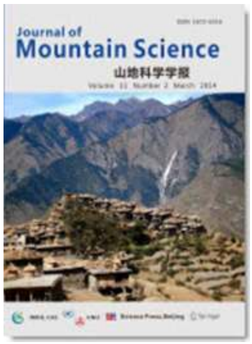

Geomorphological mapping for the valorization of the Alpine environment. A methodological proposal tested in the Loana Valley (Sesia Val Grande Geopark, Western Italian Alps)

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

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, located within the borders of the Sesia Val Grande Geopark, recognized by UNESCO in 2013 (Western Italian Alps.). 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 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 (Sesia Val Grande Geopark, Western Italian Alps)

Introduction

European Alps are among the key sites for geoheritage (sensu Osborne, 2000). The high level of geodiversity (Gray, 2013), due to the complex 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 substrates affected. 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 geotourist 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 this principle, 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 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 Science 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; Figure 2a) (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; Figure 2a) and metapelites (Mp-IV; Figure 2a) in granulite to amphibolite facies and mantle-peridotite slices (Per-IV; Figure 2). The Fobello-Rimella mylonitic schists (FR-Sch; Figure 2a) 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 Figure 2b) outcropping within both the Ivrea-Verbano Zone (Mp-IV and Mb-IV in Figure 2a) and the Fobello-Rimella mylonitic schists (FR-Sch; Figure 2a). 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 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 & 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). They are among the most dangerous processes that affect slopes mainly during Spring and reworking the typical avalanches corridors (Barbolini et al. 2011). Composite cones (sensu Baroni et al. 2007) built and reworked by 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 (see location on Figure 4): the “Nucleo Alpino La Cascina and “Le Fornaci della Calce” whose 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 1 of the 3 official catalogues of geosites concerning the area (Table 1):
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 Table 1), located at the confluence with the Eastern Melezzo river, and the Lago del Marmo (site n. 2 in Table 1), located at the head of the valley, are present in 2 of the databases even if not for the same interest. The 3 geosites, individuated by the SVGP (site n. 2, 3 and 4 in Table 1), 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 3.

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 3). 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 3). According to the field data and to the geomorphological map, we successively made an inventory of the landscape geomorphological resources (i.e., *landforms of geomorphological interest*) (step 1a, Figure 3) (e.g.; Giardino and Mortara 1999).

Then we analyzed the official geosites catalogues (step 1b, Figure 3) to obtain more information for the selection of the *Potential Geomorphosites* (*PGmfs*) and for the planning of *Geotrails* (*Gtrs*) (step 1c, Figure 3). This step concerned the analysis of the already existing hiking paths (e.g., Giardino and Mortara 1999), represented on the official maps (Carta Escursionistica, Interreg, "Valle Vigezzo, Valle Cannobina" 1:25000) 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 geotrails (step 1c, Figure 3). 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 *PGmfs* 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 3) 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 3), 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 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 3) 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 trail characteristics influencing tourist vulnerability (e.g., Bollati et al. 2013; Giardino and Mortara 1999). *GmBxs* were complementary tools at this scope (Figure 3). 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) and equations reported in the Tables 2, 3 and 4. From the numeric values attributed to single *PGmfs*, those referred to *Gtrs* were derived and normalized to the number of its 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 the reference site (GR) detected during the step 1b (Figure 3), the Pozzo Vecchio Loana waterfall (i.e., 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 to quantitatively evaluate it. *PGmfs*, GR and *Gtrs* were finally ranked (step 3a, Figure 3).

In order to spatially represent results coming from the database (step 3a, Figure 3), 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 others by a grey dotted line (see Figure 8, results paragraph). More in detail the parameters more akin to dissemination (PU; EIn; AV) were put side by side respect to those strictly linked with the scientific meaning of the site (SV, Sin, GV). 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 3).

To select *Gmfs* among *PGmfs*, we used *Threshold Values* (*TSVs*) for each attributes (SV, AV, GV, PU, Sin, EIN; Table 2, 3, 4) 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 Table 5.

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 6; Figure 4), 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 *PGmfs*. In Figure 5, the comparison between the traditional geomorphological map and the simplified version for the *GmBxs* is reported. The proposed *PGmfs* is G6 - Pizzo Stagno Complex system (Table 6, 7; Figure 6). It has been chosen to exemplify a geomorphological box as i) it obtained a very high EIn value (0,76/ over 1 see result section 4.2), 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 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 (hypothetic fault and lithological diversity along the fracture 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 (Figure 6; 7). The analyzed *PGmfs* can be considered of local/regional importance. They have been shaped by different geomorphic processes, typical for the high mountain environment (Figure 6; 7). The main modeling factors characterizing *PGmfs* are reported in Figure 8. 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 7 and in Figure 9 (step 3a). In Figure 10 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 7 and in Figure 9 are herein 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, some of them allow a comparison between the different activity degree 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.

Considering the correlation between the main evaluation parameters (GV, PU, EIn) of *PGmfs*, it is possible to obtain interesting results (Figure 11). PU (Table 3; 4) of each *PGmfs* does not correlate significantly (r^2=0.0861) with GV (Table 2; 4), suggesting they should be both considered in phase of decision, according to different selection purposes. PU and EIn (Table 3; 4) provide, on the contrary, a more correlated trend (r^2=0.7667). These relations were verified also at level of *Gtrs* but in Figure 11 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 6; Figure 4). 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*. Some of them belong to both the *Gtrs*. The *Gtrs* evaluation results, whose numeric values were normalized to the number of their own sites, are reported in Figure 12. 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 *Pgmfs* are reported in Figure 13. It is interesting to note that GR, the reference site, is above *TSVs* 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, Table 1). 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 Figure 2a). As a general outcome, it could be possible to consider worthy of attention as *Gmfs* the 53% of *PGmfs* that exceed the *TSVs* for, at least, the 33% of the parameters (G11, G6, G13, G15, G1, G3, G12, G14).

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 3); 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 3). Concerning the (ii) point, in Table 8 a classification of the typologies of 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 3) the plotting of symbols is limited to those essentials for the user to understand the characteristics and the dynamics of each *PGmfs*. 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 trails paths 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 3). 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 3), Loana Valley, especially in the investigated southern portion, results to be characterized by very representative landforms (step 1a; Figure 3) 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 3) 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 usually 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 3). In the specific case, we propose to consider as *Gmfs* only the *PGmfs* exceeding the *TSVs* with 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 PU and GV 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 3) 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 geotouristic approaches. 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 GV and favors multidisciplinary approaches (e.g., history and anthropology). Moreover the AB *Gtr*, characterized by higher PU and EIn values, result to be the more suitable for educational purpose and for dissemination to a general public. On the contrary, the AA *Gtr*, showing higher SV, AV, GV and SIn, 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 be considered 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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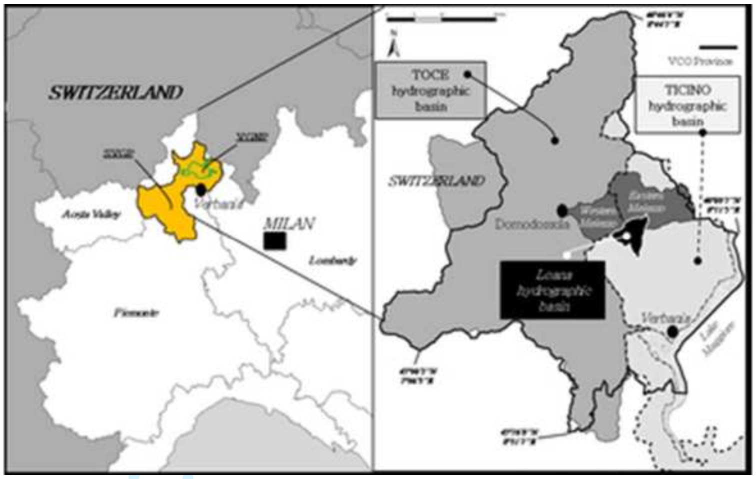

Figure 1 Geographical setting of the study area in the framework of the Northern Italy and the Verbania-Cusio-Ossola Province, with the location of the main hydrographic basins (Toce in dark grey, Ticino in light grey) and sub-basins (Western and Eastern Melezzo). The Eastern Melezzo includes the Loana minor hydrographic basin (in 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 (VGNP).

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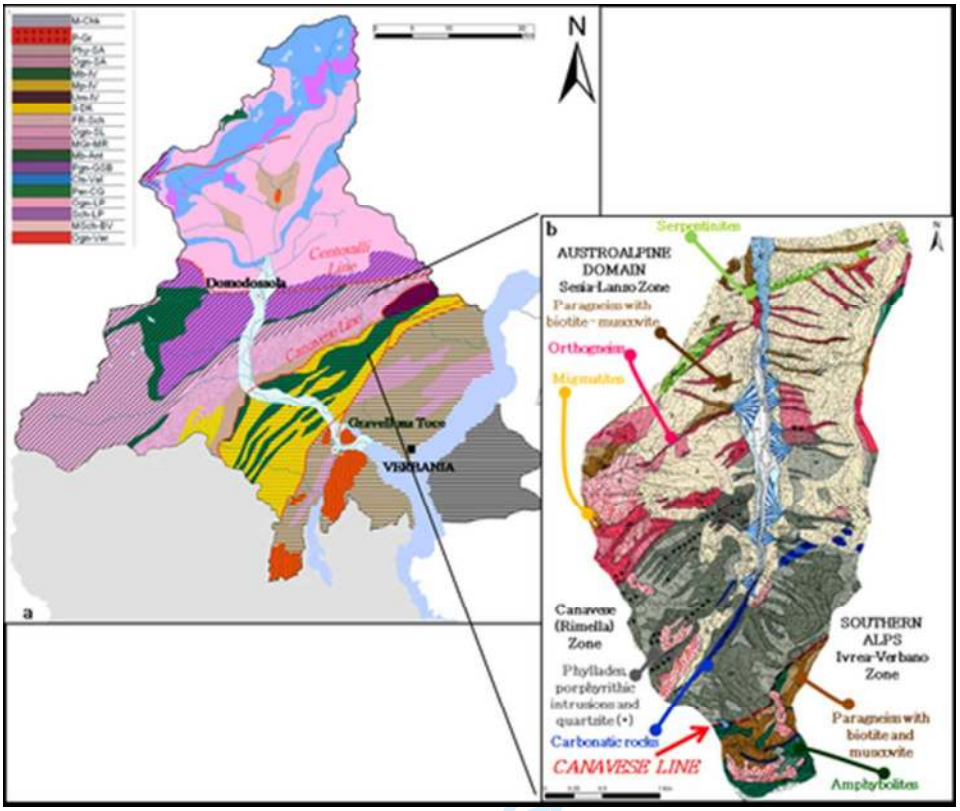


Figure 2 Geological setting of the study area in the framework of the VCO Province. a) simplified structural model of the VCO Province obtained combining the information from the Structural Model of Italy (1:500000; CNR) and the Geological Map of Switzerland (1:500000; Service géologique national) (modified from Bollati et al. 2016); b) excerpt of the geolithological map of Bigioggero et al. (1981) reporting the main lithologies outcropping in the studied portion of the Loana hydrographic basin. The codes reported in the Figure and corresponding to those cited along the text, mean as follows: M-Chk, Mesozoic basinal and pelagic deposits; P-Gr, Late and Post Hercynian Granitoides; Phy-SA and Ogn-SA, Southern Alpine crystallin basement; Mb-IV, Mp-IV and Um-IV, Ivrea Verbano zone; II-DK, FR-Sch and Ogn-SL, Sesia Lanzo zone; MGr-MR, Monte Rosa nappe; Mb-Ant, Antrona ophiolitic units; Pgn-GSB, Gran San Bernardo nappe; Cls-Val, Valais Calceschists; Per-CG, Cervandone Geisspfad units; Ogn-LP, Monte Leone - Pioda di Crana - Antigorio nappes; Sch-LP, Lebendun nappe; MSch-BV, Baceno and Varzo units; Ogn-Ver, Verampio unit.

40x33mm (300 x 300 DPI)

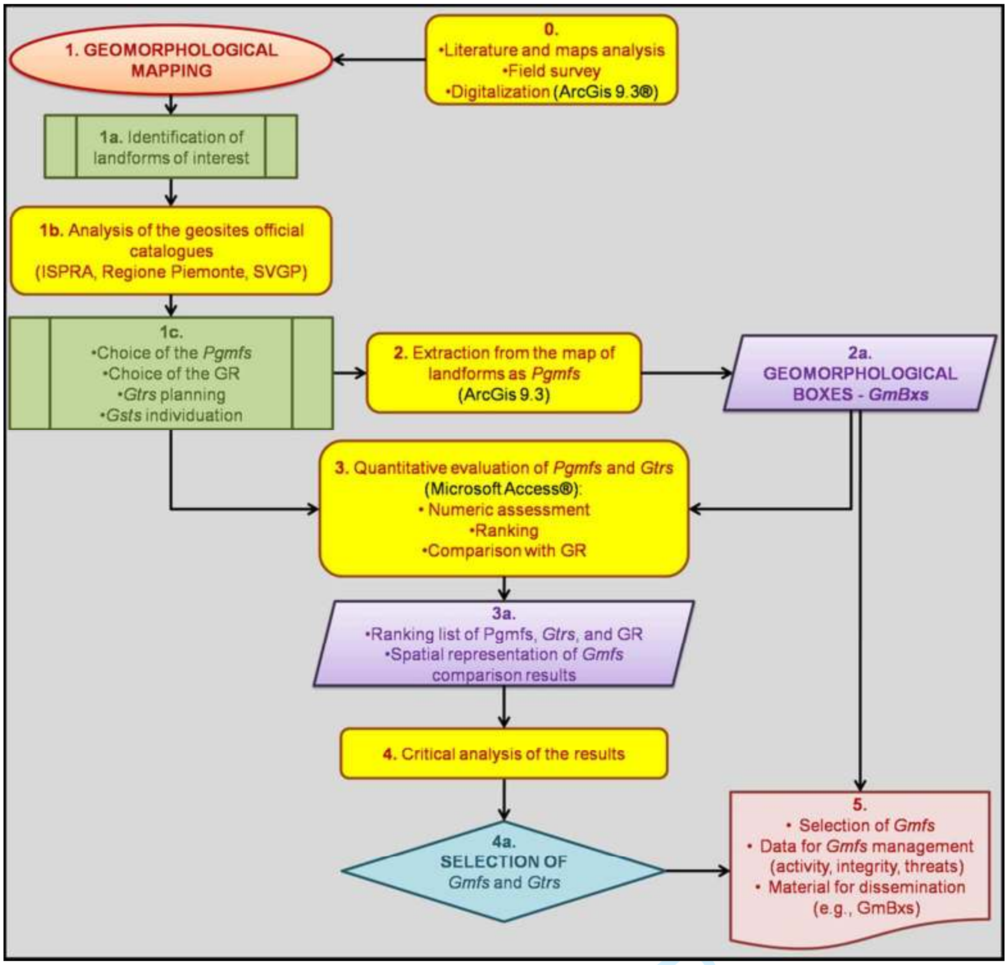


Figure 3 Flux diagram of the schematic procedure followed in the framework of the present research. The acronyms are explained along the text.

88x84mm (300 x 300 DPI)

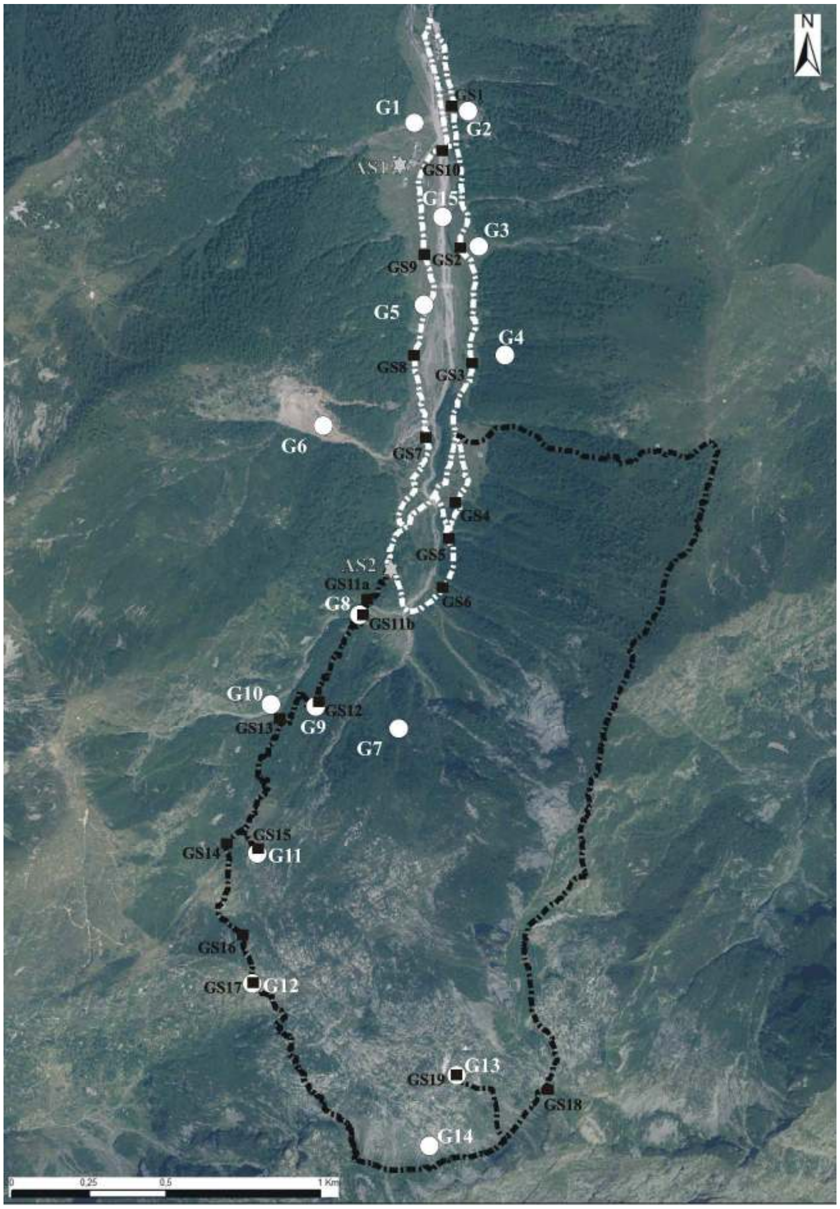
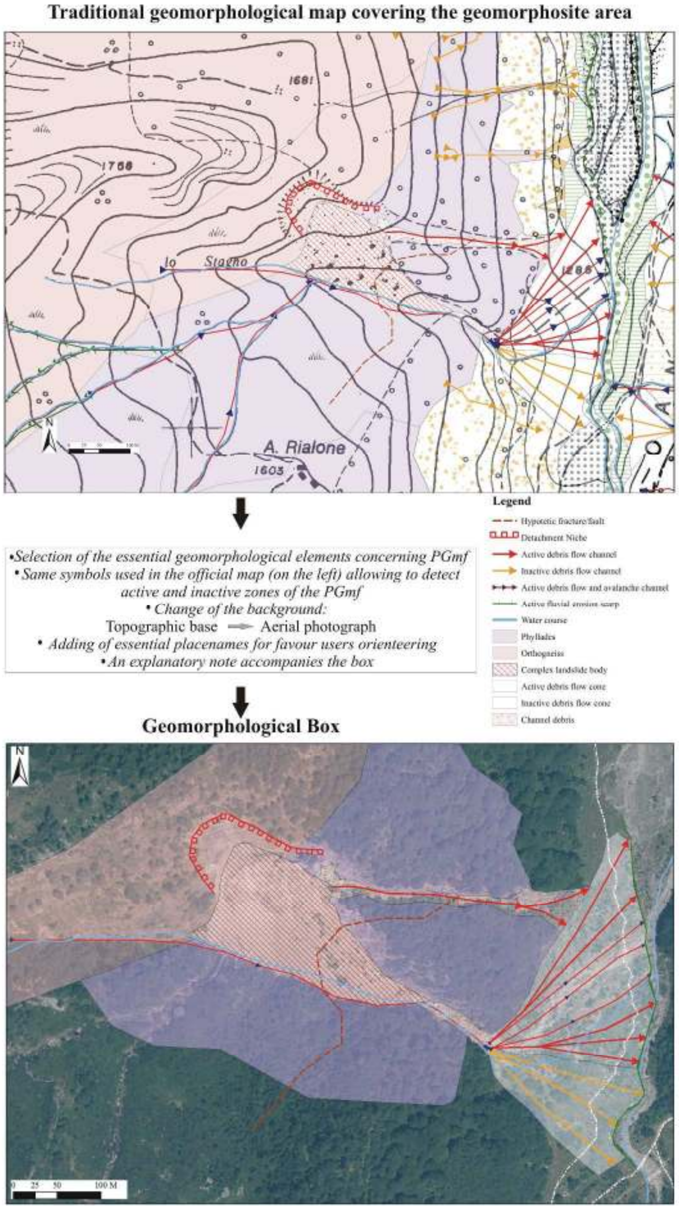


Figure 4 PGmfs (white dot), Gtrs and Gsts (black square). The white Gtr corresponds to the AB and the black one to Gtr AA in Table 4. The Gtr AA implies, at first, the passage along the Gtr AB. AS1 and AS2 (grey stars) represent the two official archeosites of Regione Piemonte, respectively "Nucleo Alpino La Cascina" and "Le Fornaci della Calce" (2012 aerial photo; courtesy of Geoportale Nazionale - Ministero dell'Ambiente).



•Selection of the essential geomorphological elements concerning PGmf
• Same symbols used in the official map (on the left) allowing to detect active and inactive zones of the PGmf
• Change of the background:
Topographic base → Aerial photograph
• Adding of essential placenames for favour users orienteering
• An explanatory note accompanies the box

Figure 5 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).

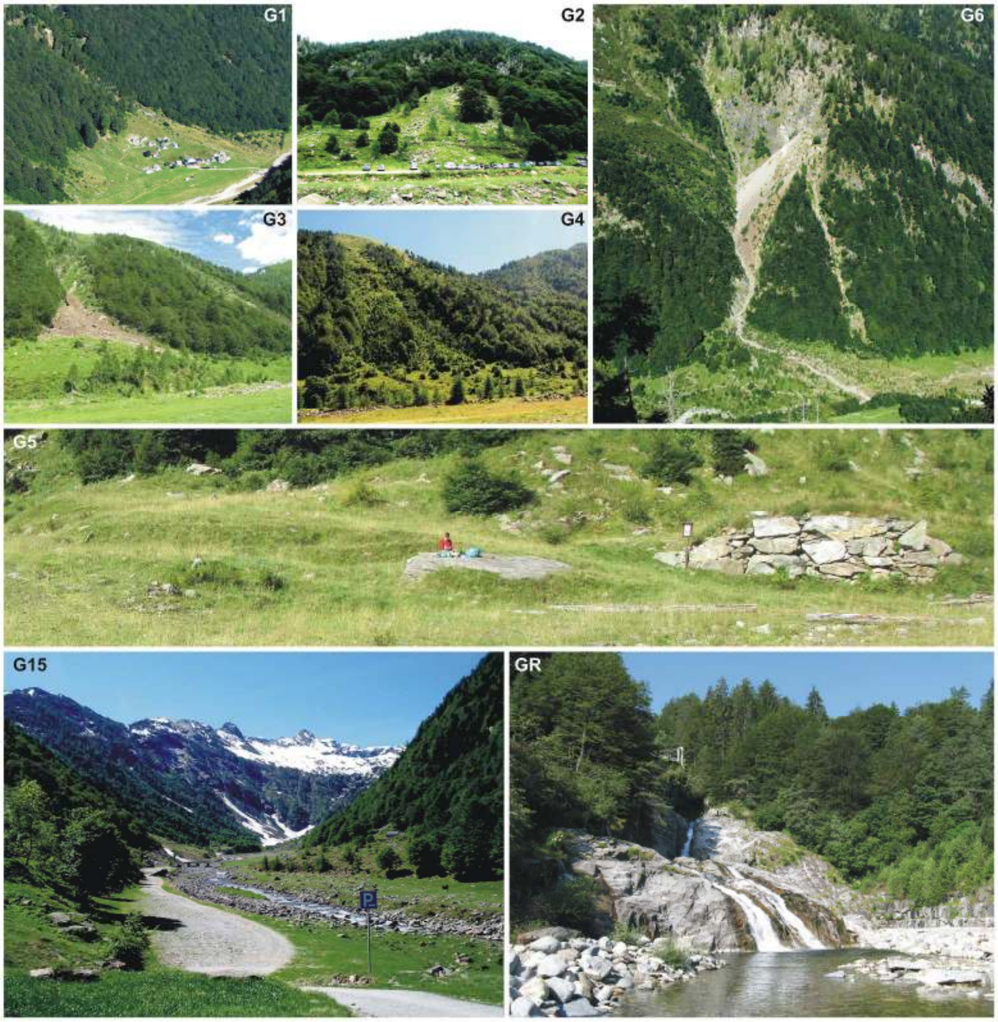


Figure 6 PGmfs characterizing mainly the AB Gtr. All the codes are reported in Table 4.

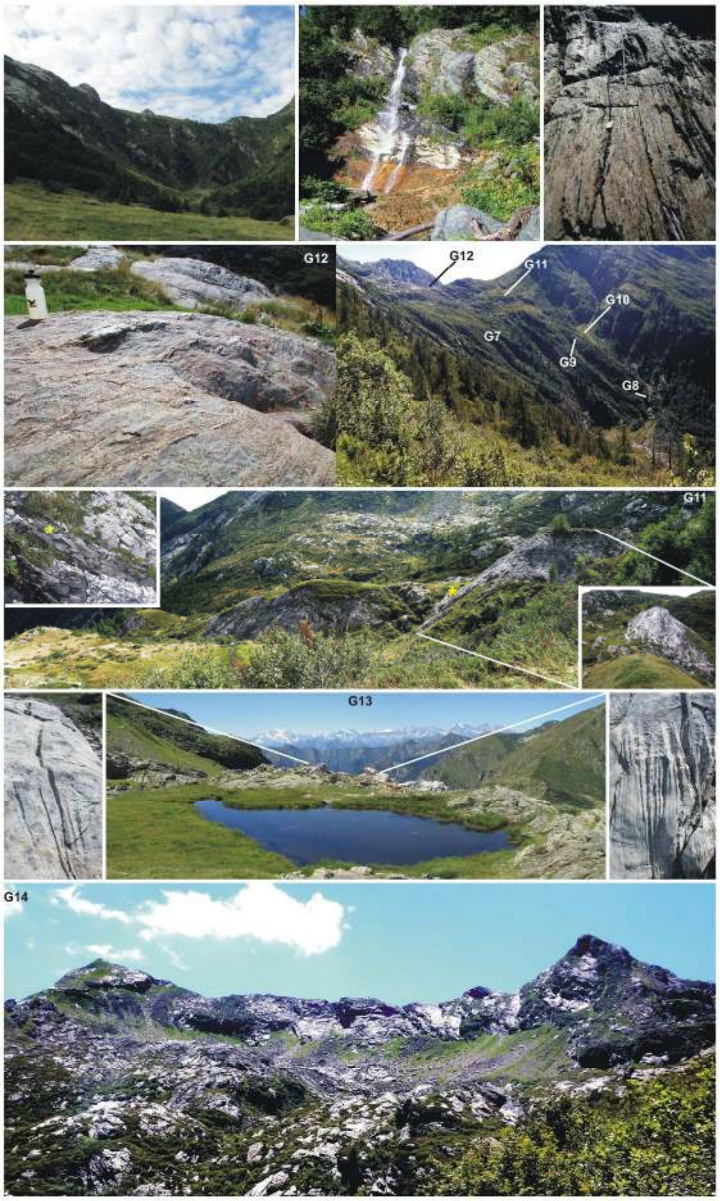


Figure 7 PGmfs characterizing mainly the AA Gtr. All the codes are reported in Table 4.

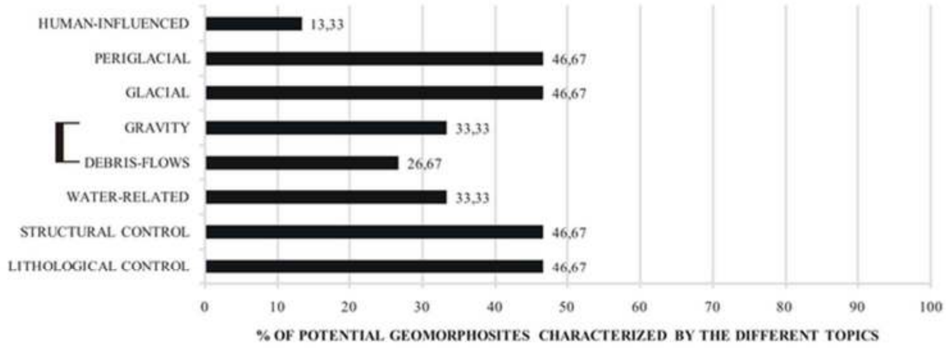


Figure 8 Percentage of PGmfs in relation with factors contributing to their modeling. Usually a combination of them is observed implying that 1 PGmf was frequently counted for more than 1 factors. GR was not included in this analysis. The braces mean the combined action of water and gravity in debris flow genesis.

61x23mm (300 x 300 DPI)

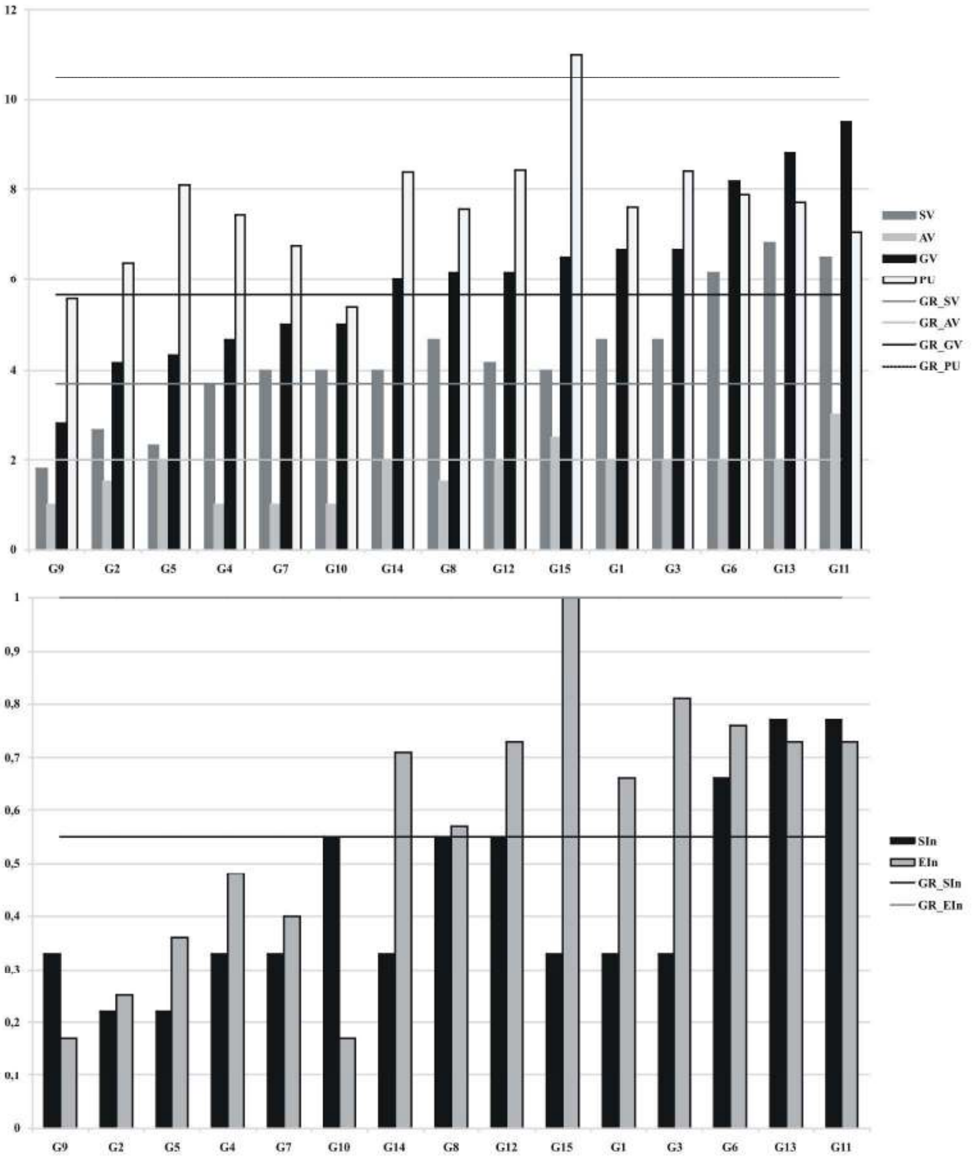


Figure 9 PGmfs assessment results. In both the graphs, lines represent the numeric values obtained by GR.

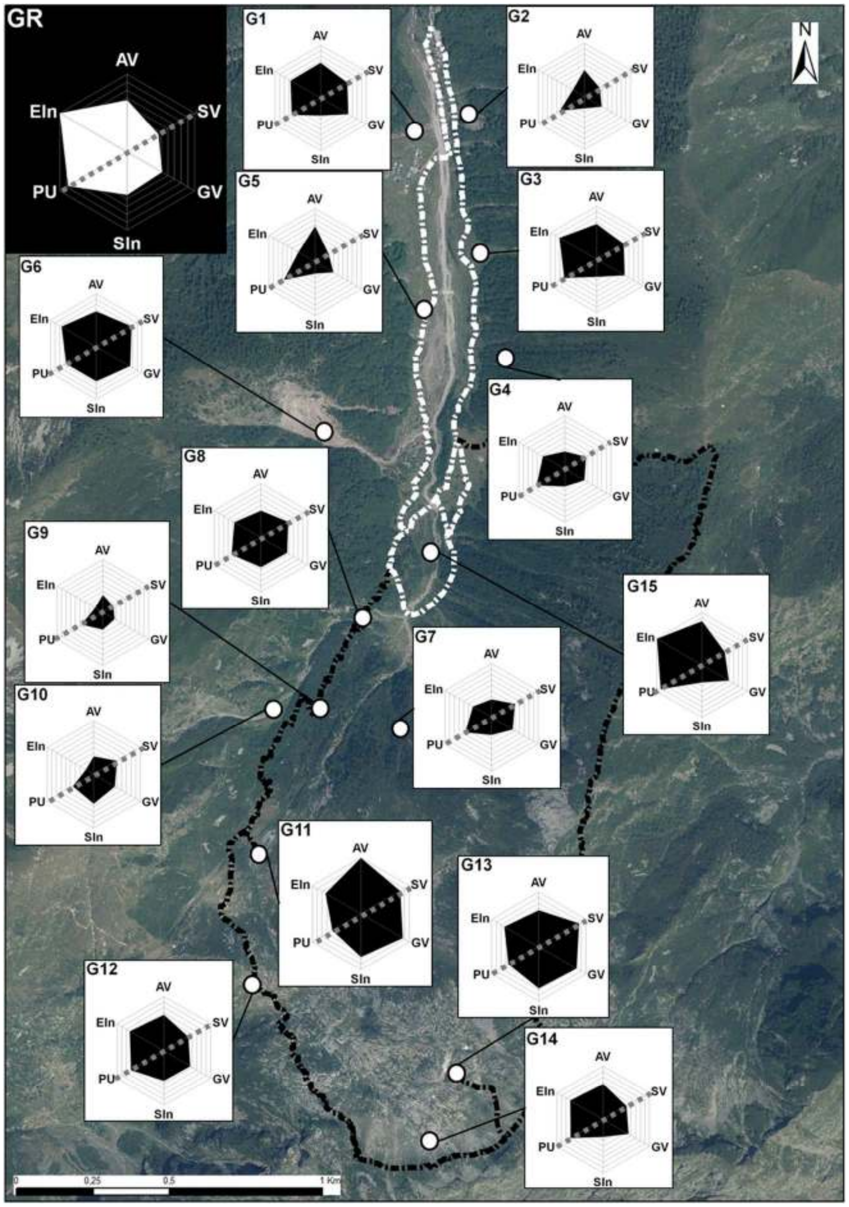


Figure 10 Multivariate representation of the macrovalues of PGmfs located along the AA and AB Gtrs. Radar graphs are reported for each PGmfs (white radar graphs) and for the reference site (black radar graph on the upper-left corner). The grey dotted line divides the parameters in function of their main meaning. The representation was reported on the 2012 aerial photo (courtesy of Geoportale Nazionale - Ministero dell'Ambiente).

88x125mm (300 x 300 DPI)

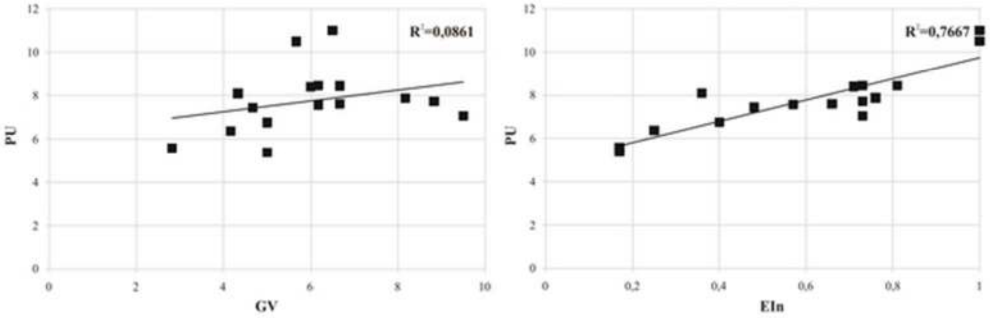


Figure 11 Correlation degree between PU-GV (on the left) and PU-EIn (on the right) of PGmfs.

54x18mm (300 x 300 DPI)

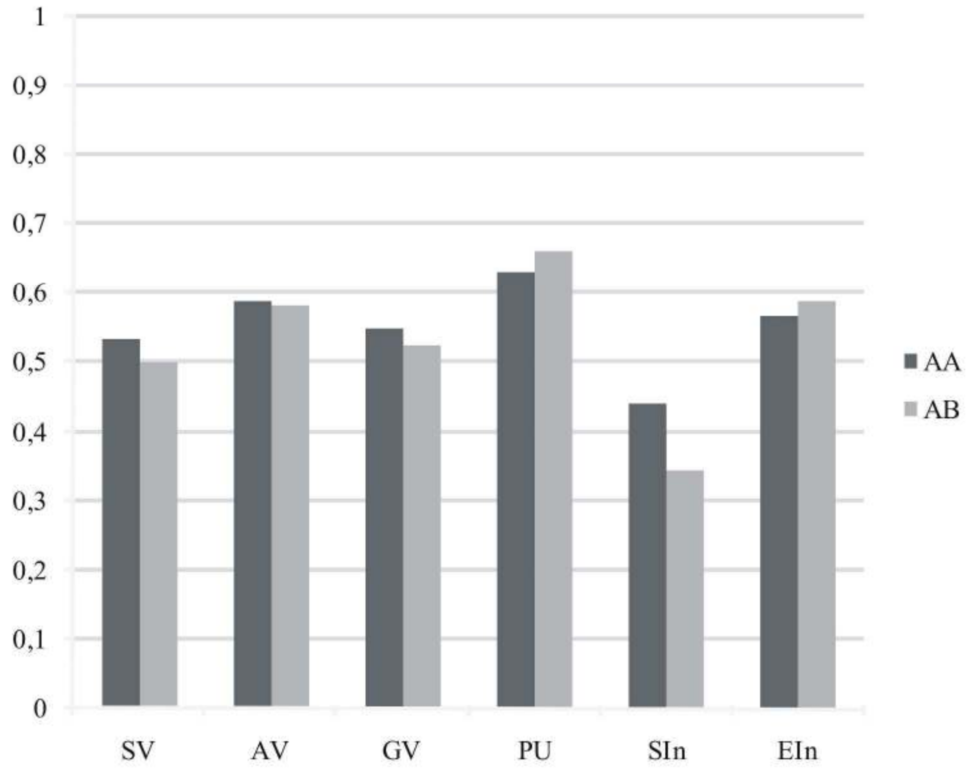


Figure 12 Gtrs numeric values.

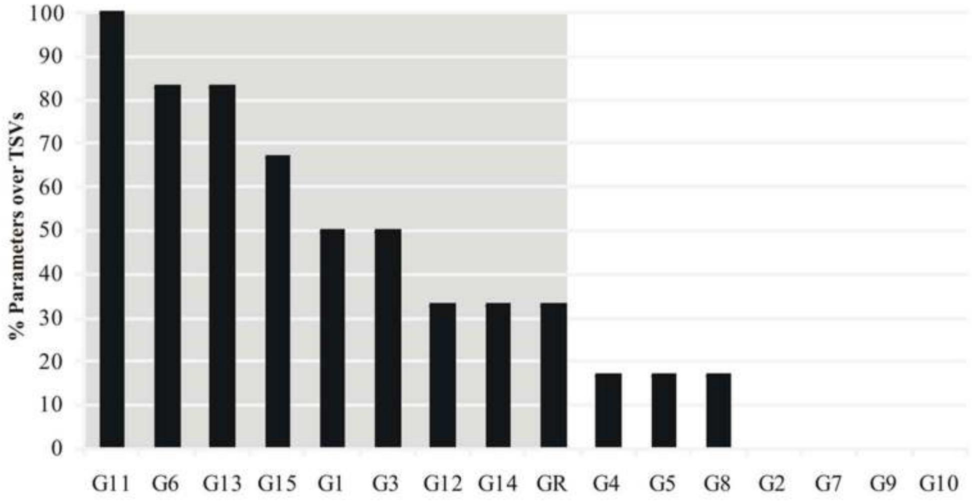


Figure 13 PGmfs ordered according the percentage of parameters exceeding the TSVs. The grey area includes the PGmfs with a percentage of parameters greater respect to GR.

89x48mm (300 x 300 DPI)

	Name	*Level of interest*	*Type of interest*	*ID*	*Database*
1	Pozzo Vecchio Cascata della Loana	Not specified	Geomorphological	1442	**ISPRA, 2017**
	Cascata della Loana	Not specified	Aesthetic	501	**Regione Piemonte, 2017**
2	Alpe Scaredi (Lago del Marmo, La Balma)	Not specified	Geomorphological	1519	**ISPRA, 2017**
	Val Loana (Lago del Marmo)	Regional	Petrographic	Not provided	**SVGP, 2013**
3	Val Loana Limestones of the Canavese Zone	Local	Petrographic	Not provided	**SVGP, 2013**
4	Val Loana (near “Le cascine”) Talc-bearing serpentinites “pietra ollare”	Local	Petrographic	Not provided	**SVGP, 2013**

SCIENTIFIC VALUE (SV)		
RGmP Representativeness of (paleo)Geomorphological Process	0	Poor/None representativeness of a morphogenetic system
	0,33	Discrete representativeness of a morphogenetic system
	0,67	Good representativeness of a morphogenetic system
	1	Exemplar representativeness of a morphogenetic system
RGP Representativeness of Geological process	0	Poor/None representativeness of a geological process
	0,33	Discrete representativeness of a geological process
	0,67	Good representativeness of a geological process
	1	Exemplar representativeness of a geological process
EE Educational Exemplarity	0	Representativeness without any educational value
	0,33	Representativeness with poor educational value
	0,67	Representativeness difficult for non experts
	1	Representativeness with excellent educational value
Gd Site Intrinsic Geodiversity	0	1 lithology, 1 main landform
	0,50	1 lithology, n-landforms
	1	n- lithologies, n-landforms
GI Geo-historical importance	0	Without production or scientific divulgation
	0,33	Low frequent topic for scientific research
	0,67	Relevant topic for scientific research
	1	Fundamental for the development of Earth Sciences in general
ESR Ecologic support role	0	Without any connection with the biologic element
	0,33	Presence of interesting flora and fauna
	0,67	The geo(morpho)logical features condition the ecosystems
	1	The geo(morpho)logical features determine the ecosystems
In Integrity	0	Essential geo(morphological elements are not preserved
	0,50	Essential geo(morpho)logical elements are just preserved
	1	Essential geo(morpho)logical elements are intact
Ra Rareness	0	Frequent also at level of the study area
	0,50	Rare at level of the study area, abundant at national level
	1	Rare at national level
ADDITIONAL VALUES (AV)		
Cu Cultural value s.s.	0	Any cultural feature in the surroundings
	0,50	Presence of cultural features not correlated with geo(morpho)logical features
	1	Presence of cultural features correlated with geo(morpho)logical features
Ae Aesthetic value	0	Not relevant
	0,50	Strong contrasts in landforms, lithologies and colours, spatial limited
	1	Strong contrasts in landforms, lithologies and colours
SEc Socio-Economic value	0	Element without exploitation or insertion in an economic area (Not touristic)
	0,33	Element with exploitation or insertion in an economic area (Not touristic)
	0,67	Element inserted in an economic-touristic area
	1	Element inserted in an economic-touristic circuit

POTENTIAL FOR USE (PU)	**TA** Temporal Accessibility	0,25	Only in summer			
		0,5	Except in winter			
		0,75	Except in rainy days			
		1	All over the year			
	SAc Spatial Accessibility	0,2	On foot, Expert Excursionists*			
		0,4	On foot, Touristic/Excursionist*			
		0,6	On foot for numerous group, because difficult access for bus			
		0,8	Allowed to means of transportation			
		1	Allowed to means of transportation, access also to disables			
	Vi Visibility	0	Not observable or great difficulties in observing it			
		0,2	Just visible or with special tools (artificial lights, ropes..)			
		0,4	Reasonable visibility but limited by vegetation			
		0,6	Good visibility but with need of moving to improve it			
		0,8	Good visibility for all geo(morpho)logical elements			
		1	Excellent visibility for all geo(morpho)logical elements			
	Se Services	0	Hotels and services far from 25 Km			
		0,33	Hotels and services far from 10 - 25 Km			
		0,67	Hotels and services far from 5 - 10 Km			
		1	Hotels and services far from 5 Km			
	NT Number of Tourists	0	Few			
		0,50	Medium			
		1	Abundant			
	SA Sport Activities	0	None			
		0,50	Yes, not correlated with geo(morpho)logical features			
		1	Yes, correlated with geo(morpho)logical features			
	LC Legal Constraints	0	Total protection, prevented use			
		0,33	Protection, limited use			
		0,67	Under protection but with few or any prevention for use			
		1	No protection or limitation in use			
	UGI Use of Geo(morpho)logical Interest	0	No divulgation or use			
		0,50	Use in academic ambit			
		1	With divulgation and use as geo(morpho)site			
	UAI Use of the Additional Interests	0	Any divulgation or use			
		0,50	Use of additional interests			
		1	Naturalistic or cultural paths already started			
	SGs Geo(morpho)sites in the Surroundings	0	Any sites in the study area			
		0,50	Sites in the neighbourhood but not genetically correlated			
		1	Sites in the neighbourhood and genetically correlated			
**CALCULATED ACCESSIBILITY (CA) (only for on foot itineraries)*	**Ti** Tipology	0	Any traces	**GM** Ground Material	0	Ice
		0,2	Traces		0,2	Snow
		0,4	Path		0,4	Coarse debris coverage
		0,6	Mule tracks		0,6	Medium debris coverage
		0,8	Dirt road		0,8	Fine or soil debris coverage
		1	Paved road		1	Bed rock or dirt/paved road
	Sl Sloping	0	Yes	**SM** Slope Material	0	Fractured rock, soils, snow and ice
		1	No		1	Rocks and coherent deposits
	SI Slope Inclination	0	> 61°	**St** Steepness		
		0,25	51°-60°		0	High
		0,5	41°-50°		0,5	Medium
		0,75	31°-40°		1	Low-null
		1	<30°			
	TI Tourist Information	0	No	**WSP** Water/Snow on path	0	Yes
		1	Yes		1	No
	Wi Width	0	<30 cm	**DC** Degree Of Path Conservation	0	Very bad
		0,25	30-50 cm		0,33	Fairly good
		0,5	50-100 cm		0,67	Good
		0,75	100 cm		1	Excellent
		1	>100 cm			
	HI Human Interventions	0	Present and increasing vulnerability			
		0,33	Absent			
		0,67	Present not influencing			
		1	Present and reducing vulnerability			

	EQUATIONS	
SV-*SCIENTIFIC VALUE*	$SV = (GM+PgM+EE+Gd+GI+EI+OI+In+Ra)$	*0-8*
AV-*ADDITIONAL VALUES*	$AV = (Cu+Ae+SEc)$	*0-3*
GV-*GLOBAL VALUE*	$GV = (SV+AV)$	*0-11*
IU-*Index of Use*	$IU = EE+ Ae$	*0-2*
Potential for Use s.s.	$PUss = (TA+Vi+Se+NT+SA+LC+UGI+UAI+SGs)$	*0,25-9*
PPU-*Partial potential for Use*	$PPU = (PUss+IU)$	*0,25-11*
CA-*Calculated Accessibility**	$CA = (Ti+St+Sl+Wi+GM+WSP+SI+SM+DC+HI+TI)$	*0-11*
AFc-*Accessibility Factor (on foot)*	if $SAc \leq 0.4$; $AFc = (CA/11)*0,5$	*0-0,5*
AFs-*Accessibility Factor (other)*	if $SAc \geq 0.6$; $AFs = SAc$	*0,6-1*
PU-*POTENTIAL FOR USE (on foot)*	$PUc = PPU +AFc$	*0,25-12*
PU-*POTENTIAL FOR USE (other)*	$PUs = PPU+AFs$	*0,25-12*
SIn-*Scientific Index*	$SIn= (GM+PgM+GI)/3$	*0-1*
EIn-*Educational Index*	$EIn= [EE+Ae+(A\_Fc/s)]/3$	*0-1*
TS-*TOTAL SCORE*	$TS = GV+PUc/s$	*0,25-23*

	SV	AV	GV	PU	SIn	EIn
TSVs	5	2.5	6.5	7	0.6	0.6

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	

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***

AIM *MAPPING METHOD*	**SCIENTIFIC AIM**	**DISSEMINATION AIM**		
		Target User	**Reference**	**Product definition**
TOTAL-COVERAGE MAPS	*Geomorphological Maps*	*Non specialists*	*(e.g., Castaldini et al. 2005)*	*Geoscientific maps for amateurs of Earth sciences*
PARTIAL-COVERAGE MAPS	*Geomorphological Sketches*	*Specialists*	*(e.g., Carton et al. 2005)*	
		Non specialists	*(e.g., Giardino and Mortara 1999; Regolini-Bissig 2010;*	*Interpretive maps*
			(present research)	*GEOBOXES*

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

Abstract:

Geomorphological mapping plays~~has~~ a key role in landscape representation: ~~and~~ it is~~represents~~ the starting point for many applications and for the realization of thematic maps, such as hazard and risk maps, geoheritage and~~maps,~~ geotourism maps. Traditional geomorphological maps are useful for scientific purposes but they need to be simplified for different aims~~purposes~~ as ~~for example~~ management and education. In~~For~~ tourism valorization, mapping of geomorphological ~~geo~~ resources (i.e., geosites, and ~~or in particular~~ geomorphosites), and of geomorphic~~as well as~~ evidences of past hazardous geomorphological events, is important for increasing knowledge about ~~both~~ landscape ~~genesis and~~ evolution and active processes, potentially involving ~~hiking trails nearby~~ geomorphosites and hiking trails. Active~~locations. Moreover, active~~ geomorphosites, as those widespread ~~with~~in mountain regions, testify the high dynamicity of geomorphic processes and their link with climatic conditions.~~climate features and changes in sensitive environments. Geomorphological mapping may be considered the starting tool to detect geo-resources and to produce outputs with geotouristic aims, obtained from the traditional geomorphological map.~~ In the present paper, we propose a method to produce and to update cartographic supports (~~(i.e.,~~ *Geomorphological Boxes*) realized starting from a traditional geomorphological survey and mapping. The geomorphological boxes are geomorphological representation of single, composed or complex~~multiple~~ 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 *Geomorphological Boxes* of each *Potential Geomorphosite* includes only landforms essential to comprehend its spatio-temporal dynamicity.~~ The method has been tested in the upper portion of the Loana Valley, located within the borders of the Sesia Val Grande Geopark, recognized by UNESCO in 2013 (Western Italian Alps.). 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 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 (Sesia Val Grande Geopark, Western Italian Alps)

Introduction

~~The~~ European Alps are among the key sites for geoheritage (sensu Osborne, 2000). The high level of geodiversity (Gray, 2013), due to the complex of geological processes and to the variety of geomorphological features, including~~elements, and the~~ 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~~. In fact, several~~ active and evolving passive geomorphosites (sensu Pelfini and Bollati 2014)~~2004)~~ can be found in the mountain territories. Some~~areas, some~~ of them~~which~~ are characterized by a fast changing rate, ~~for example~~ in response to climate change (e.g., glacial forelands). In fact time-scale of geomorphic processes is very variable, also according to the substrates affected. 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 ~~the~~ geo-resources~~, in mountain regions,~~ such as geosites and geomorphosites,~~,~~ to be conserved, are becoming a real need (e.g., Reynard et al.~~and Coratza~~ 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~~as well as of~~ naturalistic and thematic trails (e.g., glaciological trails) (~~as~~ 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).~~2016b).~~ 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 characteristic~~processes~~ (slope processes, meteorological ~~events~~ and ~~triggered~~ 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~~define~~ vulnerability for~~and to manage~~ risk management~~scenarios~~ (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~~s~~ touristic trails and where changing~~active and evolving passive~~ landforms (sensu Pelfini and Bollati 2014) are present, geo~~the~~ sites 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~~physical~~ evidences of geomorphological hazards (e.g., rockfall and debris flows~~(gravity generated~~ deposits affecting~~, historical documentation or disruptive processes involving~~ also human settlements) (e.g., Coratza and De Waele 2012), can be observed in safety conditions. Anyway,~~Moreover,~~ 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 ~~collection~~ and for the analysis~~representation~~ of the physical landscape dynamic,~~dynamics,~~ and subsequently for risk management and geo-risk education (Giardino and Mortara, 1999).~~.~~ In a single document (i.e., the geomorphological map) landforms ~~and related processes,~~ classified according to their ~~the~~ genetic processes, are represented (e.g., ISPRA 1994; 2007). As highlighted by Giardino and Mortara (1999), landforms ~~Landforms~~ mapping is hence useful ~~both~~ 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~~highlight~~ the ~~users~~ potential geomorphological hazards ~~and risks~~ affecting geotrails.

Nevertheless, for dissemination and~~purposes of geo-risk~~ education, a simplified version ~~of geomorphological maps~~ is necessary, as detailed geomorphological maps require specific reading skills. Simplified geomorphological maps aim~~s~~ 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)~~ 2005)~~ 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 geotourist maps typologies, depending on the balance between scientific and touristic data. The crucial issue is represented by~~These kinds of outputs represent a crucial issue considering~~ 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 this principle, 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 ~~and~~ are ~~really important~~ 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 ~~proposals~~ in mountain environment, taking into account the need for an easy-approachable~~easy reading~~ 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~~Fig.~~ 1). ~~The~~ Loana Valley is included in the Sesia Val Grande Geopark (SVGP; Figure~~Fig.~~ 1), officially recognized in ~~the year~~ 2013 by the European Geoparks Network and by UNESCO. In the Loana Valley, erosion and depositional landforms~~, and deposits,~~ mainly due to glacial processes, ~~debris flows,~~ mass movements, debris flows, avalanches and stream modeling, are easily observable while walking touristic and excursionist trails. Besides,~~Moreover~~ here, in the recent times, extreme meteorological events have triggered~~, in the recent past,~~ several instability events, some of which damaged~~sometimes damaging~~ infrastructures and left deep scars in the landscape (e.g., Mortara and Turritto 1989; Dresti et al. 2011).~~ and leaving deep scars in the landscape.~~ The selected area presents hence good features to test the proposed methodology and to find out tools for Earth Science education and dissemination, with particular regards to geo-risk education~~mitigation strategies~~ (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~~making a~~ inventory of *landforms of geomorphological interest* along specific trails; iii) the set of~~setting~~ a GIS procedure to create simplified geomorphological sketches (i.e., *Geomorphological Boxes*) of *Potential Geomorphosites*; iv) the evaluation~~evaluating~~ and ranking of *Potential Geomorphosites* and *Geotrails*; v) proposing a selection of *Geomorphosites*~~geomorphosites~~ for ~~valorization and~~ geoconservation and valorization according to different purposes.

1 Study ~~site~~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~~(Fig.~~ 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; Figure 2a) (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; Figure~~Fig.~~ 2a) and metapelites (Mp-IV; Figure~~Fig.~~ 2a) in granulite to amphibolite facies and mantle-peridotite slices (Per-IV; Figure~~Fig.~~ 2). The ~~CL separates the Southern Alps from the axial part of the Alpine chain and specifically from the Austroalpine system of the Sesia-Lanzo Zone (Ogn-SL; Fig. 2a), still belonging to the African continental margin. The~~ Fobello-Rimella mylonitic schists (FR-Sch; Figure~~Fig.~~ 2a) locally represent ~~locally~~ 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 Figure 2b) outcropping within both the Ivrea-Verbano Zone (Mp-IV and Mb-IV in Figure 2a) and the Fobello-Rimella mylonitic schists (FR-Sch; Figure 2a). 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~~, a big mass movement~~ in the hydrographic basin of the Stagno Stream, a tributary of the Loana River, a big mass movement in proximity to a litho-structural contact. After the 1978 instability event~~, with effects at regional scale,~~ 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~~this detailed and~~ 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 & Tien Bui, 2016) or debris flows, that pervasively affect the area. As mentioned before, the valley~~As mentioned before, the area~~ is characterized by an important structural and lithological control on landforms shaping. Mass movements (mainly rock-falls) often~~generally~~ take place ~~together with debris flows especially~~ along weakness zones. Avalanches (e.g., 1986, 2014). They are among the most dangerous processes that affect~~affecting~~ slopes mainly during Spring and reworking~~, shaping~~ the typical avalanches corridors (Barbolini et al. 2011). Composite cones (sensu Baroni et al. 2007) built and reworked by~~due to~~ gravity processes, running waters and avalanches are very common~~widespread~~ in the valley. In specific cases (i.e., in correspondence of the "Nucleo Alpino La Cascina"- see details along the paragraph), defense works ~~from mass wasting events~~ are present. Near the water divide, gravity landforms are combined with glacial ones generated~~that intensely interested the area~~ 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;~~, and~~ its more distal part is deeply incised as far as the alluvial fan, at the confluence with the Eastern Melezzo.

~~From other points of view, 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).~~ Geological ~~(features, very meaningful for what concerns~~ structural and petrographical) characteristics~~ topics,~~ are deeply connected with human settlements and geo-resources usage.~~.~~ Two regionally valorized archeological sites are~~ also~~ present (see location on Figure 4): the "Nucleo Alpino La Cascina and "Le Fornaci della Calce" whose 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.~~The second site is strictly linked with the geological framework since it is related to the usage of the carbonates, more or less metamorphosed and outcropping as intercalations 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~~locations~~ within the Loana hydrographic basin are included at least in 1 of the~~in~~ 3 official catalogues of geosites concerning the area (Table 1):

i) the ISPRA geosites database (ISPRA, 2017);~~(http://sgi.isprambiente.it/geositiweb/Default.aspx);~~
ii) the Regione Piemonte list of elements of naturalistic interest (Regione Piemonte, 2017);~~(http://www.geoportale.piemonte.it/geocatalogorp/);~~
iii) the SVGP Geosites list (SVGP, 2013).~~(http://www.parcovalgrande.it/pdf/Dossier.SesiaValGrande.pdf).~~

The Pozzo Vecchio Loana waterfall (site n. 1 in Table~~Tab.~~ 1), located at the confluence with the Eastern Melezzo river, and the Lago del Marmo (site n. 2 in Table~~Tab.~~ 1), located at the head of the valley, are present in~~ at least~~ 2 of the databases even if not for the same interest. The 3 geosites, individuated by the SVGP (site n. 2, 3 and 4 in Table~~Tab.~~ 1), 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 3.

2.1 Geomorphological mapping, census~~identification~~ 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 ~~field survey~~ (step 0, Figure~~Fig.~~ 3).~~ in order to proceed with the geomorphological map elaboration.~~ Landforms are represented according to their genetic process, as indicated by the National Geological Survey (ISPRA, 1994; 2007)~~(ISPRA)~~ and recently updated by D'Orefice and Graciotti (2015). The geomorphological map was digitalized using ArcGIS 9.3® (step 1, Figure~~Fig.~~ 3). According to the field data and to the geomorphological map, we successively made an inventory of the landscape geomorphological ~~geo~~ resources (i.e., *landforms of geomorphological interest*) (step 1a, Figure~~Fig.~~ 3) (e.g.; Giardino and Mortara 1999).~~.~~

Then~~Moreover~~ we analyzed the official geosites catalogues (step 1b, Figure~~Fig.~~ 3) to obtain more information~~data~~ for the selection~~detection, among all the mapped *landforms of geomorphological interest*,~~ of the *Potential Geomorphosites* (*PGmfs*) and for the planning of *Geotrails* (*Gtrs*) (step 1c, Figure~~Fig.~~ 3). This step~~phase~~ concerned the analysis of the already existing hiking paths (e.g., Giardino and Mortara 1999), represented~~reported~~ on the official maps (Carta Escursionistica, Interreg, "Valle Vigezzo, Valle Cannobina" 1:25000) and/or digitalized within the Regione Piemonte official shapefiles (Regione Piemonte, 2017). The trails~~(http://www.geoportale.piemonte.it/geocatalogorp/). These latter~~ were also surveyed in order to check~~verify~~ morphological features influencing accessibility, maintenance and potential hazards affecting them. Some *Geostops* (*Gsts*) were then individuated along geotrails~~them~~ (step 1c, Figure~~Fig.~~ 3). Their locations were carefully chosen~~defined~~ in order to allow the best observation of~~be able to observe~~ the *PGmfs* both on site and from other locations (e.g., opposite side of the valley). Each *PGmf*~~*s*~~ was associated to a principal *Gst* along the *Gtrs*~~s~~ 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 *PGmfs*~~,~~ 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,~~moment,~~ to facilitate ~~the~~ users in understanding the geomorphology of the site and its progressive evolution under surface processes action (Regolini-Bissig 2010).~~own dynamicity in space and time.~~ The procedure (step 2, Figure~~Fig.~~ 3) consisted in~~of~~ adding specific fields to the shapefiles attributes tables of~~ shapefiles of the~~ geomorphological polygons, lines and point in GIS environment. These additional fields contain information about~~on~~ the digitized landforms as *PGmfs*. Moreover display options and dedicated layer files, based on~~using~~ 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~~adopted~~ as background to *Gmbxs* (step 2a, Figure~~Fig.~~ 3), especially for the dissemination purposes.~~purpose.~~ This graphic support,~~ in fact,~~ in the recent times has become more familiar also to general public by using applications like Google Maps® or Google Earth® and hence 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 ~~of~~ *Gtrs* (step 3, Figure~~Fig.~~ 3) 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 trail characteristics influencing tourist vulnerability (e.g., Bollati et al. 2013; Giardino and Mortara 1999).~~features.~~ *GmBxs* were complementary tools at this scope (Figure~~(Fig.~~ 3). 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~~built~~ using a commercial package (Microsoft Office Access®) and final numeric values were calculated. The criteria ~~here~~ adopted for the implementation of the database are: i) *integrity*, that means no duplication of records (*PGmfs* and *Gtrs*) are allowed and requires a ~~the~~ maximum subdivision of information linked~~related~~ each other~~,~~ by means of the geomorphosite-ID;~~geomorphosite ID, is required;~~ ii) *logic sequence* in order to facilitate the users, through the pre-~~use of~~ 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) and equations~~formulas~~ reported in the Tables~~tables~~ 2, 3 and 4. From the numeric values attributed to single *PGmfs*, those referred to~~of~~ *Gtrs* were derived and normalized to the number of its own sites, taking into account that each *Gtr* is composed by a different number of sites, a feature that may affect the ~~final~~ results.

Moreover, we quantitatively assessed~~assesses~~ the reference site (GR) detected during the step 1b (Figure~~(Fig.~~ 3), the Pozzo Vecchio Loana waterfall (i.e., site 1; Table~~Tab.~~ 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~~that~~ of Regione Piemonte (the only indication regards the primary geomorphological interest), an analysis on the field was hence performed~~necessary~~ to quantitatively evaluate it. *PGmfs*, GR and *Gtrs* were finally ranked (step 3a, Figure~~Fig.~~ 3).

In order to spatially represent results coming from the database (step 3a, Figure~~Fig.~~ 3), besides using the classic column charts, the use of the multivariate method proposed by Reynard et al. (2016b)~~(2016c)~~ was experimented. In fact the radar graphs allow an easy identification of the evaluation parameters~~site distinction~~ 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 others by a grey dotted line (see Figure~~Fig.~~ 8, results paragraph). More in detail the parameters more akin to dissemination (PU; EIn; AV) were put side by side respect to those strictly linked with the scientific meaning of the site (SV, Sin, GV). 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~~effectively valuable~~ *Geomorphosites* (*Gmfs*) to be proposed~~propose~~ for addressing management resources, valorization or geoconservation practices (step 4 and 4a, Figure~~Fig.~~ 3).

To select *Gmfs*~~discriminate~~ among *PGmfs*, we used *Threshold Values* (*TSVs*) for each attributes (SV, AV, GV, PU, Sin, EIN; Table~~table~~ 2, 3, 4) calculated according to the equation:~~formula:~~

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

The *TSVs* considered for each attribute are reported in Table~~table~~ 5.

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.

~~4~~ 3 Results

3~~4~~.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~~(Tab.~~ 6; Figure~~Fig.~~ 4), were detected.~~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 ~~strictly~~ concerning strictly the fundamental features useful to identify the genesis and the past or current dynamic~~or past dynamics~~ of each *PGmfs*.~~to facilitate and lighten the reading of the map.~~ In Figure 5, the comparison between the traditional geomorphological map and the simplified version for the *GmBxs* is reported. The proposed *PGmfs* is G6 - Pizzo Stagno Complex system (Table~~(Tab.~~ 6, 7; Figure~~Fig.~~ 6). It has been chosen to exemplify a geomorphological box as~~since~~ i) it obtained a very high EIn value (0,76/ over 1 see result section ~~4~~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~~interested~~ by debris flows and avalanches too, processes that favor~~favoring~~ the debris transport and deposition at the confluence between the Stagno and the Loana streams. More in detail, the down-valley portion~~section~~ of the G6 site is characterized~~interested~~ by the presence of a wide composite cone in which~~where~~ 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 (hypothetic fault and lithological diversity along the fracture zone)~~fracturation belt)~~ to catch users attention on its importance in driving hydro-geological instabilities.

~~4~~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 ~~(Fig. 6; 7). Such *PGmfs* are distributed along two of the official hiking trail, here selected as *Gtrs*, characterized by different difficulty degrees for what concerns their accessibility (Tab. 6; Fig. 4). The *Gtr* AA, suitable for more expert hikers, is an extension of the *Gtr* AB, an easier and more touristic path.~~ (Figure 6; 7). ~~Both the *Gtrs* have a ring pattern and they are characterized by a different number of *PGmfs* and some of them belong to both the *Gtrs*.~~

The analyzed *PGmfs* can be considered of local/regional importance. They have been shaped by different geomorphic processes, typical for the high mountain environment (Figure~~(Fig.~~ 6; 7). The main modeling factors characterizing *PGmfs* are reported in Figure 8. The most effective~~influent~~ geomorphic processes in shaping *PGmfs* result~~s~~ to be the glacial ice and the snow action and ~~, followed by~~ structural and lithological features control landscape shaping~~controls~~ (46.67%). ~~and then by periglacial processes (40%).~~ 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~~table~~ 7 and in Figure 9 (step 3a). In Figure 10 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~~table~~ 7 and in Figure 9 are herein spatially represented. The difference between~~s among~~ very high valued sites (at least 3 parameters above TSVs: ~~(~~G11, G13, G6, G1, G3~~G13~~ and G15) and ~~the~~ very less valued (G4, G5, G8; G2, G7, G9 and G10) is evident at first sight. Among the meaningful sites, some of them allow a comparison between the different activity degree 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.

Considering the correlation between the main evaluation parameters (GV, PU, EIn) of ~~indexes at level of~~ *PGmfs*, it is possible to obtain interesting results (Figure~~(Fig.~~ 11). PU (Table~~(Tab.~~ 3; 4) of each *PGmfs* does not correlate significantly (r^2=0.0861) with GV (Table~~(Tab.~~ 2; 4), suggesting they should be both considered in phase of decision, according to different selection purposes. PU and EIn (Table~~(Tab.~~ 3; 4) provide, on the contrary, a more correlated~~similar~~ trend (r^2=0.7667). These relations were verified also at level of *Gtrs* but in Figure 11 this result~~herein~~ is not reported since less statistically significant.

The 15 *PGmfs* are distributed along~~significant, having only~~ two of the official hiking trails, here named *Gtrs*, characterized by different difficulty degrees~~points~~ for what concerns their accessibility (Table 6; Figure 4).~~calculating r^2.~~

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*. Some of them belong to both the *Gtrs*.

The *Gtrs* evaluation results, whose numeric values were normalized to the number of their own sites, are reported in Figure~~figure~~ 12. Results show that ~~AA~~ *Gtr* AA has higher SV, ~~and~~ AV, SIn and also GV respect to ~~AB~~ *Gtr* AB while this latter~~, that~~ is~~, instead,~~ more valuable in terms of PU and EIn.

~~4~~3.3 Geomorphosites (Gmfs) selection

For the *Gmfs* selection, a~~A~~ critical analysis was ~~finally~~ performed on the obtained values~~results~~ using *TSVs* and the relation between the *PGmfs* values respect to the GR values. The percentages of parameters exceeding the *TSVs* for each *Pgmfs* are reported in Figure~~figure~~ 13. It is interesting to note that GR, the reference site, is above *TSVs* only for the 33% of the calculated parameters. The only site reaching the 100% of parameters over *TSVs* is G11. Moreover, besides~~Besides~~ GR, G13 is the only *PGmfs* included in one of the official databases (i.e., site 3, Table~~table~~ 1). 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 Figure 2). As a general outcome, it could be possible to consider worthy of attention as *Gmfs* the 53% of *PGmfs* that exceed the *TSVs* for, at least, the 33% of the parameters (G11, G6, G13, G15, G1, G3, G12, G14).

~~5~~ 4 Discussions

Geoheritage in mountain environment has a great relevance for valorization, tourism promotion and geoconservation (Reynard and Coratza 2016; Reynard et al., 2016a).~~2016b).~~ In particular, geomorphosites are landforms characterized by specific attributes making them ideal key sites~~ ideal~~ 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 ~~for and affecting~~ geomorphosites genesis and/or currently affecting them,~~features,~~ can represent hazard and risk for users,~~in fruition contexts,~~ especially under changing climate conditions (Pelfini et al.~~,~~ 2009). Nevertheless, the~~ir~~ 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~~is~~ fundamental both for geo-resources management and for~~suitable forms of~~ 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, ~~depositional landforms~~ as well as the activity~~dynamics~~ of the related processes. However it~~What~~ is crucial~~fundamental is understanding how~~ 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~~rendering~~ for dissemination purposes (i.e., *GmBxs*). The geomorphological map ~~Geomorphological mapping~~ has been hence realized~~considered~~ under a double perspective: i) the scientific data collection and representation, considered indispensable for analyzing landforms of different genesis (step 0 and 1, Figure~~Fig.~~ 3); ii) the elaboration of dissemination products (*GmBxs*) to guide both the evaluator, during the analysis of landforms features as potential components~~elements~~ of geoheritage, and the final user in reading the physical landscape in a simplified but corrected way (step 2a and 5, Figure~~Fig.~~ 3). Concerning the (ii) point, in Table 8 a classification of the typologies of geomorphological maps proposed in literature and in the present research, according to the aim of the research, is reported. Some~~several~~ examples of simplified geomorphological maps for tourism~~with geotouristic aims, that cover the entire territory with less detail than the traditional geomorphological maps,~~ 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 ~~. Nevertheless, the choice herein presented is focused on creating maps for~~ 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*~~ that covers the study area. The elaboration~~ (step 2, Figure~~Fig.~~ 3) ~~aimed at limiting~~ the plotting of symbols is limited to those essentials for the user to understand the characteristics and the dynamics of each *PGmfs*.~~ dynamic.~~ The GIS shapefiles are the same of the official geomorphological map,~~does not change~~ with the advantage that the *GmBxs* data are~~remain~~ constantly updated, in real ~~-~~time, whenever the official geomorphological map undergoes to changes ~~through times~~ (e.g., local landscape transformations due to instability events, quite common in mountain areas). Aerial photographs, chosen as background of *GmBxs*, enriched with the trails paths~~ path~~ and essential placenames,~~palcenames,~~ are familiar to the general public (i.e., Google Maps®; Google Earth®) and they could become an excellent tool for facilitating the "~~approach and 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~~Fig.~~ 3).~~ as the one used in the framework of this research or those inserted in official databases.~~ As a whole, *Gmbxs*~~geomorphological mapping~~ may be proposed as ~~considered~~ a powerful tool for~~from the scientific data collection and plotting for risk management as far as~~ the valorization of high mountain geomorphic environments also under the perspective~~for example by means~~ 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~~Fig.~~ 3), Loana Valley, especially in the investigated southern portion, results to be~~is~~ characterized by very representative landforms (step 1a; Figure~~Fig.~~ 3) 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~~individuated~~ number of *PGmfs* (15; step 1b, 1c; Figure~~Fig.~~ 3) may be considered high in a so narrow area (i.e., high density). Nevertheless,~~ Anyway,~~ if we consider the official ISPRA catalogue (ISPRA, 2017), it is possible to note that~~,~~ the sites density~~ of sites~~ is variable over the Italian territory, depending on the contributions provided to the database by local administrations. Since not all the landforms can~~may~~ be considered *Gmfs*, a selection is usually necessary (Komac et al. 2011) and several are the methodologies proposed in literature (Brihla 2016b). The new~~In detail, the~~ proposal of using *TSVs* and the comparison with reference sites included in the official databases (i.e., GR), allow~~ed~~ to select the most valuable *Gmfs* among ~~discriminate between~~ the *PGmfs* (step 4 and 4a; Figure~~Fig.~~ 3). In the specific case, we propose to consider as *Gmfs* only the *PGmfs* exceeding the *TSVs* with the 33% of the parameters, as for GR. *TSVs* application~~These tools~~ together with the multivariate spatial representation of results (i.e., radar graphs; ~~(~~Reynard et al. 2016b)~~2016c) may~~ provide also easy accessible information for public administrations useful for geoheritage~~a better sites'~~ management. In this framework, as ~~the specific case,~~ PU and GV do not correlate significantly each other, ~~and so~~ they should be both considered during selection, according to~~in relation with~~ the aim of the management. A critic analysis of the sites ranking (step 4; Figure~~Fig.~~ 3) is hence indispensable: Which site, among the most valuable~~valued~~ ones, has the highest scientific meaning? Which one has the highest educational meaning? Ideally,~~Probably~~ resources for geoconservation may be addressed to protect sites characterized by high scientific value and susceptibility to degradation,~~, as in the first case,~~ while resources for dissemination and promotion could be dedicated to ~~reserved for~~ sites suitable for educational initiatives. In the studied area one of the most representative site documenting ancient and current changes in the ~~Finally, we propose to consider as *Gmfs* only the *PGmfs* exceeding the *TSVs* with the 33% of the parameters as for GR. If we consider the GV of *PGmfs* reporting significant modifications of the physical~~ landscape is~~(see Coratza and De Waele 2012) and currently undergoing to further geomorphic modifications, among the cases exceeding 33% (Fig. 13),~~ the G6 - Pizzo Stagno Complex system. Temporal variation ~~is one of the most representative and valuable *PGmfs* of the whole area (third~~ in ~~the rank according to GV; Tab. 7). The temporal differentiation of~~ processes typology and intensity, changes in frequency of geomorphic events and links~~the link~~ with human history (i.e., the 1978 disastrous event; Mazzi and Pessina 2008) allow to consider G6~~promote particularly this~~ site as ~~ideal to be valorized especially in~~ the most representative also for~~perspective of~~ geo-risk education projects according to criteria suggested, for example, by Coratza and De Waele (2012) and ~~addressed to risk mitigation (~~Alcántara-Ayala and Moreno (2016).

The~~Dealing with the analysis of *Gtrs*, 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~~conferring~~ different geotouristic approaches.~~possibilities. Morphological and vulnerability features of *Gtrs*, as well as those of *Gmfs*, should be periodically re-evaluated.~~ 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~~history, characterizing~~ both the trails, increases the GV and favors~~confers high values since favoring~~ multidisciplinary approaches (e.g., history and anthropology). Moreover~~Similarly to the analysis carried out on *PGmfs* values,~~ the AB *Gtr*, characterized by~~showing~~ higher ~~values in term of~~ PU and EIn values, result~~, seems~~ to be the more suitable for educational purpose and for dissemination~~addressed~~ to a general public.~~public, also thanks to the presence of official archeosites (i.e., Nucleo Alpino "Le Cascine" and Fornaci della Calce) linked with *PGmfs*.~~ On the contrary, the AA *Gtr*, showing higher SV, AV, GV and SIn, could be considered for geoconservation practices or used to promote, from a strictly scientific point of view, the geo~~geo(morpho)logical~~ heritage characterizing the area inside the SVGP (e.g., Smrekar et al. 2016).

Finally it is worth to be considered 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.

~~6~~ 5 Conclusions

Geomorphological mapping combined with geoheritage~~geo-resources~~ 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~~base in the framework of which it is possible to identify the~~ *PGmfs* census and~~undergoing a quantitative~~ evaluation. ~~in a following phase.~~ Dissemination products in the form herein presented~~may have different output forms. The one chosen in this research~~ (i.e., *GmBxs*), ~~is~~ 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.~~representing *PGmfs*: only the essential elements necessary to understand the dynamics of the site.~~

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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