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Post-fire erosion response in a watershed mantled by volcaniclastic deposits, Sarno Mountains, Southern Italy

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ABSTRACT

In this study we document a post-fire erosion response to a short-lived, intense rainstorm occurred on 6 September 2012 in the Sant'Angelo creek watershed, Sarno Mountains, Southern Italy. The rainstorm occurred one month after a wildfire that burned about 11 ha of the steep watershed (55 ha), almost entirely mantled by volcaniclastic deposits. The research was based on fieldwork and laboratory analysis addressed to the understanding of the geomorphic effects of the wildfire and their impact on erosional and depositional processes triggered by subsequent rainstorms. Field evidence indicates that a series of overland flows caused significant runoff and sediment yields along the hillslope and accumulation of hyperconcentrated flow deposits in a concrete channel occluded by a sealed culvert at the outlet of the watershed. The results of geomorphological and sedimentological analysis suggest that the occurrence of volcaniclastic covers mantling the slopes likely favored accelerated soil erosion, especially where vegetation and litter had been removed by the fire. Chemical analysis on sediment samples, revealed the occurrence of iron oxides that enhanced soil water repellency conditions over wide areas of the burned watershed compared to the unburned areas.

Quantitative analysis of sediment budgets showed that the rainfall-induced erosion response at Sant'Angelo creek watershed resulted in a soil loss of 19.8–33.1 tons ha^{-1} over burned areas. Post-fire erosion response following severe rainstorms needs to be considered in the spectrum of natural hazards associated with the geomorphological evolution of mountainous landscapes mantled by volcaniclastic deposits.

1. Introduction

During the last decade, the role of wildfires as geomorphic agent has been widely recognized by the scientific community (e.g. Moody et al., 2013). Direct effects of wildfires on soil and vegetation (e.g. Certini, 2005; Shakesby and Doerr, 2006; Jordàn et al., 2013) may enhance erosion through sheetwash and rilling processes, often resulting in large mass movements (Swanson, 1981; Cannon et al., 1998; Wondzell and King, 2003; Nyman et al., 2011; Moody et al., 2013; Riley et al., 2013; Santi et al., 2013). Post-fire erosion responses may have a variety of impacts on landscapes. For instance, they can dominate the long-term sediment yield in a given area, until the geomorphic system returns to the typical conditions of unburnt terrain (Swanson, 1981; Prosser and Williams, 1998; Shakesby, 2011). Moreover, they represent a severe risk for human life, where houses and other infrastructures occur (Cannon and DeGraff, 2009; Nyman et al., 2011). Post-fire catastrophic floods and deadly debris or sediment-laden flows have been reported from several areas of Canada, western United States and southeastern Australia (e.g. Moody et al., 2013; Kean et al., 2011; VanDine et al., 2005; Nyman, 2013). In the Mediterranean region, prevailingly moderate fire-related erosional events have been documented. However, as pointed out by Parise and Cannon (2008), most of research works in this area have dealt with experimental plots (e.g. Rosso et al., 2007) rather than analysis of post-wildfire landslides and erosional events. Case studies reported for Mediterranean region have mostly focused on Spain and Portugal (e.g. Lorente et al., 2002, 2003; Beguería, 2006; García-Ruiz et al., 2010, 2013; Lourenço et al., 2012) and fewer on the central countries, like in Italy and Greece (e.g. De vita et al., 1994; Tiranti et al., 2006; Calcaterra et al., 2007; Stefanidis et al., 2002; Blake et al., 2010).

The majority of the Mediterranean study areas are characterized by thin, stony soils, where surface erosion after wildfires is supply-limited with erosion rates ranging between 0.016 and 13.1 tons ha^{-1} $year^{-1}$ (Shakesby, 2011). A notable exception is represented by the volcanic

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areas of southern Italy, where local abundance of fine-grained, loose volcaniclastic material lying on steep volcanic and/or calcareous slopes may be observed (De Vita et al., 2006; Matano et al., 2016). Such material is often associated with andosols (WRB, 2006) characterized by relatively low cohesion under dry conditions (Maeda et al., 1977; Warkentin, 1984) and high erodibility when slope-stabilizing vegetation is absent (Rodríguez et al., 2002). The occurrence of wildfires in volcaniclastic settings is often reported, in fact, as a condition that enhances the probability of massive sediment-laden flows, as observed by Meyer and Wells (1997) in the Yellowstone National Park (U.S.A) and by Neris et al. (2016) in the Canary Islands (Spain). Nevertheless, according to Neris et al. (2016), hydrological and erosional response of this terrain type in the post-fire period has received little attention by the scientific community. A distinctive feature of several regions of the central Mediterranean area is the local abundance of sediment-supplying soils occurring in steep slopes characterized by a plenty of easily flammable shrubs and forests. Such increase in the natural fuel load can be enhanced by inappropriate land use and/or land abandonment and afforestation with highly flammable species (Shakesby, 2011). Due to the combination of these factors with a likely increase in the frequency of extreme climatic events through time (Arca et al., 2010; Moriondo et al., 2006), future wildfire activity is expected to increase in the overall Mediterranean area.

In this study we document a post-fire erosion response to a short-duration, high-intensity rainstorm that occurred in the Sant'Angelo creek watershed, Sarno Mountain Range, southern Italy (Fig. 1). This area, characterized by a Mesozoic carbonate bedrock covered by pyroclastic deposits and andosols, was partially burned on 4 August 2012 (Esposito et al., 2013) and hit by a first rainstorm on 6 September 2012. The aims of this study are: (i) to improve knowledge about fire effects and related soil erosion processes in steep slopes covered by volcanic soils; (ii) to highlight that high amount of soil loss can occur in such contexts; (iii) to give a valid contribution towards the documentation of post-fire erosion responses occurring in the central Mediterranean area.

The research work was based on a multidisciplinary approach integrating fieldwork with chemical, mineralogical and grain size analysis conducted on soil samples collected in the study area. Similar approach was adopted in other erosional contexts of southern Italy (e.g. Summa et al., 2007; De Santis et al., 2010), demonstrating to be very suitable to investigate the effects and causes of erosion. Laboratory and field data were also used to quantify soil loss at the watershed scale.

2. The Sant'Angelo Creek watershed

2.1. Geological background

The Sant'Angelo Creek watershed is located in the Sarno Mountain Range, along the southern slope of Mt. Torrenone, about 3 km east of the town of Sarno (Fig. 1). The ridge is mainly formed by bedded Mesozoic carbonates (Di Nocera et al., 2011) and since the Late Quaternary it has been repeatedly mantled by pyroclastic airfall deposits, as a result of explosive activity of the Somma-Vesuvius (Rolandi et al., 1998) and Campi Flegrei (Orsi et al., 1996) volcanic districts (Fig. 1). At the Sant'Angelo Creek watershed, the thickness of the volcaniclastic cover may vary significantly in different areas (Fig. 2), and it reaches a maximum of 5 m (De Vita et al., 2006; Autorità di Bacino del Sarno, 2011). However, slope-mantling deposits may be locally much thinner due to previous erosion and/or recent landslides. Fig. 2 reports the areal distribution of the varying thickness of volcaniclastic deposits that have been grouped into three classes (0.1–0.5 m; 0.5–2.0 m; 2.0–5.0 m), whereas carbonate scarps are referred to as exposed bedrock. The map indicates that in the burned area, the thickness of the pyroclastic cover mostly ranges from 0,5 m to 2,0 m. These volcaniclastic deposits are typically interbedded with a series of soil horizons classified as andosols (WRB, 2006), and characterized by a high content of glass and amorphous colloidal materials, including allophane and imogolite, and andic features ranging from high ($Alo + 0{,}5Feo > 2\%$) to moderate ($Alo + 0{,}5Feo$:1–2%) (Terribile et al., 2007).

2.2. Geomorphological setting

The morphology of the Sarno Mts. is marked by several tectonic lineaments (i.e. fault slopes) and carbonate scarps, along with gullies and karstic features with high gradients. Gullies are incised up to 30 m, and extend downslope from the ridge crest. Slope profiles are marked by a series of narrow scarps that may be followed laterally up to a few hundred meters. The scarps display heights ranging from 1–2 m to 10–15 m and typically correspond to erosion profiles of thick carbonate beds. Morphometric parameters of the Sant'Angelo creek watershed are summarized in Table 1, and a slope map of the watershed is showed in Fig. 2. Hillslopes are characterized by an average slope angle of about 35°. A marked decrease in the slope angles from 23° to 11° occurs along the channel slope at the outlet of the watershed.

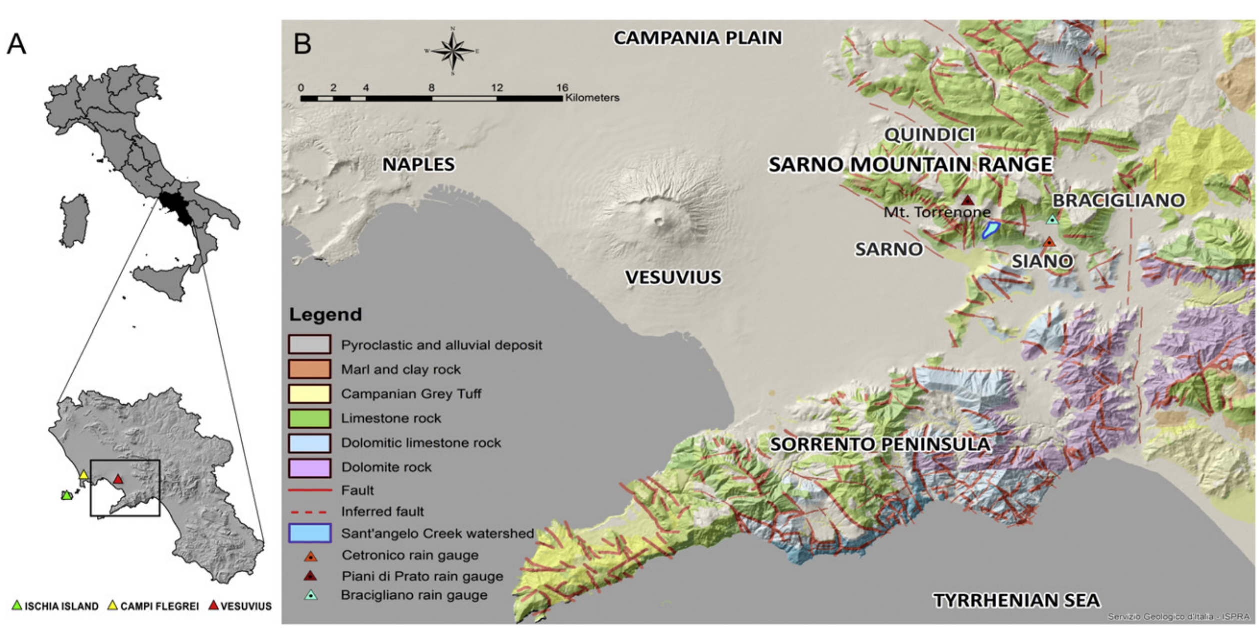

Fig. 1. A) Location of the study area; the Campania region is highlighted in black. B) Geological sketch-map of the Sarno Mountain Range and the surrounding area (ISPRA, 1976).