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A new–old approach for shallow landslide analysis and susceptibility zoning in fine-grained weathered soils of southern Italy

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ABSTRACT

Rainfall-induced shallow landslides involve several geo-environmental contexts and different types of soils. In clayey soils, they affect the most superficial layer, which is generally constituted by physically weathered soils characterised by a diffuse pattern of cracks. This type of landslide most commonly occurs in the form of multiple-occurrence landslide phenomena simultaneously involving large areas and thus has several consequences in terms of environmental and economic damage. Indeed, landslide susceptibility zoning is a relevant issue for land use planning and/or design purposes.

This study proposes a multi-scale approach to reach this goal. The proposed approach is tested and validated over an area in southern Italy affected by widespread shallow landslides that can be classified as earth slides and earth slide-flows. Specifically, by moving from a small (1:100,000) to a medium scale (1:25,000), with the aid of heuristic and statistical methods, the approach identifies the main factors leading to landslide occurrence and effectively detects the areas potentially affected by these phenomena. Finally, at a larger scale (1:5000), deterministic methods, i.e., physically based models (TRIGRS and TRIGRS-unsaturated), allow quantitative landslide susceptibility assessment, starting from sample areas representative of those that can be affected by shallow landslides. Considering the reliability of the obtained results, the proposed approach seems useful for analysing other case studies in similar geological contexts.

1. Introduction

Shallow landslides are one of the most common categories of landslides. They frequently involve large areas and different soils in various climatic zones (e.g., Kirkby, 1987; Benda and Cundy, 1990; Selby, 1993 Antronico et al., 2004; Borrelli et al., in press), and they often cause environmental and economic damage (Crozier, 2005; Glade et al., 2005) (Fig. 1). In clayey soils, shallow landslides affect the most superficial layers of soil, which are generally composed of physically weathered soils of variable thickness along the slope and are characterised by a spatially diffused and time dependent pattern of cracks (Fig. 2), usually attributed to an alternating process of wetting and drying, insolation and frost (Blight, 1997; Gullà et al., 2006; Fredlund et al., 2010). Shallow landslides exhibit different morphometric features depending on their localisation along the slope, where they have widths ranging from 3 to 15 m and lengths ranging from 10 to 100 m; the sliding surface can reach depths varying from a few decimetres to 3 m (Rogers and Selby, 1980; Gullà et al., 2004; Crozier, 2005).

Some scientific publications on shallow landslides address hydrological, geological and geomorphological aspects (Antronico and Gullà, 2000; Sorriso-Valvo et al., 2004; Crozier, 2005; Guzzetti, 2008), and others focus on geotechnical characterisation and numerical modelling (Eden and Mitchell, 1969; Lim et al., 1996; Eigenbrod and Kaluza, 1999; Claessens et al., 2007). However, in spite of many contributions, a rational framework able to link the predisposing factors of shallow landslides at small, medium and large scales has not yet been provided. This paper is aimed at overcoming this lack of methods by proposing a so-called “new–old” approach, which is based on classic geological, geomorphological and geotechnical analyses, as well as on a new framework allowing for rational and quantitative correlations between landslide occurrence and regional and local factors in a test area in southern Italy.

The procedure is based on the following simple ideas: i) the wide diffusion of shallow landslides in the test area is not casual, being strictly related to regional factors affecting the morphological evolution of the slopes, and ii) the limited thickness of these landslides is related to local factors that cause an increase in soil weathering grade until the instability conditions are reached. The procedure first distinguishes and quantifies the landslide predisposing factors and regional shallow landslide susceptibility at small and medium scales. Once the most prone areas have been clearly identified, attention is devoted to finding quantitative relationships between weathered soil and shallow landslides for the local level. The proposed procedure applies a general framework

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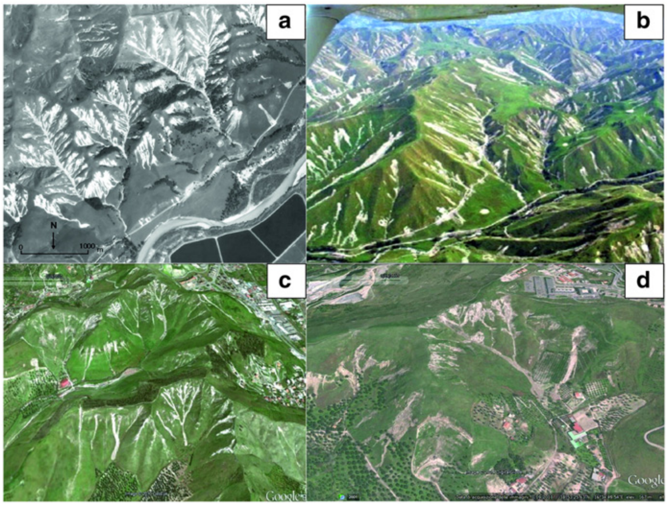

Fig. 1. Multiple rainfall-triggered shallow landslides. (a) Air photo of July 1977, Wairarapa, North Island, New Zealand (Crozier, 2005); (b) Air photo of events in New Zealand in February 2004 (Hancox and Wright, 2005); (c) 3D view from Google Earth of March 2010, Catanzaro, Calabria, Italy; (d) Typical phenomena in a morphological hollow, Catanzaro Graben, Calabria, Italy.

provided by Fell et al. (2008a) who link the size of the study areas, the scales of analysis (small, medium and large scale) and the methods of zoning (heuristic, statistical and deterministic methods), even though they do not use the proposed framework to solve practical problems. The usefulness of the framework is addressed by Cascini (2008), who refers to different geological contexts at different topographic scales as well as to landslides and soils that are different from those studied in the present work.

2. Materials and methods

2.1. Study areas

The study area is located in central Calabria, southern Italy, and falls into two distinct morphostructural sectors named Sectors II and III by Sorriso-Valvo and Tansi (1996) and characterised by different uplift rates (Fig. 3). Sector II coincides with the horst-graben system of the Coastal Chain–Sila Massif, which is characterised by predominantly N–S faults. The maximum uplift rate in this sector in the last million years, affecting the Coastal Chain, was approximately 1 mm/y, whereas the maximum uplift rate in the Sila Massif was 0.8 mm/y (Sorriso-Valvo and Tansi, 1996). Sector III corresponds to the Catanzaro graben and is characterised by the Lamezia–Catanzaro fault, with its southern end at the Maida–Girifalco–Squillace fault line. A 0.2 mm/y uplift rate was calculated for the Catanzaro graben (Sorriso-Valvo and Tansi, 1996).

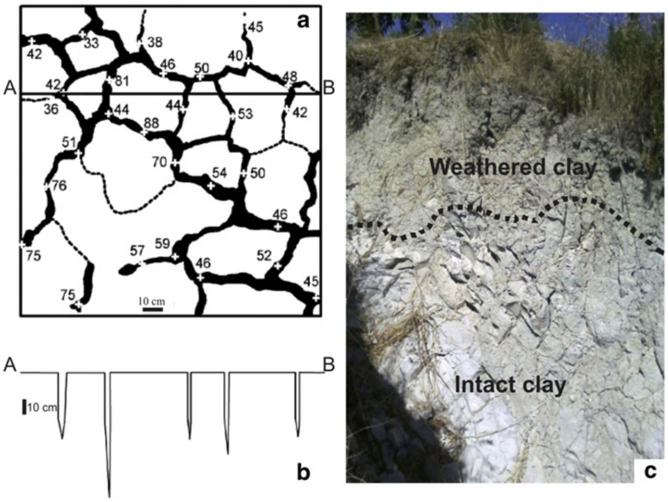

Fig. 2. Crack pattern at the soil surface. (a) Spatial distribution of cracks in a soil ploughed in spring. The numbers indicate the crack depth in centimetres (Meisina, 2006); (b) Cross-section showing the crack depths (Meisina, 2006); (c) Typical section of weathered soils in the study area.

Considering that the proposed approach uses a multi-scale analysis, a gradually smaller reference area is analysed when moving from a small to large scale (Fig. 3). In particular, at the small scale (1:100,000), the reference area extends 2000 km^2 and falls within the provinces of Catanzaro and Crotone; to the north, the area borders the Sila horst, to the south it borders the Serre horst, and to the east and the west it is delimited by the Ionian and the Tyrrhenian seas, respectively. At the medium scale (1:25,000), only a portion of the territory in the province of Catanzaro, extending for 150 km^2, is analysed because shallow landslides are prevalent there. The borders of this portion are the Sila horst to the north and the Ionian Sea to the south, and it is delimited to the east and west by the watersheds of the basins located to the hydrographical left and right of the Corace and La Fiumarella rivers. Finally, at the large scale (1:5000), the attention is focused on a morphological hollow that is chosen, investigated and analysed as being representative of the studied landslides.

2.2. Data

2.2.1. Geological and morphological data

At the small scale, geological and structural data were obtained by merging the data available from the structural geological map proposed

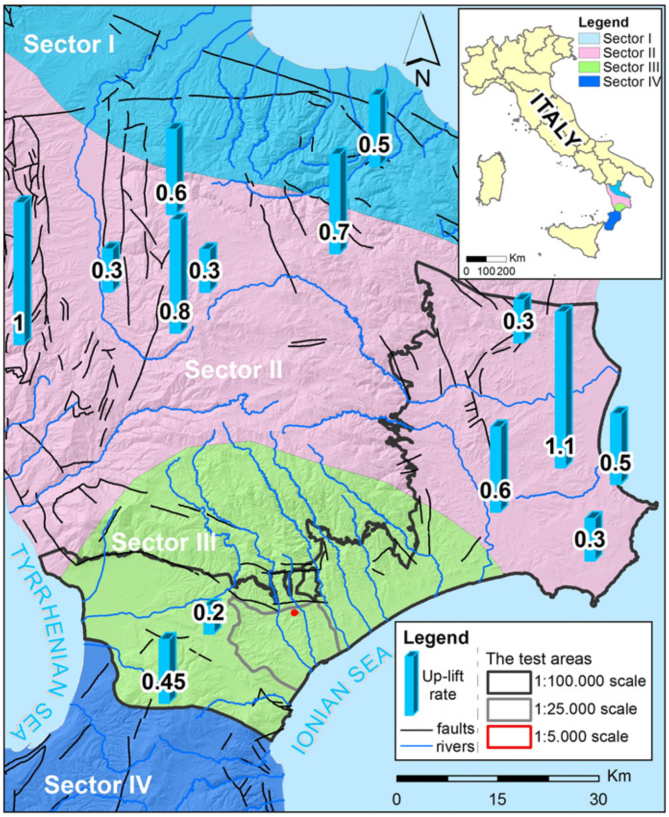

Fig. 3. Main morphotectonic structures and uplift rates in Calabria during the Quaternary Era (from Sorriso-Valvo and Tansi, 1996 modified), and the test areas at different topographic scales.