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Historical evolution of slope instability in the Calore River Basin, Southern Italy

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ABSTRACT

There is interest in knowing historical spatio-temporal patterns of landslide activity. However, this is challenging to reconstruct because it is difficult to obtain detailed records for past landslide activity. Here, we deal with hydro-geomorphological signatures, such as storms, downpours, floods, snowmelt and mass movement, to detect annual slope instability events (ASIEs) over historical times. In order to obtain ASIEs for each year, a monthly Instability Density Index (*IDI*) was used and then monthly values were summed up to obtain a yearly value. Classes of monthly *IDI* varying between 0 (no instability) and 4 (highest instability) were determined from historical documents. We present an application for the Calore River Basin, Southern Italy, using data from a 313-year long series (1701–2013 CE). After 1880 CE the information becomes more valuable with directly observed landslide frequency. By this cataloguing, 129 ASIEs were obtained. Their evolution shows slight instability during the 18th century. Uneven and greater slope instability occurred instead across the 19th century, when an important phase of deforestation coincided with intensification of agricultural activities. Slope instability events continued during the 20th century but their causes are mainly related to anthropisation and the effects of recent climate change. It was determined that stormy autumns until the 19th century and successive winter-times with enhanced snowmelt, may have driven the reactivation of widespread instability events. We also found that mountainous and hilly terrains have an acute sensitivity to climate change.

1. Introduction

Earth-surface geomorphological systems tend to be in a state of dynamic equilibrium with external driving forces (Kosmas et al., 1999). Moderate changes in climate have consequences for geomorphological processes such as storms and floods, which can, in turn, produce slope instability including accelerated soil erosion and shallow landslides. However, responses of geomorphological systems to climate and environmental changes are complex and not yet completely understood (Knight and Harrison, 2012). Long-term studies may be very useful to understand the likely trajectory of climate–vegetation–landscape interaction in river basins (Mulligan et al., 2004). Indeed, chains of linkages between climate, land-cover and land-use produce complex geomorphic responses (Viles and Goudie, 2003). Evidence suggests that vegetation reacts to severe weather events depending on many environmental factors, as well as the functional diversity of plant communities (Jentsch and Beierkuhnlein, 2008). Therefore, the geomorphological systems are dynamic since one or more of their components can be sensitive to changes in given circumstances and changes in one component can (and often do) trigger instability elsewhere in the system (Thomas, 2001). In this way, patterns of slope instability may manifest themselves in history by means of specific characteristics referred to as hydrological signatures such as storms, downpours, floods and rain or snow events (Jothityangkoon et al., 2001). However, as noted by Gutiérrez et al. (2010), records become limited as we go back in the time, and the damage caused by landslides associated with storms and floods are frequently ascribed to these other hazards.

While historical landslide records are sparse, several attempts have been made to relate geomorphological responses to well-defined climatic periods (Grove, 2001; Soldati et al., 2004; Astrade et al., 2011) or specific rainfall events (Irigaray et al., 2000; Fiorillo et al., 2001; Guadagno et al., 2005; Fiorillo and Guadagno, 2007; Cevasco et al., 2014; Persichillo et al., 2016). In more recent times, climate variability has also been associated with the incidence of precipitation extremes, which are responsible for landslides and damaging hydro-geomorphological events (Larsen et al., 2010; Bollati et al., 2012; Stoffel and

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Huggel, 2012; García-Ruiz et al., 2013; Cevasco et al., 2015). Among these, mass movements are common in steep mountain regions where they often constitute a major risk for human activities (Revellino et al., 2013). In less steep areas landslides are also feared to cause fatalities, injuries, destruction of houses, infrastructure and properties, as well as reducing productive lands. The spreading of urban settlements and transportation networks into landslide-prone areas has been increasing the potential impact of slope instability (Brandolini et al., 2012; Di Martire et al., 2012). This is due to the evolution of the connectivity between physical and social systems, where greater potential is held for interactions among people, communities and ecosystems in the path of future risk events (Hufschmidt et al., 2005). Recent observations show a worldwide increase in both the frequency and intensity of heavy rainfalls, coinciding with widespread flooding and landslides in Europe (Diodato and Bellocchi, 2010; Saez et al., 2013). As climate-related events become more intense, with less recovery time between them, the damages incurred also increase (Stern et al., 2013).

The most important extreme hydrological events to occur in Italy during the last millennium were critically analysed (Finzi, 1986; Camuffo and Enzi, 1992, 1995). Records preserved in archives and libraries constitute a valuable source for investigating past climate and hydrological changes (Enzi and Camuffo, 1996; Delmonaco et al., 2000; Polemio and Petrucci, 2012). More specifically, an overall evaluation of the use of European historical archives for landslide studies is presented in Brunsden and Ibsen (1994). A detailed national study of historical landslides and flood frequency was undertaken in Italy by the AVI (Vulnerable Areas in Italy) project. AVI is a comprehensive inventory of landslide and flood events along with their consequences, prepared and later used to define the geo-hydrological risk for the entire country (Guzzetti et al., 1994). The inventory of Guzzetti et al. (2005) was used to compile a database of floods and landslides that occurred in Italy between 1279 CE and 2002 CE and caused deaths, missing persons, injuries and homelessness. >50,000 people either died, went missing or were injured in 2580 flood and landslide events. We also confirm that the societal landslide risk is larger in Trentino-Alto Adige (in the North) and Campania (in the South) than other Italian regions (Salvati et al., 2010).

There are several limitations regarding the calculation of landslide frequencies at different temporal and land spatial scales, including: the subjectivity of historical reports due to different levels of experience, training and conscientiousness of the observer and objective constraints such as the limited time span of historical sources. Carrara et al. (2003) underline that the historical approach tends to underestimate landslide hazard largely when human structures are lacking. However, although the quality of historical evidence can be strongly dependent on recording procedures and available records, the approach based on historical research provides an indication of at least the minimum level of landslide activity in an area (Crozier and Glade, 2005). In many cases, historical information can also provide disaster risk managers with a sense of the potential consequences of a particular forecast and the types of actions that can be taken in response (Hellmuth et al., 2011).

Once the available historical data are well organised, they can be used to promote common sensitivity with respect to hydro-geomorphological damages and as an instrument of knowledge (Cipolla et al., 2000). Historical research is also desirable to provide a new perspective on the study of landscape conservation and climate change, especially in agricultural river systems that are highly dynamic and controlled by complex climatic, geomorphic and ecological processes (Krishnaswamy et al., 2000). Investigating hydro-geomorphological events is particularly important in the regions of Mediterranean Europe as torrential and erosive rainfalls frequently occur in these areas where floods are associated with high landslide hazards (Fig. 1).

Damages caused by floods and landslides in the 19th century were retrieved from some perceptive historians. For instance, in 1870, the plant scientist Giuseppe Antonio Pasquale wrote: "the distribution of rain was so inconstant in all months of the year and so unequal in its fall, that damage outweighed the benefits" (Palmieri, 2002). Other than the negative impact on the vegetative cycle (and therefore on the economy of southern Italy), storms also affected landscape stability.

Within Mediterranean Europe, the mountain features, the absence of large plains and a highly irregular rainfall pattern are the main factors that make the Italian Apennines a highly unstable area from a geomorphological point of view. This paper focuses on the Calore River Basin (CRB), which is a large watershed (~3000 km^2) located inland of the Campania Region (Tyrrhenian side of the Southern Apennines). This study compiles a catalogue of annual slope instability events (ASIEs) for rainfall-triggered events, drawing upon news reports, scholarly articles and other hazard databases to provide a landslide catalogue at the river basin scale. In this way, for the first time, the history of the slope instability of the CRB is reconstructed and the relation with climate–vegetation–landscape evolution is investigated. This catalogue not only provides a basis for future planning, but also aids rediscovering the history of the landscape and thus encourages the reconstruction of new values in the social environment and so become an educational tool for future generations. Moreover, a new methodology is employed to overcome the lack of direct knowledge of some slope instability in the

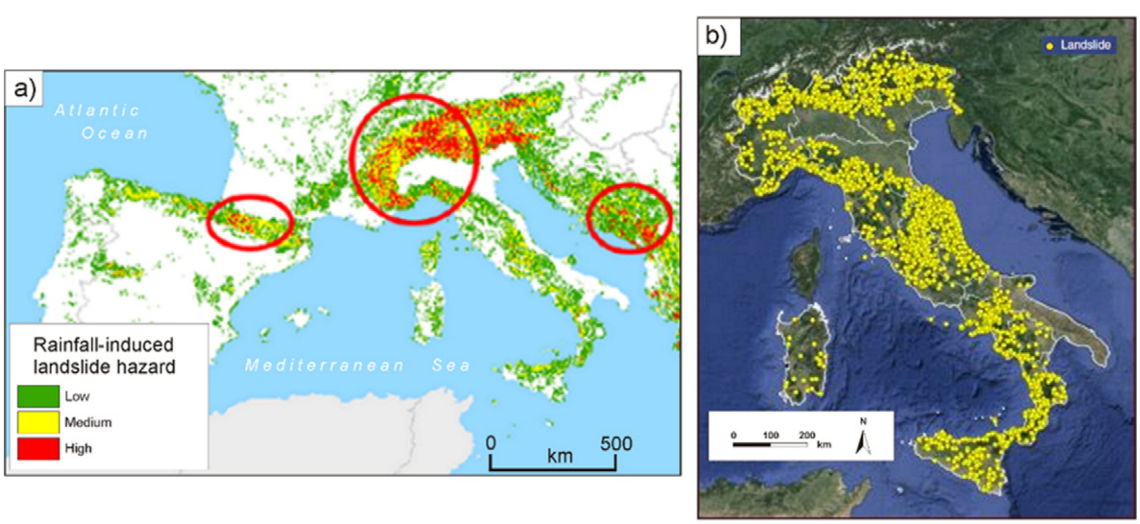

Fig. 1. (a) Rainfall-induced landslide hazard of the north-western Mediterranean region. Red circles indicate possible hot spots (modified from Jaedicke et al., 2014). (b) Map showing the location of rainfall-induced shallow landslides in Italy between 2002 and 2012 (modified from CNR IRPI, 2016).