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Large scale debris-flow hazard assessment: a geotechnical approach and GIS modelling

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Abstract. A deterministic distributed model has been developed for large-scale debris-flow hazard analysis in the basin of River Vezza (Tuscany Region – Italy). This area (51.6 km^2) was affected by over 250 landslides. These were classified as debris/earth flow mainly involving the metamorphic geological formations outcropping in the area, triggered by the pluviometric event of 19 June 1996. In the last decades landslide hazard and risk analysis have been favoured by the development of GIS techniques permitting the generalisation, synthesis and modelling of stability conditions on a large scale investigation (>1:10 000). In this work, the main results derived by the application of a geotechnical model coupled with a hydrological model for the assessment of debris flows hazard analysis, are reported. This analysis has been developed starting by the following steps: landslide inventory map derived by aerial photo interpretation, direct field survey, generation of a data-base and digital maps, elaboration of a DTM and derived themes (i.e. slope angle map), definition of a superficial soil thickness map, geotechnical soil characterisation through implementation of a back-analysis on test slopes, laboratory test analysis, inference of the influence of precipitation, for distinct return times, on ponding time and pore pressure generation, implementation of a slope stability model (infinite slope model) and generalisation of the safety factor for estimated rainfall events with different return times.

Such an approach has allowed the identification of potential source areas of debris flow triggering. This is used to detected precipitation events with estimated return time of 10, 50, 75 and 100 years. The model shows a dramatic decrease of safety conditions for the simulation when is related to a 75 years return time rainfall event. It corresponds to an estimated cumulated daily intensity of 280–330 mm. This value can be considered the hydrological triggering threshold for the whole Vezza basin.

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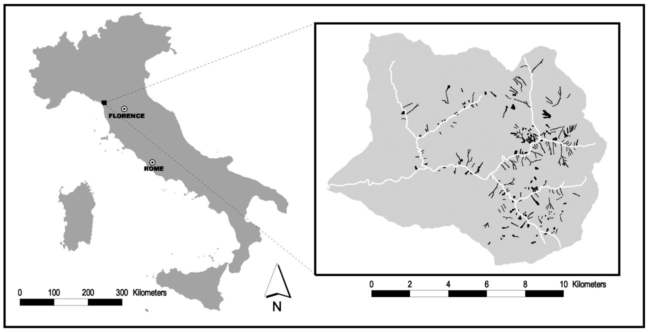

Fig. 1. Location of the River Vezza basin (NW Tuscany). Black dots refer to landslide inventored after the disaster of 19 June 1996; white lines indicate the main river network.

1 Introduction

The River Vezza basin is located in the north-western sector of Tuscany in the Apuan Alps with a total catchment area of 51.6 km^2 (Fig. 1). It experienced on 19 June 1996 a severe rainstorm event in terms of intensity and cumulated rainfall. The rainfall started at 6:30 am and terminated at 19:00 pm 478 mm of cumulated precipitation were recorded at Pomezzana corresponding to approx. 33% of long-term yearly average rainfall, with 158 mm/h as a maximum intensity (Table 1). The analysis of 3, 6, 12, 24 hours of rainfall heights referring to historical records provides return time values from 200 to 500 years (Burlando and Rosso, 1998). The rainstorm was promoted by the peculiarity of the micro-climate of Apuan Alps; this develops from the ascending and rapid cooling of Atlantic wet fronts over the Versilian chain (orographic effect), that resulted in a sudden and concentrated rainfall, in particular during the summer season.

This event caused disruptive and differentiated effects in the mountain and flood plane. A flash-flood destroyed the village of Cardoso causing 14 victims. Most of the road network was interrupted and disrupted while some hundred

Table 1. Rainfall records for Retignano and Pomezzana (19 Jun 1996)(Rapetti and Rapetti, 1996)

Stations	Height (m)	Tot.Prec (mm)	Max. Int. (mm/h)	Max. Int. (mm/5 min)	Hour	Av. Int. (mm/h)	Event starting	Event ending	Dur. (h)
Retignano	325	400,6	62,6	13,2	7:10	26,7	4.10	19.10	15.00
Pomezzana	597	477,4	158	30,8	6:30	30,8	3.50	19.20	15.30

Fig. 2. Aerial photo of NE sector of River Vezza basin. This portion of the basin (approx. 2.5 km^2) evidenced the highest landslide density (> 20 landslide/km^2 and 10% of the area affected) and damage caused by the rainstorm of 19 June 1996. The village of Cardoso, sited in the confluence of two torrents, is visible on the right bottom of the photo; The territories of Pruno (right side) and Volegno (center) have been heavily affected by landsliding.

Fig. 3. Front view of NE sector of River Vezza basin. Debris flows/slides developed along slopes are clearly visible. The villages of Pruno (right side) and Volegno (left side) were partially affected or menaced by landslides.

landslides (mostly debris flows) were triggered along the slopes (Figs. 2 and 3).

Rapid infiltration of rainfall and the increasing of pore pressures can be considered the main trigger of debris/earth flows generation (Campbell, 1974; Wieczoreck, 1987, 1996). Historical analysis has stressed that the study area is highly prone to simultaneous triggering of superficial landsliding and flooding associated with intense precipitation. Large floods occurred in 1774, 1885, 1902 while minor events have a 25–30 years return time. The flood of 25 September 1885 (Figs. 4 and 5) seems to be comparable with the 1996 disaster in terms of magnitude and associated damage (Martini and Paolini, 2000).

The analysis of the 19 June 1996 disaster as well as historical occurrences of landslides, emphasizes that heavy rainfall promotes a generalised instability of the Vezza basin. This area is highly susceptible to superficial landsliding that involves mainly the soil cover of slopes. Such condition suggests the necessity to undertake a spatial analysis for landslide hazard assessment of the area using the potentiality of a GIS. The adoption of a GIS actually allows the analysis, modelling and spatialising slope stability conditions through a physically-based approach, using rather simple geotechnical models.

In literature many techniques and methodologies on landslide hazard assessment have been proposed with respect to various approaches. A review on such methods has been recently developed by Hutchinson (1995), Aleotti and Chowdhury (1999), and Guzzetti et al. (1999).

Deterministic approaches are based on slope stability analysis (safety factor analysis) and are generally assessed through the definition of main physical parameters of terrains and application of static models, using the infinite slope model. Here the equilibrium of forces along a potential failure surface is considered (Skempton and DeLory, 1957). De-

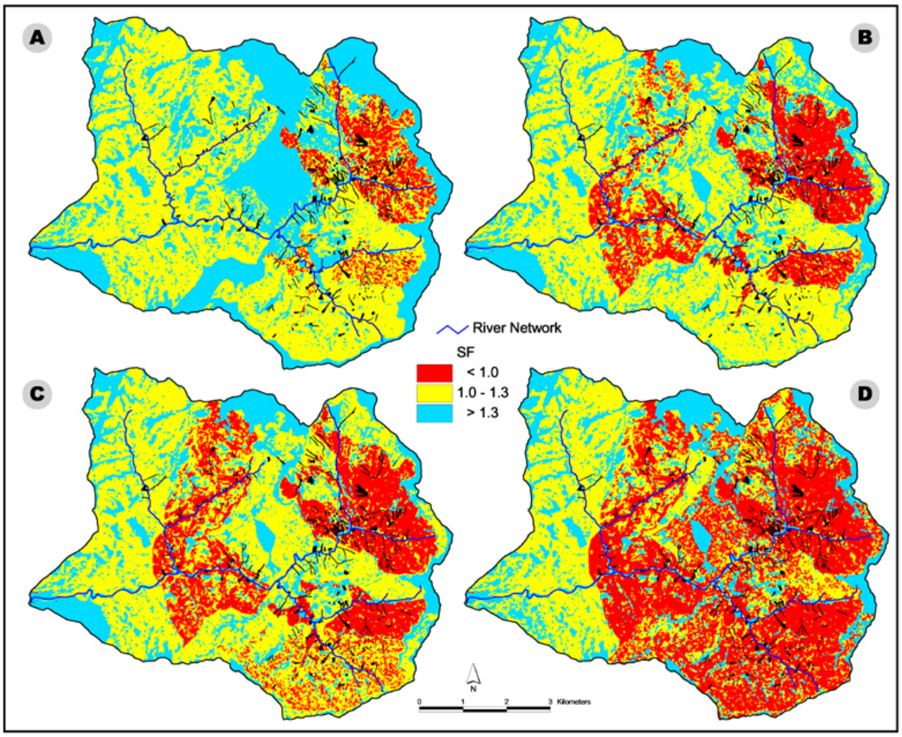

Fig. 17. Maps of safety factors (SF) distribution in the River Vezza basin calculated for the following estimated rainfall return time: **(A)** 10 years; **(B)** 50 years; **(C)** 75 years; **(D)** 100 years. Black areas show landslides of 19 June 1996.

a perched water table in the soil cover due to infiltration; results from the application of Green-Ampt analysis seems to match with field observations on landslide triggering initiation;

iii. occurrence of landslides is strictly dependent on some predisposing factors such as: presence of meta-sedimentary rocks that promote the development of superficial soil cover; high slope gradient and shape; the progressive degradation of forests due to lack of preservation;

iv. application of a deterministic distributed model has provided a scenario of potential slope instability with respect to 4 expected return time daily precipitation (10, 50, 75, 100 years). The 75 years return time precipitation may represent the critical threshold for the basin of River Vezza (almost 80% of predicted landslides vs. actual landslides);

v. predicted scenarios of instability seem to fit with observed debris-flows just after the disaster. Considering a comparison made between expected unstable areas and debris-flows source areas triggered by the 19 June 1996 event; in addition, the modelling attributes the highest susceptibility for debris flow prone areas to Pseudomacigno and Verrucano respectively. Although a certain over-estimation of potential unstable areas is likely to attribute to a conservative assessment of strength parameters of terrain, as well as to the contribution of other factors (i.e. strength of root system, local slope shape conditions);

vi. this approach can represent an effective tool for the assessment of debris-flow prone areas where the homogeneity of geological and morphological predisposing factors promotes a large diffusion of instability processes under well defined rainfall triggering values;

vii. under the above conditions, a hazard assessment by a deterministic approach can be done for large areas, starting from limited but representative data, through simplified modelling using a GIS.

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