

Analysis of Factors Controlling Landslide Susceptibility in the Aosta Valley (NW Italy): Relationship to Climatic and Environmental Changes

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Abstract

Recent climate changes are evident, especially in alpine environments, and have implications for natural hazards. Geomorphological studies have been performed at a regional scale in the Aosta Valley to better understand the spatial distribution and frequency of landslides and to investigate their controlling factors. A comparison between areas with permafrost and the rest of the territory has also carried out. Landslides inventories, permafrost distribution and geothematic maps have been produced and integrated into a GIS system. The lowest values of landslides density have been observed within the permafrost areas with respect to the whole region. The frequency of landslides has increased slightly during the last few decades in high mountain areas, possibly due to climate warming.

Keywords

Slope instability • Permafrost • Controlling factors • GIS • Alps

83.1 Introduction

Recent changes in global climate are affecting both polar and alpine environments. The observed effects have significant implications for natural hazards and risks: reduced duration of snow cover, glaciers thinning and retreat, permafrost degradation and increased slope instability in high mountain areas.

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Landslides are among the most hazardous geomorphic processes occurring in mountain areas, especially due to their unique geomorphic context: high relief, steep slope gradient and strong climatic variations over small areas. Improving knowledge of past and present slope instability is essential for better understanding their dynamics and developing reliable forecasts of slope performance under future climatic conditions.

We have carried out geomorphological studies in the Aosta Valley, a small alpine watershed in NW Italy, to better understand the spatial distribution and frequency of landslides and to investigate the main factors controlling instability. A comparison between high mountain areas, which are more affected by climate change, and the rest of the territory has been also performed.

83.2 Geological and Geomorphological Setting

The Aosta Valley is a major alpine valley drained by the Dora Baltea river. Elevations range from 400 m a.s.l., at the valley mouth on the Po Plain, to 4,810 m at Mont Blanc, the highest peak in the European Alps.

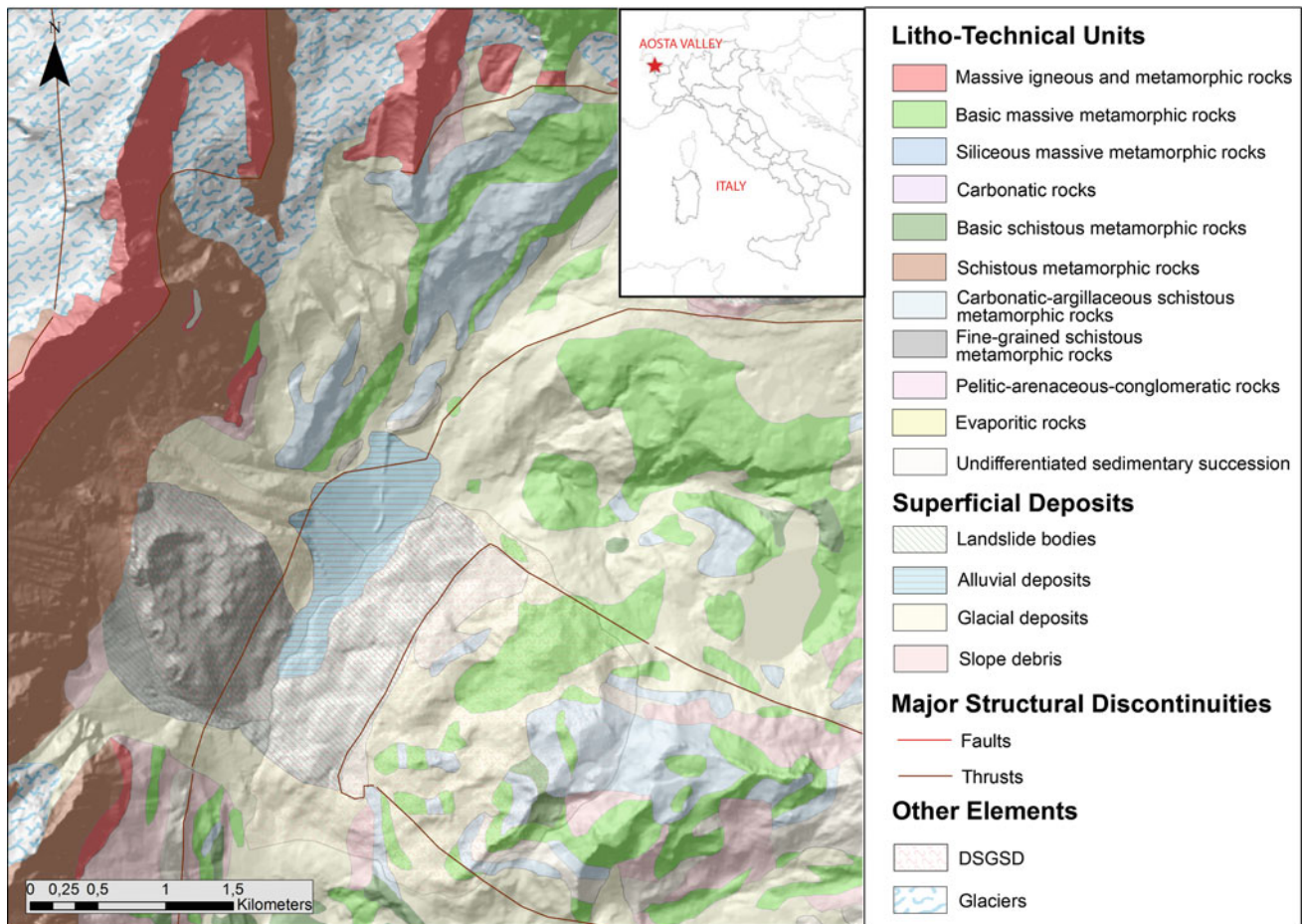


Fig. 83.1 A portion of the litho-technical map of the Aosta Valley in the Valtournenche district area

The Aosta Valley is located within the axial zone of the Western Alps, which consists of a tectonic stack of continental and oceanic metamorphic units.

Glaciers have played an important role both in eroding the landscape and leaving thick deposits of drift on valley floors. They also have indirectly influenced past and present-day slope dynamics.

Rivers have gradually deepened valleys in the Aosta watershed. Alluvial and alluvial and debris flow fans are widespread and many of them are active, as shown during recent heavy rainstorms (i.e. 13–16 October 2000).

A fundamental role in shaping the geomorphology of the region is played by gravitational phenomena, which range from simple shallow landslide to large slope instabilities. At least 18 % (580 km²) of the watershed area has been affected by landsliding (Ratto et al. 2007).

83.3 Methods

The methodology used in this research is as follow:

- production of geo-thematic maps for the study of factors controlling instability;
- data collection and incorporation in a GIS system;
- data processing and statistical analysis.

First, slope and aspect maps, derived from a Digital Elevation Model, were produced to analyze topographic factors. Litho-structural data were incorporated by producing a new simplified litho-technical map, derived from regional geological maps (Carta Geotettonica della Valle d'Aosta; De Giusti et al. 2003). (Fig. 83.1). It is a map wherein rock masses originally classified according to their affinity towards the alpine tectonic units have been assembled depending on their litho-technical properties.

Table 83.1 Comparison between the landslide spatial distribution in permafrost areas and in the rest of the region

	Area	No. of landslides	Total landslide area	Landslide index (LI)	Percentage landslide affected areas
Permafrost areas	534.11 km ²	255	58.60 km ²	0.48	10.97 %
Rest of the region	3,261 km ²	3849	635.64 km ²	1.18	19.50 %

In addition to geo-thematic maps, we collected data on slope instabilities derived from landslides inventories (IFFI Project National Database, Regional “Catasto Dissesti”) and added a potential permafrost distribution map layer (Permaclim model, Guglielmin et al. 2003; Alpine Permafrost Map, Boeckli et al. 2012).

The permafrost spatial distribution allowed us to identify two distinct sectors: one with permafrost and the other without permafrost. For each of these two areas, landslide spatial analysis was carried out, which allowed us to consider differences in the frequency, areal extent and types of landslide.

While processing the data, we calculated a “landslide index” (LI), represented by landslide density per parameter class (events/km²), for each factors controlling slope instability taken in account; in particular, we considered topographic (slope and aspect) and litho-structural factors (lithology, spatial distribution of structural discontinuities and rock masses geomechanical conditions).

83.4 Analysis and Results

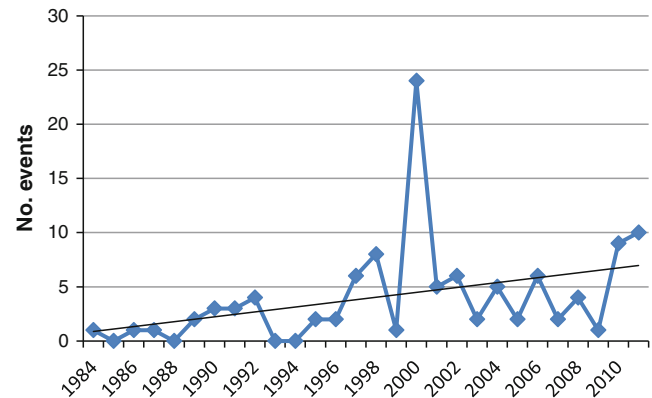
83.4.1 Spatial Landslide Distribution

The data analysis showed that there is less slope instability within permafrost areas than in the rest of the region, both in terms of LI and of the percentage of the total area affected by landslides: 0.5 events/km² and 11% versus 1.2 events/km² and 19 % (Table 83.1). Lower values of LI were observed also for almost all classes of the before-mentioned factors of instability (slope, aspect, lithology).

The most common landslide typologies in permafrost areas are rock falls, followed by deep-seated gravitational slope deformations (DSGSD); in contrast, slides and flows are very rare. In terms of the mean areal extent of landslides, the calculated values in permafrost areas are higher for almost all landslide types; e.g. the mean areal extent of rock falls in permafrost areas is considerably greater, more than 40 % over that observed in the rest of the watershed.

83.4.2 Topographic and Litho-Structural Factors

There is a progressive decrease in LI values with increasing elevation. In contrast, slope gradient analysis showed a progressive increase in the LI values with increasing slope.

**Fig. 83.2** Landslides temporal frequency above 2,000 m a.s.l. (1984–2011)

Examination of lithological factors reveals that, in permafrost areas, LI values are generally higher for competent lithological units, with the maximum values associated with “carbonatic/evaporitic” rocks. No appreciable variations in LI values were detected with distance from the main structural discontinuities.

83.4.3 Temporal Landslide Distribution

Our analysis of the temporal distribution of landslides yielded the following conclusions:

- Landslides frequency has increased in recent years, but this increase may be due to improved reporting of events, especially since 2000, following the establishment of extensive observation and monitoring networks and more widespread use of the new communication technologies.
- Only 16 % of the recorded events occurred above 2,000 m a.s.l., where rock falls and debris flows dominate, making it difficult to correctly assess landslide frequency in high mountain areas.
- A slight increase in landslides is evident during the past few decades above 2,000 m a.s.l., albeit with a large interannual variability (Fig. 83.2).

83.5 Discussions

Permafrost areas in the Aosta Valley have fewer landslides than the rest of the watershed. There are two possible explanations for this difference: (1) There is more awareness of slope processes at lower elevations, as a consequence of

the greater human presence there; (2) Permafrost increases the stability of rock and soil, resulting in fewer landslides at high elevations.

Both high LI on steep slopes and in areas of competent lithological units is expressed mainly in frequent rock falls, which occur on steep bedrock valley slopes.

Higher LI on north-facing slopes may indicate more efficient permafrost degradation, resulting in a greater number of landslides involving larger slopes' sectors.

The lack of data for high mountain areas prevent us from exactly quantifying the role of climate in the observed recent increase in landslides frequency in these areas. Nevertheless, this role has already been established in the Alps, as in the case of rock falls on the Mont Blanc Massif, where a good correlation between slope instability and warming in the past several decades has been established (Ravel and Deline 2011). According to climatic model scenarios (IPCC 2013) a further increase of rock falls activity on steep high rock slopes can be expected in coming decades.

83.6 Conclusions

A better understanding of the spatial distribution of landslides and of the main factors controlling slope instabilities, both in permafrost areas and in the rest of the Aosta Valley watershed, has been achieved by this study.

Increased landslides frequency and a complex response to climatic forcing have been observed at a regional scale; still, further data on landslides occurrence and improved knowledge on failure mechanisms are needed for high mountain sectors.

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