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PRELIMINARY ANALYSIS OF THE NOVEMBER 10, 2014 RAINSTORM AND RELATED LANDSLIDES IN THE LOWER LAVAGNA VALLEY (EASTERN LIGURIA)

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EXTENDED ABSTRACT

Durante l'autunno del 2014 la Liguria è stata interessata da vari eventi meteorici di rilievo che hanno causato fenomeni alluvionali e l'innesco di dissesti. La sera del 10 novembre 2014, in particolare, precipitazioni intense hanno interessato i bacini costieri prospicienti il golfo del Tigullio (Liguria centro-orientale) causando l'innesco di numerose frane superficiali e l'esondazione dei torrenti Rupinaro ed Entella, le cui acque hanno invaso il centro storico di Chiavari (GE). In questo studio vengono presentati i risultati preliminari delle indagini svolte in un'area che ha subito gravi danni a causa del verificarsi di frane superficiali indotte da tale evento. I dissesti hanno interessato un versante collinare posto in corrispondenza del tratto terminale della val Lavagna. Poiché la maggior parte delle aree di innesco si trova a monte di piccoli impluvi o di solchi di corrivazione piuttosto acclivi, gran parte dei corpi di frana, in parte fluidificati, si è incanalata all'interno di questi ultimi, dando origine a fenomeni di colamento che hanno raggiunto rapidamente, e con energia cinetica elevata, il piede del versante, in corrispondenza del quale si trovavano alcune abitazioni sparse. La massima espressione dell'intensità e del potenziale distruttivo del fenomeno si è manifestata quando uno dei dissesti ha travolto, demolendolo e causando due vittime, un edificio ubicato in corrispondenza dello sbocco di un modesto rivo con profilo longitudinale particolarmente acclive. Nella porzione più colpita dai dissesti gli effetti sono stati molteplici: terrazzamenti agricoli collassati, edifici danneggiati e parecchie persone evacuate. Le frane hanno coinvolto pesantemente anche la viabilità ai piedi del versante, invasa dai detriti in più punti.

Nei giorni successivi all'evento sono state avviate indagini per comprendere i fattori innescanti e predisponenti i dissesti. Dapprima sono stati effettuati rilievi geomorfologici e geologico-strutturali al fine di mappare e classificare le frane, nonché individuarne i principali elementi morfologici e i contesti di attivazione. Contestualmente è stata intrapresa un'analisi dei dati di pioggia, sia dell'evento, sia delle serie storiche, in riferimento alla stazione pluviometrica di Panesi, ubicata a soli 2 km di distanza dall'area di studio. Al fine di individuare le caratteristiche morfologiche del versante è stato realizzato, tramite dati LiDAR, un DEM con celle di lato 5 m. Da tale modello sono stati valutati i parametri morfometrici delle frane e, tramite l'analisi multitemporale di foto aeree, sono state redatte carte tematiche di dettaglio. In ultimo, mediante analisi di laboratorio su campioni rimaneggiati di terreno prelevati in corrispondenza delle aree di innesco, è stata effettuata una prima caratterizzazione fisica dei depositi di versante.

Dai risultati ottenuti è emerso che il fattore di innesco delle frane sia da ricondurre inequivocabilmente all'evento del 10 novembre 2014, caratterizzato da un picco di intensità oraria di precipitazione che ha determinato il superamento delle soglie di innesco delle frane superficiali note in bibliografia su scala globale, nazionale e locale. I significativi quantitativi di pioggia caduti al suolo nei giorni precedenti potrebbero comunque aver svolto un ruolo importante quale fattore predisponente al verificarsi dei dissesti. Altri fattori predisponenti sono riconducibili all'elevata acclività del versante, a sua volta inciso da frequenti impluvi e solchi di corrivazione a regime torrentizio, all'assetto stratigrafico e strutturale in corrispondenza delle aree di innesco e alla mancanza di un'adeguata manutenzione dei terrazzamenti agricoli.

Un aspetto di discussione di estremo interesse che questo evento ha evidenziato, riguarda l'analisi dei fenomeni e delle loro caratteristiche in relazione agli strumenti di pianificazione territoriale vigenti. In particolare, è emersa la necessità che in futuro la definizione delle aree potenzialmente a rischio di frana preveda l'introduzione della previsione di propagazione del fenomeno franoso. L'applicazione di modelli numerici fisicamente basati potrebbe essere di notevole utilità a tale riguardo.

Si prevede di proseguire lo studio compiendo una migliore caratterizzazione geotecnica e idraulica dei depositi di versante e di estendere le indagini all'intera area interessata dai dissesti. Tuttavia, si ritiene che i risultati preliminari presentati rappresentino un'imprescindibile fonte di informazioni su cui basare le successive fasi di modellazione dei fenomeni franosi e di valutazione della pericolosità; in ultimo, essi possono costituire un valido riferimento a supporto dell'attività di pianificazione delle misure per la mitigazione del rischio geoidrologico.

ABSTRACT

On the evening of November 10, 2014, eight rainfall-induced shallow landslides were triggered on a slope in the lower Lavagna valley (eastern Liguria, Italy). Most of the shallow landslides were channelled as flows into steep hollows and reached the toe of the slope, where some sparse houses were built. One of these landslides impacted and destroyed a building located just at a steep channel outlet, causing two fatalities. Damage affected also agricultural terracing as well as some other buildings and a road running at the toe of the slope, which was buried for long tracts by landslide deposits.

Since a few days after the landslides occurrence, various activities were carried out, with the aim of better understanding both the triggering and predisposing factors of landslides. These activities included field surveys, rainfall data analysis, topographic/thematic maps, DEM and aerial photo analyses, preliminary laboratory tests on soil samples.

From the analyses performed, it seems that, in addition to the rainfall characteristics of the November 10, 2014 event, the antecedent rainfall may have played an important role as landslides predisposing factor. Other relevant predisposing factors can be referred to slope steepness, presence of hollows, stratigraphic and structural settings at the source areas and lack of maintenance of terracing.

Investigations are still in progress to achieve a complete geotechnical and hydraulic characterization of soils. Furthermore, it is also expected to extend the analyses performed to the whole area affected by shallow landslides. However, we believe the results of this study can be helpful in shallow landslide modelling, hazard assessment and planning of appropriate risk mitigation measures.

***Keywords**: eastern Liguria, debris flow, intense rainfall, shallow landslide.*

INTRODUCTION

In autumn 2014, several rainstorms caused landslides and floods with terrible consequences in the Liguria region. As frequently occurred in the last decade, rainfalls and related damage mainly affected the central and eastern sectors of Liguria. Particularly, on October 9 and 10, 2014 the Bisagno River flooded the city of Genoa (Silvestro *et alii*, 2016) and many landslides caused heavy damage to the upper Scrivia valley, which is located just north of the Genoese area. On November 10, 2014, a very short and heavy rainfall hit some coastal basins of the Tigullio gulf and the middle Fontanabuona and Sturla valleys, in central eastern Liguria (Cevasco *et alii*, 2015b). The town of Chiavari suffered severe damage caused by flooding of both the Rupinaro creek and the Entella stream (Faccini *et alii*, 2015). Shallow landslides produced severe damage to settlements, road network and infrastructures; some buildings were destroyed and two casualties occurred at Leivi, in the lower Lavagna valley (Genoa province) (Cevasco *et alii*, 2015b). Another remarkable intense rainfall occurred on November 15, 2014 and affected the Polcevera valley (western sector of the city of Genoa), causing floods and widespread shallow landslides. Moreover, the high landslide susceptibility of the eastern Liguria area was highlighted also by Giannecchini *et alii* (2015) and Persichillo *et alii* (2016a; 2016b).

This paper focuses on the November 10, 2014 rainfall event and related landslides affecting a small area located in the Leivi municipality; here, the effects of rainfall on slope stability were quite well comparable with those that occurred in eastern Liguria on October 25, 2011 (Cevasco *et alii*, 2013; 2014; D'Amato Avanzi *et alii*, 2013; 2015). The results of the first analyses and observations that were carried out just a few days after the event will be reported. These activities included field surveys, analysis of rainfall data, laboratory testing on disturbed soil samples collected at different source areas and analysis of different time series of aerial photographs. Moreover, some comments regarding the effects of the rainfall event and the current land planning tools will be reported in the discussion section.

STUDY AREA

The study area is located in central-eastern Liguria (north-western Italy), just a few kilometres inland of the town of Chiavari (Fig. 1). In particular it consists of a steep slope on the orographic right side of a wide bend of the Lavagna stream, a few hundred meters downstream from its confluence with the Sturla stream and a few kilometers upstream its confluence with the Graveglia stream (Fig. 1). This slope, located in the Leivi municipality and exposed towards ESE, is about 600 m long and extends from the Lavagna valley floor (25 m a.s.l.) to a ridge elongated NE-SW (200-220 m a.s.l.).

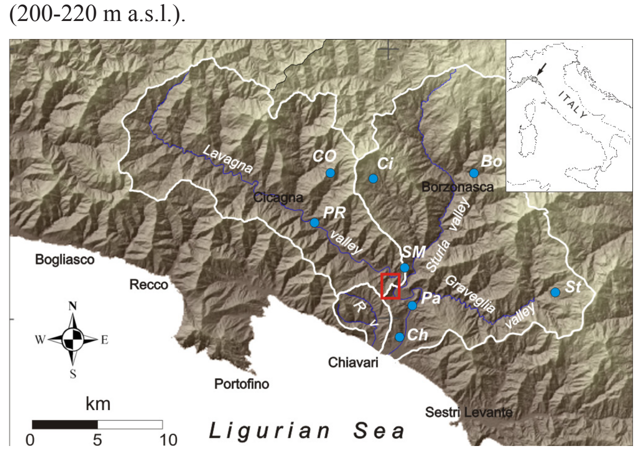

Fig. 1 - Location of the study area (after Cevasco et alii, 2015b, modified). White boundaries: Lavagna, Sturla, Graveglia and Rupinaro (R v) basins; blue points: rain gauges cited in the text (BO: Borzone; Ch: Chiavari; Ci: Cichero; CO: Croce di Orero; Pa: Panesi; PR: Pian dei Ratti; SM: S. Martino del Monte; St: Statale); red box: study area

From a geological point of view, the bedrock is represented by formations belonging to the Gottero Unit (Internal Ligurid Units of the Northern Apennines). From SW to NE they outcrop in the following order (Fig. 2; Abbate *et alii*, 2011): Palombini Clays, Manganesiferous Shales and M. Verzi Slates. The Palombini Clays (Berriasian-Santonian p.p.) are formed of grey claystones and silstones with dark grey limestone interbedding; the Manganesiferous Shales (upper Santonian-lower Campanian) are constituted by arenaceous-pelitic turbidites with exclusively siliciclastic composition whereas the M. Verzi Slates (Campanian) are represented by arenaceous-pelitic-turbidites interbedded by siliciclastic and marly-limestone levels (Elter *et alii*, 2005). Such formations are tightly folded with axes NW-SE striking and show a dominant bedding attitude oriented south-westwards.

The geomorphological features of the study area include high slope steepness and the presence of steep hollows with ephemeral hydrological regime. Slopes are usually steeper than 26° with wide sectors steeper than 36°. Despite an overall homogeneity, the south-eastern side of the Leivi slope sometimes shows a quite irregular morphologic profile due to some small low steepness areas located at different altitude, which are mainly attributable to ancient and probably dormant landslide deposits (Fig. 7). In the north-eastern sector, one of them is located in the middle slope between the altitudes of 100 and 150 m; another one is clearly recognizable at altitudes between 30 and 80 m. On these areas, the low slope gradient associated to such landslide deposits allowed the development of scattered settlements (Buggigo, Loreto). Similarly, other small extents can be recognized in the south-western sector between 140 and 160 m; between 180 and 190 m and between 110 and 120 m (Case Selaschi).

The land use is mainly characterized by terraced areas cultivated with olive groves, which currently are in state of partial abandonment. Where terraces and cultivations were abandoned, the state of conservation of the dry stone walls is quite poor because of lack of maintenance. On the contrary, small plots of land properly maintained and cultivated with olive grove still survive. On areas which were abandoned since long time, mixed woods are grown.

RAINFALL

The November 9-11, 2014 rainfall

The November 10, 2014 rainstorm affected the entire Liguria, particularly hitting some small coastal basins of the Tigullio Gulf and both the middle Fontanabuona and Sturla valleys. Actually, the rainfall event began with low quantities on the evening of November 9, 2014 and ended on November 11, 2014. Inside the most affected area, the rainfall amount and intensity were recorded by some raingauges of the ARPAL (Liguria Region) meteorological network (Fig. 1). These were located at Borzone (386 m a.s.l.), Chiavari (6 m), Cichero (615 m), Croce d'Orero (640 m), Panesi (25 m), Pian dei Ratti (70 m) and Statale (593 m). The cumulated rainfall recorded on November 10, 2014 were almost 200 mm at Panesi and Borzone (194 mm and 193 mm respectively), whereas slightly lower values were recorded by the other rain gauges (Fig. 3a; Tab. 1). Rainfall intensity peaks were recorded in all the raingauges in the evening of November 10, 2014 (Fig. 3b; Tab. 1). The highest rainfall intensity was recorded

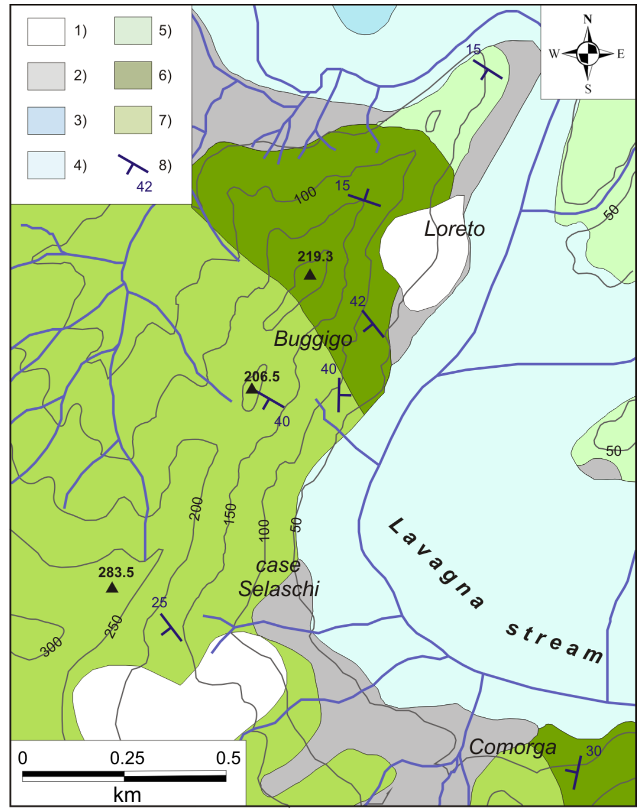

Fig. 2 - Geologic map of the study area (after Abbate et alii, 2011, redrawn and modified.). Legend: 1) landslide deposit; 2) slope deposit; 3) terraced alluvial deposit; 4) alluvial deposit; 5) M. Verzi Slate; Manganesiferous Shales; 6) Palombini Clays; 7) bedding attitude

Rain gauge	Maximum hourly rainfall intensity		Cumulated rainfall		
	Nov. 10, 2014 [mm/hr]	Time [UTC]	Nov. 10, 2014 [mm]	Nov. 9-11, 2014 [mm]	Nov. 3-11, 2014 [mm]
Borzone	42.0	20.00-	193	250	523
Chiavari	58.4	21.00-	162	212	365
Cichero	52.2	20.00-	171	245	514
Croce d'Orero	28.0	20.00-	98	175	384
Panesi	**66.0**	**20.00-**	**194**	**247**	**413**
Pian dei Ratti	31.4	20.00-	116	196	415
Statale	45.6	22.00-	166	218	386

Tab. 1 - Maximum hourly rainfall intensity recorded on November 10, 2014 and cumulated rainfall related to different time periods recorded at some raingauges of ARPAL meteorological network at Panesi, which is located about 2 km east from the study area. The 1h maximum intensity reached 66 mm between 20.00 and 21.00 UTC (Fig. 3b). The same raingauge recorded 147 mm/4h from 18.00 to 22.00 UTC. As an example of the very low lag time characterizing most of the Liguria basins, the hydrometric level of the Lavagna Torrent at Carasco raised 5.5 m in only three hours (from 19.00 to 22.00 UTC).

However, it is interesting to point out that during the week before the event significant rainfall occurred. In fact, between November 3 and 6, 2014, cumulated rainfalls reaching 273 mm at Borzone, 153 mm at Chiavari, 269 mm at Cichero and 166 mm at Panesi raingauges were recorded (Fig. 3b; Tab. 1). Therefore, in the period between November 3 and 11, 2014 the cumulated rainfall exceeded 500 mm at Borzone and Cichero raingauges and 400 mm at Panesi raingauge.

Landslides and damage

In the evening of November 10, 2014 eight shallow landslides (Fig. 4) occurred on an area of just 160.000 m^2 (0.16 km^2). According to the landslides classifications proposed by Cruden & Varnes (1996) and Hungr *et alii* (2014), such landslides can be classified as debris slides, debris flows and debris avalanches. Shallow landslides affected terraced slopes which were characterized by different state of conservation. Abandoned terraced areas (partially invaded by mixed woods) were mainly affected by landslide activity, even though large portions of well maintained and cultivated terraces with olive grove were also scoured and damaged. However, solely one of the considered landslides affected a sparsely vegetated area. Landslide activity involved man reworked debris covers (from 0.5 m to about 3-4 m thick) and portions of the weathered and fractured bedrock. In all cases, landslide deposits reached the toe of the slope, involving one road and some sparse houses. In the south-western sector, one of such houses was destroyed by a debris flow (Fig. 4), causing two casualties, whereas a nearby service station for water supply was impacted and damaged by debris deposits, leading to a long time interruption of water distribution. Damage also affected other two houses located in the central and the north-eastern sector of the slope, respectively. The first one was impacted and partially destroyed; the second one was only damaged by landslide deposits. Long tracts of the road running parallel to the Lavagna stream at the slope's toe were buried by landslides debris, producing interruption which currently continues. As a consequence of the severe damage, all the people living on slope settlements were evacuated.

METHODS AND DATA

Historical rainfall analysis

The analysis of historical rainfall series was made with reference to the Panesi raingauge, which is the closest to the study area. This is located just 2 km SE of the study area and it has a quite continuous rainfall data records since 1935. The available data records for annual, monthly and maximum intensity (in 1, 3, 6, 12 and 24 h) rainfall cover a period of 80 years between 1935 and 2014. Some missing data were filled using records from stations located nearby to the study area in zones with climatic features similar to Panesi (Fig. 1). In particular, gaps in monthly rainfall were filled using records of Chiavari (years 1945, 1960, 1979, 1988, 1989) and Statale (2002), which are located 2.5 km S and 9.5 km E of Panesi, respectively. Regarding gaps in the maximum intensity rainfall data (1946, 1947, 1950, 1959, 1960, 1979, 1989, 1996) we referred to Chiavari (1946, 1947, 1950, 1959, 1960, 1979, 1989) and S. Martino del Monte (1996), the latter being located 2.5 km N of Panesi (Fig. 1).

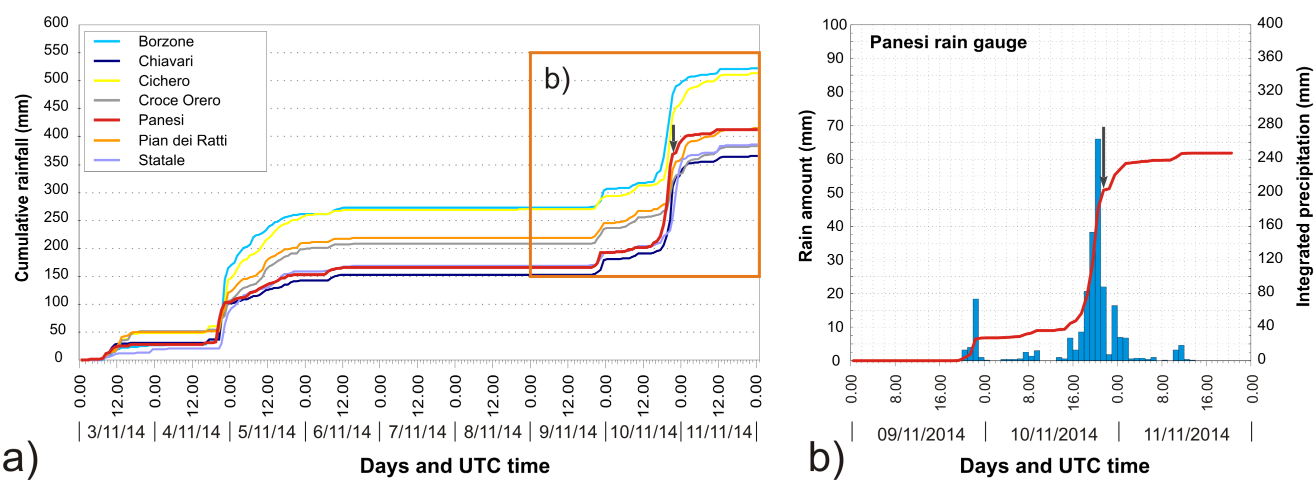

Fig. 3 - a) cumulative rainfall recorded by different raingauges located in the Lavagna, Sturla and Graveglia valleys from November 3, 2014 to November 11, 2014 (data from Regione Liguria-ARPAL 2014);. b) hyetograms (blue bars) and cumulative rainfall (red line) of November 9-11, 2014 recorded at the Panesi raingauge (after Cevasco et alii, 2015b, modified). The dark green arrows reported in a) and b) mark landslides a and a1 occurrence

Shallow landslides analysis

The shallow landslide analysis was performed using data from field surveys, which were carried out just after a few days from the landslides occurrence, and derived from the available thematic maps, different time series of aerial photographs and LiDAR data.

The purposes of the field surveys were to map, classify and identify morphological features of the rainfall-induced shallow landslides. During field surveys, in order to achieve a preliminary geotechnical characterization of the soil slope covers, disturbed soil samples were collected at different landslide source areas for grain size analysis and determination of the main physical properties. In addition, eyewitness accounts from local inhabitants were collected so as to obtain information about the time of landslides triggering. The landslides mapping was made in a GIS environment drawing landslide crowns as lines while landslide deposits and the entire landslide perimeters were drawn as polygons. The reliability of the morphological features of landslides has been also checked by means of post-event remote sensing images (Google Earth).

In order to identify the predisposing factors of rainfall-induced landslides, the available maps regarding geological, geomorphological and land use features of the study area were analysed. With reference to geology, the available maps coming from the CARG Project (Abbate *et alii*, 2011) and from the Basin Master Plan (Provincia di Genova, 2003) were consulted. In order to analyse the morphological features of the Leivi slope, a 5×5 m Digital Elevation Model (DEM), obtained by LiDAR data, was built. The LiDAR data were acquired in 2008 and 2010 by the Ministry for Environment, Land and Sea (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, MATTM), within the framework of the 'Extraordinary Plan of Environmental Remote Sensing' (PST-A). The average density of LiDAR points was 0.8 points/m^2 for coastal areas and 1.5 points/m^2 for the inland basins. The morphometric parameters of the shallow landslides were derived by the 5×5 m DEM adopting the method proposed by Di Crescenzo & Santo (2005). Land use data were obtained modifying the Land Use Map 1:10,000 scale of the Liguria Region (Regione Liguria, 2012) through the analysis of recent aerial photographs (https://www.bing.com/maps/).

The slope dynamics occurred in the last decades were studied by analyzing topographic maps and different time series of aerial photographs. The aerial photographs referred to 1974, 1982 and 1990 flights, taken from an altitude of about 2000 m (Regione Liguria, 2014), were analyzed.

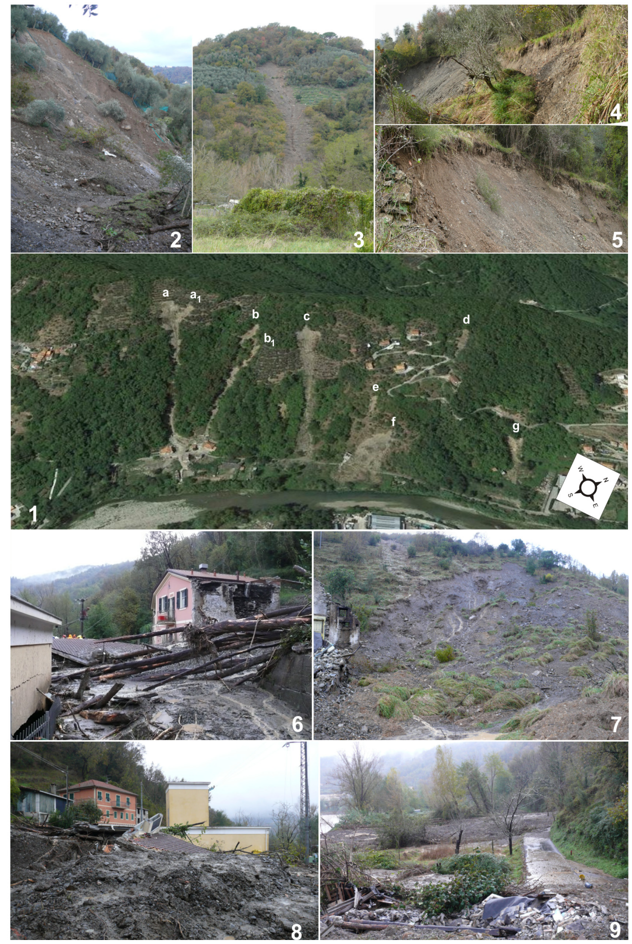

Fig. 4 - Views of the shallow landslides triggered on November 10, 2014 in the study area and related damage. 1) aerial image (from Google Earth); letters indicate the landslides; 2) detail of the source area of a large shallow landslide that gave rise to a debris flow (landslides a, a1); 3) landslide c; 4) detail of the scar of the landslide c; 5): detail of the scar of the landslide d; 6) and 8) view of the toe of the slope, where a debris flow (landslides a and a1) destroyed one building, causing two casualties; 7) landslide f; 9) damage to roads and private properties by landslide activity

RESULTS

Historical rainfall analysis

As mentioned above, the historical rainfall data recorded at the Panesi raingauge, available from 1935 to 2014, were collected and analysed. For the 80-years time period analysed, the assessed Mean Annual Precipitation (MAP) is 1164 mm, the minimum and the maximum annual rainfall are 627 mm (detected in 1981) and 2122 mm (referred to 2014), respectively (Fig. 5a). The rainiest month is November, with a mean precipitation of 166 mm, whereas July appears the driest month, with a mean precipitation of 36 mm (Fig. 5b). The maximum rainfall intensity analysis showed that the 1h peak intensity of November 10, 2014 was largely exceeded already in 1936, 1955, 1963 and 1979, as well as the 3h peak intensity, exceeded in 1936, 1953 and 1963 (Fig. 5c). Decreasing trends for 1h, 3h, 6h and 12h maximum rainfall intensity were observed in the reference period whereas there was a substantially stable trend regarding 24 h maximum rainfall intensity.

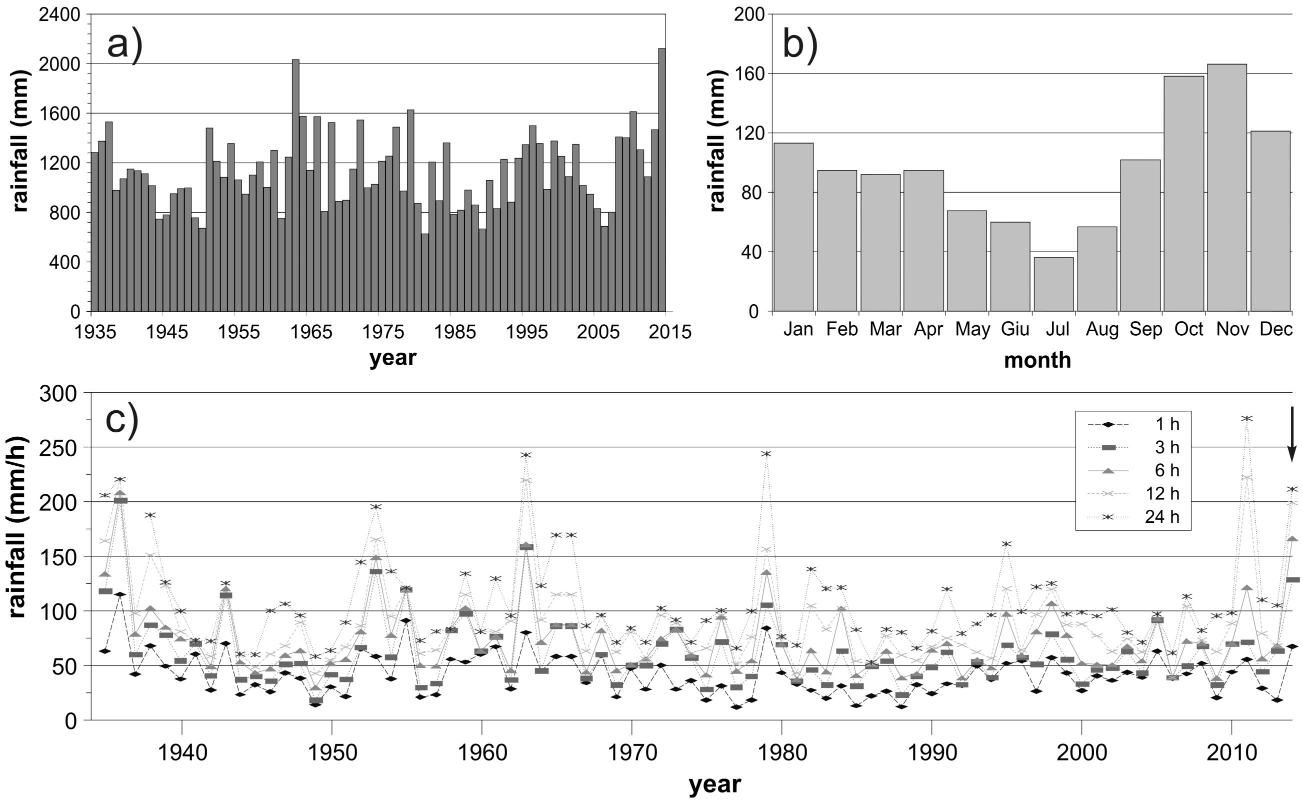

Fig. 5 - Historical rainfall data at Panesi (1935–2014 period). a) Mean annual precipitation; b) mean monthly precipitation; c) maximum intensity rainfall in 1, 3, 6, 12 and 24 h. The black arrow indicates the maximum intensity rainfall in 1, 3, 6, 12 and 24 h recorded at Panesi during the November 9-11, 2014 rainfall event

With reference to the 1963 event (which occurred on September 4th), return times higher than 50, 500 and 200 years were assessed for the maximum intensity rainfalls in 1, 3, 6 and 12 h, respectively (ARPAL-CFMI-PC, 2013). No data about the return times of the maximum rainfall intensity were available regarding the September 25, 1936 intense rainfall. However, the maximum rainfall intensity data referred to the Chiavari raingauge highlighted that the intensity values recorded on November 10, 2014 were about doubled on September 25, 1936, with maximum rainfall intensity in 1, 3, 6 and 12 h equal to 115, 201, 208 and 220.4 mm, respectively. Taking into account the distribution of the maximum rainfall intensity events in the analyzed time period, the last fifty years (1964-2014) seem quieter with respect to the 1935-1964 period. The maximum rainfall intensity values in 3 and 6 h recorded on November 10, 2014 were the highest of the last fifty years (Fig. 5c). Moreover, it is interesting to note that the value of the mean rainfall of the rainiest month (166 mm) was equalled on November 10, 2014 by the maximum intensity rainfall only in 6 h. This would suggest a strongly localized in time and space heavy precipitation event, which would explain the resulting effects at the surface.

The rainfall intensity recorded at the Panesi raingauge exceeded the worldwide (Caine, 1980), national (Brunetti et alii, 2010) and local rainfall intensity-duration thresholds (Cevasco *et alii*, 2008, 2010; Giannecchini *et alii*, 2015) for shallow landslides activation (Fig. 6). As regards the time of landslides triggering, information coming from local people and newspapers revealed that the most destructive phenomenon was triggered on November 10, 2014 between 21.00 and 22.00 (UTC), which means just before the maximum 1h intensity peak recorded at the Panesi raingauge.

Landslides analysis

Shallow landslides features and morphometric parameters

The morphological features of the landslides are shown in Fig. 7. The scars of the four main landslides that evolved into flows (a, b, c, d in Fig. 7) are located at similar height, ranging between 160 m and 185 m a.s.l. On the contrary, three shallow landslides (e, f, g in Fig. 7) initiated and affected the middle-lower slope, with scars reaching altitudes ranging between 60 and 100 m a.s.l. On-site observations showed that most of the landslides (a, b, c, d, g) initiated in hollows or in concave slopes; in all cases the landslide material reached the toe of the slope by means of a movement which can be classified from rapid to very rapid (Fig. 7).

As regards landslides morphometric parameters, the method

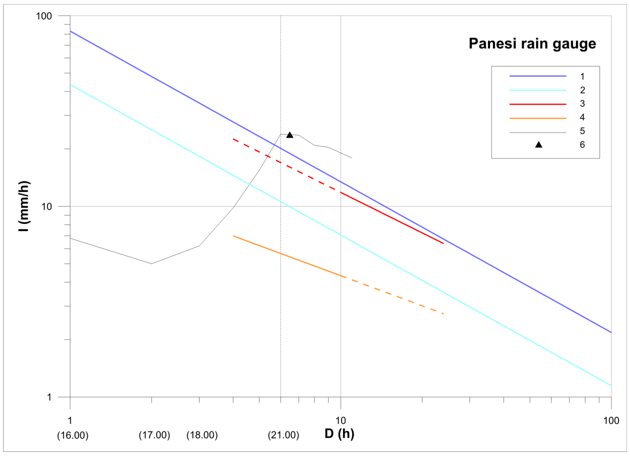

Fig. 6 - Rainfall I-D thresholds established locally for triggering shallow landslides. The UTC time is shown, in brackets, on horizontal axis. Legend: 1) Eastern Ligurian Riviera (upper) (Giannecchini et alii, 2015); 2) Eastern Ligurian Riviera (lower) (Giannecchini et alii, 2015); 3) Bisagno valley, Genoa (upper) (Cevasco et alii 2008; 2010); 4) Bisagno valley, Genoa (lower) (Cevasco et alii 2008; 2010) 5) November 10, 2014 rain path at Panesi raingauge; 6) landslides a and a1 occurrence

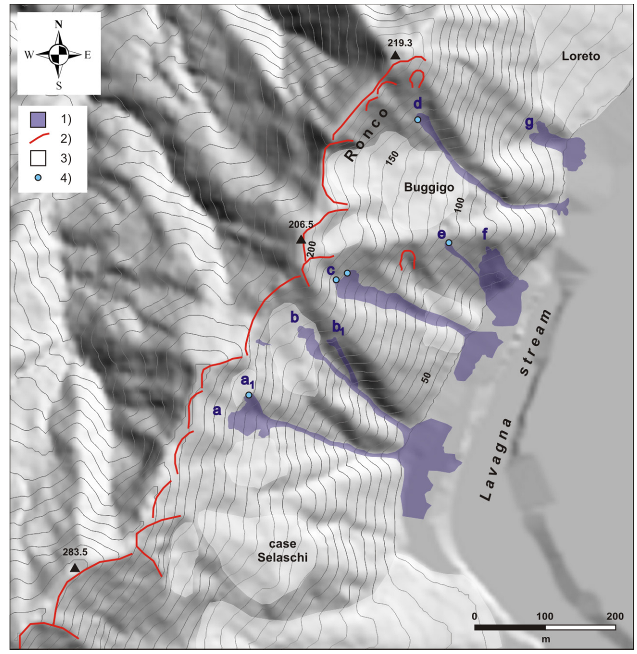

Fig. 7 - Map of shallow landslides occurred on November 10, 2014 in the Leivi slope and morphological features of ancient landslides. Legend: 1) shallow landslides occurred on November 10, 2014 in the Leivi slope; 2), 3) scars and deposits of ancient landslides detected by the analysis of topographic maps and aerial photographs; 4) location of sampling points

proposed by Di Crescenzo & Santo (2005) was applied (Fig. 8). The main morphometric parameters obtained for the four main landslides that evolved into flows (a, b, c and d) are showed in Tab. 2. They included slope angle of the crown (Cs) and of the sliding zone (Szs), crown altitude (ac), areal extent of the landslide source areas and sliding zone (Ass), areal extent of landslide deposits (Ad), length of the landslide (L), height of the landslide crown zone (Hl), slope steepness (Ss) and slope relief energy (Sre). According to Di Crescenzo & Santo (2005), the slope relief energy was calculated as the difference in height between the divide of the landslide slope (ar) and the first break of slope at the foot of the slope (fbs).

The length of landslides a, b, c, d ranges between 258 m (landslide c) and 342 m (landslide a) while the extent of source areas and sliding zones varies between about 1,800 m^2 (landslide b) and 4,000 m^2 (landslide c). The length of landslides occurred in the middle lower slope (e, f, g) is lower than the previous ones and ranging between 88 m (landslide g) and 120 m (landslide f), as well as the extent of landslide source areas and sliding zones (Ass), which ranges between 360 m^2 (landslide e) and 1800 m^2 (landslide f). In the cases of landslides a, b, c and d, the slope steepness ranges between 32° (landslide d) and 39° (landslide b) while the crown steepness varies between 30° (landslide b) and 39° (landslide d). Values of sliding zone steepness are slightly lower than the previous ones, ranging between 26° (landslide d) and 33° (landslides a and c). As for the relief energy of slopes (Sre), the landslides a, b, c and d occurred on slopes between 114 m (landslide d) and 180 m (landslide a) in height. There is a small difference between the total extent of landslide source areas and

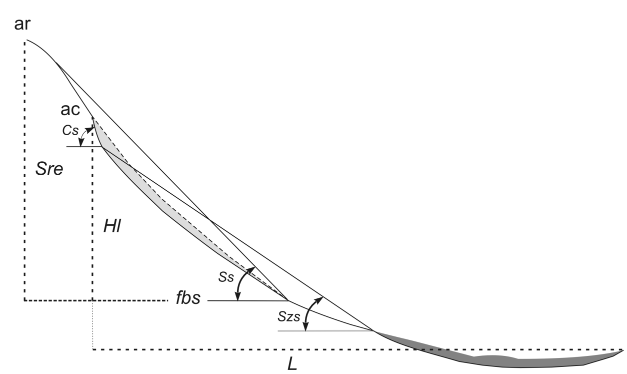

Fig. 8 - Morphometric parameters considered for the main earth-debris avalanches/earth-debris flows (after Di Crescenzo & Santo, 2005, modified). Legend: ar) altitude of the ridge (a.s.l.); ac) altitude of the landslide crown (a.s.l.); fbs) altitude of the first break of slope at the foot of the slope (a.s.l.); Sre) slope relief energy; Hl) height of the landslide crown zone; L) length of the landslide; Ss) slope steepness; Cs) crown steepness; Szs) sliding zone steepness; Ass) extent of the landslide source area; Ad) extent of the landslide deposit

sliding zones (Ass) and the total extent of landslide deposits (Ad), estimated as 14,773 m^2 and 14,944 m^2 respectively. The total area affected by landslides (source areas, sliding zones and deposits) was assessed as about 29,717 m^2.

Relations with land use and previous slope dynamics

As stated previously, in the source areas the land use setting prevalently consists of terracing characterized by different state of maintenance. Where terracing has been abandoned since short and long time, scrubs and woods had grown, respectively. As can be seen in Fig. 9, most of the shallow landslide source areas affected abandoned terracing (landslides b, b1, c, d, e, f, g), which currently appear occupied by vegetation cover of different age. In particular, the source areas of landslides b, c and d were triggered on short time abandoned olive groves, where a sparse vegetation has grown. On the contrary, the source areas of landslides b1 and g were triggered on long time abandoned olive groves, where a mixed wood had grown. The source areas of landslides e and f affected very scarcely vegetated areas. Lastly, well maintained terraces with olive grove cultivations were involved by landslides source areas belonging to landslides a and a1 (Fig. 9).

The topographic maps analysis has allowed to recognize several morphological features, such as landslide crowns and deposits, testifying ancient landslides occurrence on the Leivi slope. Information on recent slope dynamics came from the local inhabitants and from the analysis of different time series of aerial photographs (referred to years 1974, 1982, 1990). On the contrary, no information on landslides was available from the IFFI (Inventario dei Fenomeni Franosi in Italia) landslides inventory. As shown in Fig. 7, the results of these investigations revealed an active slope dynamics also in recent periods. In particular, several landslide crowns affect the top of the slope above 200 m a.s.l. whereas landslide deposits have been mainly detected in the middle-upper slope, between 100 m a.s.l. and 200 m a.s.l. In addition, a shallow landslide, quite similar to those which evolved into flows on November 10, 2014, affected the north-eastern sector of the slope before 1974. This landslide, whose crown was located slightly higher than that of landslide d, was still visible on aerial photographs of 1982, but was completely hidden by vegetation in 1990. From oral sources collected on sites, it seems that a cowshed located at the toe of the slope, exactly where one house has been destroyed on November 10, 2014, was already damaged in the 1920's. This fact highlights another important issue, already pointed out by Giannecchini & D'Amato Avanzi (2012) namely the need of mapping and carrying out a proper database of landslide events rapidly. In fact, occurrences as the November 2014 event usually produce superficial effects (shallow landslides, debris flows, floods, etc.), which are typically obliterated in a few years without any significant morphological traces. The areas involved in shallow landslides are usually re-carpeted by vegetation, while the hydraulic structure of rivers and torrents is rapidly restored, especially in urban areas.

Slope materials

In order to obtain a preliminary geotechnical characterization of the soil slope covers, five disturbed soil samples were collected

Landslide	Morphometric parameters							
	ac	L	Sre	Ss	Cs	Szs	Ass	Ad
	[m a.s.l.]	[m]	[m]	[°]	[°]	[°]	[m²]	[m²]
a	185	342	180	33.5	33.7	32.2	3,413	
a₁	181.5	333	175	32.9	36.9	32.5		7,436
b	162	270	150	39.2	30.4	32	1,819	
b₁	145	n.c.	n.c.	n.c.	n.c.	n.c.	582	
c	165	258	176	34.6	35.5	32.6	4,047	2,585
d	161	280	114	32.3	38.7	26.4	1,929	270
e	102	n.c.	n.c.	n.c.	n.c.	n.c.	362	3,100
f	74	120	n.c.	n.c.	n.c.	n.c.	1,774	
g	58	88	n.c.	n.c.	n.c.	n.c.	847	1,553

Tab. 2 - Morphometric parameters of landslides triggered in the study area on November 10, 2014 (see also Fig. 8): ac: crown altitude; L: length of the landslide; Sre: slope relief energy; Ss: slope steepness; Cs: slope angle of the crown; Szs: slope angle of the sliding zone; Ass: extent of the landslide source area; Ad: extent of the landslide deposit

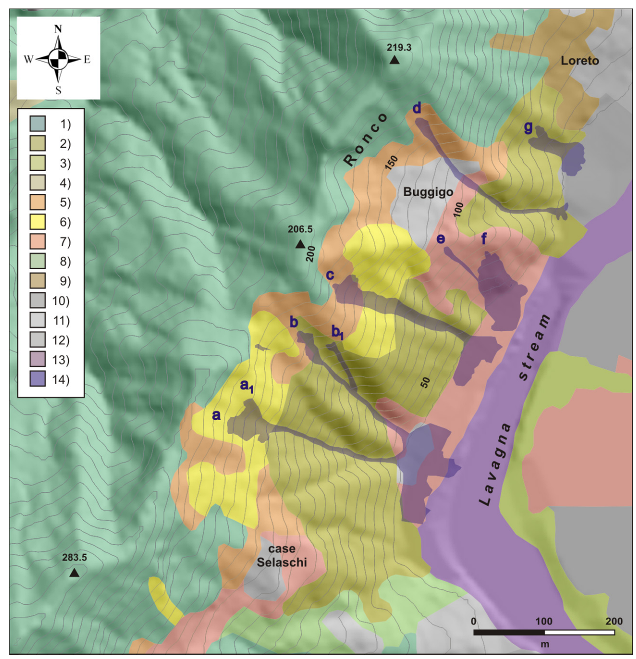

Fig. 9 - Map of shallow landslides that occurred on November 10, 2014 in the Leivi slope and land use. Legend: 1) chestnut; 2) mixed wood; 3) wood of hygrophilous species; 4) area with shrub vegetation in evolution; 5) abandoned olive grove 6) olive grove; 7) complex cropping system; 8) grassland; 9) vineyard and olive grove; 10) industrial areas; 11) sparse residential fabric; 12) dense residential fabric; 13) riverbeds with scarce vegetation; 14) November 10, 2014 shallow landslides

in different landslide source areas. Laboratory tests allowed both the soil classification and the determination of the physical properties (Fig. 10). According to the U.S.C.S. soil classification system, the soils can be classified as silty sands with gravel (SM). The results of the grain size analysis showed that the slope materials are somewhat homogeneous (Tab. 3). All the soils are very poorly sorted, with coefficient of uniformity (CU) values greater than 100. Gravel content often reaches 45%, while sand fractions are 30% on average. The fines contents are usually less than 30%, and the clay contents rarely exceed 12%. The gravel fraction consists of angular and platy pebbles with a strong fissility. Liquid limits were not very high, ranging between 29.1% and 36.2% (Tab. 4). The Plasticity Index (PI) values, ranging between 8.3% and 10.7%, show a low plasticity of the soils. Lastly, the specific gravity of the soil particles ranges from 2.5 to 2.7 g/cm³.

DISCUSSION AND FINAL REMARKS

Investigations carried out in this study provide a framework of morphological features, as well as triggering and predisposing factors, of shallow landslides that affected a slope in the lower Lavagna valley on November 10, 2011. Moreover, this study allows to overcome an important issue, already pointed out by Giannecchini & D'Amato Avanzi (2012), namely the need of mapping and carrying out a proper database of landslide events rapidly. In fact, occurrences as the November 10, 2014 event usually produce superficial effects (shallow landslides, debris flows, floods, etc.), which are typically obliterated in a few years without any significant morphological traces. The areas involved in shallow landslides are usually re-carpeted by vegetation, while the hydraulic structure of rivers and torrents is rapidly restored, especially in urban areas.

Field evidences and analyses carried out in this study show that mass movements triggered in the evening of November 10, 2014 were the result of an intense and concentrated rainfall. Nevertheless, the rainfall analysis performed in this study showed that the maximum rainfall intensity recorded at Panesi on November 10, 2014 cannot be considered so exceptional for the study area, especially if compared with rainfall intensities referred to some rainstorms that recently affected both central and eastern Liguria (Silvestro *et alii*, 2012; 2016; Cassola *et alii,* 2015; Cevasco *et alii*, 2015a; D'Amato Avanzi *et alii*, 2015). Such statement was also confirmed by the analysis of historical maximum rainfall intensity, which revealed that some events occurred in the last eighty years exceeded the intensity peaks recorded on November 10, 2014. However, currently there is no detailed information about the effects triggered by past extreme events in the study area. It is likely that, in this case study, the antecedent rainfall may have played a key role as landslides predisposing factor. Information about the runoff at the surface or about the soil capacity to absorb the rain after a few days of precipitation could be useful to clarify the role played by the antecedent rainfall in landslides activation. For sure, slope steepness and the presence of hollows, which allowed the convergence of surface and subsurface flows, played an important role in the occurrence of the studied shallow landslides. In addition, structural setting of the bedrock must be considered. In fact, various sectors of the slope have dip slope bedding. However, other predisposing factors were probably involved, such as the contrast in physical-mechanical properties and permeability between soil slope covers and bedrock but also the lack of maintenance of dry retaining walls.

Investigations aimed at a better geotechnical and hydraulic characterization of soil slope cover involved in landsliding have been also undertaken. However, until completed it will not be possible precisely establishing a specific predisposing factor nor

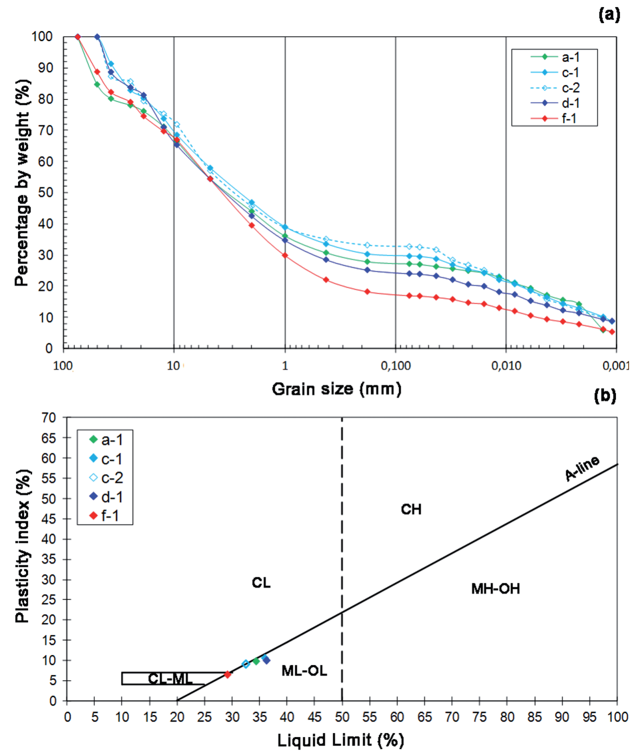

Fig. 10 - Grain size distribution (a) and Casagrande Plasticity Chart (b) of the soil samples collected at different landslide source areas

Sample	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	USCS	CU
a-1	45.5	27.3	14.9	12.3	SM	>100
c-1	42.0	28.3	17.7	12.0	SM	>100
c-2	42.9	24.4	21.3	11.4	SM	>100
d-1	45.5	30.4	13.3	10.8	SM	>100
f-1	45.5	37.4	9.7	7.3	SM	>100

Tab. 3 - Grain-size distribution parameters and USCS classification of the soil samples collected in different landslide source areas (CU coefficient of uniformity)

Sample	LL (%)	PL (%)	PI (%)	γ_s (g/cm³)
a-1	34.3	24.4	9.9	2.69
c-1	35.9	25.2	10.7	2.51
c-2	32.5	23.4	9.1	2.54
d-1	36.2	26.1	10.1	2.56
f-1	29.1	20.9	8.3	2.50

Tab. 4 - Atterberg limits and physical properties of fine-grained portion of soil samples collected in different landslide source areas (LL liquid limit, PL plastic limit, PI plasticity index, γ_s specific gravity of the soil particles) understanding the failure mechanism referred to each landslide. Probably, a physical modelling basing on a detailed and robust geotechnical and hydrogeological soil characterization will be useful in order to achieve these purposes.

Nevertheless, some additional comments, particularly regarding the effects of November 10, 2014 rainstorm and current land planning tools, can be currently made. Although the event was properly predicted and the maximum level of alert state for Civil Protection declared, this example demonstrates that the methods adopted in land planning for the landslide susceptibility and risk assessment should be improved. Despite the fact that the Leivi slope was included in the medium-high degree class of landslide susceptibility of the Basin Master Plan (Provincia di Genova, 2003), the foot areas, where the impact of the debris damaged the buildings, fell in the medium-low degree class of landslide susceptibility. As a consequence, since in these areas there were only a few scattered settlements, the level of risk was just moderate or low. This fact undoubtedly suggests the importance of improving the existing planning tools in potentially exposed areas. This could be achieved taking into account the hazard and risk associated to the shallow landslides runout in potentially exposed areas. In other words, we believe it is necessary to implement the susceptibility maps considering the distance coverable by runout in relation to the different types of mass movement but also assessing the exposure of manmade structures that could be potentially intercepted by shallow landslides and debris flows. From this point of view, proper numerical models based on the morphologic features of the slope and on the reology of the mobilized materials could be helpful in forecasting the area exposed at risk.

A last comment focuses on land management. As the Cinque Terre zone, which was severely affected by shallow landslides in 2011, some portions of the study area are still well maintained by few local farmers working on agricultural terracing. A long-term prevention strategy for landslide risk mitigation is desirable. The aim of this strategy may not only be planning a series of structural measures, but it should (Brandolini & Cevasco, 2015; Brandolini *et alii*, 2016; Galve *et alii*, 2016; Diodato *et alii*, 2017). also support wide restoration of abandoned terraces, recovery of drainage systems, maintenance and management of wooded areas.

It is also expected to extend the analyses to the whole area affected by shallow landslides. However, we believe the results obtained can be helpful in shallow landslide modelling, hazard assessment and planning of appropriate risk mitigation measures.

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