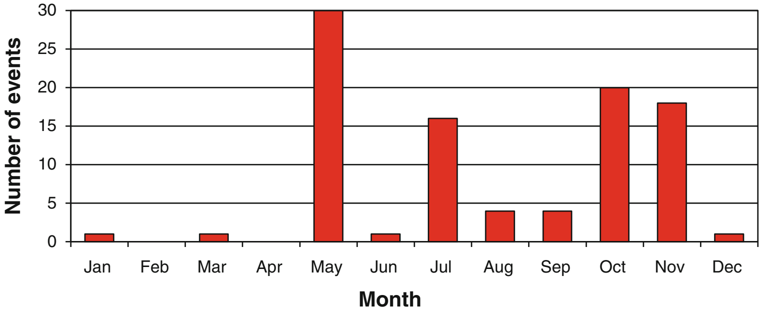


Fig. 6 Monthly distribution of events triggered by heavy precipitations

were recorded in the territory of the Municipality of Grosio, in the northern part of the study area. On the contrary, rock falls are equally distributed over the entire study area, and many of them are located in remote uninhabited zones at high altitudes.

One triggering cause is provided at least for 70% of the events. Figure 5 shows causes associated to the different processes. Precipitations are the most frequent trigger of instability in May, July, October and November (Fig. 6), in the wettest months of the year; erosion is the second main cause.

For landslides, data about geometry (length and area) are often available; unfortunately, data referring to other magnitude characteristics and consequently to the damage potential (velocity and/or accumulation thickness) are almost absent.

4.3.1 Floods

In the database, there are 86 flood records distributed all over the territory, but especially in the Teglio and Tirano municipalities. The records cover the period from 1616 to 1987, and processes can be divided in flood plain inundations (about 60%) and events in which only a rapid increase of discharge was registered (about 40%), even if event characterisation is not always easy. The events for which information about the month is available occurred mainly in the period between July and November. Quantitative data are available only for the records related to high discharges and only for the Adda River, while in case of plain inundations, a general description of affected areas and occurred damage is usually provided. Inundations geo-referencing posed several problems, since most events are represented only by points, without any further specification of their areal extent. Aerial photos can help in outlining flooded areas, but unfortunately they are available only for the main events, as those which occurred in 1987. Up to now, not even many ground photos have been found to delimit the old flooded zones. Adda River is responsible for almost half of the events, and in 9 cases, it acted in synergy with two of its main tributaries, the Poschiavino and Roasco torrents. The other events were caused by tributary rivers/torrents. Thirty per cent of floods occurred on fans. In 5 cases, inundations were caused by dike breaks: they happened in Bianzone, Teglio and Tirano in the second half of the 19th century.

4.3.2 Landslides

On a whole, 460 landslide events, dating from 1600 to 2008, are stored with geographical coordinates in our database. They include various landslide types, rock falls and muddy-debris flows. Sometimes, on alluvial fans, it is not possible to clearly distinguish between hyperconcentrated flows and muddy-debris flows (see also Guzzetti et al. 2005). To classify the process type, the original information was used. It has to be noted, however, that going back in time this classification becomes more uncertain. Half of the records are dated; 64% occurred during the 20th century, mostly in its last quarter. They include: rock falls (40%), rotational and translational slides (31%), muddy-debris flows (11%), complex slides (6%) and landslides not precisely classified (12%). Event magnitude, expressed as length, width and/or area of the whole landslide, is reported in 27% of the records.

Many events occurred in the Grosio municipality (168 recorded events–1.3 events/km^2) that is the largest municipality (127 km^2) within the Consortium. It could be surprising that the smallest municipality, Sernio (9.6 km^2), has the highest number of events compared to its area (44 recorded events–4.9 events/km^2). This is due to the presence of an alluvial fan with frequent torrential activity and to a deep-seated gravitational slope deformation, with a large number of superficial slides (Masuccio Mountain). The remaining territory of the Mountain Consortium has an average density of 1.4 events/km^2.

4.3.3 Combined events

About 11% of the records are related to combined events, i.e. a combination of intensive erosion processes, flooding and/or consequent landsliding. These events are generally referred in the historical sources as ‘disruptions’ with no further specification. The erosion was generally linear along drainage channels. In some cases, also slope toe erosion or processes on alluvial fans were observed. Events are geographically distributed over the entire study area, even if most of them occurred close to streams and torrents. Temporal information is available for half of the events.

4.4 Damage classification

For a rough estimation of direct losses from hydro-geomorphological disasters, a classification of the database records was made, distinguishing four levels of damage. High damage class relates to situations where human casualties were registered or buildings were affected. Medium damage class corresponds to destruction or damage of infrastructure (roads, power lines, etc.), while low damage class is restricted only to losses of

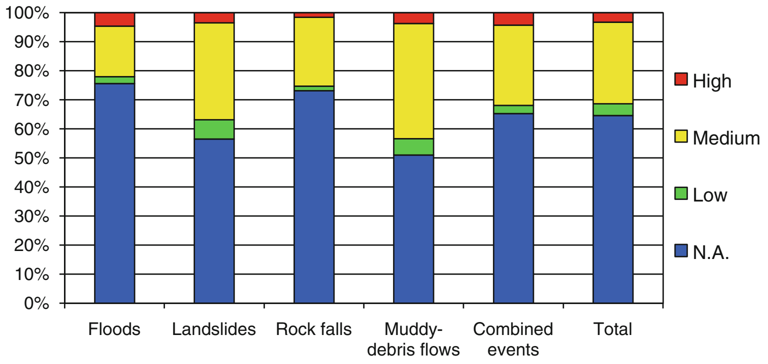


Fig. 7 Damage information for the five main hazardous processes. *High* people and buildings affected, *Medium* infrastructure affected, *Low* agricultural and forest areas affected, *N.A.* no information available

agricultural land or forests. The last class (N.A.) is assigned where no direct losses were reported or no information is available.

Figure 7 shows that the last class is the most frequent. Most of the information about damage refers to muddy-debris flows, followed by landslides, and combined events. Least information is connected with rock falls and flood events. This situation can be partly explained by the different spatial extent of the processes. Muddy-debris flows and landslides represent phenomena with moderate extent compared to floods and rock falls. Moreover, their localisation can be well defined and losses can be theoretically estimated more precisely. In case of floods, which usually cover a larger area, damage estimation is complicated. Rock falls on the contrary represent much more localised phenomena affecting limited areas, in many cases in uninhabited zones. As a consequence, much damage information might be missing.

The percentage of high, medium and low damage levels is almost proportional in all types of phenomena. The majority of recorded losses are in the medium damage class (infrastructure). The least reported damage falls into the high damage class (casualties and buildings affected). For a more accurate analysis, more data have to be collected (e.g. type of houses involved and their degree of damage, affected agricultural/forest area, length of road, etc.). However, this information is hard to gather, especially when analysing older events.

Spatial distribution of the different reported damage is illustrated in Fig. 8. It is clearly visible that high level of damage is usually reported within and nearby the main Adda River valley floor, which is also the most inhabited area. Most of the records are classified as medium damage, affecting mainly roads and other infrastructure. Light level of damage to agriculture and forests is predominant on slopes adjacent to the main valley. Records with no damage information are proportionally distributed over the entire study area.

4.5 Case study

A case study was selected from the database, in order to show how the information collected can be useful for Civil Protection purposes and, in particular, for scenario preparation. Vine-terraced slopes immediately above the village of Tresenda in the Teglio municipality were chosen as they experienced twice muddy-debris flows caused by intense and prolonged rainfalls and dry-stone walls collapse, with considerable damage to people

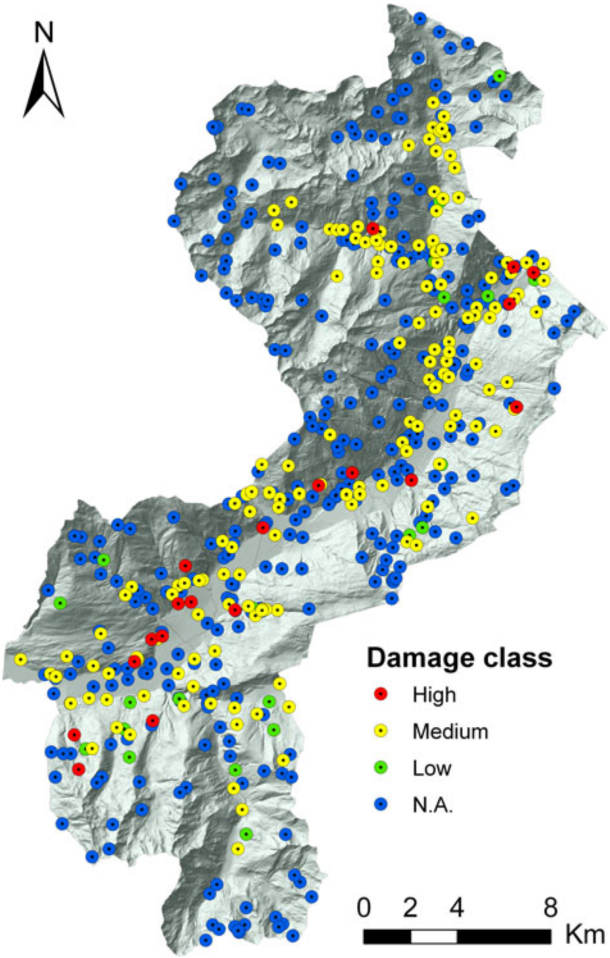


Fig. 8 Distribution of damage types over the studied territory. *High* people and buildings affected, *Medium* infrastructure affected, *Low* agricultural and forest areas affected, *N.A.* no information available

and environment. The scenario was prepared assuming triggers, typology and intensity of processes similar to the ones occurred in the past (Fig. 9).

4.5.1 Historical damaging events

In May 1983, a severe rainfall triggered more than 200 shallow landslides and debris flows in Valtellina (Cancelli and Nova 1985). In Aprica, a cumulated precipitation of 453 mm was measured during the month, which corresponds to 34% of the total annual precipitation (Guzzetti et al. 1992). In 3 days, 175.8 mm was recorded by the Castelvetro rain-gauge (Teglio municipality), with a maximum intensity of 8.6 mm/h. Landslides occurred mainly on vine-terraced slopes between Tirano and Sondrio. Most of them started on slopes between 30° and 40°, and their runout was less than 50 m (Cancelli and Nova 1985).

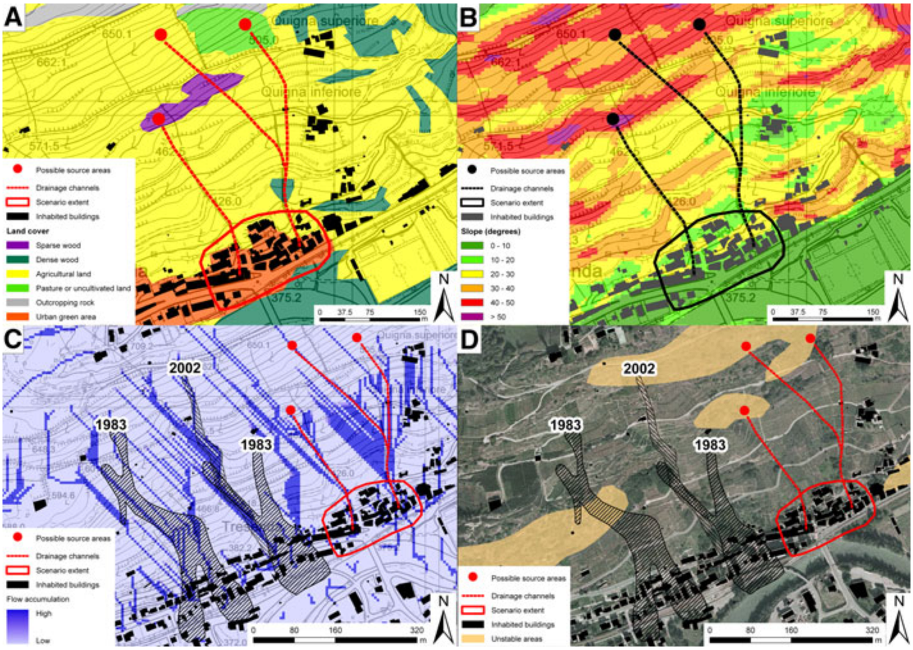


Fig. 9 Case study area showing past damaging flows and the hypothetical scenario, including source areas and extent of affected areas, based on **a** land-use map; **b** slope map; **c** flow accumulation map; and **d** location of unstable areas for slope movements, derived from the geological map of the Teglio municipality

In Teglio, on the 22nd and 23rd of May, three soil-slips evolved into larger muddy-debris flows with runout from 300 up to 460 m. Two of them occurred on the slopes above the village of Tresenda, and the other one on the close slope of Valgella. In Tresenda, a debris flow caused 14 casualties (Cancelli and Nova 1985); buildings were destroyed, and properties were damaged. The national road S.S. 38 was blocked, and this made impossible to reach the upper part of the valley for several days. Crosta et al. (2003) reported as causes of the failure severe precipitations and bad maintenance of dry-stone walls supporting terraces. However, according to interviews with local inhabitants, another important cause is closely connected with the paving of paths and roads on the vineyards, made at the beginning of 80s. As a consequence, the water was unable to infiltrate into the soil and was discharged rapidly on the steep roads that acted as channels. The water left the road in the bends, causing a high runoff leading to a rapid increase of the water table stage. This caused the outburst of some dry-stone walls that lead to the initiation of the landslide. Then, the volume of the moving mass rapidly increased due to a 'domino-effect' involving other dry-stone walls located down slope.

A similar event happened on the same slope on November 26th, 2002, but it fortunately produced less damage and no victims. The flow remained confined and caused a minor flooding of the area close to the village due to an obstruction in the drainage channel. In this case, the triggering factor was probably the presence of a temporal spring, which was observed in the scarp area after the event. (Di Trapani 2009, personal communication).

Several sources mention these events. Information about extent and triggering is usually provided, but quantitative data about flow velocities and thickness of debris during the runout is not available. The analysis of magnitude can help in defining the level of damage, though with approximation. However, the extent of flows and impacted areas are well outlined.

4.5.2 Construction of a hypothetical scenario

Terraces are predominant on the slopes above the village of Tresenda, but there are neglected areas where bushes and sparse woods are growing (Fig. 9a). These slopes could be source areas for muddy-debris flows, especially where the slope is steeper (Fig. 9b). The morphology of the area was analysed using a 5 m DEM, based on a 1:2,000 and 1:10,000 topographical survey. Comparing the flow extent of 1983 and 2002 events with the flow accumulation map, generated from the DEM in ArcGIS 9.2 Spatial Analyst Toolbox, it can be seen that, once the muddy-debris flows were generated, the movement of material followed clearly the drainage lines down to the village of Tresenda (Fig. 9c). It can be supposed that a similar process could occur approximately 200 m eastward, on the same slope, under similar predisposing conditions after prolonged rainfall. Muddy-debris flows could be triggered by the collapse of dry-stone walls, or by the movement of unconsolidated material from one of the areas already identified as unstable in the geological map of the Teglio Municipality (Fig. 9d). This strengthens the consistency of the prospective scenario chosen in the analysis.

As the soil thickness varies between 70 and 150 cm, and moving material is characterised by varied granulometry (including boulders from the dry-stone walls being destroyed), it is expected that a flow with a thickness varying from 1 to 2 m (Cancelli and Nova 1985) could cross minor roads to the vineyards and impact buildings in Tresenda, while following slope drainage lines. This is a severe scenario, as it is assumed that a volume comparable to the one mobilised in 1983 may be involved. A less severe scenario would entail only road obstruction by debris accumulation.

Assuming the occurrence of the worst case scenario and considering potential spreading, the possible impacted area was outlined. For this purpose, since data about intensity of past events are not available, only qualitative data could be used. The first vulnerable elements encountered by the flow, i.e. residential buildings, will suffer the most from the debris impact, while the damage will diminish moving down slope and away from the main drainage lines. Casualties and serious damage can be expected, the obstruction of a main road can occur, and it will be necessary to remove the accumulated material. The initiation and evolution of the process probably can not be forecasted, even if the area should be monitored when local rainfall thresholds for the initiation of muddy-debris flows (Cancelli and Nova 1985; Ceriani et al. 1992; Luino et al. 2008) are exceeded. It would be probably more appropriate, however, to start an evacuation, immediately after over passing the triggering thresholds. These are defined by law (Regione Lombardia 2007) and set up at 70, 90 and 145 mm per 12, 24 and 48 h, respectively. These thresholds control the change of the critical state from moderate to high level.

5 Discussion

The diffusion of GIS technology has facilitated the application of quantitative techniques and models in hazard assessment, which should refer to accurate and precise databases, related to dangerous events and their causal factors. Setting up a database on historical events and related disasters is a quite complex issue, mainly because it aggregates information from different sources, which operate at various scales and with different purposes and so comprise very heterogeneous data. This aspect was highlighted also by Tropeano and Turconi (2004) and Salvati et al. (2009). First of all, identifying the specific acting processes is difficult because descriptions are often quite generic and more importance is given to the overall feelings impressed on the observers, especially in the oldest times. This is truer for landslides, while the situation for floods is that available data relate mainly on river discharges, and less importance is given to the description of the inundation process and to the identification of overflowing sites, which are fundamental information for hazard assessment. Moreover, the correct location of events is problematic, because uncertainties can be high, especially for not well defined events (e.g. 'disruptions'), and areal delimitation is generally lacking. Furthermore, the amount of information is often inadequate to appropriately define the main quantitative characteristics of the event. Finally, an occurred event could have not been registered because it did not produce any damage (see also Salvati et al. 2009). It has to be also remembered that historical information does not take into account all the environmental, territorial and societal changes that have occurred along the time span covered by the database. All these uncertainties are hardly avoidable but should not discourage the collection, analysis and integration of historical data.

Information about damage is crucial not only for the assessment of prospective consequences but also for the computation of vulnerability functions for landslides (Quan Luna et al. 2011) or stage damage curves for floods (Luino et al. 2006). However, this information is usually very limited or not accessible for public. In the presented database, only basic information on damage was available, and this only permitted to classify it in a qualitative way. For future studies, it is essential to collect and analyse quantitative information about damages in order to increase precision of the natural risk assessment approaches.

Despite its limitations, which are mainly due to data availability and reliability, the described database represents a valuable source of information that could support scenario preparation, when more sophisticated approaches cannot be implemented, e.g. for lack of funds or adequate data. Moreover, it can serve as a basis for empirical hazard models calibration (Blahut et al. 2010).

Besides the usefulness for Civil Protection purposes, the use of historical databases facilitates in general good policy for land use and natural hazard reduction strategies (Tropeano and Turconi 2004). Moreover, they could be referred to define insurance policies, if enough information about damages is available (see Luino et al. 2009).

Although the identification and mapping of past and present dangerous processes remain a highly subjective action, it constitutes a fundamental step for predicting future events (Carrara et al. 1995). The construction of a hypothetical scenario for Civil Protection allows a rapid estimate of expected consequences, which are of great value for stakeholders and local authorities. However, for an accurate assessment of disaster outcomes, this information has to be coupled with outputs from numerical models.

6 Concluding remarks

A geo-referenced database of past events related to geo-hydrological hazards was designed for the area of Valtellina di Tirano, in the Central Italian Alps. It includes a large amount of historical information and covers a period from 1600 till 2008. Five main types of natural processes acting on slopes and the valley bottom were distinguished, and their causes were presented. Losses from damaging events were classified into four categories of damage intensity.

Historical knowledge allows to identify areas prone to instability on the base of the frequency of past events and, in combination with geological report analysis, to locate source areas of possible future events. The Tresenda study case shows that when assuming predisposing and triggering conditions and dynamics similar to the ones which acted in the past, with the aid of some simple slope morphological analysis techniques, realistic hazard scenarios characterised by different levels of severity related to natural processes can be set. The construction of hypothetical scenarios for Civil Protection purposes permits to identify affected elements, which are of great value for stakeholders and local authorities. However, for an accurate assessment of disaster consequences, this information has to be coupled with outputs from numerical models.

Obviously, results improve when more information about intensity of past events becomes available. This is the reason why it is important to have this database as rich as possible of information, and to keep it continuously updated. Future work should be focused on that, and particularly on trying to define with more accuracy, the type of processes that caused disruptions and to describe their evolution (spatial and temporal) and effects with more detail. Besides the enrichment of scenarios, this will allow to better distinguish among processes and their causes and to avoid misunderstandings that could have serious consequences in emergency planning.

Collecting information on past geo-hydrological disasters is sometimes a very exhausting and time-consuming work but still represents the main input for hazard and risk scenario modelling and assessment. However, the process of identification and mapping of events could be quite subjective (Carrara et al. 1995). Moreover, historical knowledge does not account for possible recent changes of parameters affecting hazard and risk prediction (e.g. climate change, urbanisation, realisation of defence works). As a consequence, this approach has to be used in combination with other analysis techniques (heuristic, statistic, probabilistic and physical models) targeted to hazard assessment, socio-economic evaluations and risk management, above all.

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