Geomorphologic landslide inventory by air photo interpretation of the High Agri Valley (Southern Italy)

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ABSTRACT
Landslide inventories provide the knowledge basis for many geomorphological applications and also planning and emergency management. Detailed landslide inventories should also be prepared where pre-existing inventories are available, as knowledge updates. In this paper, we present a new geomorphological landslide inventory for an area of the High Agri Valley, Southern Italian Apennines. The map was prepared through systematic interpretation of historical aerial photographs testing extensive use of anaglyph glasses in StereoPhoto Maker freeware. A total of 2124 landslides were classified based on the type of movement, estimated depth, estimated relative age and three levels of uncertainty, providing landslide attributes and map constraints useful for land planning and hazard studies. The map also documents the relationships between landslides and fluvial landforms of different generations, recording important information to investigate the geomorphological evolution of the area further. We expect that landslide mapping in similar environments will benefit from the workflow here presented.

1. Introduction
Knowledge of the spatial and temporal distribution of landslide phenomena is crucial to investigate landscape evolution and its relationships with human activities and land management. The easiest way for describing the distribution of landslides in a territory is by preparing landslide inventory maps (LIMs). If event landslide inventories portray the distribution of landslides triggered in a territory by a particular event (seismic, meteorological, volcanic or anthropic, Ardizzone et al., 2012, 2007; Giordan et al., 2017), geomorphological inventories can be defined as maps that report the cumulative effect of many events through the last (tens of) thousands of years (Bucci et al., 2016a; Guzzetti et al., 2012).

Due to the importance of landslide mapping to assess landslide susceptibility and hazard, a growing number of LIMs have been compiled (Cignetti et al., 2019; Santangelo et al., 2014) at different scales and by different methods and criteria, mainly scattered over areas where landslides caused victims and damage to infrastructures and cultural heritage (Bentienga et al., 2015; Giordan et al., 2020; Niculiţă et al., 2016; Zumpano et al., 2020).

Despite the fact that geomorphological LIMs are particularly useful for land management and planning, their widespread use over large areas is rather limited due to their inhomogeneous spatial distribution and the use of different mapping criteria, classifications and methods (Guzzetti et al., 2012).

Here, we present a new geomorphological LIM for the NE mountainous margin of the High Agri Valley, Southern Italy, where landslides of different types and sizes are abundant, and their relationships with the geological structures, although locally documented (Bucci et al., 2019), remain largely under-explored.

2. Study area
The study area extends for 235 km², between 40°16′ and 40°29′N, and 15°44′ and 15°59′E, in Southern Italy (Figure 1(A)). The Bifurno and Pesco streams, flowing from SW to NE into the Camastra river, drains a little part (45 km²) of the area toward NE. Most of the area (190 km²) is drained by the Agri River (Figure 1(B)), which flows from NW to SE and encompasses the NE flank of the upper Agri basin, an NW–SE-trending fault-bounded post-orogenic trough formed in the Quaternary in the central part of the Lucania Apennines (Figure 1(C)).

The upper Agri basin is filled by Quaternary continental deposits that cover complex assemblages of pre-
Quaternary sedimentary rocks (Giocoli et al., 2015, Figure 1(C)) comprising Mesozoic to Cenozoic platform limestone deposited on top of Upper Triassic dolomite of the Apennine platform domain (Palladino et al., 2008). Clay and sandstone deposited in deep-sea conditions (Liguride and Sicilide units; Bonardi et al., 1988) tectonically overlie carbonate rocks of the Apennine platform domain, which in turn were thrust on top of coeval pelagic rocks of the Lagonegro domain and on younger Miocene synorogenic siliciclastic sediments (Pescatore et al., 1999). Exposure of these rock assemblages dominates the study area, where carbonatic antiformal ridges prevail in the western and central parts, while terrigenous reliefs are widespread eastward. Elevation in the area ranges from 532 m (coastline of Pertusillo lake) to 1835 m (top of Monte Volturino).
with a maximum relative relief approaching 1000 m along the western slopes of the Monte Volturino and II Monte (Figure 1(B,D)) summits.

3. Methods

The geomorphological LIM was prepared through systematic visual interpretation of two sets of black and white, stereoscopic aerial photographs acquired in 1955 and 2003, both at 1:34,000 scale. The aerial photographs, in digital format at 300 dpi resolution, were interpreted using the freeware StereoPhoto Maker (SPM, http://stereo.jpn.org/eng/stphmkr/) that allows for the anaglyph or shutter glasses 3D view of stereo-pairs. SPM can perform an automatic or manual relative orientation of the images and allows for manual colour adjustments (contrast, light, hue and saturation) and alignment. These features provide the possibility to set up the interpretation work in a few seconds. As a drawback, SPM does not allow yet for any digitisation of features in the 3D environment, but features have to be manually drawn on a topographic base map on the fly. This could introduce some error in the final map in terms of positioning, size and geometry of each landslide, particularly for small ones (Santangelo et al., 2015).

The continuous zoom capability of SPM can be as little as 5% and overcome 200%, which makes it very easy to pass from general overviews to highly detailed views (Figure 2). From this point of view, SPM is more powerful than continuous zoom optical stereoscopes, which usually do not allow general overviews.

As a further advantage, SPM allows opening multiple instances simultaneously, which allows observing more than a single stereo-pair at once. In this study, we used this feature by loading simultaneously images of 1955 and 2003. Comparing the appearance of the landscape in different epochs can reduce uncertainty in the interpretation. To further reducing subjectivity in mapping, SPM allows for multiple operators examining simultaneously the stereo-pairs, which is comparable to the "discussion" stereoscopes feature. Finally, limited support for polarised glasses makes the use of anaglyph glasses unavoidable, which causes eyestrain in case of intensive use.

Interpretation of the aerial photographs was aided by field surveys and the review of historical and bibliographical data, including geological and geomorphological maps (Bucci et al., 2012; Giano, 2016; ISPRA, in press-a; Zembo, 2010; in press-b), and the available landslide inventories (Lazzari & Gioia, 2016, 2018) produced within a national-scale LIM (Trigila et al., 2010) at 1:10,000 scale.

The geomorphological information was directly drawn on a digital topography, which consisted of a high resolution (1 × 1 m) LiDAR DEM and the 10-m spaced derived contour lines superimposed to it to represent multiscale landforms.

Landslides recognised in the study area were classified according to Cruden and Varnes (1996) and Hungr et al. (2014). In addition, according to WP/WLI (1990, 1993, 1995) landslides were classified based on the estimated depth (as shallow or deep-seated), the inferred relative age (as relict, very old, old or recent), and the degree of uncertainty (identification, delineation and classification). For the deep-seated landslides, the crown area marking the upper part of the depletion zone was mapped separately from the deposit. Finally, the landslide map was completed by mapping other geomorphological elements associated with slope evolution.

Figure 2. Examples of stereoscopic aerial photographs prepared using the freeware StereoPhoto Maker (SPM). (A) – Simultaneous view of more than a single stereo-pair on each display. (B) – Zoom capability of SPM which makes it very easy to pass from general overviews (5%) to highly detailed views (200%). A vertical two panels figure illustrates the digital aerial photographs in anaglyphs mode, prepared using the freeware StereoPhoto Maker (SPM). Panel A shows two computer screens, each displaying two anaglyphs prepared for the photo-interpretation of two different flights. Panel B shows four progressively detailed enlargements, namely of the 5%, 50%, 100% and 200%, of an artificial dammed lake. The images reveal the zoom capability of SPM, which allows for a multiscale investigation of the landscape.
Figure 3. Details of the Main map showing separately the three main groups of geomorphological elements reported in the legend. (A) – Different landslide types; landslide scarp and deposit represented differently. S, slide; SEF slide-earth flow; EF, earth flow; RF, rockfall; DF, debris flow; Sk, sackung. Subscript E, escarpment; subscript D, deposit; subscript C, channel. (B) – Widespread landslide processes; no distinction is made between source and deposit. WRF, widespread rockfalls; WRF/WDF, widespread rock fall/debris flows; WDF, widespread debris flows; T, talus. (C) – Geomorphological elements other than landslides; they include alluvial plain and alluvial fan deposits. AD, alluvial deposits; AFr, recent alluvial fan; AFO, old alluvial fan. (D) – Relationships amongst landslides and old and recent alluvial fan deposits. See text for further comments. A four panels figure separately illustrates the main group of geomorphological elements in map, using a shaded relief as background. Panel A, shows a landslide dominated area, where the different landslide types in the legend are all represented. Landslide scarp and deposit are represented differently. Panel B illustrates a detail of Panel A reporting widespread landslide processes, with undistinguished source and deposit, mainly represented by diffuse rockfalls and debris flows along steep slopes, and talus where slope decreases. Panel C shows a recent alluvial fan at the outlet of a high gradient stream, which covers a larger old alluvial fan partially dismantled by minor watercourses draining toward the alluvial deposit and the main course of the Agri River. Panel D shows widespread slides and slide-earth flows, which surround an isolated relief and rest with their feet on the valley floor. Here, several alluvial fans punctuate the outlets of minor streams draining the larger landslide deposits.
3.1. Definition of the legend

An important preliminary step to the preparation of LIMs is the definition of a legend, that is the types of objects that the interpretation will identify and formalise in the map. Information reported in the legend is generally compatible with the (i) techniques used for the landslide inventory making, (ii) morphological characteristic of the area (e.g. the landslide type expected) and (iii) scale of the final map. A legend imposes that interpreters systematically adopt the same scheme for their interpretation, and it prevents non-systematic errors, which are the hardest to correct once the work is at an advanced state.

This paragraph deals with the definition of the legend adopted to classify landslide types of movement (3.1.1), landslide relative age (3.1.2) and the levels of uncertainty in mapping (3.1.3), and other geomorphological features (3.1.4).

3.1.1. Landslide types

Landslide types included in the legend of the LIM are (i) slide, (ii) earth flow, (iii) slide-earth flow, (iv) debris flow, (v) rockfall and (vi) sackung (Figure 3(A)). Within the ‘slide’ item, rotational and translational landslides were considered. Such failures present a well-defined scarp which can be semicircular (rotational slides) or angular (translational slides). The slides deposit is convex in both cases, but it is usually less regular for translational slides. In both cases, it is reasonable to expect a volume balancing between escarpment and deposit areas since slides are usually characterised by low mobility of landslide material.

Earth flows are landslides characterised by an overall elongated planar shape, with the median part narrower than detachment and accumulation zones. The mobility of earth flows is generally higher than slides, which is also evident in their more elongated shape.

Slide-earth flows are landslides that initiate as slides, then evolving into flows. Therefore, they show the characteristics of slides (most commonly rotational) in the escarpment area, whereas the transport zone and accumulation zone are more similar to earth flows.

Debris flows are rapid-moving landslides that occur along steep slopes. They are shallow features that consist in the detachment of the debris cover along steep slopes due to runoff along channels or open slopes. Leves and tongue-shaped deposits are marked features of the deposition area of debris flows that make them highly recognisable.

Rockfalls are fast-moving landslides that occur along steep rocky slopes. Talus or debris slopes at the foot of sub-vertical cliffs represent the distinctive elements of rock falls.

A sackung is a deep-seated gravitational slope deformation strictly linked to the local tectonic discontinuities (Agliardi et al., 2009; Coltorti et al., 2009 Nemčok, 1972; Zischinsky, 1969). A slope affected by sackung is gently more convex than surrounding slopes, with the most deformed part generally concentrated at the top, where arched systems of scarps and counter-scarps can be from poorly visible to very well-developed (similar to horst and graben systems).

Other features in the LIM represent areas where individual landslides and slope deposits were too small to be represented at the scale of the map, thus requiring that those features were generalised in, (i) areas affected by debris flow, (ii) widespread rock falls, (iii) associated rockfalls and debris flows and (iv) talus (Figure 3(B)). In the LIM, also linear features are reported, such as debris flow channels and debris flow source areas. They are all features that are unsuitable to draw as a polygon at the publishing scale of the map.

3.1.2. Landslide relative age

Landslides were also classified according to their estimated relative age (sequential panels at the bottom of the Main Map) applying two criteria. The first was indicated by Keaton and DeGraff (1996). According to it, the morphologic and radiometric evidences of landslides become less and less evident (and more difficult to detect) with the increasing age, due to erosion processes and vegetation growth. Such pieces of evidence were also referred to as ‘morphologic radiometric signature’ by Fiorucci et al. (2018). Depending on this criterion, we identify relict landslides, very old landslides and old landslides. Relict landslides appear dissected, heavily dismantled, so that part of their original border has to be inferred, and they are suspended over the present-day local base level (Migoni et al., 2014). Very old landslides are less dismantled than relict landslides, and they mainly differ from relict landslides because they are yet connected to the present-day local base level. Old landslides appear clearly and poorly to not dismantled or dissected, and their borders appear continuous or solely interrupted by slope failures belonging to subsequent generations. They are connected to the local base level and can show signs of (partial) reactivation in aerial photographs of different epochs. The second criterion adopted to classify landslides relative age is a cross-cut criterion. Younger landslides cover the older ones. This criterion allowed us to detect four landslides generations within the old landslides, one generation within the very old landslides, and two generations within the relict landslides. As opposed to the three major age classes, the minor subdivisions can be applied only to landslides that overlap. Therefore, within the same age class (e.g. ‘old’), no relative age information is given for landslides that have no spatial relationship.
3.1.3. Mapping uncertainty

Uncertainty levels associated with each landslide were also defined, namely, uncertainty in landslide: (i) delineation, (ii) classification and (iii) identification (Panel LU in Main Map). A landslide that was mapped with uncertainty in the delineation was clearly detected and classified. However, at least in some locations along the border, the delineation was not unambiguous, which may have led to mapping errors in the area and/or location and shape of the landslide (Ardizzone et al., 2002). When also classification is involved, it means that even fewer evidences were present to correctly delineating the landslide and defining its type of movement. In this case, there is also a potential thematic error in the final LIM. Finally, in some cases, landslides appear strongly dismantled, their borders are partially inferred as no more evident, and they are particularly large and not unambiguously defined as slope failures (Goetz et al., 2014). In such cases, also uncertainty associated with landslide identification was assigned to the feature reported in the LIM.

Arguably, errors and uncertainties arise and become increasingly important with the increasing age of landslides. This is evident looking at Panel LU in Main Map, where landslides have been coded based on their degree of uncertainty. Only relict and very old landslides show degrees of uncertainty, as opposed to old landslides, which are considered all certain, in delineation, classification and identification.

3.1.4. Other geomorphological features

Finally, other geomorphological features such as alluvial deposits, present-day and relict alluvial fans, and terraces were included in the LIM as geomorphological elements (Figure 3(C)). In particular, alluvial deposits are flat and always located in the lowest portions of the Agri valley and its main tributaries, as they are considered as the present-day alluvial plain deposits. Older deposits of the Agri River valley are nowadays suspended over the alluvial deposits. Furthermore, alluvial fans were recognised and mapped in two relative age classes according to their appearance. They were classified as relict if they look dismantled and dissected, and their border is not completely evident in the aerial photographs due to incision by the present-day river network. Alluvial fans were instead classified as recent if their morphology is well preserved in the present-day morphology. When alluvial fans superimpose each other within the same age class, they were represented within the same relative age class, but according to a cross-cut principle.

Although these features are not directly linked to landslides, they are useful to help geomorphologists identify them. For example, large landslides deposits show the presence of alluvial fans which develop as erosion takes place on landslide deposits (Figure 3(D)).

4. Geomorphological landslide inventory map

Our inventory covers an area of 235 km² and consists of 2124 landslides, for which we obtained the area $A_l$ (in m²) in a GIS in the range $1.16 \times 10^2 < A_l < 1.15 \times 10^7$ m². Landslides cover an area of 90.3 km², which represents 38% of the study area. Percentage increases to 52% for the hilly and mountainous portion of the study area (74% of the entire study area), excluding the Agri valley plain. Similarly, the average landslide density throughout the study area is 9 landslides per square kilometre, which rises to 12.2 landslides per square kilometre excluding plain areas.

Descriptive statistics of landslide number and size is shown in Table 1 and Figure 4(A–B). In the first section, Table 1 reveals that slides are the most common landslide types. On average, slides are the larger slope movements, rock falls are the smallest and the less represented. Figure 4(A) shows that relict and very old landslides are not represented by debris flows, rock-falls and earth flows, whose size are typically smaller than those of the other landslide types, e.g. sackings, slide and slide-earth flow, recognised in the inventory. It appears obvious that small landslides also occurred at the time of very old and relict landslides, but it is reasonable that subsequent landslides and erosion

| Num | Amin (m²) | Amax (m²) | $\lambda_{tot}$ (m²) |
|-----|-----------|-----------|----------------------|
| Type |           |           |                      |
| Slide | 1291 | 117 | 11,039,495 | 81,571,290 |
| Slide-earth flow | 642 | 499 | 4,157,964 | 41,197,266 |
| Sackung | 75 | 907 | 344,707 | 1,575,417 |
| Earth flow | 110 | 911 | 416,012 | 5,073,676 |
| Rock fall | 5 | 790 | 27,434 | 36,187 |
| Landslide relative age | | | |
| O4 | 33 | 2077 | 60,018 | 508,095 |
| O3 | 202 | 688 | 352,691 | 6,253,290 |
| O2 | 612 | 531 | 1,065,125 | 22,392,748 |
| O1 | 1253 | 117 | 3,013,190 | 59,291,617 |
| R1 | 17 | 143,095 | 7,991,139 | 20,345,917 |
| R2 | 1 | Na | na | 3,453,469 |
| R1 | 6 | 525,377 | 11,559,995 | 28,768,698 |
| Landslide uncertainty | | | |
| Certain | 2100 | 117 | 3,013,190 | 88,445,750 |
| Uncertain (delineation) | 20 | 143,095 | 7,991,139 | 25,040,843 |
| Uncertain (delineation and classification) | 2 | 1,474,280 | 3,453,469 | 4,927,750 |
| Uncertain (delineation, classification and identification) | 2 | 11,039,495 | 11,559,995 | 22,599,490 |

Note: Landslides are classified according to three classification methods, and namely: (i) type of movement, (ii) relative age, (iii) uncertainty degree. Landslide number (Num), Landslide area (A). Old landslides: first generation (O1), second generation (O2), third generation (O3) and fourth generation (O4). Very old landslides: first generation (V1). Relict landslides: first generation (R1) and second generation (R2).
obliterated them. Further evidence emerging from Figure 4(A) is that a large portion of the total landslide area is occupied by a few relict and very old kilometre-scale large slope failures. The evidence was also presented in a paper by Bucci et al. (2016b), showing that the majority of the landslide volume was mobilised in a different morpho-climatic regime.

As reported in the second section of Table 1 and in Figure 4(A), most of the old landslides (1235) are classified as first-generation, and landslides number progressively decreases with the increase of generation (second to fourth) (Figure 4(A)). Besides, within the clusters of landslides, those of generations higher than the first are typically smaller than those of first generations (Figure 4(B)), suggesting a threshold size effect of previous landslides on subsequent slope movements. In particular, in Figure 4(B), relict and very old landslides show median areas of at least one order of magnitude larger than old landslides (generally two orders of magnitude), while the old landslide size range has narrowed asymmetrically through time, with a progressively decreasing size of the larger slope failures, and a median landslide area constant at around 10,000 m². We interpret these pieces of evidence as the result of local morphological and hydrological perturbations induced by the occurrence of the first failure.

The third section of Table 1 shows the uncertainty degree affecting landslide identification, classification and delineation. Uncertainty in defining the delineation of landslide borders is considered a common feature in mapping very old landslides, whose boundaries are usually deeply dismantled by erosion or covered by more recent slope failures. We acknowledge there is a control of landslide age on the uncertainty degrees in landslide mapping. However, we do not have information on the age of the landslides, and only base our considerations on relative age criteria of classification (Keaton & DeGraff, 1996). Based on landslides morphological appearance (McCalpin, 1984; Wieczorek, 1984) and the findings of recent studies on landslide age in Southern Apennine (Gioia & Schiattarella, 2010) and elsewhere (Pánek et al., 2014), we hypothesise that the majority of the landslides in our study area occurred in the last 10–20 Kyr. However, we cannot exclude that some of the largest landslides, in particular those classified as a relict, are older.

Inspection of the Main Map reveals that the local relief and geological setting control the type and spatial distribution of the landslides. (i)Slides and complex/composite failures are most abundant where clay-rich layers are associated with hard sedimentary rocks. (ii)Earth flows have formed primarily where sheared shales and marls crop out. (iii)Debris flow and rockfall cluster at the toe of the western...
slopes of II Monte, Mt. Volturino and Mt. Lama, where relative relief is largest and calcareous rocks prevail. (iv) Large, relict and very old deep-seated landslides are controlled by the spatial arrangement of stratigraphic and tectonic discontinuities, a typical condition for the development of deep-seated landslides in the Apennines (Conforti et al., 2012; Guzzetti et al., 1996). Below, we list and describe several remarkable examples of these landslides which are considered representative of the overall
(i) The pattern of the slide type and complex movements is often associated with their relative position within anticline-syncline pairs. This is clear in the northern part of the study area, where pelagic rocks of the Lagonegro domain are extensively exposed in the Monte Lama – Monte Calvelluzzo anticlinal ridge (ML MC in Figure 1(B–C)). Here, landslides are present along the normal and inverted limbs. Failures on normal limbs occurred either along planar or compound surfaces where the anticlinal limb is less steep or along curvilinear surfaces at the core of minor synclines along very steep limbs. This is the case of the Camporotondo landslide (Figure 5(A,B)), described by Bucci et al. (2013), and included with modification in this inventory. The Monte Lama – Monte Calvelluzzo anticline is bounded on its eastern side by a thrust (Figure 1(C)). Landslides are abundant along the thrust zone, characterised by multiple shear surfaces that separate mostly vertical or overturned bedding at the hanging-wall, from asymmetrical synclines at the footwall (Bucci et al., 2020). In this area, and in a similar structural setting in the study area, synclines mainly involve weak and marl-rich rocks, which concentrate water in the upper part of the slopes and favour the evolution of large slides and slide-earth flows (Figure 5(C–D)).

(ii) Earth flows are more abundant in the southern portion of the study area, where sheared shales and marls of the Miocene siliciclastics and the Albidona formation crop out (Figure 1). In these flysch complexes, failure initiate usually as translational movements, mainly along bedding interfaces, and can turn into earth flows depending on the local lithological characteristics. Consequently, a large variability of landslide types was mapped at these locations.
(Figure 5(E)). The relative relief of this sector is lower compared to those in the central and northern part of the area and represents a threshold condition for landslide size, which are also smaller, on average. On the other hand, landslide density is very high here (Main Map). Multiple slides and earth flows are common, which gives the topography its typical hummocky appearance (Figure 5(F)).

(iii) Debris flows originate where the availability of loose slope breccias is more abundant and particularly: (i) where relative relief is large and calcareous rocks prevail, especially if slopes are affected by pre-existing deep-seated landslides (Figure 5(A–B)); (ii) from talus or scree slopes (Figure 3 (A–B)), (iii) along the shear zone of regional normal faults (Figure 1(C)). The main observations related to debris flows were carried out along the W and SW slopes of Il Monte and Mt. Volturino where all these predisposing factors are clearly recognised (Main Map; see also Figure 6(A)). Commonly, debris flows coexist with rock falls, which occur on largely pre-existing discontinuities in the bedrock such as bedding planes, joints, fault surfaces and related fractures.

(iv) In the west side of Il Monte, we mapped diffuse evidences of mountain slope sagging (Figure 6 (A)). They include low-lying areas bounded by step, up-slope and down-slope facing escarpments parallel to the mountain crests on the divides and along the slopes. We assigned to the observed sagging phenomenon the maximum level of uncertainty due to the coexistence of morphologic escarpments (Figure 6(B)), supposed to be gravitational in origin, and fault-related scarp (Figure 6(C)) well-recognised and described in the geological literature (Benedetti et al., 1998). Just north of Il Monte, the south and eastern sides of Mt. Volturino are also dominated by other very large and very old failures (Main Map). Similar to the previous case, we assign high levels of uncertainty to these landslides because of the potential morphological convergence resulting from conflicting interpretation (tectonic-driven vs gravitational-driven) of the same landform (Bucci et al., 2014).

5. Conclusions

The new landslide inventory map represents an updated catalogue of landslide phenomena in the High Agri Valley, based on the classification of landslide type and relative age, which provides new data to further investigation of the Quaternary evolution of the landscape of this part of the Southern Apennines. The map was produced thanks to a systematic exploitation of a free non-photogrammetric freeware, StereoPhoto Maker in anaglyph mode for the visual interpretation of two sets of stereo-aerial photographs.

The map also presents a systematic classification of landslides by relative age and uncertainty. A total of seven levels of relative age were identified: two for relict, one for very old and four for old landslides. Analysis of the data revealed that the great majority of landslide volume was mobilised by relict and very old landslides, whereas the landslide maximum size decreased over time and tended to cluster around pre-existing failures. The map also documents previously unreported unknown kilometre-scale relict and very old landslides that mimic the equal-scale geological structure, and the relationships between landslides and other geomorphological elements in the map.

The new inventory map has a large number of potentials uses due to the highly detailed geomorphological information shown.

The landslide information on the map can be used (i) to determine the statistics of landslide size (Malamud et al., 2004), (ii) to trigger detailed studies on types, pattern, and distribution of landslides in relation to geological structures (Guzzetti et al., 1996), tectonic and climatic forcing (Schiattarella et al., 2017), (iii) as a base map for landslide susceptibility and hazard assessment (Guzzetti et al., 2005).

The fluvial related landforms (alluvial deposits, and alluvial fans) can be used as input data to (i) investigate the allometry of old and recent alluvial fans (Miranella et al., 2018), (ii) study quaternary depositional and erosional events (Mancini et al., 2019), (iii) and in combination with landslide information, study the interplay of gravitational and fluvial processes (Santangelo et al., 2013).

Software

We used (i) Google Earth© (https://www.google.com/earth/) for geo-location of the photo-interpreted data, and for visualisation of the outcrops and of geological and geomorphological sites during the fieldwork, (ii) StereoPhoto Maker (SPM, http://stereo.jpn.org/eng/stphmkr/) for the visual interpretation of the stereo-aerial photographs, (iii) ArcGIS®10.6 version and QGIS® 3.4 version (http://www.qgis.org/) to digitally organise and analyse the data, and to use the remotely sensed satellite imagery through OGS Web Map Services (WMS), and (iv) to assemble the final map for publication and graphical editing.

Cartographic information

The topographic base map consists of a shaded relief of a LiDAR DEM with GSD of 1 m and contours
extracted from the same DEM at a distance of 25 m. All the other features in the topographic maps (elevation points, toponymy, structures and infrastructures) were obtained from the Regional Technical Cartography at 1:10,000 scale. The map is made freely available and usable by the Regione Basilicata GeoPortal (http://rsdi.regione.basilicata.it/viewGis/?project=f8f85db9-54f9-4a61-90f3-49fca31a1b2).

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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