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The role of land use changes in the distribution of shallow landslides

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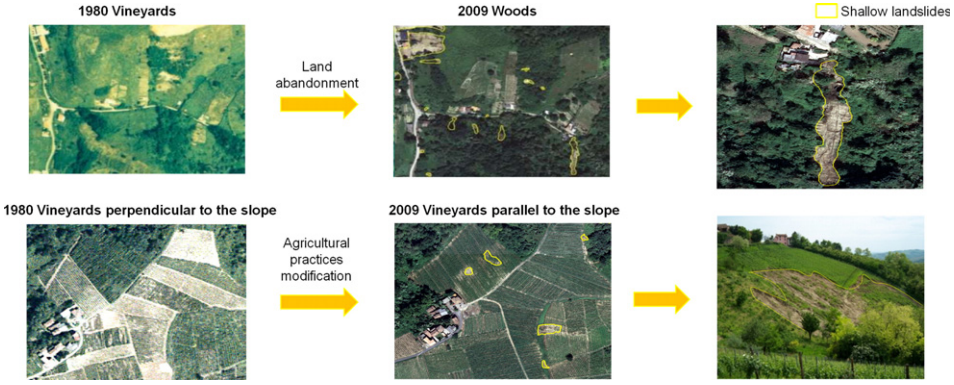
HIGHLIGHTS

- The interaction between lithosphere and anthroposphere has been addressed.
- Improved knowledge on the role of land use changes on shallow landslide occurrence.
- Historical land use change profiles and degree of transformation were identified.
- The land use change classes more prone to shallow landsliding were determined.
- Important information to improve land conservation strategy was provided.

GRAPHICAL ABSTRACT



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ABSTRACT

The role of land use dynamics on shallow landslide susceptibility remains an unresolved problem. Thus, this work aims to assess the influence of land use changes on shallow landslide susceptibility.

Three shallow landslide-prone areas that are representative of peculiar land use settings in the Oltrepò Pavese (North Apennines) are analysed: the Rio Frate, Versa and Alta Val Tidone catchments. These areas were affected by widespread land abandonment and modifications in agricultural practices from 1954 to 2012 and relevant shallow landslide phenomena in 2009, 2013 and 2014.

A multi-temporal land use change analysis allows us to evaluate the degree of transformation in the three investigated areas and the influence of these changes on the susceptibility to shallow landslides.

The results show that the three catchments were characterised by pronounced land abandonment and important changes in agricultural practices. In particular, abandoned cultivated lands that gradually recovered through natural grasses, shrubs and woods were identified as the land use change classes that were most prone to shallow landslides.

Additionally, the negative qualities of the agricultural maintenance practices increased the surface water runoff and consequently intensified erosion processes and instability phenomena.

Although the land use was identified as the most important predisposing factor in all the study areas, some cases existed in which the predisposition of certain areas to shallow landslides was influenced by the combined effect of land use changes and the geological conditions, as highlighted by the high susceptibility of slopes that are characterised by adverse local geological (thick soils derived from clayey-marly bedrocks) and geomorphological (slope angle higher than 25°) conditions.

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Thus, the achieved results are particularly useful to understand the best land conservation strategies to be adopted to reduce instability phenomena and the consequent economic losses in areas that are strongly linked to agricultural land use in these territories.

1. Introduction

Shallow landslides are particularly destructive phenomena because of the absence of incipient movement evidence and the high velocity of propagation. Effectively, the absence of warning signs from unstable landslide-prone areas makes shallow landslides very difficult to monitor. Despite the small soil volume that is involved (generally <2.0 m), shallow landslides can be densely distributed across territories. Thus, their rapid formation and high velocity of propagation makes correct and early predictions of their occurrence difficult to achieve, causing significant property damage to cultivation, structures and infrastructures and sometimes human losses.

As stated by Glade (2003), the type of movement, occurrence and behaviour of shallow landslides is often strongly influenced by land use and land use change dynamics, which are recognized throughout the world as one of the most important factors that influence the occurrence of shallow landslides.

In particular, the vegetation cover has important effects on shallow landslide susceptibility because of its effects on the hydrological processes and mechanical structure of the soil. To date, the literature has mainly focused on the mechanical effects of vegetation in terms of providing additional mechanical root reinforcement to be used in slope stability models (Bischetti et al., 2009; Greenway, 1987; Schmidt et al., 2001). The mechanical contributions, which affect the soil strength, are derived from the physical interactions of plant root systems with the slope. Two main actions are recognized. The first involves small flexible roots that mobilise their tensile strength by soil-root friction, increasing the compound matrix (soil-fibre) strength. The second involves large roots intersecting the shear surface, which mobilise a soil-root friction force instead of the entire tensile strength (Waldron, 1977; Bischetti et al., 2009).

The magnitude of such effects depends on the environmental characteristics (structure and texture of the soil, and the humidity, temperature and competition between the different species) and on the genetic properties of the different species (development of root systems). The environmental characteristics, in particular, induce great spatial variability in root patterns, introducing dramatic heterogeneity in soil reinforcement across different depths, planes and locations.

Thus, understanding the main land use changes through time could be very useful to evaluate the role of vegetation cover on slopes that are prone to shallow landslides and, in particular, the effect of its modification over the time on shallow landslide susceptibility (Carone et al., 2015; Glade, 2003; Reichenbach et al., 2014; Van Beek and Van Asch, 2004).

Generally, changes in vegetation cover are related to a combination of natural and socio-economic processes that operate at different spatial and temporal scales and often modify shallow landslide behaviour. Of particular interest is the role of human activity on vegetation changes. In fact, large areas can be changed in a short time because of anthropogenic processes, influencing the environmental factors that control landscape stability (Glade, 2003).

In some cases, land use changes may be also a consequence of landslide activity instead of its major cause. Some works underlined that the occurrence of environmental hazards such as landslides in farmland areas can represent an important threat to human security, leading to greater difficulty in continuing to manage the land and causing possible migration and land abandonment (Warner et al., 2010; Piguet, 2013).

In Europe, particularly in the Mediterranean region, land abandonment has been one of the most specific environmental processes that caused the most important land use changes over the last century (Gerard et al., 2010). In particular, the agricultural abandonment in the Italian Alps and Apennines led to substantial increases in forest area, depending on the altitude and changes in the structural diversity of the landscape (Falcucci et al., 2007). These modifications have important effects on the hydrological processes and mechanical structure of the soil, leading to important positive and negative consequences for slope stability (Bischetti et al., 2009; Greenway, 1987; Reichenbach et al., 2014; Schmidt et al., 2001; Schwarz et al., 2010; Wu, 2012). In many cases, changes in land use along steep terrains that are prone to shallow landslides, especially changes that are linked to the degradation and progressive abandonment of cultivations, had negative effects on the predisposition for landslide occurrence (Begueria, 2006; Cevasco et al., 2014; Crosta et al., 2003; Galve et al., 2015; Glade, 2003; Lorente et al., 2002).

For example, Lorente et al. (2002) and Begueria (2006) showed the negative effects of land degradation on landslide processes. In particular, these authors studied an extremely degraded area in the Central Pyrenees, where shifting agriculture on steep slopes and the frequent use of fire to control the expansion of thorny vegetation led to soil erosion and general land abandonment. This situation strongly contributed to shallow landslides even decades after human activities had ceased and after re-vegetation by shrubs or trees, confirming the strong influence of land degradation on the occurrence of shallow landslides. Other authors (Cevasco et al., 2014; Crosta et al., 2003; Galve et al., 2015) showed that the abandonment of cultivated plants and the lack of maintenance of human structures, such as drainage ditches and retaining walls, along the steep slopes of different Alpine and Apennines hilly areas increased erosional processes and the instability of slopes that were cultivated with vineyards and oliveyards. Moreover, other studies (Bordoni et al., 2016a; Bordoni et al., 2016b) highlighted the effect of vineyards and their abandonment on shallow landslide susceptibility, demonstrating that cultivated vineyards provide greater reinforcement to soil than abandoned grapevine plants.

However, directly relating the occurrence of shallow landslides to land use variations is difficult. Thus, the main aim of this research is to investigate geomorphic responses to land use changes, specifically by studying the temporal dynamics of land use variations, especially in abandoned agricultural lands.

In particular, this work focuses on the following:

i). The characterization of the land use changes and the modification of management practices in three shallow landslide-prone areas with peculiar land use and geological settings;
ii). The identification of the land use classes in each study site that are more prone to shallow landslides by analysing the distribution of past shallow landslides across several land use types;
iii). The effect of land use changes on the occurrence of shallow landslides.

A multi-temporal analysis is performed to obtain historical profiles of the study areas and to evaluate the main land use modifications that occurred over the last 58 years (from 1954 to 2012). Then, the main vegetation and agricultural land use classes (vineyards, arable areas, uncultivated areas, woods and grasslands) are analysed in detail to assess their degree and rate of transformation according to the characteristics of the land abandonment phenomena that affected the study areas. Finally, the Frequency Ratio Method (FRM - Lee and Talib, 2005)