

Mapping geomorphological hazards in relation to geotourism and hiking trails

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1. Introduction

The activity of geotourism necessarily involves the interaction with the natural environment, and the degree of contact will vary depending on the geotourists' cultural background and physical ability (Swarbrooke et al., 2003; Dowling & Newsome, 2006). In this sense, there are increasing requests to exploit a territory by creating suitable networks of trails (Gray, 2004; Brandolini et al., 2007; Reynard et al., 2009). It is, therefore, necessary to survey the potential hazards and the geomorphological features that could impede progress along tourist itineraries in order to allow tourists to enjoy the landscape and avoid potential harm (Bell, 1999; Piccazzo et al., 2007; Reynard, 2008; Pelfini et al., 2009). The knowledge of the natural environment represents the first step in the risk mitigation.

Climate and meteorological variability play an important role in the increase of both the geomorphological and environmental hazard levels, for example debris flows and avalanche triggering. These factors also increase the vulnerability of human visitors, due to the presence of slippery paths, wet rocks, and high temperature and humidity in low altitude and coastal environments, or due to loss of orientation or a worsened physical condition in the case of bad weather at high altitudes.

The high-altitude mountain environment, for example, appears to be significantly modified in recent decades because of the rapid and intense reduction in glacier masses, the degradation of permafrost, and the ever-increasing diffusion of tourist settlements and infrastructures. Today, alpine skiing, alpinism, and other extreme sports practised beyond walking routes or on paths with limited accessibility are of great popularity. In areas recently uncovered by glaciers, numerous unsettling phenomena are occurring: slopes and valley bottoms are covered with abundant unstable debris, glacial deposits only partially consolidated and often with an ice core are easily removed by running water, glacier fronts are sometimes suspended over valley bottoms with the possibility of discharging masses of ice or boulders and glacier lakes are susceptible to rapid emptying. These progressive climatic variations have led to environmental changes that are rendering some alpine trails impossible to pass, glacier-covered areas, used for summer skiing, unpracticable and stretches of excursion trails inaccessible.

Along the coasts, the intense expansion of tourism facilities such as residences, docks, bathing and sporting areas, and an increase in the number of visitors over the last few decades, have caused significant changes in the original morphological balance and the natural dynamics of the coastline and the coastal slopes. The growing dispersion of coastal trails, mainly steep seaside access routes at the foot of slopes or cliffs, has necessarily led to an increase in the risk of accident, heightened by the fact that people using these paths are often inadequately equipped.

This is particularly important when new itineraries are proposed for environmental valorisation and for geomorphosite use. Moreover, temporary situations due to meteorological and climate influences can modify hazard and risk scenarios.

In the framework of the national research project “Geomorphological heritage as a resource for a sustainable tourism” and of the Italian Association of Physical Geography and Geomorphology (AIGEO) Working Group “Geomorphological hazard in relation to tourist activities”, a method to establish a census, in a standardised way, of all the elements that can contribute to the risk assessment in tourism applications was proposed and tested. It was successively applied to different morphoclimatic and morphogenetic situations, in different environments, coastal and mountain areas, mainly in the western Ligurian rocky coast and in the central Alps (Lombardy and Trentino Alto Adige).

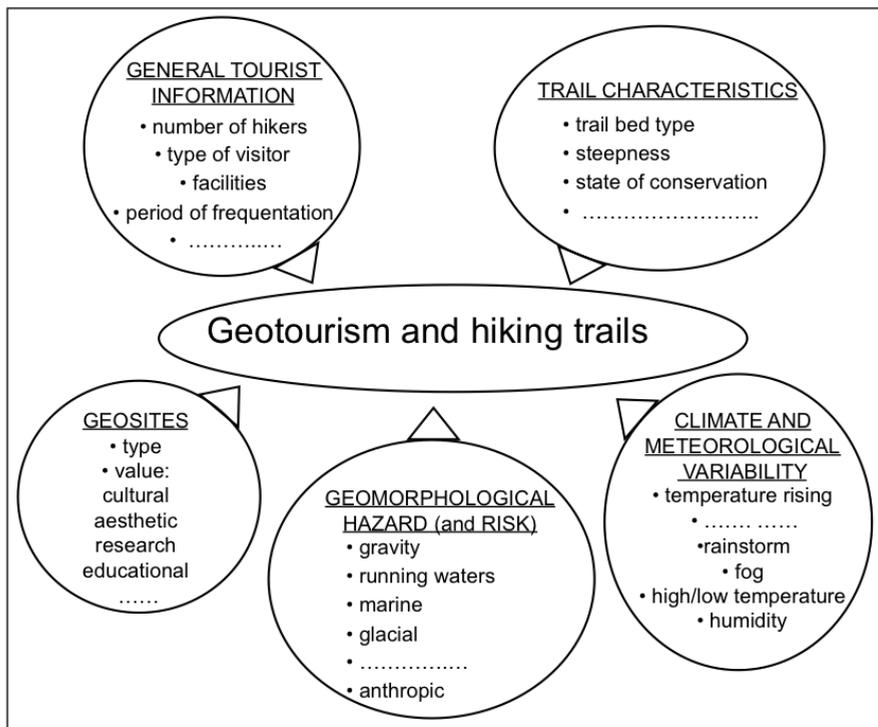


Fig. 1 Main topics to be considered in geotourist promotion, planning and management of hiking trails.

Some main topics were considered with the aim of realising specific thematic maps (geotourist maps), which should be readable by a large number of users and not only by specialists. The maps will include general tourist information (number of hikers, type of visitors, facilities, period of frequentation, etc.); geosites (type, value, cultural, aesthetic, research, educational, etc.); trail characteristics (trail bed type, steepness,

state of conservation, etc.); geomorphological hazard and risk (running water, marine, glacial, anthropogenic hazards, etc.); climate and meteorological variability (rainstorm, fog, high/low temperature, humidity etc.) (Fig. 1).

The goal of this article is to point out typical situations of geomorphological hazard and tourist vulnerability along hiking trails, in order to highlight the importance of an easily readable geotourist map following the guidelines proposed by Coratza & Regolini-Bissig (2009). Two examples are presented, using different scales in order to show maps and detailed situations.

2. Methods

2.1 Hazard survey

The first step is the census of geomorphological hazards through traditional geomorphological surveys and the mapping of them at different scales, by using a scientifically accepted legend (e.g. Gruppo Nazionale Geografia Fisica e Geomorfologia, 1986; 1993)

In the frame of the national project "Climate and geomorphological risks in relation to tourism development" (Piccazzo et al., 2007), we proposed a standardised analysis methodology (data collection model) for risk assessment in tourist areas (Brandolini et al., 2004; 2007). A survey protocol was defined to quantify the geomorphological hazard levels, to undertake a census of elements of vulnerability of a given area including the morphological elements and the geographical-physical processes that may highlight the vulnerability, to approach risk scenarios.

The method consists of the compilation of five sheets during the survey phase related to the description of the area or tourist itinerary, the mapping and describing of the geomorphological hazard, the mapping and describing of the geomorphological elements that can increase vulnerability, the analysis of tourism vulnerability (tourist influx and infrastructures) and the estimation of geomorphological risk (Aringoli et al., 2007).

		SYMBOL	Ref
TRAIL			1
Location	plan surface		2
	slope		3
	sharp edge		4
	rounded edge		5
Trail bed type	rocky		6
	debris covered		7
	ground		8
	Swampy with vegetation		9
	paved		10
	woody		11
	metal covered		12
	ice covered		13
	snow covered		14
	Trail bed shape	flat	
concave			16
convex			17
step			18
shape by rill wash			19
Slope morphology above and below the trail	vertical mountain side		20
	inclined mountain side		21
	vertical valley side		22
	inclined valley side		23
Trail section set up	reverse slope inclination		24
	like the slope inclination (downwards)		25
Width (can transit at time)	one person		26
	two persons		27
	more than two persons		28
Protection structure	railing		29
Safety structure	handrail to place on the side of the path where it is present		30
	fixed cords		31
Vegetation	grass		32
	shrubs		33
	trees		34

Fig. 2 A proposal of symbols to represent trail features in geotourist maps (modified after Pelfini et al., 2007).

2.2 Trail network analysis

The second step is a census of natural aspects, including the morphological elements of the route, which are not hazardous in the strictest sense, but which may impede or render passage difficult. The physical and morphological characteristics of trails make their use more or less suitable for different users. Additional elements change according to the stability of the substrate or due to the dynamic processes in progress or to the weather conditions. Several of these aspects may increase the difficulty of passage. On most occasions, tourist vulnerability varies in relation to knowledge of the territory, physical and psychological preparation, and equipment. These are important aspects but that cannot be generalised or coded with certainty. The trails are analysed and subdivided into segments with homogenous characteristics, synthe-

sising more information concerning the path in a unique, easily understandable, symbol. The symbol represents a combination of simple signs representative of the geometric characteristics of the trail and of the slope on which the trail passes. For the whole description, see Pelfini et al., 2007 (Fig. 2).

2.3 Vulnerability analysis

The successive analysis considers the main characteristics of visitors that mainly frequent a trail. Detailed trail information is particularly important and useful to mitigate vulnerability of inexperienced tourists that have little environmental knowledge about natural hazards. A typical example is represented by trails used for accessing beaches along rocky coasts (Brandolini et al., 2006). Here the equipment is generally not adequate because the aims are sun bathing and swimming. Acclivity and rock exposure can represent risk for users. Analogous environmental characteristics are generally better approached in a mountain environment where excursionists are, in general, more conscious of mountain characteristics and undertake trails with better equipment. Nevertheless, reports on accidents reveal both changing environmental situations and increasing vulnerability. In fact, access facilities (e.g. cableways) allow people to reach high altitudes (especially glacier environments) easily; in these cases, the ignorance of processes and morphological elements inducing risks (e.g. crevasses) can be very dangerous.

2.4 Meteorological related information

Meteorological information is particularly important where geomorphosites are frequented by people not accustomed to natural hazards. High temperatures could increase human vulnerability in summer along coastal trails as well as the cold and rain can in high mountain environments. Clouds at low altitudes can lead to a loss of positioning. Moreover, in any morphoclimatic environment rainstorms can increase both trail walking and slope instability phenomena. A census of morphological situations susceptible to modifications in relation to meteorological events is, therefore, very useful.

2.5 Data computerisation

All the data are collected into computer supports, inserted in a Geographical Information System environment, also using a pocket PC with Global Positioning System (GPS) tools.

3. Case studies

3.1 An example from the Ligurian coast (Northwestern Italy)

* (with the contribution of F. Faccini)

A typical case representative of a tourist area in a coastal environment is Palmaria Island in the Liguria region (Northwestern Italy). With a land area of 1.65 km² and a maximum elevation of about 190 m a.s.l., it is a very small island, which is inscribed in the UNESCO World heritage list. It is a site of great geomorphological and cultural value, characterised in particular by the presence of historic quarrying traces of Portoro marble – a grey-black limestone with yellow veins – dated back to Roman times (Brandolini et al., 2005, 2009).

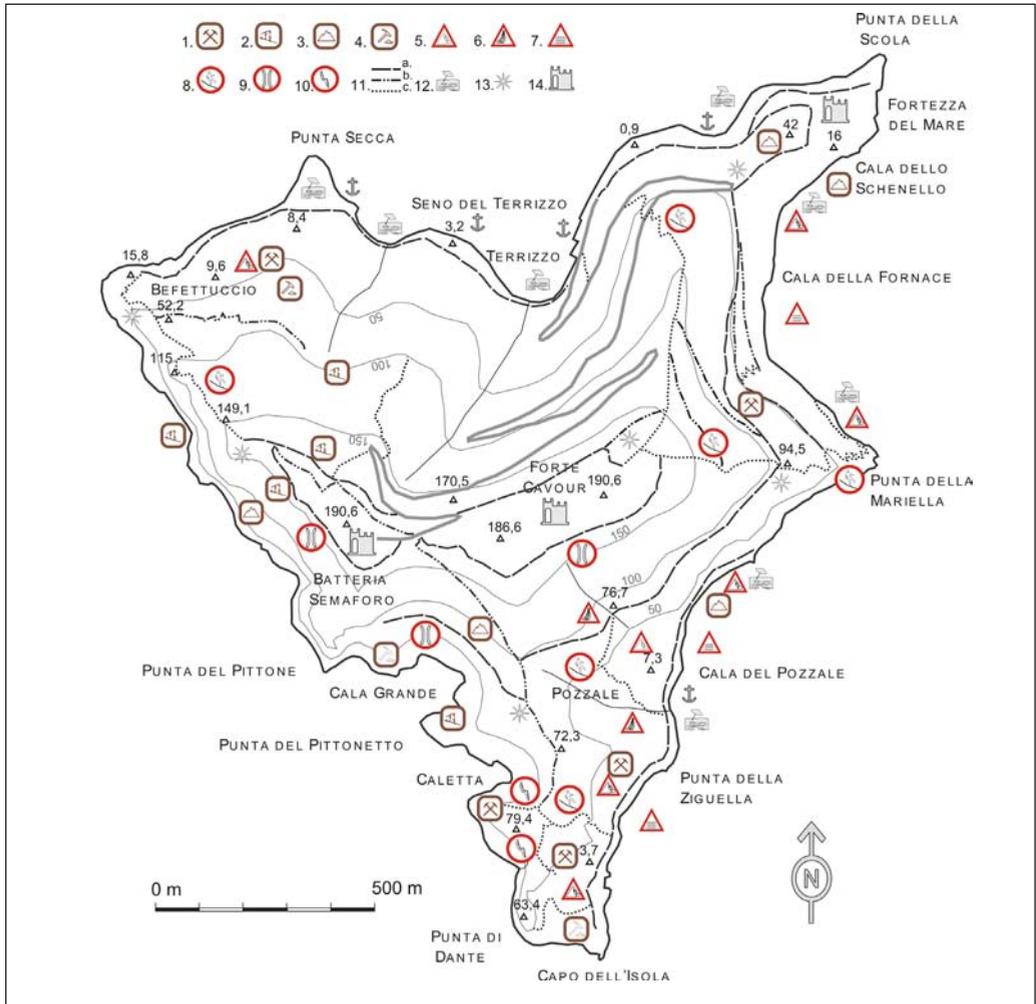
High rocky cliffs on the western and southern slopes characterise the island, whereas small promontories and pocket beaches feature along the remaining coastline. The geomorphological setting of the coastline and of the drainage pattern appears to be conditioned by NW-SE and NE-SW tectonic lineations: the processes in progress are mainly related to marine, gravity and running water activities, subordinately to karst phenomena. Man-made landforms related to quarrying and mining, agricultural terracing and military structures are also important.

The climate of the islands is characterised by an annual mean rainfall of about 900 mm, with a maximum in October (120 mm) and a minimum in July with values below 30 mm, and an annual mean temperature of about 15°C. Mean air temperature data shows a minimum in the winter months (8-9°C) and a maximum in July and August (23°C).

It is possible to visit the whole island in half a day, walking along a ring trail of approximately 4 km, ranging from sea level to 190 m a.s.l. The path is articulated in some sections to detour to peculiar geo-panoramic points of interest and geosites related, in particular, to significant outcrops of "Portoro marble" both in open-cast and underground quarries, to exemplary cliffs, wave-cut in dolomite and limestone bedrocks and sometimes bordered by pocket beaches, and to sea and karst caves, which indicate traces of sea level changes and human presence in the Prehistoric Age (Brandolini et al., in press).

The geotourist map (Fig. 3) shows the location of the main geosites, geo-panoramic points, and historical sites related to hiking trail features and presence of geomorphological hazards.

Several rock fall phenomena have been detected along some parts of the trail network. Among these, we note potential rock falls, especially near the vertical fronts of the numerous abandoned quarries and the beaches frequented for sun tanning and bathing. Along the littoral, hazards are connected to strong sea storms, particularly those from the SW and SE (Fig. 5).



Types of geosites	Tourist vulnerability (hiking path features)
1. Geomine	8. Slippery or rambling track
2. Karst	9. Narrow trail
3. Geomorphological	10. Exposed path
4. Geological	11. Track steepness – a. low; b. medium; c. high
Geomorphological hazards	Other geotourist emergences
5. Rock fall	12. Beach
6. Debris flow (associated with heavy rainfall)	13. Geo-panoramic point
7. Sea storm	14. Military structures

Fig. 3 Geotourist map of Palmaria Island and legend (after Brandolini et al., 2009).



Fig. 4 Trail sectors in the western side of Palmaria Island affected by geomorphological hazards due to running water and rock fall processes.



a)

b)

Fig. 5 Eastern sector of Palmaria Island. Cala del Pozzale (a) and Cala dello Schenello (b) beaches, affected by rock fall and debris slide phenomena.

Following the criteria, mentioned in the previous paragraphs, for subdividing the trails into segments with homogeneous characteristics, the pathway in southeastern and southwestern sectors of Palmaria Island is distinguished by a location along steep slopes, by frequent narrow stretches, mainly dirty or debris covered. The state of

conservation of the trails is, in general, quite good, with the exception of the steeper sectors, where the trail bed is affected by erosional phenomena due to running water. In the case of sudden and heavy rainfall, the path can become uneven and very slippery, and can be affected also by debris flows (Fig. 4).

In the northern sector of the island, the trail – dirty or asphalted – is located in a plain zone, just along the coast, a few meters above the beach, or along the embankment in the berthing area, and it presents, in general, a good state of conservation, with the exception of one segment affected by wave erosion attack.

3.2 An example from the Ortles-Cevedale Group, Italian Alps*

*(with the collaboration of M. Bozzoni and V. Garavaglia)

A typical situation from the Alpine environment is represented by trails in the Solda Valley (Province of Bolzano), at the boundary between Lombardy and Trentino Alto Adige, in the Stelvio National Park (Central Italian Alps). This is a glacial valley deeply worked by glacier fluctuations and clear signals of their activity are conserved in the moraine systems bordering the glaciers; these are now strongly shrinking or already extinguished. One of the trails crosses the western side of the valley where three glaciers, considered glacial geomorphosites, are located: Vedrette “Alta” and “Bassa del Marlet” and Vedretta del Finimondo. Along the path, examples of hazard and risk are present.

The trail connects three mountain huts: Coston, K2 and Tabaretta. It is highly frequented especially in the middle part (K2-Tabaretta) where a chairlift allows visitors to reach the K2 refuge easily; a gentle walk through the forest makes it possible to reach and then to cross the glaciers. It is possible to observe glacial geomorphosites interesting, also, from an educational point of view (Pelfini 2007; Garavaglia and Pelfini submitted). The Finimondo Glacier is located in a short, narrow valley on the eastern side of the Ortles; snow accumulation is due mainly to avalanches and the tongue is covered by debris; the glacier is used for winter skiing. The Alto del Marlet Glacier is situated at the bottom of a steep valley; it is fed mainly by avalanches from the Ortles peak and shows a very steep topography, uneven and covered by debris. It is now catalogued as a *debris covered glacier*. The Basso del Marlet Glacier moves down valley from the northern crest of Mount Ortles, in an easterly direction; it occupies a steep narrow valley, the tongue is very crevassed and in the upper part, avalanche deposits accumulate, whereas the lower part is half debris covered. The two Marlet glaciers deposited a huge moraine system formed by lateral ridges built during the Little Ice Age fluctuations.

The trail system located on the western side of the Solda valley, consisting of nine paths, was carefully analysed paying particular attention to morphological characteristics and geomorphological hazards that can affect trails. Morphological evidences possibly representing difficulties for passage and causing an increase in vulnerability

were marked along the trail, and numerical values related to slope and exposure were deduced by automatic functions from the digital elevation model (DEM). Finally, seasonal geomorphological hazards and situations along the trails were outlined (avalanches, residual snow cover, etc.).



Fig. 6 Panoramic view of the western side of the Solda valley. Coston and K2 huts are indicated by triangles drawn on the limit of the trail. The trail is characterised by hazard sites and/or sites where vulnerability could increase because of local morphology or temporary situations (residual snow). Some of these situations are shown in figures 7, 8 and 9.

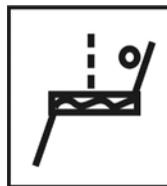


Fig. 7 A portion of the trail Coston-K2. Here the trail is cut into a steep rocky slope. The trail bottom can maintain its track thanks to a wooden support. Only one person at time can walk on it, with a steel rope for assistance. The symbol evidences the flat bottom of the trail and the material that characterises the trail (rectangular form), the slope inclination, the passage of only one person at time; the small circle indicates the presence of the safety support (steel rope).



Fig. 8 A portion of the trail Coston-K2. The trail is hidden by residual snow. The picture was taken in June 2005. Snow patches are very frequent at the beginning of the summer season above 2500 m a.s.l. The symbol shows a grey rectangle corresponding to the snow cover; the inclination of the rectangle indicates the trail bottom height on the slope; the two segments, above and below the trail, represent approximately the inclination of the slope. The two dotted lines evidence the possibility of the passage of two people at time.

Fig. 9 Another portion of the same trail (represented in Fig. 6) partially buried under a deposit of debris and blocks. This is an example of a typical situation occurring at high altitudes at the beginning of the summer season. Due to the frequency of these instability phenomena, annual maintenance is required and, sometimes, new works after heavy rainstorms. This kind of hazard, if evidenced on geotourist maps, allows walkers to frequent trails with more safety. Moreover, public managers can use the same information to decide on modifications of the itinerary, temporary interruptions or in taking other decisions.



A portion of the trail connecting the Coston and K2 huts is analysed here (Fig. 6). Many of the situations correspond not only to geomorphological hazards but also to morphological situations inducing an increase of the tourist vulnerability, (Fig. 7-9).

4. Conclusions

In the framework of planning and management of existing or new itineraries, the examples reported in this paper are not exhaustive of the whole range of possible cases correlated to geomorphological hazard and risk. They are just representative of an emerging necessity to provide hikers with objective information for the evaluation of their own vulnerability, using suitable and objective symbols on maps, which should help the hikers to evaluate the path difficulties in relation to their own skills.

In fact, information such as "difficult or easy trail" should be avoided because perception of trail difficulties (trail bed type, steepness, width, etc.) are subjective and depend on training, equipment, as well as the environmental knowledge of the hikers.

The selection and simplification of information and the symbols placed on a map must be adequately related to the scale of the map. It is also appropriate not to insert too many symbols in order to simplify the comprehension of the geotourist map.

Nevertheless, hiking trails demarked as hazardous or difficult to access should not be understood as a means of causing alarm, but rather as a useful instrument for risk mitigation, with the aim of developing and promoting sustainable tourism initiatives such as geotourism. Finally, we firmly hope that local authorities would exploit such knowledge in order to implement suitable prevention measures where necessary.

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