Geomorphology 119 (2010) 36–51

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Analysis of landslide inventories for accurate prediction of debris-flow source areas

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ARTICLE INFO

Article history:
Received 9 June 2009
Received in revised form 18 February 2010
Accepted 23 February 2010
Available online 1 March 2010

Keywords:
Landslide inventory
Debris flow
Susceptibility analysis
GIS
Italian Alps

ABSTRACT

For the generation of susceptibility maps on medium scales (1:25,000 to 1:50,000) using statistical techniques, a reliable landslide inventory is needed, together with factor maps used as inputs. This paper compares landslide susceptibility maps obtained with the same methodology but using different landslide inventories: the official Italian landslide inventory GeoIFFI for the Lombardy Region and a recently mapped inventory (DF2001). The analysis included four main steps: (i) preparation of debris flow inventories using both random and spatial partitions and factor maps as explanatory variables; (ii) calculation of accountability and reliability indices for a preliminary susceptibility analysis and selection of an appropriate combination of the factor maps for detailed analysis; (iii) evaluation and validation of the obtained susceptibility maps; and (iv) comparison of the results and selection of the final map. The study area is located in the Valtellina Valley in the Central Italian Alps. The analysis identified highly susceptible areas of shallow landslides that may generate debris flows. It was demonstrated that more precisely delimited source areas for landslide-induced debris flows produce better susceptibility maps. However, the improvement of these maps was relatively limited when the inventories were randomly subdivided. Higher improvements were observed after the subdivision of the inventories into three geographical parts with different geomorphological characteristics. Although the modelling showed very similar results if evaluation is made using standard techniques, the spatial pattern of the susceptibility maps was highly variable and dependent on the combination of the factor maps used.

1. Introduction

Landslides are among the most significant natural damaging events in mountain environments. They are one of the primary causes of property damage, loss of life and injuries of persons. To better predict future occurrences of landslides and improve protection, hazard or susceptibility analyses are performed. Landslide susceptibility analysis (or so called spatial probability of landslide occurrence) using statistical techniques is based on the assessment of terrain conditions in an area subjected to previous landslides (Carrara et al., 1995). The conditions that caused the landslides are assumed to be the same for future landslides. Such a landslide susceptibility analysis on a medium scale (1:25,000 to 1:50,000) has been used as one of the first steps in landslide hazard assessment (Remondo et al., 2005; Fell et al., 2008). The performance of the models can be effectively evaluated and the prediction power of the models could be validated using techniques such as ROC plots, or success and prediction rate curves with areas under curves (Chung and Fabbri, 1999, 2003; Beguería 2006).

A main problem in landslide hazard assessment is the definition of magnitude and frequency of prospective events. Although there are many methods for landslide susceptibility assessment, only a few techniques convert the result into landslide hazard maps based on temporal probability assessment. One of them is the use of event based inventory maps. The return periods of landslide triggering events are used for assessing temporal probability which is then combined with size and spatial probabilities generated from event-based inventories (Guzzetti et al., 2006a). However, only a few complete landslide inventories are available. Italy is one of the countries where such inventory databases have been made in a consistent manner.

This study focuses on the mapping of source areas of landslide-induced debris flows in the Valtellina Valley. According to Crosta et al. (1990), the majority of debris flows in the study area originate from soil-slips or shallow slides. They usually leave broad sheet-like scars which are easily recognizable on aerial photographs.

Statistically based susceptibility assessment for the source areas of landslide-induced debris flow was performed using different landslide inventories in order to evaluate the effect of the accuracy of the input data on the prediction capabilities of the resulting susceptibility maps. The same input data and analytical methods were used for both inventories. This study also evaluates the improvement of the

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doi:10.1016/j.geomorph.2010.02.017

predictions when the area is divided into geomorphologically homogeneous zones.

2. Study area

The study area, the Valtellina valley (Fig. 1), is a typical alpine valley located in the Lombardy Region in northern Italy. The valley has U-shaped transversal profiles derived from Quaternary glacial activity. The axis of the valley corresponds to the Adda River, flowing through the towns of Bormio, Tirano and Sondrio to the Como Lake. The valley has prevalently an E–W orientation from Dubino to Teglio, where it enters the study area and takes an NE turn for a few kilometres, and then turns almost to N after Grosio. The orientation of the valley is related to the location of a regional fault that separates the proper Alps (the Austroalpine, Penninic and Helvetic nappes) from the Variscan basement of the Southern Alps. This Periadriatic Fault (or so called Insubric Line or Tonale Fault) runs on the northern slopes of the valley, some 500 m above the Adda river floodplain. The bedrock in the valley is mainly composed of metamorphic rocks (gneiss, mica schist, phyllite and quartzite) and intrusive rock units, with subordinate sedimentary rocks. Due to the proximity of the fault, cataclastic and mylonitic zones are present. The alluvial plain of the Adda River is up to 3 km wide, and alluvial fans at the outlet of tributary valleys can reach a considerable size, with a longitudinal length up to 3 km.

The study area lies in Consortium of Mountain Municipalities of Valtellina di Tirano, an area of about 450 km^2. Its territory is subdivided in 12 municipalities and has about 29,000 inhabitants, mainly on the valley bottom. The northern part of the study area is composed mainly of gneiss, while in the south micaschists and sedimentary rocks dominate. Both flanks of the valley are covered by morainic sediments and colluvial deposits of variable thickness. The bottom of the valley is covered by fluvial sediments. The lowest altitude in the study area is about 350 m a.s.l. near San Giacomo di Teglio where the Adda River flows out from the study area. The highest elevation is reached in the northern part of the study area on Cima Viola: 3370 m a.s.l.

The Valtellina Valley has a long history of intense and extensive landsliding. A large percentage of landslides are represented by rainfall-induced small slides and soil slips which are the sources for debris flows (up to 1.5 m thick), with volumes ranging from a few to thousands m^3 (Crosta et al., 1990, 2003). These phenomena affect

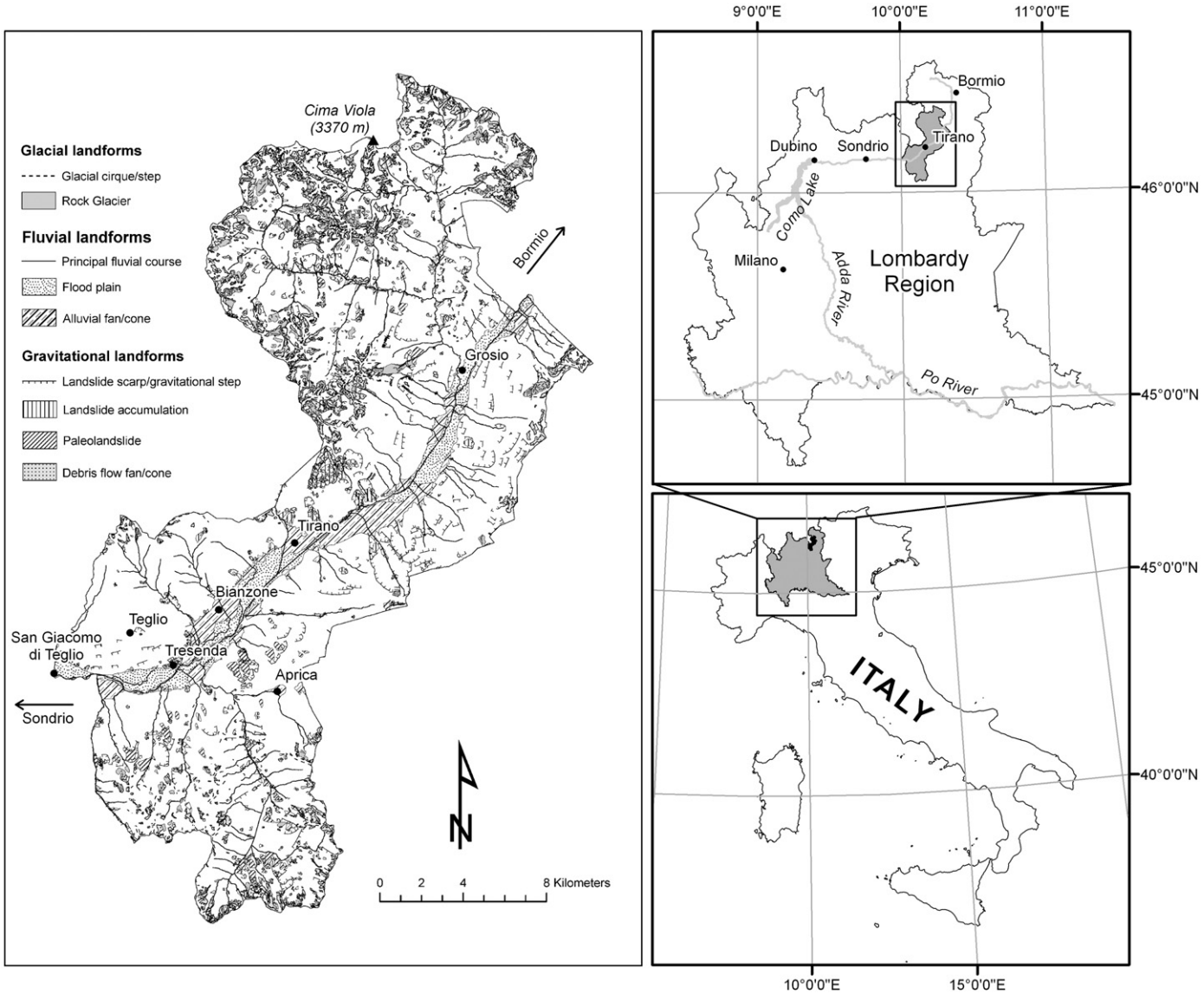

Fig. 1. Simplified geomorphological map of the study area of the Consortium of Mountain Municipalities of Valtellina di Tirano. The location of the study area in the Lombardy Region and in Italy is shown on the right.