Shallow Landslides Triggered by the 25 October 2011 Extreme Rainfall in Eastern Liguria (Italy)

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Abstract

A very heavy rainstorm hit Eastern Liguria (Vara Valley and Cinque Terre area) and North-western Tuscany (Magra Valley) on 25 October 2011. This event produced floods and hundreds of shallow landslides, causing 13 casualties and severe damage to villages, infrastructures and roads. In the Vara Valley the Brugnato rain gauge recorded 468.8 mm in 6 h, with a maximum rainfall intensity of 143.4 mm/h. A landslide inventory map was carried out, together with a database including the main features of the source areas. At present, the database is complete for the Pogliaschina Torrent basin (Vara Valley), where at least 658 shallow landslides (mainly soil slip-debris flows and debris flows) were triggered. The shallow landslides induced by the 25 October 2011 event were analysed, together with geological, geomorphological and land use features of their source areas, with the aim of identifying common triggering conditions. This paper shows preliminary results of the comparison between the landslide inventory and the main slope features of the Pogliaschina Torrent basin.

Keywords

Shallow landslide • Debris flow • Rainstorm • Triggering factor • Liguria

85.1 Introduction

On 25 October 2011 extreme rainfalls hit the Eastern Liguria (Vara Valley and Cinque Terre area) and the North-western Tuscany (Magra Valley). The rainstorm triggered hundreds and hundreds of shallow landslides and floods, causing 13 fatalities and severe damage to villages, infrastructures and roads (Cevasco et al. 2013; D'Amato Avanzi et al. 2013).

The rain gauges located at Brugnato, Calice al Cornoviglio, Casoni di Suvero (Vara Valley), Levanto, Levanto S. Gottardo and Monterosso (Cinque Terre) recorded 538.2, 452.8, 304.8, 273.0, 333.0 and 381.8 mm in 24 h (Fig. 85.1) and 468.8, 348.4, 227.4, 214.2, 264.8 and 340.8 mm in 6 h, respectively.

The highest rainfall intensity was recorded at Brugnato (143.4 mm/h from 13.00 to 14.00), Calice al Cornoviglio (121.0 mm/h from 15.00 to 16.00) and Levanto S. Gottardo (100.6 mm/h from 10.00 to 11.00).

Similar conditions occurred in the Magra Valley, where the Arzelato, Parana, Pontremoli and S. Giustina rain gauges recorded 325.9, 313.8, 365.8 and 375.6 mm in 24 h, respectively (Fig. 85.1). The highest rainfall intensity was recorded from 16.00 to 17.00 at Parana (85.0 mm/h), S. Giustina (67.2 mm/h) and Pontremoli (64.2 mm/h).

The Magra River Basin Authority and the Earth Sciences Department of the University of Pisa promoted a study aimed at analysing the shallow landslides triggered by the rainstorm: a landslide inventory map was carried out and a landslide database was implemented, including the main geological, geomorphological and land use features of the source areas. At present, the inventory and the database of landslides are complete for the Pogliaschina Torrent basin (Vara Valley; Figs. 85.2, 85.3a). This paper shows preliminary results of the comparison between the landslide inventory and the main slope features of the Pogliaschina T. basin.

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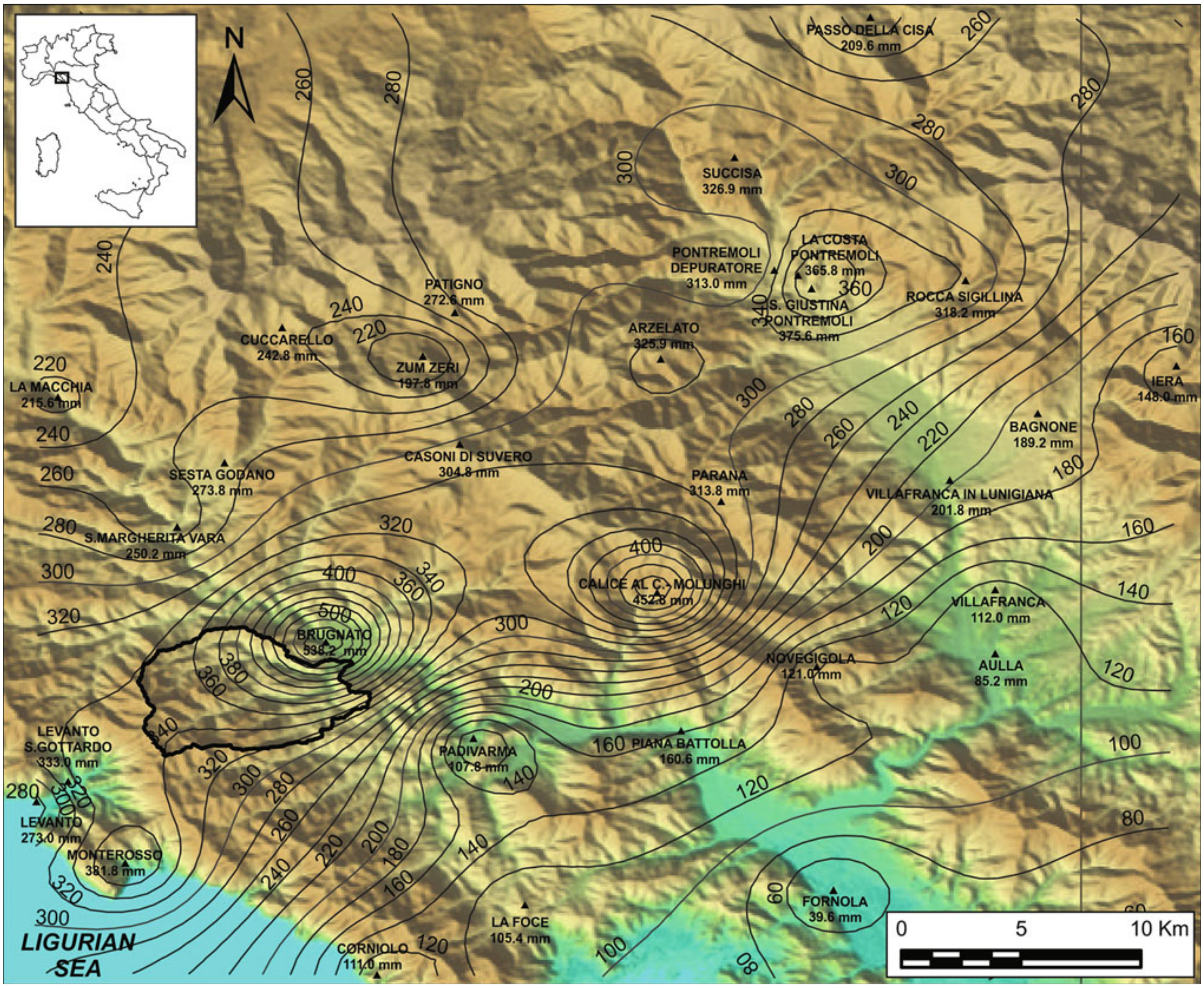

Fig. 85.1 Isohyet map of the 25 October 2011 rainstorm (cumulative rainfall in 24 h). The black line borders the Pogliaschina T. basin (Geographic Coordinate System: GCS_WGS_1984)

85.2 Landslide Features

The Pogliaschina T. basin is 25 km^2 wide and has a maximum altitude of about 720 m a.s.l., while the valley bottom is about 95–100 m a.s.l. (Fig. 85.3b). The bedrock is mainly formed of arenaceous formations (Fig. 85.2; Puccinelli et al. 2013), such as the Macigno Fm. (MAC, Tuscan Nappe Unit, Tuscan Domain) and the Arenarie di Monte Gottero Fm. (GOT, Gottero Unit, Ligurian Domain), that constitute the 46.9 % (west-southwest portion of the basin) and the 34.1 % (northeast portion) of the whole basin (Fig. 85.2), respectively.

In the Pogliaschina T. basin the October 2011 rainstorm triggered at least 658 shallow landslides (Figs. 85.2, 85.3a). Most of them were first-time movements, mainly referable to complex, translational debris slide-flow (Cruden and Varnes 1996), commonly named soil slip-debris flows (Campbell 1975; Crosta et al. 1990; D'Amato Avanzi et al. 2004). They were usually superficial (0.3–2 m thick), linear (width/length ratio 0.03–0.5) and involved mostly coarse-grained soil and sometimes portions of fractured bedrock. Channelized debris flows prevailed, while open-slope debris flows were a minority. These features allow defining most of the shallow landslides as extremely rapid, saturated debris flows following established channels over most of their path (Hungr et al. 2001).

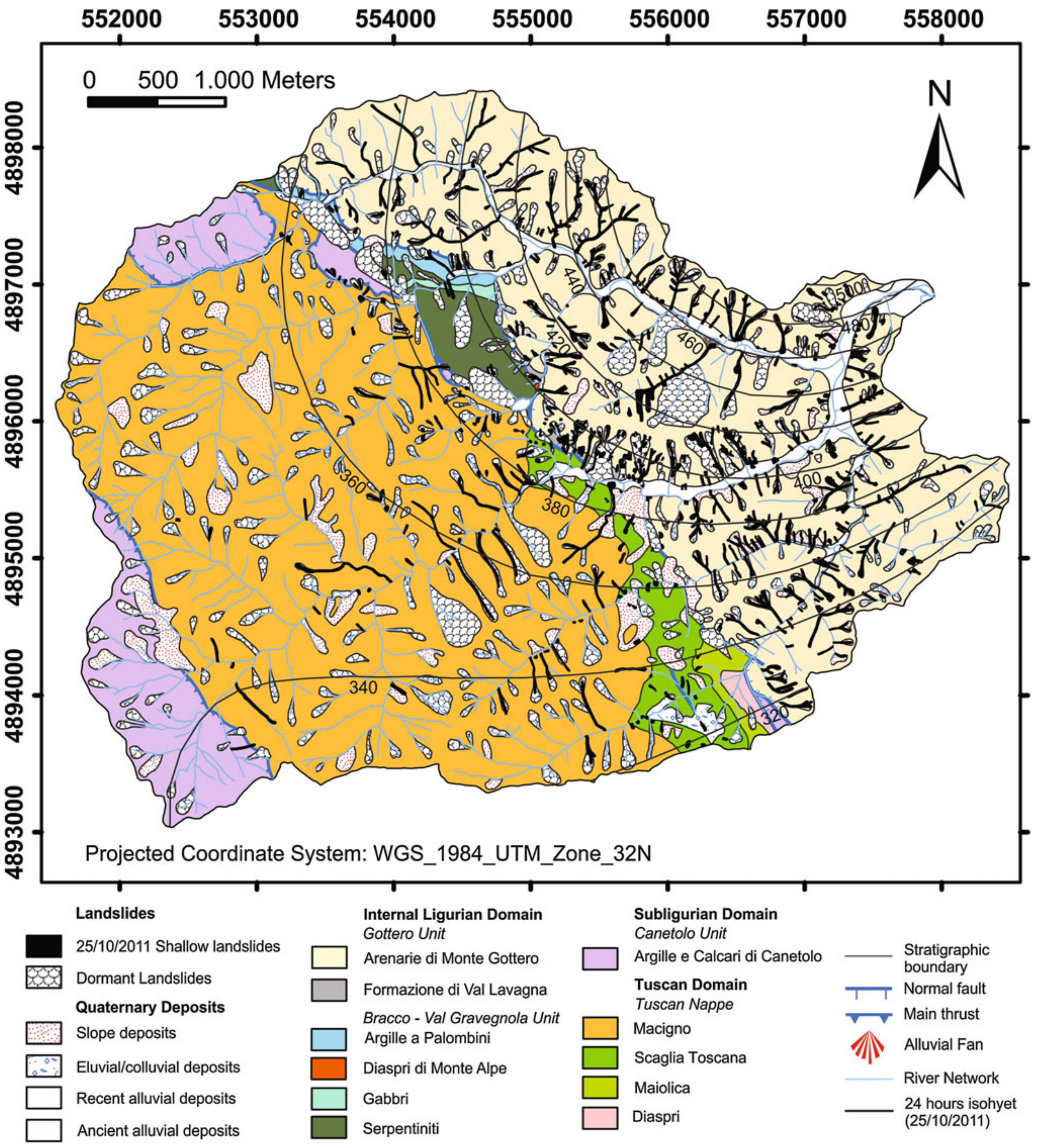

Fig. 85.2 Geological sketch map of the Pogliaschina T. basin. Black areas represent the shallow landslides triggered by the 25 October 2011 rainstorm

Failures mainly initiated in hollows of slopes at the top of zero-order basins. About 45 % of the sliding material flowed into the hydrological network. In such sites, the concave morphology caused runoff concentration and infiltration, while the concave soil-bedrock interface induced concentration of subsurface flow, saturation, build-up of pore pressures and deterioration of slope stability.

Considering a mean soil thickness involved in landsliding of about 1.5 m and a landslide area of 783,000 m^2, the volume of material mobilized by shallow landslides was

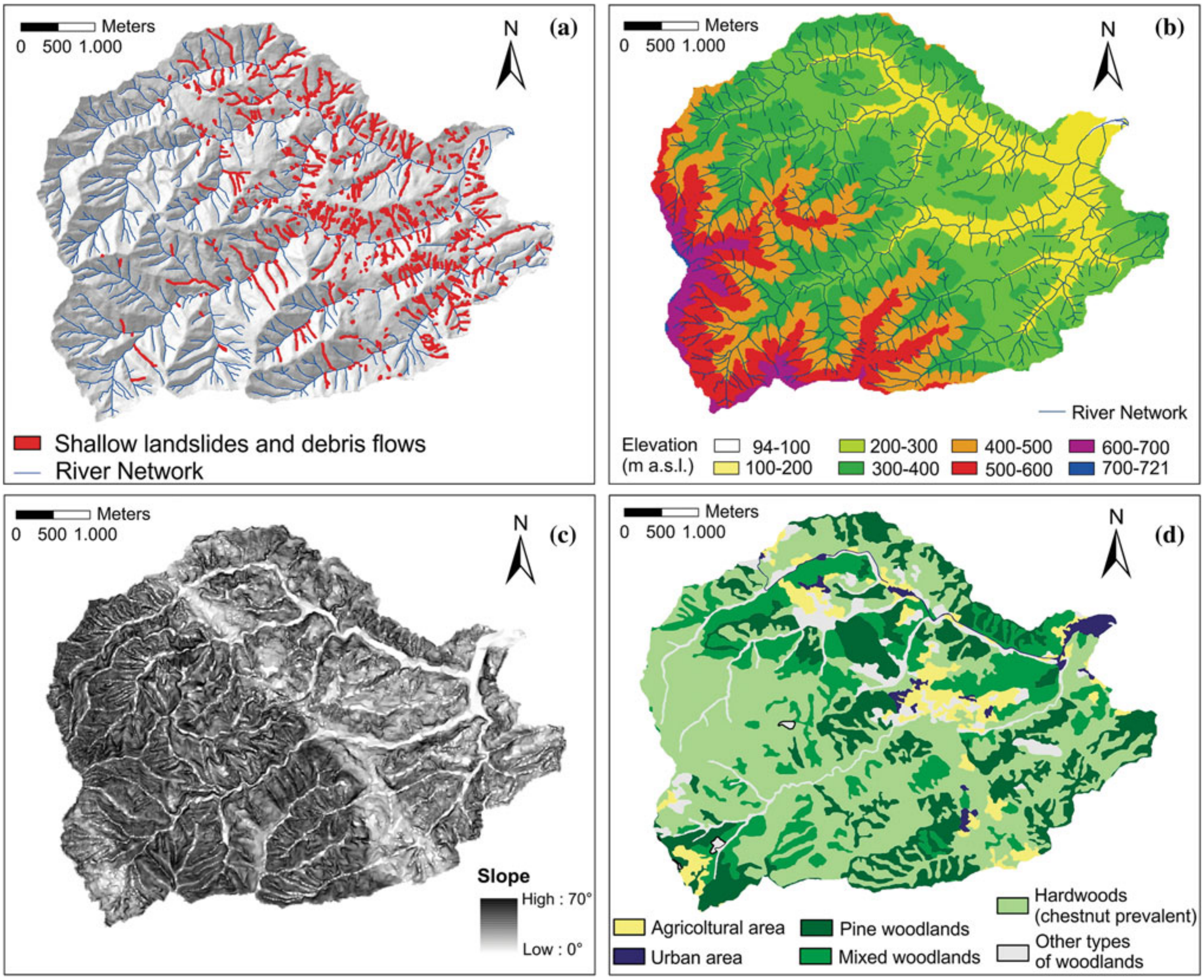

Fig. 85.3 **a** Hillshade map of the Pogliaschina basin with shallow landslides triggered by the 25 October 2011 rainstorm. **b**, **c** and **d** Digital elevation model (DEM, cell resolution 5 × 5 m), Slope and Land use maps, respectively

estimated at 1,174,500 m^3. This material largely flowed into the hydrological network.

85.3 Landslide Distribution and Triggering Factors

With the aim of determining the main characteristics of the source areas, a detailed field survey and an aerial view interpretation allowed analysing the shallow landslides triggered in the Pogliaschina T. basin together with the most important geological, geomorphological and land use features (Fig. 85.3).

Shallow landslides almost exclusively involved the soil covering the GOT and MAC Fms. These formations underlie 76.4 and 14.3 % of the 2011 landslides (Fig. 85.2), respectively. Despite similar lithological features, the MAC Fm. underlies a smaller number of shallow landslides; this is probably attributable to the less intense rainfall hitting the area underlain by the MAC Fm. (W portion of Fig. 85.2). In fact, in the area underlain by the GOT Fm. rainfall ranged between 340 and 500 mm in 24 h, with a maximum intensity up to 108,1 mm/h in 6 h (from 9:00 to 15:00); while in the MAC Fm. area a rainfall variable from 320 to 380 mm in 24 h was recorded (Fig. 85.2). Landslide indexes (percentage ratio between the landslide area for each formation and the total area underlain by the same formation) of the GOT Fm. and of the MAC Fm. are 6.9 and 1.3 %, respectively.

The correlation between shallow landslides and slope gradient of the source areas (Fig. 85.3c) was also analysed, and nine slope gradient classes were defined. The distribution of slopes in these classes is rather homogeneous, although the class 31–35° prevails. The gradient classes of 26–30°, 31–35° and 36–40° include the 21.1, 23.7 and

13.8 % of the source areas, respectively. The remaining shallow landslides were triggered on slopes characterized by gradient ≤25° (30.1 %) or >40° (11.3 %).

Moreover, the shallow landslides distribution was compared with the type of vegetation and land use (Fig. 85.3d). However, it is difficult to assess the influence of vegetation on the landslide occurrence, because geological, geomorphological and soil features of slopes can influence vegetation, as well as the landslide distribution (Wieczorek et al. 1988).

By means of on-site survey, photo aerial interpretation and land use map of the Liguria Region, the Pogliaschina T. basin was subdivided into three main land use classes: urban area (1.6 % of the basin), agricultural area (5.6 %) and woodland area (92.8 %). These classes include 1.8, 14.9 and 83.3 % of the shallow landslides source areas, respectively. Woodlands are subdivided into hardwood woodlands with prevailing chestnuts (50.6 %), pine woodlands (21.6 %), mixed woodlands (prevailing chestnuts and pines 16.8 %), and other types (3.8 %). 34.6, 20.4, and 16.4 % of the source areas fall into the first three classes of woodlands, respectively.

The high percentage of shallow landslides in woodlands is probably attributable to their poor management. In addition, chestnuts (*Castanea sativa*) and pines (*Pinus pinaster*) were recently infested by tiny insects (*Dryocosmus kuriphilus* and *Matsucoccus feytaudi*, respectively), which kill or weaken them. These phenomena are likely to have contribute to the deterioration of slope stability.

85.4 Final Remarks

Based on the distribution of the shallow landslides occurred during the 25 October 2011 rainstorm in the Pogliaschina T. basin, some conclusions on the typical slopes susceptible to landsliding can be drawn.

The bedrock lithology appears to be an important factor in the localization of the source area of the shallow landslides. 90.7 % of them were triggered on soil covering arenaceous formations (GOT and MAC Fms.). The GOT Fm. showed the highest landslide index (6.9 %).

The comparison between shallow landslides distribution and slope morphology indicates that the failures mainly initiated in hollows of slopes with a steepness ranging from 26 to 40°. Moreover, chestnut and pine woodlands exhibit the highest landslide area (34.6 and 20.4 % of the whole landslide area in the basin, respectively).

Further investigations will be performed, in order to quantify geotechnical and hydrogeological parameters of the soil covering the slope: soil cohesion, friction angle and hydraulic conductivity. Pore pressure regime or rainfall infiltration model are not at present well-known. This will contribute to understand the features of shallow landslide source sites and to predispose landslide susceptibility maps and risk scenarios. Finally, rainfall thresholds for shallow landslides initiation are under study and will help to improve forecasting and warning systems.

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