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# Geomorphological mapping for the valorization of the alpine environment. A methodological proposal tested in the Loana Valley (Sesia Val Grande Geopark, Western Italian Alps)

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**Abstract:** Geomorphological mapping plays a key role in landscape representation: it is the starting point for many applications and for the realization of thematic maps, such as hazard and risk maps, geoheritage and geotourism maps. Traditional geomorphological maps are useful for scientific purposes but they need to be simplified for different aims as management and education. In tourism valorization, mapping of geomorphological resources (i.e., geosites, and geomorphosites), and of geomorphic evidences of past hazardous geomorphological events, is important for increasing knowledge about landscape evolution and active processes, potentially involving geomorphosites and hiking trails. Active geomorphosites, as those widespread in mountain regions, testify the high dynamicity of geomorphic processes and their link with climatic conditions. In the present paper, we propose a method to produce and to update cartographic supports (*Geomorphological Boxes*) realized starting from a traditional geomorphological survey and mapping. The *Geomorphological Boxes* are geomorphological representation of single, composed or complex landforms drawn on satellite images, using the official Italian geomorphological legend (ISPRA symbols). Such cartographic representation is also addressed to the analysis (identification, evaluation and selection) of *Potential Geomorphosites* and *Geotrails*. The method has been tested in the upper portion of the Loana Valley (Western Italian Alps), located within the borders of the Sesia Val Grande Geopark, recognized by UNESCO in 2013. The area has a good potential for geotourism and for educational purposes. We identified 15 *Potential Geomorphosites* located along 2 *Geotrails*; they were ranked according to specific attributes also in relation with a Reference Geomorphosite located in the Loana hydrographic basin and inserted in official national and regional databases of geosites (ISPRA; Regione Piemonte). Finally, the ranking of *Potential Geomorphosites* allowed to select the most valuable ones for valorization or geoconservation purposes. In this

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framework, examples of *Geomorphological Boxes* are proposed as supports to geo-risk education practices.

**Keywords:** Geomorphological mapping; Geomorphological Boxes; Mountain geomorphosites; Geotrails; GIS - Geographical Information Systems; Loana Valley ;Western Italian Alps

**Notation:**

| | |
|---|---|
| *PGmf* | Potential Geomorphosites |
| *Gtrs* | Geotrails |
| *Gsts* | Geostops |
| *GmBxs* | Geomorphological Boxes |
| *TSVs* | Threshold Values |
| SV | Scientific Value |
| AV | Additional Values |
| GV | Global Value |
| PU | Potential for Use |
| SIn | Scientific Index |
| EIn | Educational Index |
| VGNP | Val Grande National Park |
| SVGP | Sesia Val Grande Geopark |

## Introduction

European Alps are among the key sites for geoheritage (Osborne 2000). The high level of geodiversity (Gray 2013), due to the complexity of geological processes and to the variety of geomorphological features, including several Geosites (Wimbledon 1996) and Geomorphosites (Panizza 2001), which constitute the local and the national geoheritage, represent meaningful situations to approach concepts as geo-valorization, management and conservation. These latter are fundamental in the framework of sustainable tourism, considering the sensitivity of mountain areas to natural changes and Man-induced impacts (Giardino and Mortara 1999; Beniston 2003). Several active and evolving passive geomorphosites (sensu Pelfini and Bollati 2014) can be found in the mountain territories. Some of them are characterized by a fast changing rate, in response to climate change (e.g., glacial forelands). In fact time-scale of geomorphic processes is very variable, also according to the affected substrates. Moreover, geosites may be dismantled in short or long times under the action of the same processes responsible for their genesis or by different ones (Giardino and Mortara 1999; Pelfini and Bollati 2014).

Geoconservation strategies have recently undergone a growing interest in the framework of the scientific researchers on Earth Sciences and of the UNESCO Commitee for the World Heritage protection (UNESCO 2015). Nevertheless, management policies and funding systems do not seem to follow the same trend (Brihla 2016a). Hence, researches on methodologies useful to individuate geo-resources, such as Geosites and Geomorphosites, to be conserved, are becoming a real need (e.g., Reynard et al. 2016a), as well as the strategies to promote them in a sustainable way (Giardino and Mortara 1999). Geoheritage promotion and valorization is often perceived through the creation of geotrails (e.g., Burlando et al. 2011; Wrede et al. 2012) and naturalistic and thematic trails (e.g., glaciological trails) (Martin 2010; Bollati et al. 2013). Geotrails are usually addressed to a general public (e.g., tourists, scholars) for exploring geoheritage, raising awareness on the possible threats caused both by human and natural factors, and for unconventional teaching and field activities (e.g., Bollati et al. 2011; Garavaglia and Pelfini 2011; Bollati et al. 2016; Pelfini et al. 2016).

Changing landforms are considered very significant components of Geoheritage (e.g., Pelfini and Bollati 2014; UNESCO 2015) and testify the high dynamicity of geomorphic processes, especially when climate related, as in the mountain environment (Beniston 2003; Reynard and Coratza 2016). Nevertheless, the high dynamicity of the mountain environment and its fast changing rate make necessary a deep knowledge of surface processes and landforms evolution. Active slope processes, as for example debris flows or avalanches, commonly affect the high mountain hiking trails network and can indeed represent geo-hazards. Moreover tourists vulnerability is linked both to the knowledge of environmental characteristics (slope processes, meteorological and geomorphic events), to slope morphology and hiking trails features (Bollati et al. 2013). As a consequence also such components need to be considered to better analyze vulnerability for risk management (Pelfini et al. 2009; Komac et al. 2011; Brandolini et al. 2006; 2012; Smith et al. 2009; Raso et al. 2016).

High-frequented hiking trails allow investigating the tourist perception of landscape changes, as the ones dominated, by glacial processes (Comanescu and Nedelea 2015; Moreau 2010; Garavaglia et al. 2012) or by dangerous landslides (Luino 2005; Alcántara-Ayala and Moreno 2016). Where geomorphic processes affect areas surrounding touristic trails and where changing landforms (sensu Pelfini and Bollati 2014) are present, geosites are also suitable for risk education, the first step for risk mitigation (Giardino and Mortara 1999; Coratza and De Waele 2012; Bollati et al. 2013; Alcántara-Ayala and Moreno 2016). This is possible when geomorphological evidences of geomorphological hazards (e.g., rockfall and debris flows deposits affecting also human settlements) (e.g., Coratza and De Waele 2012) can be observed in safety conditions. Anyway, the scenic value of many sites offers opportunities for the regional and local tourism as documented by the growing number of proposals (e.g., thematic itineraries, cultural trails).

Geomorphological mapping is indispensable, first of all for the representation of the collected scientific data and for the analysis of the physical landscape dynamic and, subsequently for risk management and geo-risk education (Giardino and Mortara 1999). In a single document (i.e., the geomorphological map) landforms classified according to their genetic processes, are represented (e.g., ISPRA 1994; 2007). As highlighted by Giardino and Mortara (1999), landforms mapping is hence useful for detecting the most interesting *Landforms of geomorphological interest* (i.e., *Geomorphosites*, Panizza 2001), for promotion and protection (Komac et al. 2011) and then to evidence the potential geomorphological hazards affecting geotrails.

Nevertheless, for dissemination and education, a simplified version is necessary, as detailed geomorphological maps require specific reading skills. Simplified geomorphological maps aim at easy communicating landforms activity degree to specialists (e.g., Carton et al. 2005) and non-specialists (Castaldini et al. 2005; Coratza and Regolini-Bissig 2010; Regolini-Bissig 2010) and providing elements useful to improve the knowledge of dynamic landscapes (e.g., Pelfini et al. 2007). Coratza & Regolini-Bissig (2010), for example, proposed guidelines for geomorphosites mapping (user, purposes, theme, level, scale, dimensionality, design, form and size, costs). Regolini-Bissig (2010) provided also a categorization of geotourism maps typologies, depending on the balance between scientific and touristic data. The crucial issue is represented by the detection of proper tools that guarantee the integrity of scientific concepts and favor an easy reading by local operators, public administrations and general public. According to Regolini-Bissig (2010), the ideal type of geotourist map may be considered an *interpretive map* that "tries to interpret the represented landscape by revealing its particularities" and it may be "used to communicate with a public of non-specialists. It focuses on the communication of geoscientific themes in order to provide the opportunity for the user to understand geomorphological or geological phenomena, formation or evolution. Tourist information are of secondary importance" (Regolini-Bissig 2010).

Not only traditional methods but also new technologies, based for example on GIS (Geographic Information Systems), remote sensing and satellite imagery applications (e.g., Google Earth®) allow multi-temporal analysis. Moreover, they are especially important in mountain areas where valorization and promotion must be linked with education and management in relation with the high dynamicity of the environment (Regolini-Bissig 2010; Martin et al. 2014).

Herein we propose a systematic procedure to join geomorphological mapping criteria, geomorphosites analysis and valorization in mountain environment, taking into account the need for an easy-approachable document, also for non-specialists. The study case is located in the upper portion of the Loana Valley (Verbano-Cusio-Ossola Province –VCO), in the Western Italian Alps, one of the most important access to the "Val Grande National Park" (VGNP; Figure 1). Loana Valley is included in the Sesia Val Grande Geopark (SVGP; Figure 1), officially recognized in 2013 by the European Geoparks Network and by UNESCO. In the Loana Valley, erosion and depositional landforms, mainly due to glacial processes, mass movements, debris flows, avalanches and stream modeling, are easily observable while walking touristic and excursionist trails. Besides, here, in the recent times, extreme meteorological events have triggered several instability events, some of

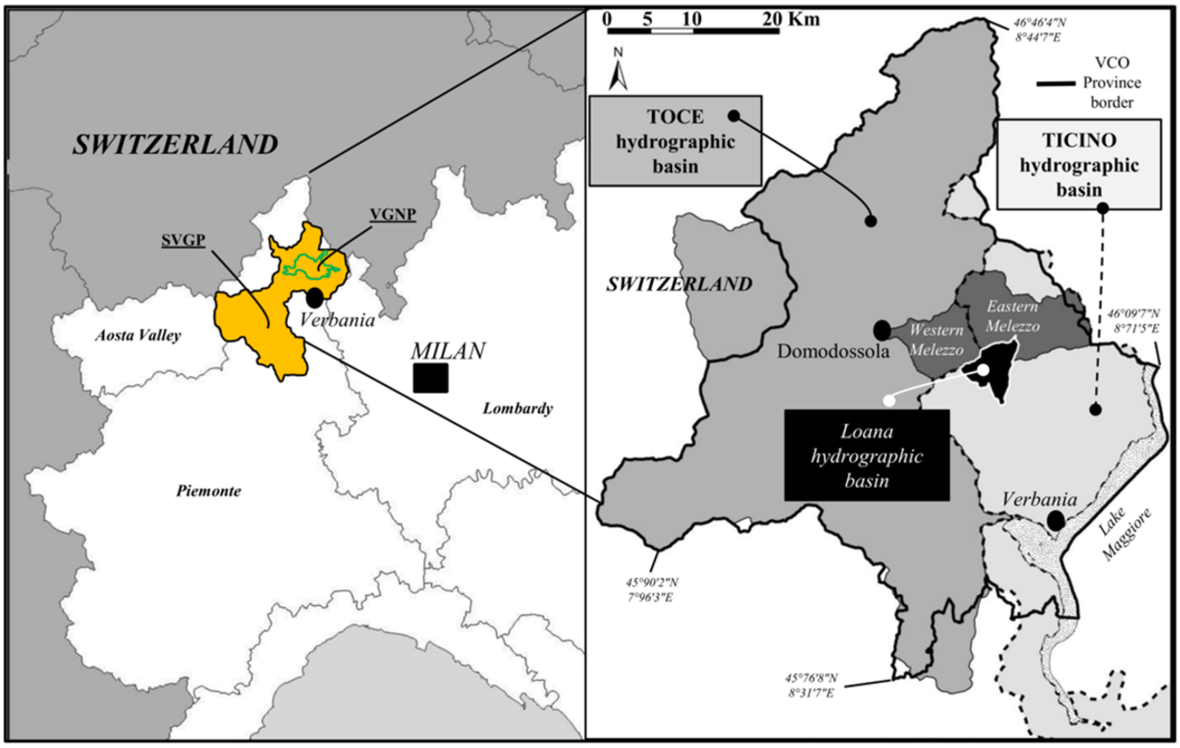


**Figure 1** Geographical settings of the study area in the framework of the Northern Italy (on the left) and of the Verbania-Cusio-Ossola Province (VCO; black line) (on the right). The location of the hydrographic basins (dashed line border) Toce, (dark grey), Ticino (light grey) and Western and Eastern Melezzo (very dark grey) is reported in the right figure. The Eastern Melezzo includes the Loana minor hydrographic basin (black). The area of the Sesia Val Grande Geopark (SVGP) is indicated in orange on the left figure and the green perimeter within it is related to the territory occupied by the Val Grande National Park.

which damaged infrastructures and left deep scars in the landscape (e.g., Mortara and Turritto 1989; Dresti et al. 2011). The selected area presents hence good features to test the proposed methodology and to find out tools for Earth Sciences education and dissemination, with particular regards to geo-risk education (e.g., Bollati et al. 2013).

The main aims of this paper are: i) the mapping of the geomorphology of a selected area, ii) the creation of an inventory of *Landforms of geomorphological interest* along specific trails; iii) the set of a GIS procedure to create simplified geomorphological sketches (i.e., *Geomorphological Boxes*) of *Potential Geomorphosites*; iv) the evaluation and ranking of *Potential Geomorphosites* and *Geotrails*; v) proposing a selection of *Geomorphosites* for Geoconservation and valorization according to different purposes.

## 1 Study Area

The Loana hydrographic basin occupies an area of about 27 km$^2$ and it is placed within the Ticino hydrographic basin, at the boundary with Toce basin (Figure 1). Loana Valley is a tributary of the Vigezzo Valley, which is characterized by a divergent fluvial pattern: i) the Eastern Melezzo stream flows toward the Maggiore Lake (East) continuing its course in the Swiss portion of the valley, named Centovalli; ii) the Western Melezzo river flows into the Toce River (West). The Loana stream is a tributary of the Eastern Melezzo.

From the geological point of view, in the upper Loana Valley the Insubric Line (locally named Canavese Line; CL) separates the Southern Alps (on the SE) from the axial part of the Alpine chain represented here by the Austroalpine (on the NW) Domains (Ogn-SL; Appendix 1a) (Bigioggero et al. 2006). The first domain, Africa-vergent, is characterized by a low dominant Alpine deformation while the second one, Europe-vergent, underwent pervasively to an Alpine tectonic imprint that restructured the whole rocks. More in detail, Southern Alps, a portion of the African passive continental margin, are here represented by the Ivrea Verbano Zone, which is related to the lower continental crust and to the upper mantle: metabasites (Mb-IV; Appendix 1a) and metapelites (Mp-IV; Appendix 1a) in granulite to amphibolite facies and mantle-peridotite slices (Per-IV; Appendix 1a). The Fobello-Rimella mylonitic schists (FR-Sch; Appendix 1a) locally represent the product of the deformation along the CL. This wide deformation belt occupies the head of the valley conferring weakness to rocks and favoring their weathering and degradation. Significant are the calcareous intercalations (blu stripes in Appendix 1b) outcropping within both the Ivrea-Verbano Zone (Mp-IV and Mb-IV in Appendix 1a) and the Fobello-Rimella mylonitic schists (FR-Sch; Appendix 1a). They underwent different degrees of metamorphism, in some cases being completely transformed in marbles, like those characterizing the Ivrea-Verbano Zone.

The Toce hydrographic basin shows clear evidences of glacial modeling. Hantke (1988) reconstructed its evolution since the Miocene individuating several episodes of transfluence into the Ticino Glacier, along the Centovalli.

The VCO province is characterized by intense rainfall events that recently and repeatedly affected the area (e.g., 1978, 1987, 1993, 2000; Cat Berro et al. 2014). Climatic and meteorological conditions, joined with geological features (lithology and regional deformation systems) and hydrographic basin morphology, locally favor heavy instability phenomena and debris flow events (Hantke 1988; Cavinato et al. 2005; Mortara and Turritto 1989; Luino 2005; Dresti et al. 2011). In particular, on 7th August 1978 heavy rains provoked, in the hydrographic basin of the Stagno Stream, a tributary of the Loana River, a big mass movement in proximity to a cataclastic belt and a litho-structural contact. After the 1978 instability event the Regione Piemonte produced a series of detailed maps (geolithological, geotechnical and maps of the hydro-geological instability effects) for the whole Melezzo Basin (e.g., Bigioggero et al. 1981).

Except for such applicative studies and for the technical maps produced in the framework of the Municipality urbanistic plan, the Loana Valley is not deeply studied from the geomorphological point of view and scarce is the related literature (Cerrina 2002; Barbolini et al. 2011). Barbolini et al. (2011) proposed a models for detecting areas susceptible to avalanches but no similar models have been yet elaborated for landslides (e.g., Hoang and Tien Bui 2016) or debris flows, that pervasively affect the area. As mentioned before, the valley is characterized by an important structural and lithological control on landforms shaping. Mass movements (mainly rock-falls) often take place along weakness zones. Avalanches (e.g., 1986, 2014) are among the most dangerous processes that affect slopes mainly during Spring and rework typical avalanches corridors (Barbolini et al. 2011). Composite cones (sensu Baroni et al. 2007), built and reworked by combined activity of gravity processes, running waters and avalanches, are very common in the valley. In specific cases (i.e., in correspondence of the "Nucleo Alpino La Cascina"- see details along the paragraph), defense works are present. Near the water divide, gravity landforms are combined with glacial ones generated during the Pleistocene glacial stages. The Loana River course has been deeply modified by human interventions, mainly addressed to facilitate grazing or to regulate water flow; its more distal part is deeply incised as far as the alluvial fan, at the confluence with the Eastern Melezzo.

Geological (structural and petrographical) characteristics are deeply connected with human settlements and geo-resources usage. Two regionally valorized archeological sites are present: the “Nucleo Alpino La Cascina and “Le Fornaci della Calce”. Their protection is regulated by the Piano Paesaggistico Regionale. The second site is strictly linked with the geological framework since it is related to the usage of the carbonates outcropping in the area, for producing lime.

Finally the Loana Valley, especially in the upper portion, at the border with the VGNP, has been recently analyzed for its physical features as ecological corridor (PNVG 2001; Bionda et al. 2011).

Four sites of geomorphological interest located within the Loana hydrographic basin are included at least in one of the three official catalogues of geosites concerning the area (Appendix 2):

i) the ISPRA geosites database (ISPRA 2017);

ii) the Regione Piemonte list of elements of naturalistic interest (Regione Piemonte 2017);

iii) the SVGP Geosites list (SVGP 2013).

The Pozzo Vecchio Loana waterfall (site n. 1 in Appendix 2), located at the confluence with the Eastern Melezzo river, and the Lago del Marmo (site n. 2 in Appendix 2), located at the head of the valley, are present in two of the databases even if not for the same interest. The three geosites, individuated by the SVGP (site n. 2, 3 and 4 in Appendix 2), are currently provisional and reported by the SVGP exclusively for their petrographic meaning.

## 2 Methods

The methodology herein illustrated consists of a schematic procedure articulated in different phases of analysis, elaboration and outputs realization, as resumed in Figure 2.

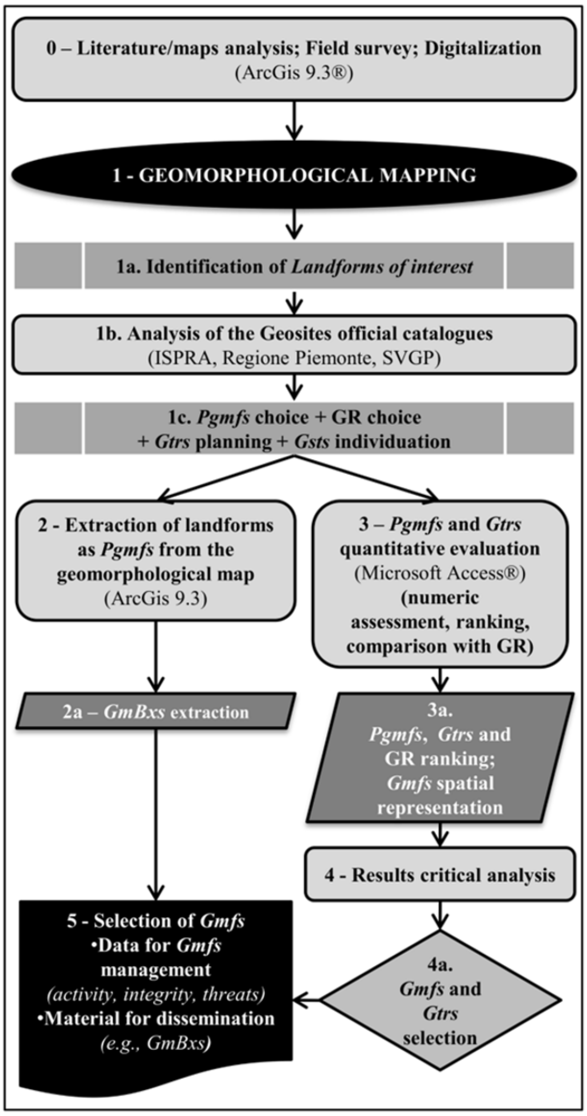


**Figure 2** Flux diagram of the schematic procedure followed in the framework of the present research. The acronyms are explained along the text and in the Notation table.

### 2.1 Geomorphological mapping, census of landforms of geomorphological interest and geotrails planning

The first step concerned literature and cartographic sources analysis, followed by a field survey addressed to geomorphological mapping (step 0, Figure 2). Landforms are represented according to their genetic process, as indicated by the National Geological Survey (ISPRA 1994; 2007) and recently updated by D'Orefice and Graciotti (2015). The geomorphological map was digitalized using ArcGIS 9.3® (step 1, Figure 2). According to the field data and to the geomorphological map, an inventory of the landscape geomorphological resources (i.e., *Landforms of geomorphological interest*) was successively made (step 1a, Figure 2) (e.g.; Giardino and Mortara 1999).

Then, the official geosites catalogues were analyzed (step 1b, Figure 2) to obtain more information for the selection of the *Potential Geomorphosites* (*PGmfs*) and for the planning of *Geotrails* (*Gtrs*) (step 1c, Figure 2). This step concerned the analysis of the already existing hiking paths (e.g., Giardino and Mortara 1999), represented on the official maps (Provincia VCO 2012) and/or digitalized within the Regione Piemonte official shapefiles (Regione Piemonte 2017). The trails were also surveyed in order to check morphological features influencing accessibility, maintenance and potential hazards affecting them. Some *Geostops* (*Gsts*) were then individuated along *Gtrs* (step 1c, Figure 2). Their locations were carefully chosen in order to allow the best observation of the *PGmfs* both on site and from other locations (e.g., opposite side of the valley). Each *PGmf* was associated to a principal *Gst* along the *Gtrs* and to additional ones, from which the site could be even better observed.

### 2.2 Geomorphological boxes realization

*Geomorphological boxes* (*GmBxs*) were elaborated for each *PGmf* according to specific criteria (e.g., scientific integrity, easy reading by using familiar supports), at first to help the evaluators in assessing their features and, in a second phase, to facilitate users in understanding the geomorphology of the site and its progressive evolution under surface processes action (Regolini-Bissig 2010). The procedure (step 2, Figure 2) consisted in adding specific fields to the shapefiles attributes tables of geomorphological polygons, lines and point in GIS environment. These additional fields contain information about the digitized landforms as *PGmfs*. Moreover display options and dedicated layer files, based on the same symbols of the geomorphological official legend, were set to plot, each time, elements useful to understand the site dynamics. In this way, if the official geomorphological map is updated in GIS, the deriving output boxes will be automatically updated too. For the export, additional layers were included (e.g., official trails, mountain huts positioning) to provide spatial references for the users.

Aerial photographs at disposal (2012 aerial photo, courtesy of Geoportale Nazionale - Ministero dell'Ambiente) were used as background to *GmBxs* (step 2a, Figure 2), especially for the dissemination purposes. This graphic support, in the recent times has become more familiar also to general public by using applications like Google Maps® or Google Earth® and hence it allows to link scientific data with a real scenery, facilitating the approach and the reading of geomorphological symbols (e.g., Regolini-Bissig 2010; Martin et al. 2014).

### 2.3 Potential Geomorphosites (*PGmfs*) and Geotrails (*Gtrs*) evaluation

The quantitative assessment of *PGmfs* and *Gtrs* (step 3, Figure 2) started from specific field data collected through dedicated field forms, regarding geomorphological and geological features, activity degree of surface processes, landforms size, geomorphological hazards and trails characteristics influencing tourist vulnerability (e.g., Bollati et al. 2013; Giardino and Mortara 1999). *GmBxs* were complementary tools at this scope (Figure 2). The quantitative evaluation was performed according to the method proposed by Bollati et al. 2016 (with modifications) that had been elaborated considering attributes and values defined in the recent literature (e.g., Panizza 2001; Reynard et al. 2007; Brihla 2016b). Data were organized by means of a relational database realized using a commercial package (Microsoft Office Access®) and final numeric values were calculated. The criteria adopted for the implementation of the database are: i) *integrity*, that means no duplication of records (*PGmfs* and *Gtrs*) are allowed and requires a maximum subdivision of information linked each other by means of the Geomorphosite-ID; ii) *logic sequence* in order to facilitate the users, through the pre-set forms, during the data storage phase. The database is equipped with export functions that, acting through pre-set queries, allow the operator to create tables of *PGmfs* and *Gtrs* data to be joined or directly loaded, once transformed into shapefiles, within GIS. The database was set using the evaluation parameters (SV, AV, GV, PU; SIn, EIn, see the Notation table) and equations reported in the Appendix 3, 4 and 5. From the numeric values attributed to single *PGmf*, those referred to *Gtrs* were derived and normalized to the number of their own sites, taking into account that each *Gtr* is composed by a different number of sites, a feature that may affect the results.

Moreover, we quantitatively assessed a reference site (GR) detected during the step 1b (Figure 2) (i.e., Pozzo Vecchio Loana waterfall, site 1; Table 1) that is present, for its geomorphological meaning, in 2 of the investigated official geosites databases. Since GR is described in detail neither in the official form of ISPRA nor in the one of Regione Piemonte (the only indication regards the primary geomorphological interest), an analysis on the field was hence performed before quantitatively evaluating it. *PGmfs*, GR and *Gtrs* were finally ranked (step 3a, Figure 2).

In order to spatially represent results coming from the database (step 3a, Figure 2), besides using the classic column charts, the use of the multivariate method proposed by Reynard et al. (2016b) was experimented. In fact the radar graphs allow an easy identification of the evaluation parameters at first sight. The same Authors however indicated the presence of a graphical bias for this kind of representation: the surface representing the evaluation depends on the physical proximity or distance, on the graph, between parameters with similar numeric value and by their meaning. In order to reduce this bias, the parameters with a similar meaning were put on the same side of the graph and separated from the

**Table 1** Potential Geomorphosites (*PGmfs*), Geotrails(*Gtrs*) and Geostops (*Gsts*) codes. GR and 13 corresponds, in Appendix 2, respectively to the geosites n. 1 and 2. Difficulty is reported according to the classification of the Italian Alpine Club.

| Code | Gtr | Difficulty |
|---|---|---|
| AB | Ring path along the valley floor | Touristic |
| AA | Ring path along the valley floor as far as to Alpe Scaredi, Alpe Cortechiuso, La Forcola and back to the valley floor | Touristic and locally for Expert hikers |
| Code | PGmfs | Gtr |
| G1 | Composite cone (debris flows, avalanches) - La Cascina | AB |
| G2 | Inactive slope debris - Fondo li Gabbi | AB |
| G3 | Composite cone (debris flows, avalanches) | AB |
| G4 | Avalanche track | AB |
| G5 | Loana Paleochannels | AB |
| G6 | Pizzo Stagno Complex system | AB |
| G7 | Loana Valley Glacial step and waterfall | AA, AB |
| G8 | Waterfall on marble and phyllades | AA |
| G9 | Structural and lithological control on glacial exharation (i.e., striae and scours) | AA |
| G10 | Composite cone (debris flows, avalanches) and structural control on the hydrographic network | AA |
| G11 | Structural and lithological control on glacial exharation (i.e., roche moutonnéeWhalebacks)(Alpe Cortenuovo) | AA |
| G12 | Glacial saddle and lithological control on glacial exharation (i.e., striae and scours) (Alpe Scaredi) | AA |
| G13 | Glacial sovraexcavation basin (Lago del Marmo)* | AA |
| G14 | Glacial cirque (Cima Laurasca and Cimone Cortechiuso) | AA |
| G15 | Loana Glacial Valley ad its hydrographic basin | AA, AB |
| GR* | Pozzo Vecchio Loana waterfall | / |
| Gst Code | PGmfs observed from the Gst | Gtr |
| GS1 | G1, G2 | AB |
| GS2 | G3 | |
| GS3 | G4 | |
| GS4 | G6 | |
| GS5 | G6, G7 | |
| GS6 | G6, G7 | |
| GS7 | G6 | AA |
| GS8 | G4, G5 | |
| GS9 | G3 | |
| GS10 | G1, G2, G7, G15 | |
| GS11-a | G8 | |
| GS11-b | G8 | |
| GS12 | G3, G4, G9, G15 | |
| GS13 | G10 | |
| GS14 | G11 | |
| GS15 | G11 | |
| GS16 | G11, G13, G15 | |
| GS17 | G12, G15 | |
| GS18 | G13, G14 | |
| GS19 | G13, G14 | |

others by a grey dotted line. More in detail the parameters more akin to dissemination (PU, EIn, AV; see Appendix 3, 4 and 5) were put side by side respect to those strictly linked with the scientific meaning of the site (SV, SIn, GV; see Appendix 3, 4 and 5). This should allow a graphic view that more emphasizes difference between sites and facilitate discrimination according to different valorization purposes.

### 2.4 Geomorphosites (*Gmfs*) selection

Results from the *PGmfs* quantitative evaluation were used to select the most representative *Geomorphosites* (*Gmfs*) to be proposed for addressing management resources, valorization or geoconservation practices (step 4 and 4a, Figure 2).

To select *Gmfs* among *PGmfs*, we used *Threshold Values* (*TSVs*) for each attributes (SV, AV, GV, PU, SIn, EIN; Appendix 3, 4 and 5) calculated according to the equation:

$$TSV = [\left(\frac{MAX}{2}\right) + \left(\frac{MAX}{10}\right)]$$

The *TSVs* considered for each attribute are reported in Appendix 6.

The GR values were then used as reference to discuss the numeric values obtained for the *PGmfs* and, together with *TSVs*, to help in discriminating among sites.

## 3 Results

### 3.1 Geomorphological boxes (*GmBxs*)

After the fieldwork (step 0), the geomorphological map realization (step 1) and the analysis of the official geosites catalogues (step 1b), 15 *PGmfs*, observable from 19 *Gsts* (Table 1; Appendix 7), were detected. For each one of the 15 *PGmfs*, a *GmBx* was elaborated (step 2a). *GmBxs* are thought to be addressed both to scientific and professional users, for different level of knowledge deepening. As mentioned before, the plotted symbols include only the elements concerning strictly the fundamental features useful to identify the genesis and the past or current dynamic of each *PGmf*. In Figure 3, the comparison between the traditional geomorphological map and the simplified version for the *GmBxs* is reported. The proposed *PGmf* is G6 - Pizzo Stagno Complex system (Table 1, 2; Appendix 8), crossed by both the trails analyzed in the framework of this research. It has been chosen to exemplify a *GmBx* as i) it obtained a very high EIn value (0.76/ over 1 see result section 3.2), ii) it includes evidences of active, passive and evolving passive landforms providing different hazards issues, and, last but not least, iii) it is one of the most important geomorphic evidence (deep scarp due to mass movement composed by rock fall and sliding) of the hydro-geological instability event occurred in 7th August 1978 in the Melezzo hydrographic basin. The deposit is still not stable and it is affected by debris flows and avalanches too, processes that favor the debris transport and deposition at the confluence between the Stagno and the Loana streams. More in detail, the down-valley portion of the G6 site is characterized by the presence of a wide composite cone, crossed by the hiking trail, in which the northern portion is currently affected by debris flows and avalanches while the southern portion seems to be more stable, even if it shows evidences of similar processes active in the past. In 1982 an additional deep scar in the landscape developed and a supplementary way to the debris transportation to the main valley was naturally activated. The influence of geological structure is also represented in the *GmBx* simplified version (i.e., hypothetic fault and lithological diversity along the cataclastic zone) to catch users attention on its importance in driving hydro-geological instabilities.

### 3.2 Potential Geomorphosites (*PGmfs*) and Geotrails (*Gtrs*) evaluation

*PGmfs* well represent the 3 geomorphosites categories related to the surface processes activity: active, passive and evolving passive (Appendix 8; 9). The analyzed *PGmfs* can be considered of local/regional importance. They have been shaped by different geomorphic processes, typical for the high mountain environment. The main modeling factors characterizing *PGmfs* are reported in Appendix 10. The most effective geomorphic processes in shaping *PGmfs* result to be the glacial ice and the snow action and structural and lithological features control landscape shaping (46.67%). Gravity and water-related processes result to be less represented in term of interesting landforms (33.33%) even if, at present, gravity processes are the most active. Debris flows (26.67%) have been considered separately as borderline forms, involving both water-related and gravity processes. Human modified landforms are less abundant (13.33%) even if meaningful.

Quantitative evaluation results for *PGmfs* are reported in Table 2 and in Figure 4 (step 3a). In Appendix 11 the multivariate representation of numerical values (step 3a) is illustrated and it refers to all the evaluated *PGmfs* (white radar graphs) and to the GR (black radar graph on the upper-left corner). The trends highlighted in Table 2 and in Figure 4 are therein spatially represented. The difference between very high valued sites (at least 3 parameters above TSVs: G11, G13, G6, G1, G3 and G15) and very less valued (G4, G5, G8; G2, G7, G9 and G10) is evident at first sight. Among the meaningful sites, a comparison between some of them allow to observe different activity degrees respect to the same process. G1 for example, may be considered quiescent respect to avalanches, as it is affected only by the most powerful events (e.g., 1986), while G6 records a more regular (quite annual) frequency of avalanche events.

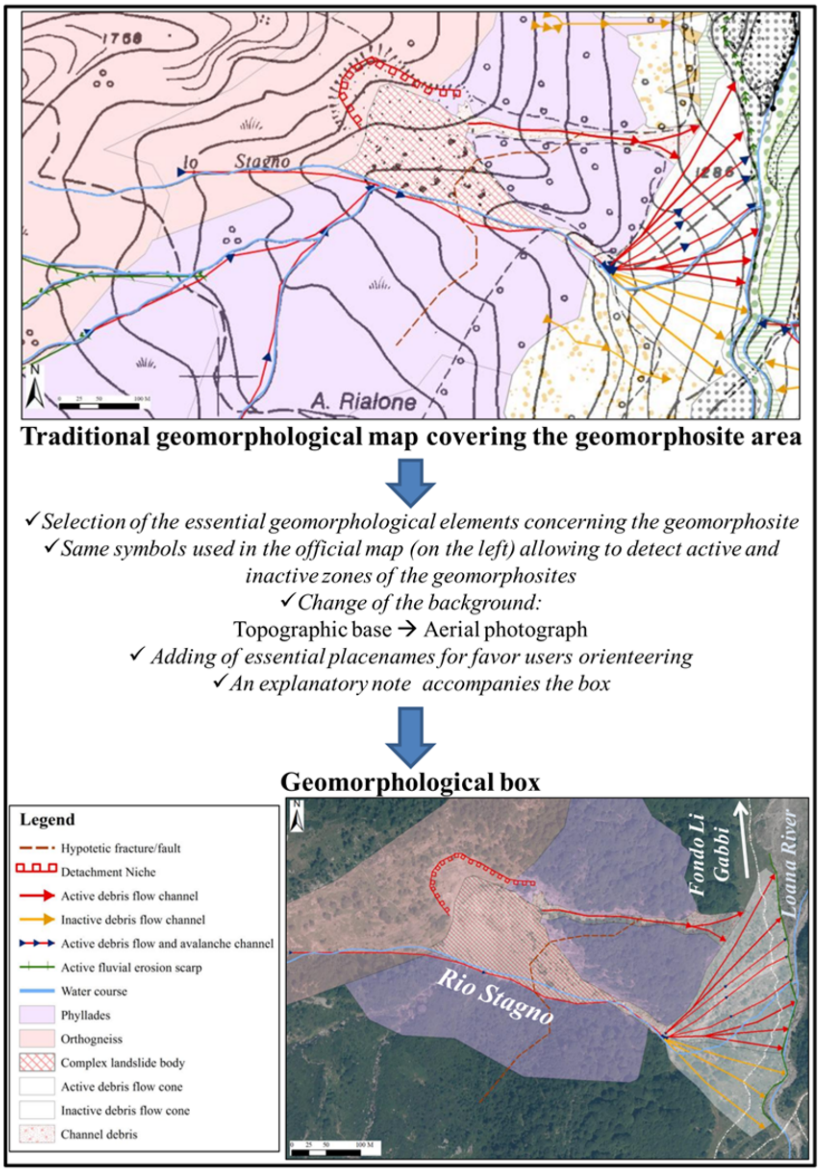


**Figure 3** Comparison between the traditional geomorphological map (in the upper part) and the simplified version for the *GmBxs* (in the lower part). The *GmBx* was plotted on the 2012 aerial photo (courtesy of Geoportale Nazionale - Ministero dell'Ambiente).

Considering the correlation between the main evaluation parameters (GV, PU, EIn) of *PGmfs*, it is possible to obtain interesting results (Appendix 12). PU (Appendix 4 and 5) of each *PGmfs* does not correlate significantly ($r^2$=0.0861) with GV (Appendix 3 and 5), suggesting they should be both considered in phase of decision, according to different selection purposes. PU and EIn (Appendix 4 and 5) provide, on the contrary, a more correlated trend ($r^2$=0.7667). These relations were verified also at level of *Gtrs* but in Appendix 12 this result is not reported since less statistically significant.

The 15 *PGmfs* are distributed along two of the official hiking trails, here named *Gtrs*, characterized by different difficulty degrees for what concerns their accessibility (Table 1; Appendix 7). The *Gtr* AA, suitable for more expert hikers, is an extension of the *Gtr* AB, an easier and more touristic path. Both the *Gtrs* are characterized by a ring pattern and by a different number of *PGmfs*, since some of them belong to both the *Gtrs*. The *Gtrs* evaluation results, whose numeric values were normalized to the number of their own *PGmfs*, are reported in Figure 5. Results show that *Gtr* AA has higher SV, AV, SIn and also GV respect to *Gtr* AB while this latter is more valuable in terms of PU and EIn.

## 3.3 Geomorphosites (*Gmfs*) selection

For the *Gmfs* selection, a critical analysis was performed on the obtained values using *TSVs* and the relation between the *PGmfs* values respect to the GR values. The percentages of parameters exceeding the *TSVs* for each *Pgmf* are reported in Figure 6. It is interesting to note that GR, the reference site, is above *TSVs*

**Table 2** *PGmfs* numeric values obtained through the quantitative assessment. Sites are ordered according to the global value (GV). The most valuable site (all the parameters above the *TSVs*) is highlighted in italic and the site used as reference is reported in the light blue line.

| COD | SV | AV | GV | PU | SIn | EIn |
|---|---|---|---|---|---|---|
| G11 | *6.5* | *3* | *9.5* | *7.05* | *0.77* | *0.73* |
| G13 | 6.83 | 2 | 8.83 | 7.72 | 0.77 | 0.73 |
| G6 | 6.17 | 2 | 8.17 | 7.88 | 0.66 | 0.76 |
| G1 | 4.67 | 2 | 6.67 | 7.6 | 0.33 | 0.66 |
| G3 | 4.67 | 2 | 6.67 | 8.44 | 0.33 | 0.81 |
| G15 | 4 | 2.5 | 6.5 | 11 | 0.33 | 1 |
| G8 | 4.67 | 1.5 | 6.17 | 7.57 | 0.55 | 0.57 |
| G12 | 4.17 | 2 | 6.17 | 8.45 | 0.55 | 0.73 |
| G14 | 4 | 2 | 6 | 8.4 | 0.33 | 0.71 |
| GR* | 3.67 | 2 | 5.67 | 10.5 | 0.55 | 1 |
| G7 | 4 | 1 | 5 | 6.75 | 0.33 | 0.4 |
| G10 | 4 | 1 | 5 | 5.38 | 0.55 | 0.17 |
| G4 | 3.67 | 1 | 4.67 | 7.44 | 0.33 | 0.48 |
| G5 | 2.33 | 2 | 4.33 | 8.09 | 0.22 | 0.36 |
| G2 | 2.66 | 1.5 | 4.16 | 6.37 | 0.22 | 0.25 |
| G9 | 1.82 | 1 | 2.82 | 5.58 | 0.33 | 0.17 |
| *TSV* | ***5*** | ***2.5*** | ***6.5*** | ***7*** | ***0.6*** | ***0.6*** |

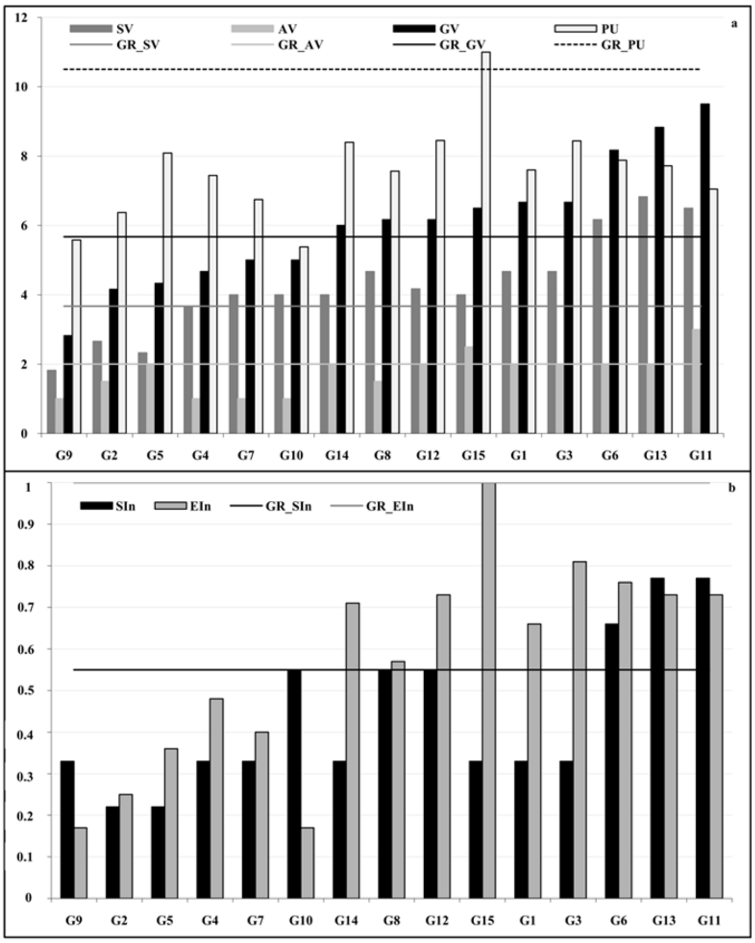


**Figure 4** *PGmfs* assessment results (see abbreviations in Table 1). In both the graphs, lines represent the numeric values obtained by GR.

only for the 33% of the calculated parameters. The only site reaching the 100% of parameters over *TSVs* is G11. Moreover, besides GR, G13 is the only *PGmfs* included in one of the official databases (i.e., site 3, Appendix 2). It is indicated in the ISPRA database (ISPRA 2017) for its geomorphological meaning while within the SVGP list of geosites (SVGP 2013) it is considered exclusively for its petrographic meaning (i.e., marble intercalations within the Ivrea-Verbano Zone; Mp-IV and Mb-IV in Appendix 1a). As a general outcome, it could be possible to consider worthy of attention as *Gmfs* the 53% of *PGmfs* (G11, G6, G13, G15, G1, G3, G12, G14) that exceed the *TSVs* for, at least, the 33% of the parameters.

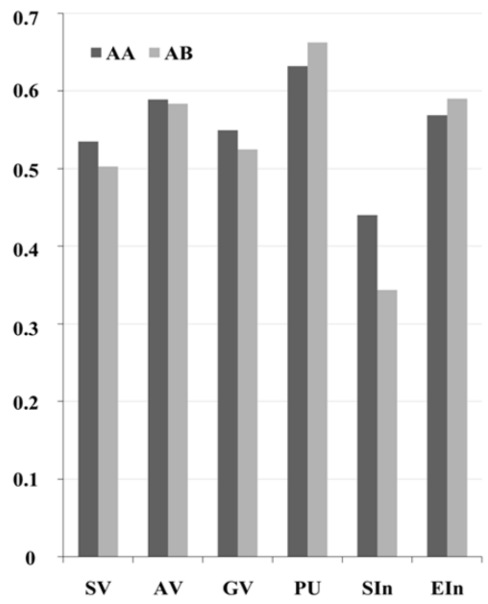


**Figure 5** *Gtrs* numeric values for Scientific Value (SV), Additional Values (AV), Global Value (GV), Potential for Use (PU), Scientific Index ( SIn) and Educational Index (EIn). AA and AB are *Gtrs* as reported in Table 1.

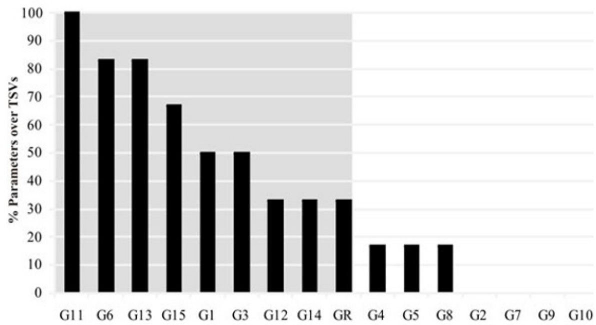


**Figure 6** *PGmfs* ordered according the percentage of parameters exceeding the *TSVs*. The grey area includes the *PGmfs* with a percentage of parameters greater respect to GR (see Table 1).

## 4 Discussions

Geoheritage in mountain environment has a great relevance for valorization, tourism promotion and geoconservation (Reynard and Coratza 2016; Reynard et al. 2016a). In particular, geomorphosites are landforms characterized by specific attributes making them ideal key sites for cultural itineraries, addressed to general public and exploitable for outdoor education activities (Bollati et al. 2016). On the other side, geomorphic processes, responsible of geomorphosites genesis and/or currently affecting them, can represent hazard and risk for users, especially under changing climate conditions (Pelfini et al. 2009). Nevertheless, the morphological evidences can represent also an opportunity to approach geo-risk education (Giardino and Mortara 1999; Coratza & De Waele 2012; Bollati et al. 2013; Alcántara-Ayala and Moreno 2016). Hence, information about landscape features and dynamics are fundamental both for geo-resources management and for tourism (e.g. geotrails), helping in spreading knowledge and awareness in high mountain environment fruition. Geomorphological mapping allows, through a unique document, to synthesize landforms related to erosion and deposition, as well as the activity of the related processes. However it is crucial to translate it for different targets of users. These considerations represented the starting point for this research that deals properly with geomorphological mapping, its usage in identification, evaluation and selection of *PGmfs* and *Gtrs* and its final version for dissemination purposes (i.e., *GmBxs*). The geomorphological map has been hence realized under a double perspective: i) the scientific data collection and representation, considered indispensable for analyzing landforms of different genesis (step 0 and 1, Figure 2); ii) the elaboration of dissemination products (*GmBxs*) to guide both the evaluator, during the analysis of landforms features as potential components of geoheritage, and the final user in reading the physical landscape in a simplified but corrected way (step 2a and 5, Figure 2). Concerning the (ii) point, in Table 3 a classification of the typologies of

**Table 3** Geomorphological maps restituition for different aims. Classification in the last column are partially reprised by Regolini-Bissig (2010).

| Coverage maps | Scientific aim | Dissemination aim | | |
|---|---|---|---|---|
| | | Target User | Reference | Product definition |
| Total | Geomorphological Maps | Non specialists | Castaldini et al. 2005 | Geoscientific maps for amateurs of Earth sciences |
| Partial | Geomorphological Sketches | Specialists | Carton et al. 2005 | |
| | | Non specialists | Giardino and Mortara 1999; Regolini-Bissig 2010 | Interpretive maps |
| | | | Present research | GEOBOXES |

geomorphological maps proposed in literature and in the present research, according to the aim of the research, is reported. Some examples of simplified geomorphological maps for tourism have been already proposed in literature (e.g., Coratza & Regolini-Bissig 2010; Castaldini et al. 2005) with different approaches. These maps may cover wide areas without providing details about landforms as the traditional geomorphological maps do. The usefulness of *GmBxs* is to provide geomorphological sketches for each single *PGmfs*, extracting data in GIS environment, starting from a traditional total-coverage geomorphological map. The proposed methodology upgrade previous proposals addressed both to not-specialists (e.g. Giardino and Mortara 1999; Regolini-Bissig 2010) and to specialists (Carton et al. 2005) thanks to the use of free aerial photos as background. With *GmBxs* (step 2, Figure 2) the plotting of symbols is limited to those essential for the user to understand the characteristics and the dynamics of each *PGmf*. The GIS shapefiles are the same of the official geomorphological map, with the advantage that the *GmBxs* data are constantly updated, in real time, whenever the official geomorphological map undergoes to changes (e.g., local landscape transformations due to instability events, quite common in mountain areas). Aerial photographs, chosen as background of *GmBxs*, enriched with the hiking trails and essential placenames, are familiar to the general public (i.e., Google Maps®; Google Earth®) and they could become an excellent tool for facilitating the "reading" of the physical landscape, maintaining the scientific integrity (Regolini-Bissig 2010; Martin et al. 2014). *GmBxs*, comparable hence to the "interpretive maps" by Regolini-Bissig (2010), could be proposed as illustrating material within *PGmfs* description forms (step 5, Figure 2). As a whole, *Gmbxs* may be proposed as a powerful tool for the valorization of high mountain geomorphic environments also under the perspective of geo-risk education (Wearing 2008; Coratza and De Waele 2012; Bollati et al. 2013; Alcántara-Ayala and Moreno 2016).

Concerning geoheritage analysis (step 1a, 1b, 1c, 3, 4 and 4a; Figure 2), Loana Valley, especially in the investigated southern portion, results to be characterized by very representative landforms (step 1a; Figure 2) differently affected by processes and so useful for the comprehension of quiescent and active status of sites, respect to a single process (e.g., G1 and G6 for avalanches). The number of *PGmfs* (15; step 1b, 1c; Figure 2) may be considered high in a so narrow area (i.e., high density). Nevertheless, if we consider the official ISPRA catalogue (ISPRA 2017), it is possible to note that the sites density is variable over the Italian territory, depending on the contributions provided to the database by local administrations. Since not all the landforms can be considered *Gmfs*, a selection is strictly necessary (Komac et al. 2011) and several are the methodologies proposed in literature (Brihla 2016b). The new proposal of using *TSVs* and the comparison with reference sites included in the official databases (i.e., GR), allow to select the most valuable *Gmfs* among the *PGmfs* (step 4 and 4a; Figure 2). In the specific case, we propose to consider as *Gmfs* only the *PGmfs* exceeding the *TSVs* with, at least, the 33% of the parameters, as for GR. *TSVs* application together with the multivariate spatial representation of results (i.e., radar graphs; Reynard et al. 2016b) provide also easy accessible information for public administrations useful for geoheritage management. In this framework, as Potential for Use and Global Value do not correlate significantly each other, they should be both considered during selection, according to the aim of the management. A critic analysis of the sites ranking (step 4; Figure 2) is hence indispensable: Which site, among the most valuable ones, has the highest scientific meaning? Which one has the highest educational meaning? Ideally, resources for geoconservation may be addressed to protect sites characterized by high Scientific Value and susceptibility to degradation, while resources for dissemination and promotion could be dedicated to sites suitable for educational initiatives. In the studied area one of the most representative site documenting ancient and current changes in the landscape is the G6 - Pizzo Stagno Complex system. Temporal variation in processes typology and intensity, changes in frequency of geomorphic events and links with human history (i.e., the 1978 disastrous event; Mazzi and Pessina 2008) allow to consider G6 site as the most representative also for geo-risk education projects according to criteria suggested, for example, by Coratza and De Waele (2012) and Alcántara-Ayala and Moreno (2016).

The two analyzed *Gtrs* (AA and AB) offer the possibility to observe, in safety conditions, the geomorphological evidences of hazardous processes and related landforms (i.e., *PGmfs*) from different points of view (i.e., *Gsts*) allowing to propose different approaches towards geotourism. The link with topics related to human settlements and geo-resources usage, (i.e., the official archeosites Nucleo Alpino "Le Cascine" and Fornaci della Calce) observable along both the trails, increases the Global Value and favors multidisciplinary approaches (e.g., history and anthropology). Moreover the *Gtr* AB, characterized by higher Potential for Use and Educational Index values, results to be the more suitable for educational purpose and for dissemination to a general public. On the contrary, the *Gtr* AA, showing higher Scientific Value, Additional Values, Global Value and Scientific Index, could be considered for geoconservation practices or used to promote, from a strictly scientific point of view, the geoheritage characterizing the area inside the SVGP (e.g., Smrekar et al. 2016).

Finally it is worth to consider that the morphological features and values of *Gtrs* and of *Gmfs*, has to be periodically reassessed, especially when located in a dynamic environment as the mountain one.

## 5 Conclusions

Geomorphological mapping combined with geoheritage analysis (i.e., identification, evaluation and selection) can be considered part of a unique methodology, useful to find good practices for the management of the (high) mountain environment as the Alpine one herein analyzed. Geomorphological mapping provides a starting point for *PGmfs* census and evaluation. Dissemination products in the form herein presented (i.e., *GmBxs*), based on the use of the Italian official geomorphological legend plotted on a background (i.e., aerial photos), familiar to the general public and to young people, represent an useful instrument also for Geosciences education.

In conclusion *GmBxs* will hopefully allow people to: i) better understand the main elements of a specific physical landscape characterized by a spatio-temporal differentiation in dynamic processes; ii) acquire ability in reading and interpreting landforms and processes in a simplified but scientifically correct way and iii) acquire also awareness on possible geomorphic hazards affecting trails, for better enjoying mountain and Alpine environments.

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