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PS-driven inventory of town-damaging landslides in the Benevento, Avellino and Salerno Provinces, southern Italy

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ABSTRACT

The Apennine provinces of Campania Region (southern Italy), Benevento, Avellino and Salerno, are known for their ‘unstable towns’ suffering periodic damage from landslides. Their identification and mapping are very challenging tasks, since boundary mapping under urban settlements is not always possible without time-consuming field analysis of building damage and/or expensive mid-term diffuse ground-surface deformation monitoring. To overcome this problem, an inventory of town-damaging landslides, guided by available Permanent Scatterers (PS) ground-deformation data, was prepared. It provides an updated tool suitable to guide future land planning and historical site restoration in the Apennine provinces of Campania Region. Our fourteen Map Sheets show active and local reactivation of suspended/dormant landslides. Overall, 356 landslides were identified, amongst which 162 were identified as flows, 101 as slides, 1 as a spreads and 92 as complex landslides. To supplement our maps, a simplified distribution analysis based on major landslide morphometric characteristics was completed.

1. Introduction

Inventory maps are of basic importance for landslide hazard and risk assessment, documenting landslide location, extent, distribution and typology (e.g. Brabb, 1991). As underlined by Guzzetti et al. (2012), the preparation of a landslide inventory relies on few basic assumptions that guide and limit landslide detection and mapping: (a) Landslides leave discernible signs, most of which can be recognized, classified, and mapped … Most of the signs left by a landslide are morphological … , (b) The morphological signature of a landslide depends on the type and the rate of motion of the mass movement … the same type of mass movement will result in a similar landslide signature, (c) Landslides do not occur randomly … Knowledge on landslides can be generalized, and information on failure gained in an area can be used to detect and map landslides other areas, (d) For landslides, geomorphologists adopt the principle … of uniformitarianism … recognizing recent slope failures is important to detecting and mapping past landslides. Following these assumptions, landslide inventories are often prepared through visual interpretation of aerial and satellite imagery (Mondini et al., 2011), geomorphological field mapping, and visual interpretation of high-resolution LiDAR data (e.g. Conforti, Pascale, & Sdao, 2015; Conforti, Pascale, Pepe, Sdao, & Sole, 2013; Guerriero et al., 2012; Lazzari & Gioia, 2016; Lazzari, Gioia, & Anzidei, 2018; Murillo-García & Alcántara-Ayala, 2017). Both interpretative and field mapping are oriented to the identification of the landslide boundary, and, the collection of general information like typology, age, activity, estimated depth, and velocity. In natural landscapes, the identification of a landslide can be limited by dense vegetation or by the absence of a well-defined boundary. In these conditions, the combination of multiple perspectives derived by the analysis of aerial imagery and the direct observation in the field is often the key to accurately report a landslide and its mesoscopic features in a map (e.g. Ardizzone et al., 2012; Calista et al., 2016; Guerriero et al., 2013; Guerriero et al., 2016; Guerriero et al., 2017a; Revellino, Grelle, Donnarumma, & Guadagno, 2010; Santangelo, Gioia, Cardinali, Guzzetti, & Schiattarella, 2015). Conversely, in urban areas, landslide identification is not always possible due to the masking action of urban settlements. This can result in the incompleteness of the inventories and consequently in the lack of crucial data for local risk evaluation. In this condition, the analysis and classification of building damage as well as diffuse ground surface deformation monitoring might help landslide delineation (e.g. Del Soldato et al., 2017; Infante, Confuorto, Di Martire, Raimondini, & Calcaterra, 2016), even if periodic human
restoration activities can make past structural failures not recognizable, and surface monitoring might be very expensive (e.g. Guerriero, Guerriero, Grelle, Guglielmo, & Revellino, 2017b).

In the last decades, the long-lasting availability of SAR imagery from different satellite platforms has provided an opportunity to measure millimetric deformation of the Earth surface using Differential Interferometric Synthetic Aperture Radar (DInSAR) techniques (e.g. Bru et al., 2017; Confuorto et al., 2017). In 2002, the Italian Ministry for Environment, Land and Sea Protection funded the Not-Ordinary Plan of Environmental Remote Sensing (in Italian, Piano Straordinario di Telerilevamento Ambientale, PST-A) to build up a national database of active or potential instability phenomena based on SAR-derived deformational data on the whole Italian territory (e.g. Costabile, 2010). In this framework, Persistent Scatterers (PS) deformation-rate data were produced by using Persistent Scatterers Interferometry SAR technique (PSInSAR, Ferretti, Prati, & Rocca, 2001) of ERS1/ERS2 and ENVISAT SAR images acquired between 1992 and 2008. In a second phase, the existing dataset was updated through processing of ENVISAT SAR images acquired between 2008 and 2010. Image processing provided a total of about 14 million of PSs derived from ERS imagery and 28 million of PSs derived from ENVISAT imagery. Subsequently, a new database updating has been completed through the processing of COSMO-SkyMed data acquired, between 2011 and 2014, over selected areas of Italy (100 frames for 7.400 km² of its territory). These areas were also ground validated, updating the national landslide database (Costantini et al., 2017; Di Martire et al., 2017).

PS data derived from SAR imagery, acquired during the PST-A, have been already used as basis for updating regional landslide inventories. For instance, Rosi et al. (2018) used ERS and Envisat derived PS data to update the landslide inventory of Tuscany. On this basis and considering the need for an updated tool to guide future urban planning and preserve historical sites of high cultural value in the Apennine Provinces of the Campania Region (Benevento, Avellino and Salerno), well-known for their ‘unstable towns’ (see ‘Studio dei centri abitati instabili della Regione Campania’ Study of Campania Region unstable towns, in English, De Riso, Di Nocera, & Pescatore, 2005, Figure 1), ERS and Envisat PS data, recently acquired digital orthoimages and field data were used to derive an inventory map of town-damaging landslides. Our maps represent a contribution toward a better understanding of landslide risk in urban areas of Campania Region, and can be considered as a supplement of existing regional and local inventories and an update of the above mentioned Studio dei centri abitati instabili della Regione Campania. Additionally, our maps have the potential to guide further site-specific analyses of the long-term instability of damaged towns, and the possible evolution of the processes also connected to earthquake occurrence in a very complex geological environment (e.g. Vitale & Ciarcia, 2018).

2. Data and mapping method

The 1:40,000-scale inventory maps of town-damaging landslides of the Benevento, Salerno and Avellino Provinces, were produced using multiple data and mapping methods. For a small part of the Salerno province, the inventory map was not produced because of the absence of actively town-damaging landslides (see Figure 1). In detail, landslide identification and delineation were completed using PS data derived from PSTA-1 (i.e. ERS and Envisat imagery), high-resolution orthoimages, Digital Elevation Models (DEM) and, in selected cases, field observations. For our analysis ~670,000 PSs have been selected. The digital orthoimages are DigitalGlobe high-resolution (<1 m single sided pixel dimension) imagery acquired in September 2018, while the DEM is derived by the 10 m TINITALY DEM (single sided pixel dimension; Tarquini et al., 2007) using a moving-window low-pass Gaussian operator. Field observations were conducted in selected cases of particular complexity. Specifically, we documented both the presence of the morphologic signature of landslides and multiple types of damage to
structures and infrastructures. The scale of field observation was consistently lower than that of our maps, so that in few cases multiple landslides (coalescent landslides, sensu Hansen, 1984; and Revelino et al., 2010; landslide complexes, sensu Parise & Jibson, 2000) were grouped and reported in the maps as complex landslides. In this perspective, these landslides can be considered as kinematic elements of the mapped landslide.

Landslide identification and mapping was completed into a GIS environment in two subsequent steps. As a first step, both ascending and descending PS data were used to identify the presence of potential unstable areas as a function of their geodetic signature (i.e. PSs ground deformation rate). For unstable area identification, only PS data showing an average velocity higher than 3 mm/year (∼32,500 PSs) were considered, for both geometries and for westward and eastward movement directions. This value was determined multiplying two times the threshold values for the identification of the stability range indicated by the data provider (e.g. Rosi et al., 2018). In this way we expect to obtain a more reliable distribution of slope deformation across complex terrains. Landslide identification was completed within a defined area using a buffer of 500 m from the boundary of mapped towns. Once identified the geodetic signature, landslides were mapped through visual interpretation of recent orthoimages and digital topography. Local field observations were used to improve landslide boundary positioning and overall geometry. Especially, in cases where just one or a few PSs indicate slope deformation (e.g. Ponte). In addition, field observations and orthoimage analysis were used to update our interpretation of the state of activity of landslides previously defined with ERS-Envisat PSs (e.g. Sturno and Frigento area). Among data acquired in the field, building damage indicators and interviews to locals oriented to the definition of date of formation of new features indicating landslide activity across the ground surface and on buildings/infrastructures assumed key importance. In this way the perception of locals that live in unstable areas of the ongoing landslide movements guided our interpretation (e.g. Guerriero et al., 2015). It is important to notice that deformation data extrapolated by PSInSAR technique are limited to LOS displacements lower than λ/4 between two consecutive images (e.g. Colesanti & Wasowski, 2006). For ERS and Envisat imagery, λ/4 equals to 1.4 cm that, considering a revisiting time of 35 days, corresponds to a velocity of 14.5 cm/year. Thus, our PS driven analysis is oriented only to the identification of very/extremely slow moving landslides (Cruden & Varnes, 1996). Large displacement characterizing fast-moving landslide cannot be tracked by this technique.

For our 14 Map Sheets, terminology and classification simplified from Cruden and Varnes (1996) were used. In this way, each landslide was described in the map reporting the interpreted type of movement (i.e. sliding, flowing, spreading), the state of activity (active, suspended/dormant), and position and extent of major morphological elements like source zone and toe region. Following Cruden and Varnes (1996), landslides showing multiple types of movement were considered as characterized by a complex style. All of the active landslides, involving part of an urban area or located very close to them, were reported in the maps as well as suspended/dormant landslides characterized by a partial/local reactivation. Despite the local presence of PS data indicating ongoing ground deformation, we did not consider and map landslides involving major infrastructures outside or far from urban areas. Similarly, we did not take into account vertical deformation in flat areas induced by subsidence and sinkhole phenomena.

Each Map Sheet contains a shaded relief base map created using the available DEM and ascending PS data. Descending PS data were reported in 1:15,000 scale inset-maps (i.e. Descending inset) created for locations where these data better represent the ground deformation induced by landslides. The choice of showing only ascending PS data in the Map Sheets is motivated by their completeness over the study area. In contrast, descending PS data have only a partial coverage for the Benevento, Avellino and Salerno provinces. Where needed, inset maps are reported along the upper or the left side of the Map Sheet and show mapped landslides, towns and descending PS data over a shaded relief base map.

3. Landslides affecting towns

Our inventory includes 14 maps depicting 356 landslides, 101 of which are slides, 162 are flows, 1 is a spread and 92 are complex landslides (Table 1). Map Sheets no. 1, 2, 3 and 4 report landslides mapped within the Benevento Province. Map Sheets no. 2, 3, 4, 5, 6, 7 and 8 report landslides mapped within the Avellino Province. Map Sheets no. 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15 report landslides mapped within the Salerno Province.

In the Benevento Province a total of 79 town-damaging landslides were identified, 48 classified as flows, 18 as slides, and 13 as complex (Table 2). No landslide showing spreading mechanism was identified. Only 4 landslides were identified as a partial reactivation of a larger suspended/dormant landslide body. In the Avellino Province a total of 75 town-damaging landslides were identified, 37 classified as flows, 22 as slides, and 16 as complex (Table 3). No landslide showing spreading mechanism was identified. Only 2 landslides were identified as a partial reactivation of a larger suspended/dormant landslide body. In the Salerno province a total of 202 landslides damaging towns were
identified, 77 classified as flows, 61 as slides, and 63 as complex (Table 4). A single landslide showing spreading mechanism was identified. Only 2 landslides were identified as a partial reactivation of a larger suspended/dormant landslide body.

Graphs of Figures 2–4 show the distribution of the landslides (total and for each specific type) of the Benevento, Avellino and Salerno Provinces, respectively, in terms of total axial length, total area and average slope angle. Overall, flow-type landslides are longer, have a larger area and move along less inclined slopes, in comparison with slides and complex landslides. Spreads are not considered for this kind of analysis since their number have not statistical significance.

It is worth to mention some mapped landslides involving the towns of Castelpagano, Civitella Licino, Casalduni, Cautano, Foiano di Val Fortore and Paupisi, in the Benevento Province, Bisaccia (already studied by Di Martire, Novellino, Ramondini, & Calcaterra, 2016), Senerchia (Savage & Wasowski, 2006), S. Andrea di Conza, Banzano and Calitri (Martino & Mugnozza, 2005), in the Avellino Province, and Valva, San Cipriano Piacentino, Acquara, Castel San Lorenzo, Postiglione, Moio della Civitella, Centola, Roccacloriosa, San Giovanni a Piro and Alfano, in the Salerno Province.

These landslides have had tangible effects on buildings and local infrastructures that needs periodic restoration (e.g. Figure 5). Despite such effects, some of these landslides are not reported in the IFFI landslide inventory (in Italian, Inventario dei Fenomeni Frasosi in Italia, Trigila, Iadanza, & Spizzichino, 2010; e.g. Castelpagano, Casalduni, Cautano,
Senerchia, S. Andrea di Conza, Banzano, Valva, San Cipriano Piacentino, Acquara, Centola, Roccagloriosa, San Giovanni a Piro) or their mapped boundary is not consistent with our current interpretation based on orthoimages, topography and PS ground deformation data (e.g. Civitella Licino, Bisaccia, Calitri, Postiglione, Castel San Lorenzo, Moio della Civitella, Alfano, San Giovanni a Piro).

4. Conclusions

Our 1:40,000-scale, Map Sheets report position, extent and typology of active and locally active suspended/dormant landslides damaging urban areas of the Apennine provinces of the Campania region in southern Italy. They represent an updated contribution toward a better knowledge of landslide processes affecting towns and have the potential to support urban planning and historical sites restoration in the Benevento, Avellino and Salerno Provinces, already known for their ‘unstable towns’. In our opinion, this might be related to (i) the objective difficulty in landslide identification under urban settlements, without (or with limited) field recognition and settlement-damage analysis, and (ii) a possible recent evolution of detected landslides, many of which are characterized by intermittent kinematics controlled by different triggers (e.g. rainfalls, earthquakes and anthropogenic activities). The use of PS ground deformation data as a guide allows to overcome this drawback and made our maps able to support further analyses of selected cases of particular interest for their characteristics and impact on the society. In this perspective, since the investigated area is among the most active seismic areas in Italy, our inventory might be of basic importance for a re-evaluation of the stability of urbanized slope under seismic conditions. In addition, our PS distribution indicates high-velocity values in correspondence of urban centers located in alluvial plains and/or littoral zones (e.g. Benevento, Sarno, Nocera Superiore, Castel San Giorgio, Eboli, Capaccio etc …). These velocities...
could be potentially connected to ground subsidence phenomena, due to sediment compaction and/or groundwater exploitation, that might be the object of future researches.

Software

The map was made using Golden Software Map Viewer 8. Landslide mapping through PS data, DEM and orthoimages interpretation was completed using Quantum GIS, Open Source Geographic Information System, licensed under the GNU General Public License. Quantum GIS is an official project of the Open Source Geospatial Foundation (OSGeo, public domain software).

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No potential conflict of interest was reported by the authors.

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