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A WebGIS for the dissemination of information on historical landslides and floods in Umbria, Italy

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Abstract A web site was designed to disseminate new information on historical landslides and floods in Umbria, central Italy. The historical information was compiled through a thorough review of existing catalogues of historical landslide and flood events, supplemented by an extensive search of local historical archives and chronicles, for the period before 1900. The new catalogue lists 1983 landslide events in the period from 1139 to 2001, and 1956 flood events in the period from 860 to 2001. In the considered period, in Umbria there were at least 1,531 sites affected one or more times by landslides, and at least 1,071 sites affected one or more times by inundations. The seasonal distribution of landslides and inundations was found different before and after 1900, most probably because of incompleteness of the historical record prior to 1900. WebGIS technology was used to disseminate the geographical and thematic information on historical landslides and floods in Umbria. The GIS-based web site is aimed at a diversified audience of experts and private citizens seeking information on geo-hydrological hazards in Umbria.

Keywords WebGIS · Flood · Landslide · Historical Catalogue · Umbria · Hazard

1 Introduction

WebGIS technology extends to the Internet functionalities typical of a Geographical Information System (GIS) [8, 9, 11]. In a WebGIS environment, operations such as access to geographical databases, map production, theme overlay, and visualization of map attributes are possible using a standard Internet browser (e.g., Mozilla Firefox©, Microsoft Internet Explorer©, Opera©) and without specific or proprietary software on the computer client (e.g.,

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Applets Java, Active X). WebGIS technology is particularly interesting for the dissemination of information on geo-hydrological events, such as landslides and inundations [1, 4].

For the Umbria region, central Italy, a catalogue of historical landslide and inundation events was compiled through the systematic analysis of various archive and information sources. Sites affected by historical landslides and inundations were identified and mapped at 1:25,000 scale. A specific Web site was designed to disseminate the available historical information, and WebGIS technology was adopted to show the location of the sites historically affected by landslides and inundations in Umbria.

In this paper, we describe the available information on historical landslides and floods in Umbria, we perform a temporal and a spatial analysis of the collected historical information, and we present a Web site designed to disseminate the information.

2 Study area

The Umbria region extends for 8,456 km^2 in central Italy, with elevations ranging from 50 to 2,436 m a.s.l. (Fig. 1). Landscape is hilly or mountainous, with open valleys and large intra-mountain basins. The Tiber River, a tributary of the Tyrrhenian Sea, drains the area. Climate is Mediterranean, with distinct wet and dry seasons. Rainfall occurs mainly from October to December and from March to May, with cumulative annual values ranging between 500 and 2,100 mm. Snowfall occurs every year in the mountains and about every 5 years at lower elevations. Due to the physiographic and climatic setting, landslides and floods are common in Umbria, and cause severe damage [3, 5, 6, 10].

3 Historical information on landslides and floods in Umbria

The Umbria Region has a long history of landslides and floods (Fig. 2) [3, 5, 6, 10].

For the Umbria region, the AVI Project, a national inventory of historical landslides and floods in Italy [2, 4, 5, 12] collected information on 1,482 landslide events at 1,286 sites, and on 1,257 inundation events at 525 sites. Most of the events occurred in the 83-year period from 1918 to 2001. Information on landslides and floods occurred before 1918 is available for a limited number of events in the national catalogue. The historical information on landslides and floods listed in the AVI inventory was obtained searching local and national newspapers, interviewing local experts on mass movements and floods, and through the systematic review of published and unpublished technical and scientific reports [2, 4, 5, 10].

Inspection of the temporal distribution of the inventoried historical landslides and floods events in Umbria (Fig. 3) reveals that the completeness of the historical catalogue varies with time. The increased number of events reported after about 1950 is attributed chiefly to the augmented number and to the better quality of the historical information; the result of better and more abundant information sources [4, 5].

More recently, the AVI inventory for Umbria was updated through a systematic revision of the existing information on historical landslides and floods in Umbria, and a thorough search for new information on historical landslides and floods occurred before 1900 in Umbria [1, 14]. The new information was obtained searching: (1) old serials and monographic publications, (2) manuscripts and printed documents, and (3) published or unpublished reports. The searched documents were stored in two National Archives (Perugia and Terni), two Public Libraries (the “Biblioteca Augusta” in Perugia and the Terni Public Library), and the Historical Archive of the Todi Municipality.

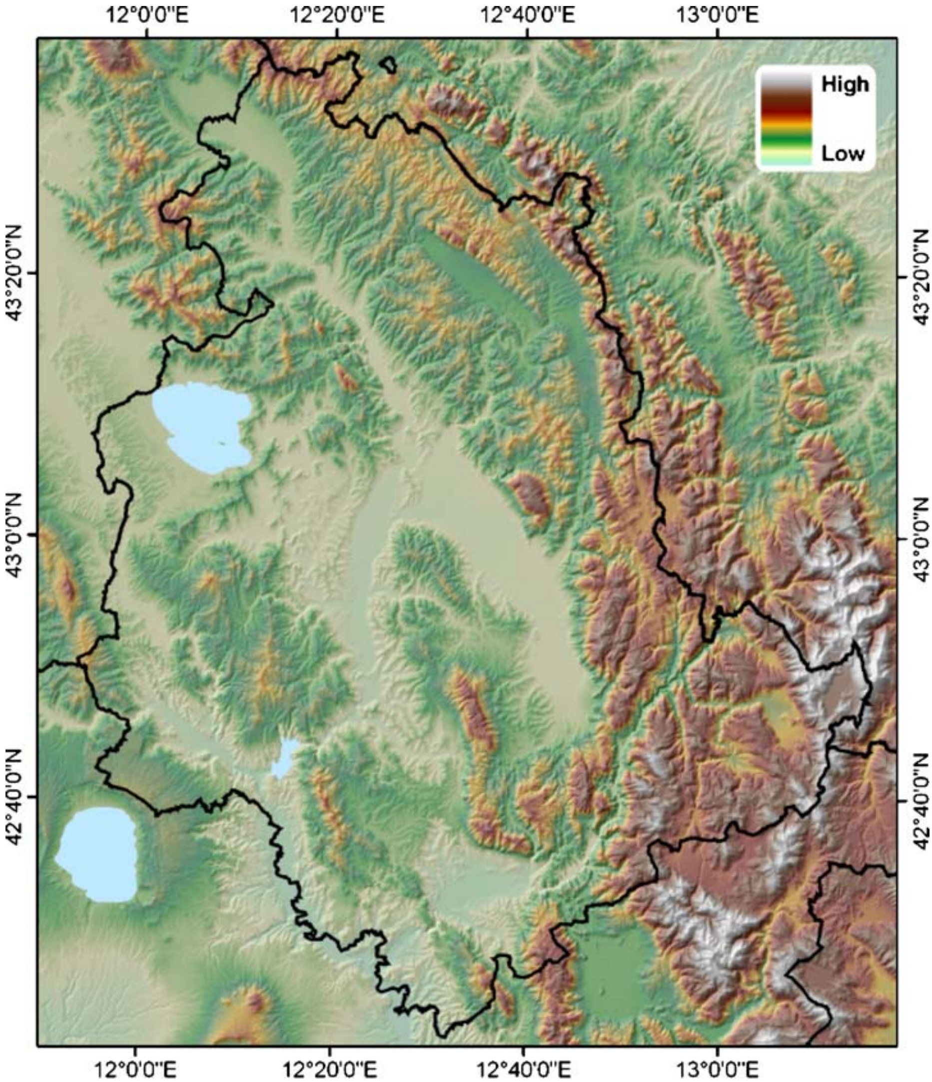

Fig. 1 Map showing the location and morphology of the study area (Umbria region, central Italy)

A digital catalogue listing all the collected information on historical landslide and flood events in Umbria was compiled [14]. For each event, the following information was collected: (1) location of the event, (2) date or period of the event, (3) type of mass movement and volume of the material involved, (4) hydrological and meteorological characteristics of a flooding event; (5) temporal and spatial evolution of the landslide or inundation event, (6) triggering mechanism, (7) geological and morphological characteristics of the affected area, and (8) type and extent of the damage. Not all the information was available for all the events.

A unique numeric value was assigned to each site where a landslide or a flood occurred. The unique code allowed linking an individual "site" (represented by a single set of

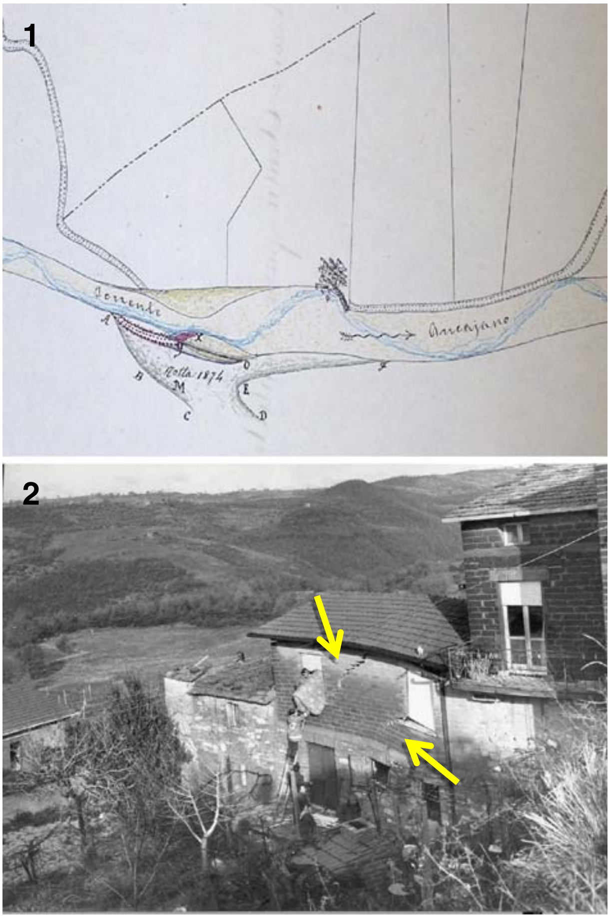

Fig. 2 (*1*) Historical drawing showing location of a levee break (*red line*) occurred in October 1881 along the Ancajano Torrent near Ferentillo. Letters from *A* to *F* show the area flooded during a previous event occurred in 1874. (*2*) Photograph showing damage to private homes caused by the 22 December 1982 Monteverde landslide

geographical coordinates) to one or more "events" (each represented by a date or period) occurred at the site. For each site, geographical coordinates were obtained at 1:25,000 scale adopting the following procedure. First, the original source of information was analysed searching for all the elements that could help locating the landslide or the inundation events. Where necessary, lists of local names-of-places were used to help locating the event. Next, the site affected by a landslide or an inundation was mapped as a point on topographic base maps at 1:25,000 scale. Sites for which the location remained undetermined were mapped in the municipality main centre. Lastly, the geographic coordinates for each site were obtained through hand digitization in a GIS. A degree of certainty in the geographic location was attributed to each site.

Figure 4 shows a sample of the map of sites affected by historical landslides and floods in Umbria for the Orvieto village. Inspection of Fig. 4 reveals the cartographic detail of the mapping, and the local abundance of the historical information.

The new historical catalogue for Umbria lists information on 1,983 landslide events at 1,327 sites in the 863-year period from 1139 to 2001, and information on 1,956 flood events at 972 sites in the 1,142-year period from 860 to 2001.

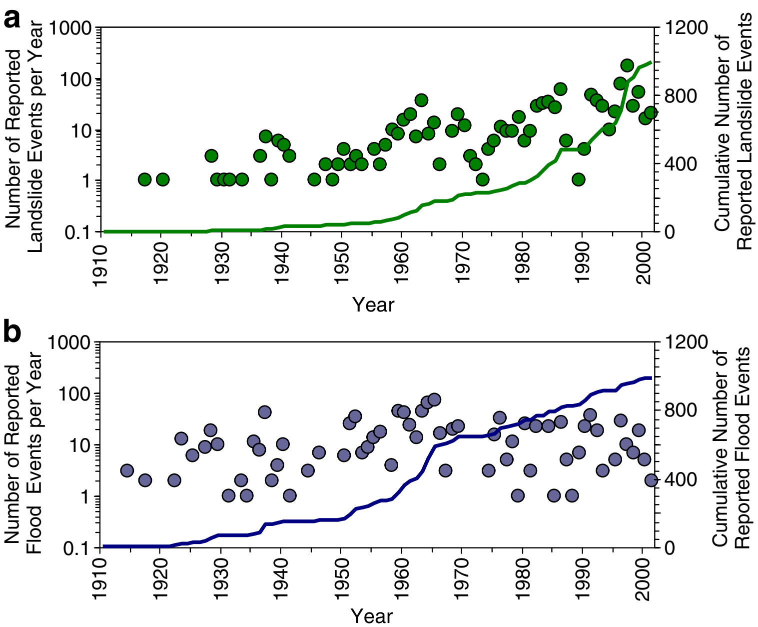

Fig. 3 Temporal distribution of historical landslide (**a**) and inundation (**b**) events in Umbria in the 92-year period from 1910 to 2001

4 Analysis of the new historical catalogue

The new catalogue of historical landslides and floods in Umbria can be used to investigate the spatial and the temporal distribution of the reported events. This is important information for landslide and flood hazard and risk assessment [3, 4, 7, 13].

4.1 Geographical distribution of historical events

Figure 5 shows the geographical distribution of sites affected by historical landslides and floods in Umbria. The map shows the location of 1,324 sites affected by landslides, and 1,003 sites affected by inundations, in the period from 860 to 2001. Inspection of the map reveals clustering of the reported landslide information in urban areas (e.g., the cities of Perugia, Todi, Orvieto). This has several causes, including: (1) a higher concern of local administrators for urban areas, (2) the larger and most frequent damage caused by historical landslides in urban areas, compared to the damage caused in rural areas, and (3) a certain easiness in reporting landslides in urban areas, when compared to similar events occurred in rural areas. Further inspection of Fig. 5 reveals clustering of the reported information on historical floods at specific sites or areas, chiefly along the Tiber River and its major tributaries. This reflects the higher frequency of events in these areas that, for this reason, should be considered at high risk of inundation.

Figure 6 shows the density of landslide and flood sites (i.e., the number of events per square kilometres) in the 92 municipalities in Umbria. Inspection of the map reveals that municipalities most affected by historical landslides were Orvieto (281 events), Todi (236), and Perugia (149); and municipalities most affected by historical floods were Deruta (141

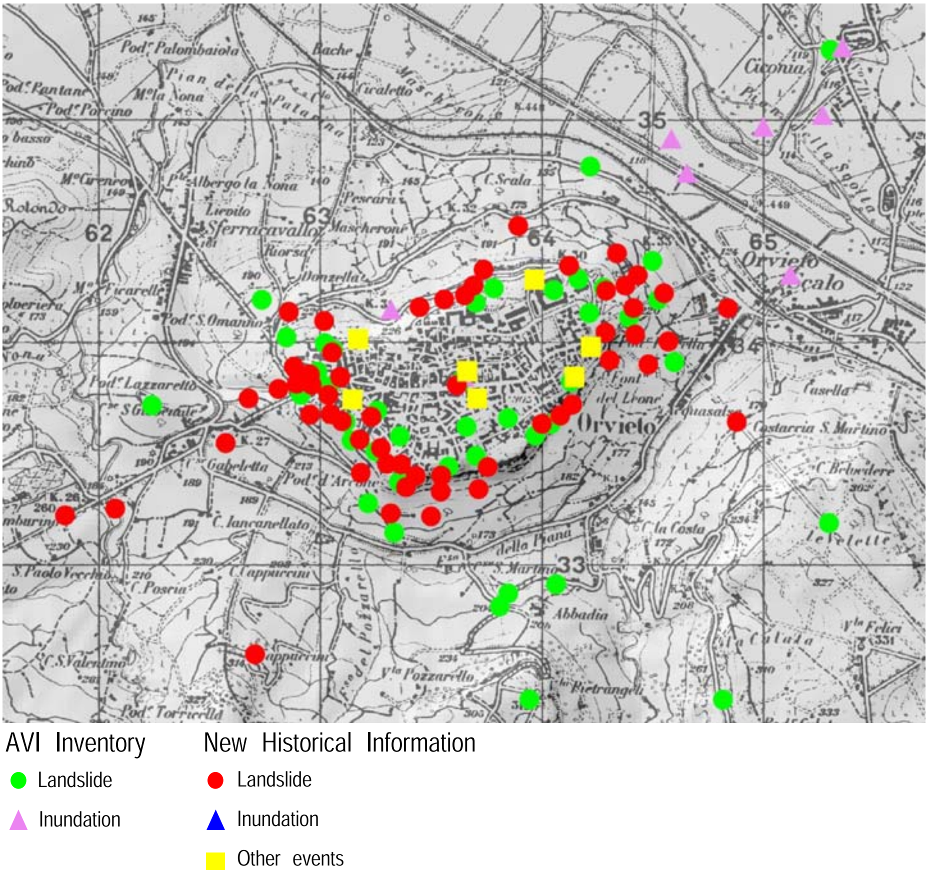

Fig. 4 Detail of the map of sites affected by historical landslides and floods in Umbria for the Orvieto village. Affected sites are shown by different symbols and colours, depending on the type of the event and the source of the information

events), Marsciano (112), Terni (112) and Perugia (101). Of the 92 municipalities in Umbria, 90 municipalities (covering 99% of the territory) experienced at least once a landslide, and 79 municipalities (91% of the territory) experienced at least once an inundation. For two municipalities (Montecchio and Sigillo) no information on historical landslides or floods is listed in the historical catalogue. These two municipalities cover 0.1% of the Umbria region. In the two municipalities landslides and floods may have occurred, but they may have not been noticed or they may have not been reported e.g., because they did not cause damage.

4.2 Temporal pattern of historical events

In the new catalogue of historical landslide and flood events in Umbria, the date, month, or year of occurrence is known for 1,496 landslide events (75.4%) and for 1,956 flood events (99.8%; Fig. 7). These events can be used to investigate the temporal pattern of historical landslide and flood events in Umbria. Inspection of Fig. 7 reveals that the distribution of the reported events varies with time. Before about 1600, only a handful of events were

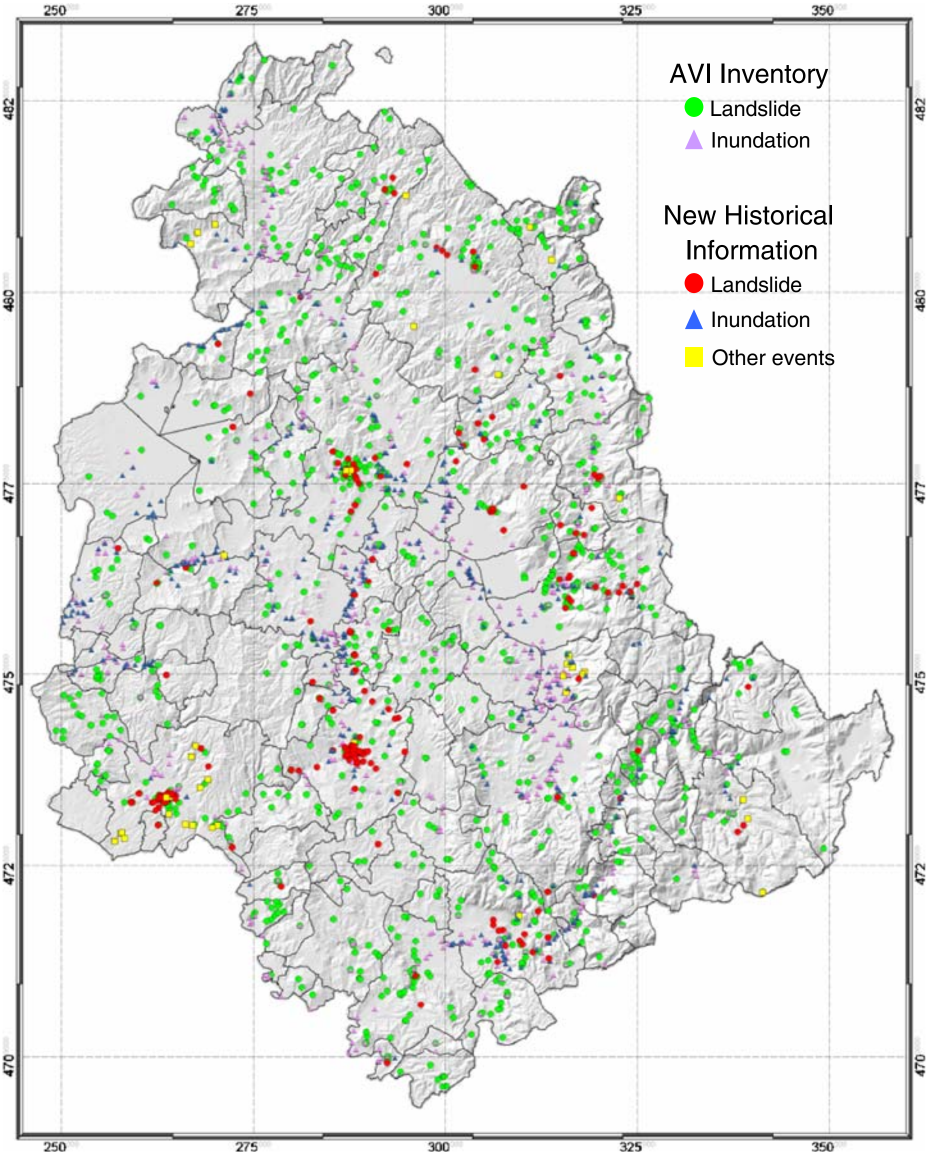

Fig. 5 Map showing the geographical distribution of sites affected by historical landslides and floods in Umbria, in the period from 860 to 2001. Affected sites are shown by different symbols and colours, depending on the type of the event and the source of the information

reported. The number of reported events increases after about 1800, is more distinct in the second half of the nineteenth century, and is particularly evident after about 1950.

In an historical catalogue of natural events the lack of occurrences in any given period may be due either to the catalogue's incompleteness or to variation in the conditions that led to the events [3, 4, 13]. Decoupling the two effects is difficult. For the new catalogue of historical landslide and flood events in Umbria, both effects are present. In Umbria, the

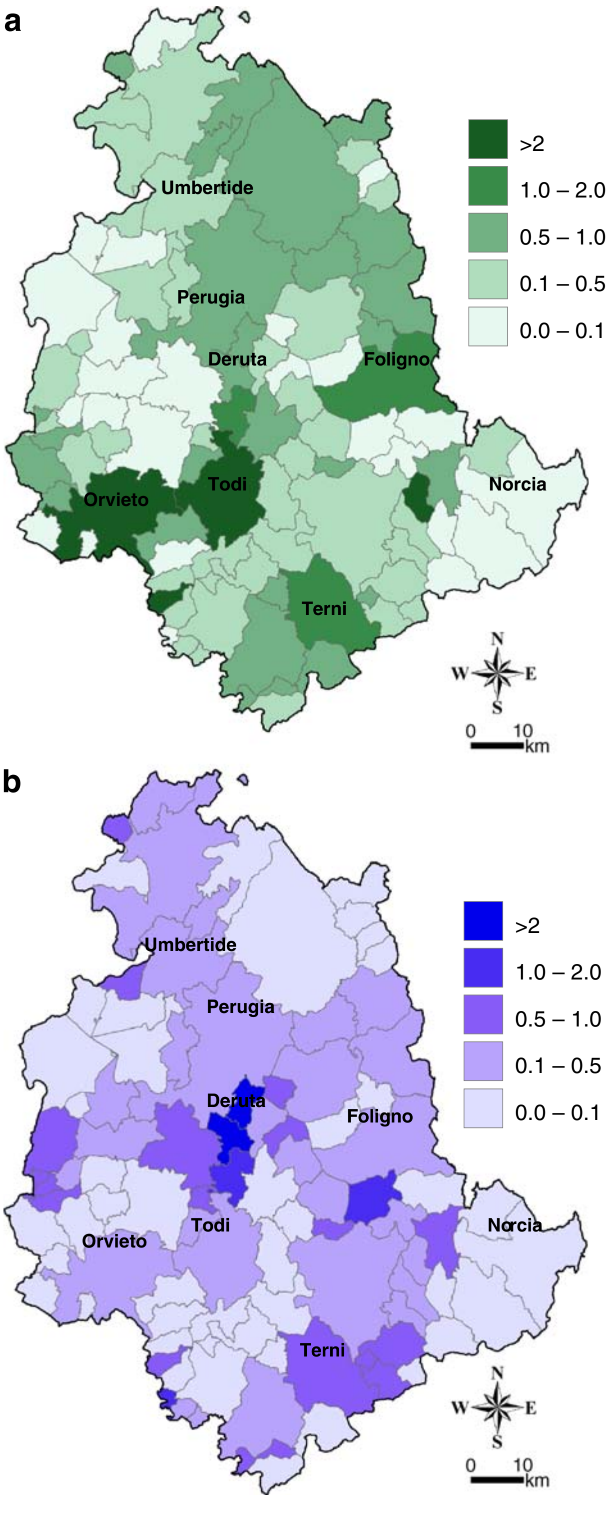

Fig. 6 Density of historical landslide (**a**) and flood (**b**) events in Umbria, in the period from 860 to 2001. *Shades* of *colours* portray the number of inventoried events in each municipality per square kilometre

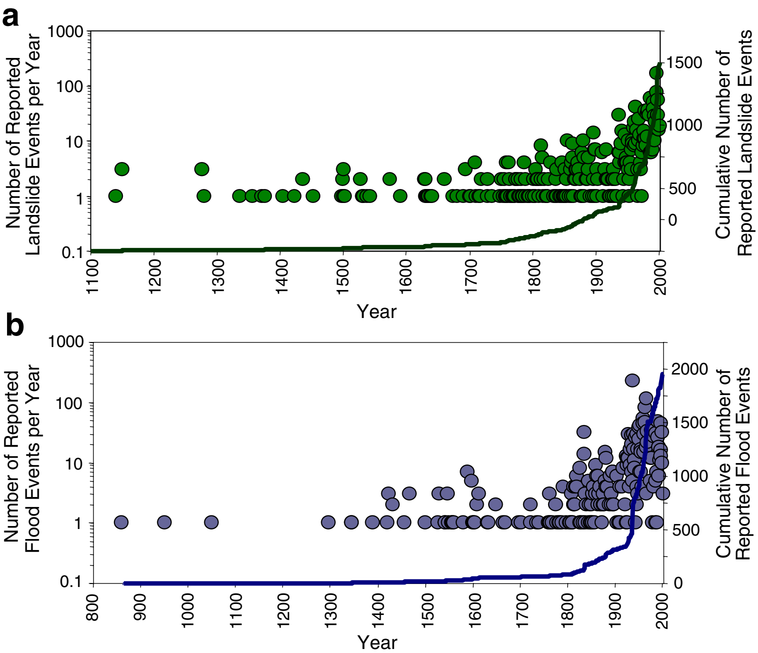

Fig. 7 Temporal distribution of historical landslide (**a**) and inundation (**b**) events in Umbria in the 1,142-year period from 860 to 2001

population went from 442,000 inhabitants in 1860 to 825,000 inhabitants in the year 2001. The number of vulnerable elements (e.g., houses, roads, etc.) increased proportionally. The augmented number of reported landslide and flood events—particularly after 1950—is at least partly the result of the larger population and the increased number of vulnerable elements. However, we maintain that the increase in the number of reported events in the catalogue is largely the result of incompleteness of the historical record.

4.3 Monthly distribution of historical events

In the new historical catalogue, the date or the month of occurrence is known for 952 landslide events (48.0%) and for 1,760 inundation events (89.8%). These events can be used to investigate the seasonal distribution of historical landslides and floods in Umbria (Fig. 8).

Inspection of Fig. 8 reveals that the seasonal distributions of landslide events before 1900 and after 1900 are different. Before 1900 (201 events), reported landslides were particularly abundant in the period between October and November, and in the period from March to May. Landslide events were also abundant in July. After 1900 (751events), landslide events concentrate in the period form September to April, with a peak in February. The seasonal distribution of historical inundations is also different before and after 1900. Before 1900 (244 events), reported inundations were particularly abundant in the period from September to December, with the largest number of reported inundations in September, i.e., at the beginning of the rainy season. After 1900 (1,516 events), inundations are most frequent from September to February, with the maximum number of events reported in December and a distinct (relative) minimum value in January.

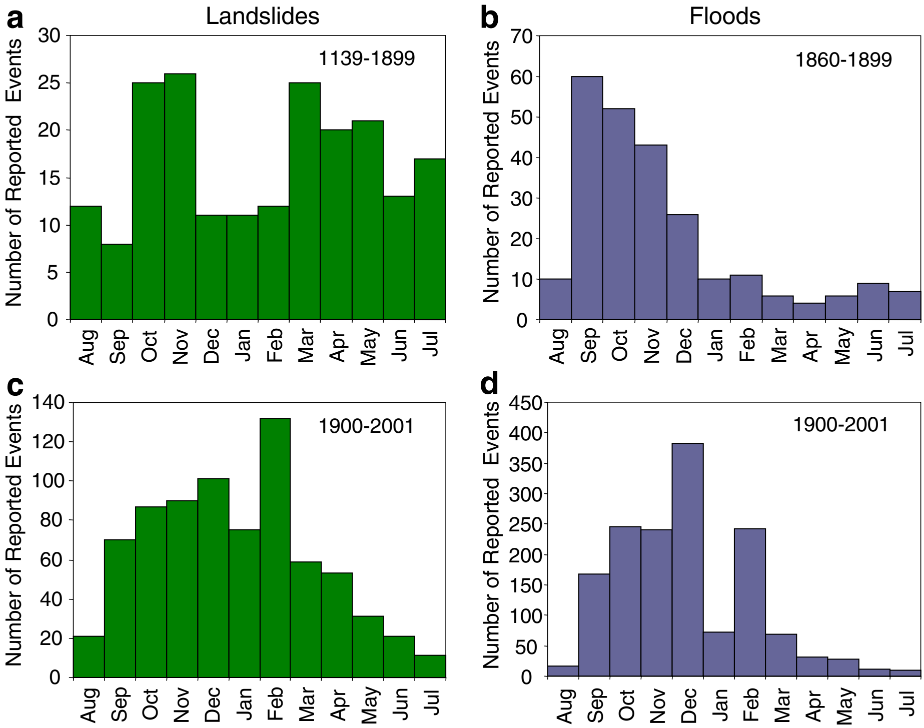

Fig. 8 Monthly distribution of historical landslide (**a**, **c**) and inundation (**b**, **d**) events in Umbria for different periods. **a** and **b**, before 1900. **c** and **d**, between 1900 and 2001

The observed differences in the seasonal frequency of landslides and inundations with time may have several causes, including: (1) incompleteness of the catalogue for the earlier part of the record, (2) changes in land-use types that have affected slope stability and surface runoff, and (3) climatic and meteorological variations that have affected the pattern and intensity of the triggering events.

4.4 Recurrence of historical events

Analysis of the historical catalogue reveals that some sites were affected by landslides or inundations repeatedly. This information can be used to investigate the recurrence of landslide and inundation events at specific sites. Figure 9 shows the number of times each site was affected by a landslide or an inundation (*y*-axis) against the rank of the event (*x*-axis), ordered from the largest number of events to the least number of events.

Inspection of Fig. 9 reveals that the total number of damaged sites is large for both landslides and inundations, confirming that slope failures and flooding are frequent and widespread in Umbria. Further inspection of the graphs reveals that the number of sites affected repeatedly is relatively low. Of the 1,071 sites affected by inundations, 296 sites (27.6%) were affected two or more times, 63 sites (5.8%) were affected five or more times, and only 17 sites (1.6%) were affected ten or more times. Of the 1,531 reported landslide sites, 203 sites (18.9%) experienced two or more events, 24 sites (2.2%) were affected five or more times, and only nine sites (0.8%) experienced ten or more slope failure events.

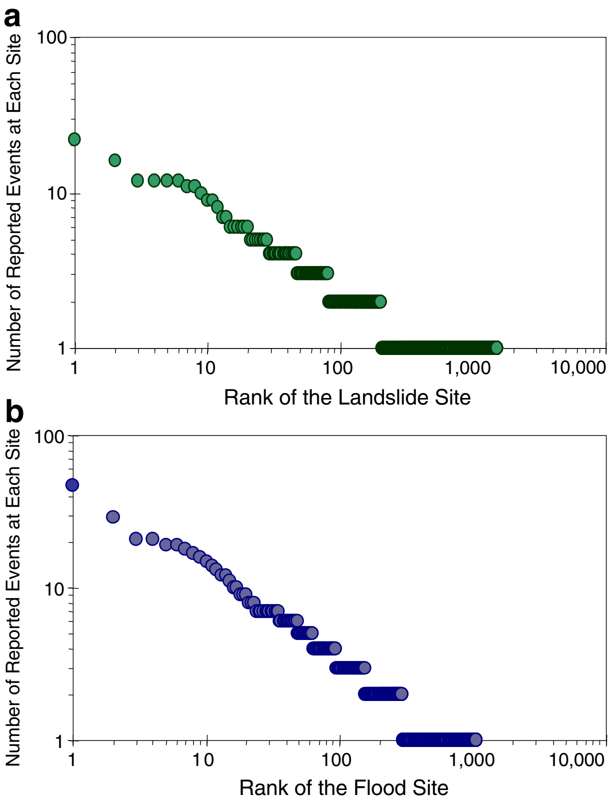

Fig. 9 Number of damaging events at each site (*y*-axis) vs. the rank of the site (*x*-axis). **a** landslides, **b** inundations

These figures confirm that the areas where landslides and inundations are frequent—and for this reason can be considered at risk—are limited, and that landslides are a more widespread phenomenon than inundations. This was expected, as inundations occur along the river network, whereas landslides can occur everywhere a slope exists.

5 WebGIS for historical landslides and floods in Umbria

For the dissemination of the information on historical landslides and inundations in Umbria, a specific Web site—available at http://eventistoriciumbria.irpi.cnr.it—was designed. Since the collected historical information has a significant geographical component (sites affected by landslide or flood events are located by their geographical coordinates), WebGIS technology was adopted to show the location of sites historically affected by landslides and inundations in Umbria.

The Web site runs on an Apache HTTP Server version 2.0.55 (http://www.apache.org). The WebGIS engine is MapServer version 4.10.0 (http://mapserver.gis.umn.edu). The shared geographical and thematic data are stored in the Web and WebGIS server computer: an Intel® Pentium IV processor (3.2 GHz) running Linux OS (Fedora Core 4) with two SATA hard disks (160 GB capacity each) and 1 GB of RAM.

MapServer, an open source environment for building spatially enabled Internet applications developed by the University of Minnesota in cooperation with NASA and

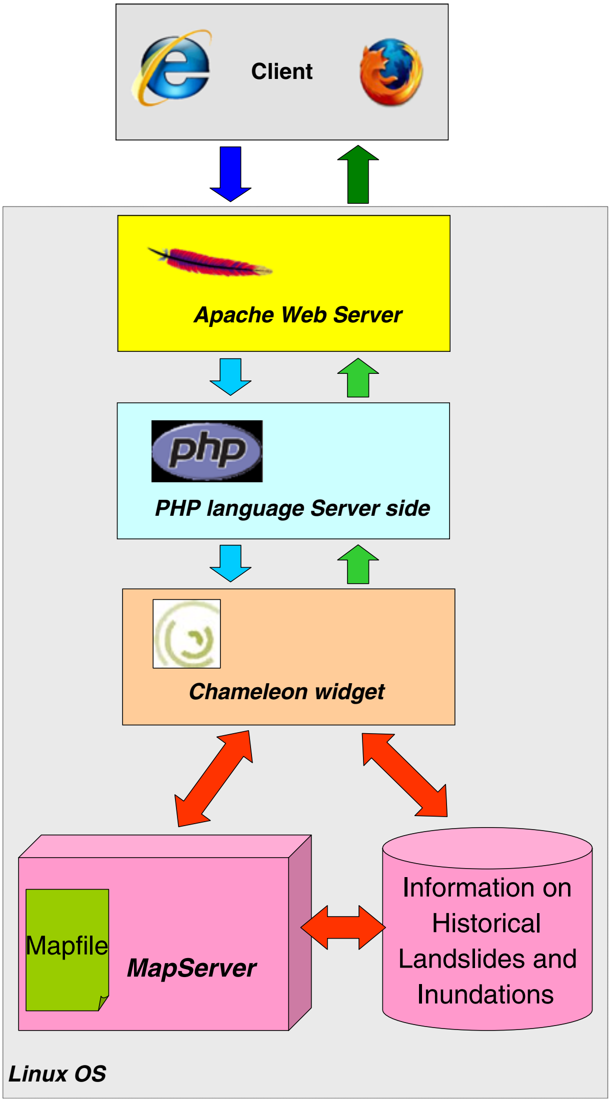

Fig. 10 Scheme of the Web (Apache) and the WebGIS (MApServer) servers used to publish on the Internet information on historical landslides and inundations in Umbria

the Minnesota Department of Natural Resources, implements a "server-based" architecture for the publication of geographical information on the Internet. Queries submitted by a "client" using a standard Internet browser that supports the HTML language, are received by the Web server and passed to MapServer. The WebGIS engine receives the query and process it, generating the requested maps "on-the-fly", and sending the result to the "client" (via the Web server) as a single image file (e.g., a PNG raster file). With this respect, MapServer is an "image server", for distributing cartographic information. The main advantage of the "server-based" architecture consists in the fact that the "client" does not need specific or proprietary software to use (i.e., query) the WebGIS server.

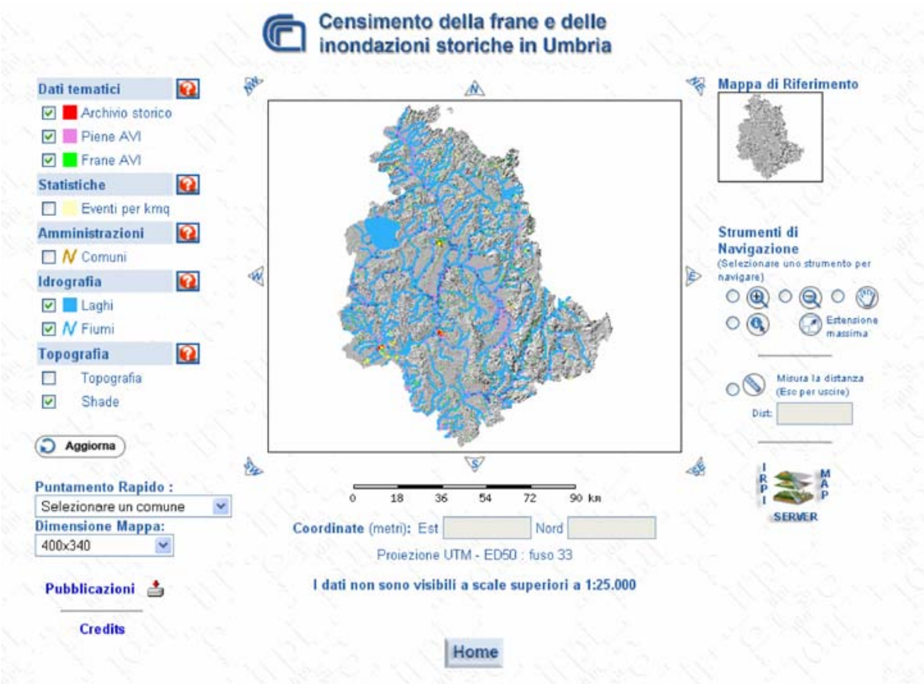

Fig. 11 Home page of http://eventistoriciumbria.irpi.cnr.it, the WebGIS site for the publication through the Internet of geographical and thematic information on historical landslides and inundations in Umbria

MapServer has the following additional characteristics:

1. Runs as a Common Gateway Interface (CGI) program, a standard procedure for interfacing external application software with an information/web server
2. Exploits the OGR Simple Feature Library for vector data, and the GDAL (Geospatial Data Abstraction Library) for raster data to convert from one file format to another
3. Supports the PostgreSQL database (http://www.postgresql.org) and its PostGIS extension for handling geographical information (http://postgis.refractions.net/)
4. Supports a number of proprietary GIS formats, including ESRI® Shapefile®
5. Integrates the PROJ4 library, for the conversion of geographical coordinate from different projection systems
6. Integrates the LibTiff, LibGeoTiff and LibJPEG libraries for Tiff, GeoTiff and Jpeg support
7. Complies with standards proposed by the Open Geospatial Consortium (OGC), including the Web Map Service (WMS) and the Web Feature Service (WFS) standards

Figure 10 portrays a scheme for the Web and the WebGIS servers used to publish on the Internet information on historical landslides and floods in Umbria.

The ability of MapServer to serve geographical information through the Web is based on a single ASCII file: the “mapfile”. In a “mapfile” the available geographical information is indexed, and the relationships between the geographical information and the display objects are defined. The established relationships uniquely specify the layout, organization, style, and scale of publication of the geographical information. In a “mapfile” geographical information is organized in separate layers. For each layer, classes are defined and styles of

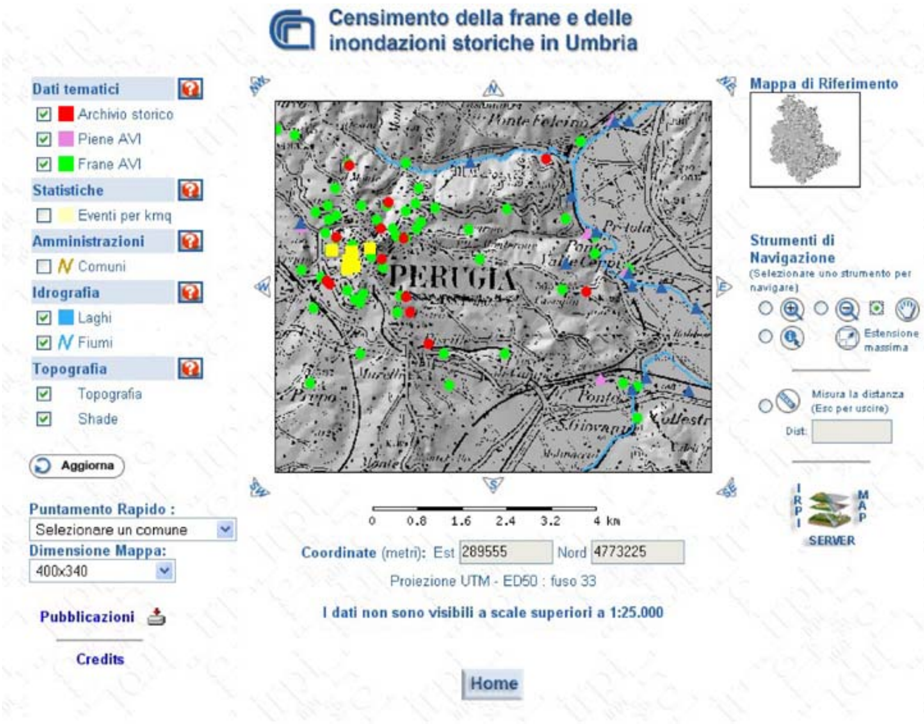

Fig. 12 The WebGIS site for the publication of geographical and thematic information on historical landslides and inundations in Umbria (http://eventistoriciumbria.irpi.cnr.it). Example of map showing historical landslides and inundations near the city of Perugia, central Umbria

visualization are associated to each class. The structure is flexible, allowing for, e.g. the publication of maps using different styles (colours, patterns, symbols) depending on the scale of visualization of the geographical information.

Preparation of a functioning "mapfile" by hand is possible, but it is a tedious and error prone operation. To facilitate the preparation of complex "mapfiles", a number of software applications have been developed, including Map-Lab (http://www.maptools.org/maplab/) and QuantumGis (http://www.qgis.org/). Software applications are also available to help designing Web pages to show cartographic information delivered by MapServer. These Web-designing tools include Chameleon (http://chameleon.maptools.org/), Ka-Map (http://ka-map.maptools.org/), and Map-Lab (http://www.maptools.org/maplab/). To prepare the "mapfile" used for the publication of the geographical information on historical landslides and inundations in Umbria, Map-Lab was used. Optimization and refinement of the "mapfile" was performed by hand, using a standard text editor. To design the Web-GIS home page, Chameleon was used. Chameleon is a distributed and configurable environment that incorporates the ability to quickly setup new WebGIS applications from a common pool of widgets that can be placed in an HTML template file. The widgets provide fixed functionalities, but the representation of the widget is configurable.

Figure 11 shows the layout of the main Web page used by MapServer to display the geographical information on historical landslides and floods in Umbria. The Web page is subdivided into three main areas. The "map area" is located in the central part of the Web page. In this area, the geographical information is shown as a single map. Tools are provided to move through the map. Information on the display scale and on the geographical coordinates is shown below the map. To the left of the central map, the geographical information available for display is listed. The information is organized by themes. For each theme, a legend is provided. The order of the themes specifies the sequence used to prepare the map through overlay of the selected themes. Question marks are links to Web pages describing the individual themes. In the lower-left corner of the web page widgets are provided to zoom to a specific municipality, and to change the size of the map area, e.g. depending on the size and resolution of the computer screen. To the right of the main map, an index map is shown, and widgets to navigate through the main map are provided.

Figure 12 portrays an example of a map published by MapServer. The map shows historical landslides and inundations near Perugia, central Umbria. In the map, historical landslides and inundations are shown by different symbols, depending on the type of event and the source of information.

6 Conclusions

The new catalogue of historical landslide and flood events in Umbria was presented. The catalogue spans the period from 860 to 2001 [14], and lists information on 1,983 landslide events at 1,327 sites, and on 1,956 flood events at 972 sites. The historical information was collected through the systematic review of the existing information on historical landslides and floods in Umbria [2, 4, 5, 10, 12], and the systematic analysis of new information obtained by searching national and municipality archives and public libraries [14]. Analysis of the collected historical information allowed investigating the geographical distribution of the affected sites, and the temporal distribution of landslide and inundation events. A Web site designed to disseminate the available information on historical landslides and floods in Umbria was discussed. The site exploits WebGIS technology to show the location of the sites historically affected by landslides and inundations in Umbria. The Web site is aimed at a diversified audience, encompassing scientists, decision makers and individual citizens seeking information on geo-hydrological hazards in Umbria.

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Fausto Guzzetti graduated in geology from the University of Perugia in 1983, and received a Ph.D. in geography from the University of Bonn in 2006. As senior research scientist at the Italian National Research Council, Guzzetti leads the CNR IRPI landslide hazard and risk assessment team in Perugia.

Gabriele Tonelli graduated in engineering from the University of Bologna in 1995. He collaborates with the landslide hazard and risk assessment team of the National Research Council in Perugia as expert in database, GIS, and WebGIS.