D.1.4.2. Landslide inventory maps

Rijeka, Croatia, 2025.

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Name of the lead partner organisation	University of Rijeka, Faculty of Economics and Business
Project title	Climate RESiliEnt COastal planning in Adriatic
Project acronym	CRESCO Adria
Programme priority	Green and resilient shared environment
Specific objective	2.1: Promoting climate change adaptation and disaster risk prevention, resilience, taking into account eco-system based approaches

Activity: **1.4 Pilot area climate change sensitivity survey**

Deliverable: **D1.4.2. Landslide inventory map – DRAFT version**

Name of the partner organization: University of Rijeka, Faculty of Civil Engineering (GRADRI)

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Content

1. INTRODUCTION

This document presents a **draft report on Deliverable D1.4.2.**, *Landslide inventory maps*, from Activity 1.4, *Pilot Area Climate Change Sensitivity Survey*, developed within the international project CRESCO Adria, funded by the Interreg Italy-Croatia program.

This study focuses on landslide inventory mapping in the pilot area in the Municipality of Vinodol, with the primary objective of determining the total number, spatial distribution, types and relative age of the landslides.

The Faculty of Civil Engineering in Rijeka will conduct the landslide inventory mapping in the pilot area using expert knowledge method of the visual interpretation of high resolution LiDAR (Light Detection and Ranging) Digital Terrain Model (DTM), generated from the airborne laser scanning data collected between 2020 and 2022. The LiDAR DTM at 1 x 1 m spatial resolution is available for the entire territory of the Republic of Croatia.

The final deliverable will be the **Landslide inventory map at a scale 1:10.000 for the pilot area in the Municipality of Vinodol**.

2. PILOT AREA

The **pilot area** (53 km^2) is a part of the territory of the Municipality of Vinodol (153 km^2), situated in the north-western coastal part of the Republic of Croatia (**Figure 1**). It is situated in the Vinodol Valley, stretching along the western part of the Minicipality, in the NW-SE direction, between the settlement of Križišće in the northwest and the City of Novi Vinodolski in the southeast. The area is predominantly rural, with more than 50 small settlements situated in the valley connected by a relatively dense road network.

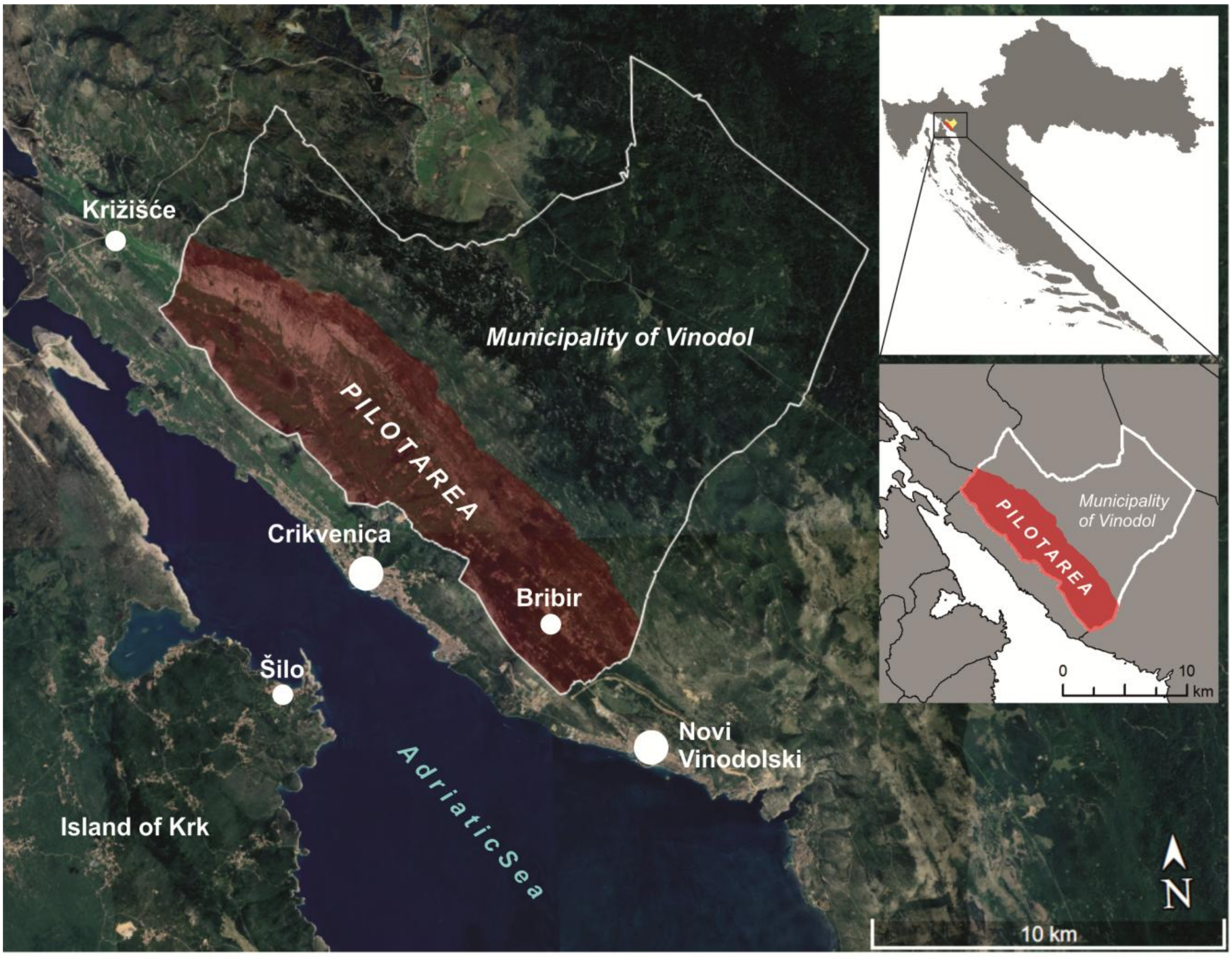


Figure 1. Geographical position of the pilot area in the Municipality of Vinodol.

Elevation range from 12 to 922 meters above sea level (**Figure 2a**). Prevailing elevations are in the range between 100 and 200 m a.s.l., with an average elevation of 283 m a.s.l. Slope angles (**Figure 2b**) between 5° and 20° prevail, and the average angle is 16°. The valley has an irregular, elongated shape. The steep valley flanks are built of Upper Cretaceous and Paleogene carbonate rocks, while the lower parts and the bottom of the valley are built of Paleogene flysch rock (Šušnjar et al., 1970; Blašković, 1999).

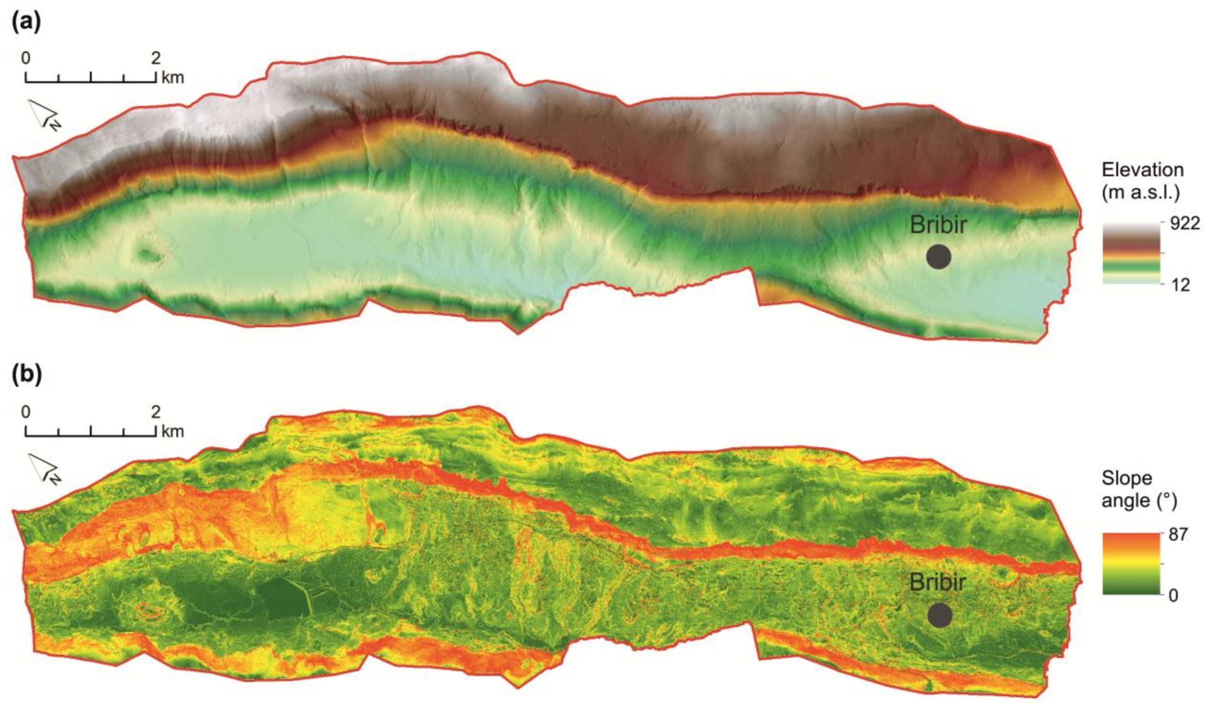


Figure 2. Pilot area in the Vinodol Valley, Municipality of Vinodol: (a) elevation map, (b) slope map.

Flysch bedrock is almost entirely covered by Quaternary eluvial, colluvial, and proluvial soils (Đomlija, 2018; Jagodnik et al., 2020a), which are formed by geomorphological processes active both in the carbonate and flysch rock mass.

The climate is maritime (Zaninović et al., 2008), with mean annual precipitation between 300 and 700 mm. The rainy period lasts from November to May, with precipitation at its maximum in November when rainstorms of high erosive potential frequently occur. Forests cover an area of 32.19 km^2 (CAEN, 2008). Other important land covers are schrubs (6.17 km^2), and natural pastures (5.66 km^2). The topography of the Vinodol Valley has been generally divided into three parts, i.e. the northwestern, the central and the southeastern parts (Đomlija et al., 2017). The northwestern and the central parts belong to the Dubračina River Basin, while the southeastern part belongs to the Suha Ričina River Basin.

3. METHODOLOGY

3.1. Airborne LiDAR datasets

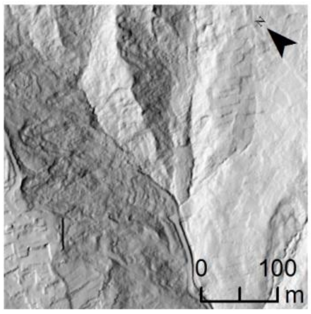
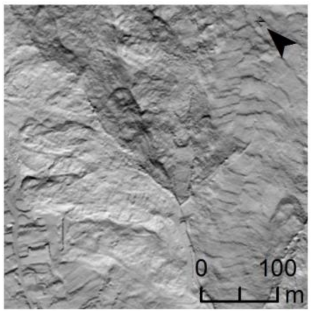
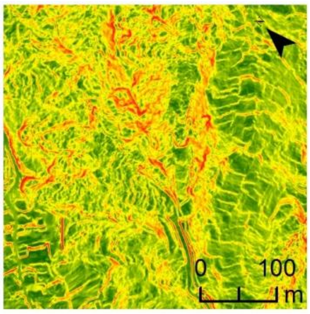
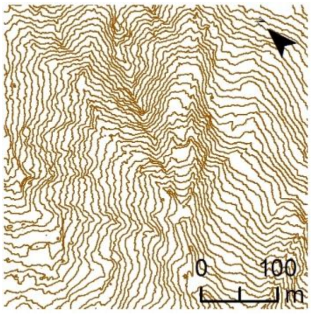
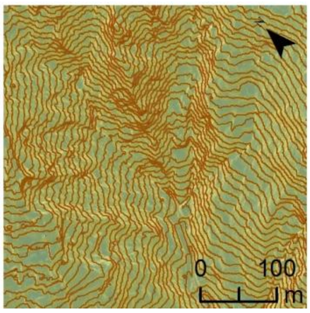
The airborne LiDAR DTM used in this study is the official state DTM for Croatia, with a spatial resolution of 1 m × 1 m. It was acquired by the State Geodetic Administration (SGA) between 2020 and 2022. Morphometric datasets derived from the LiDAR DTM using standard Spatial Analyst tools and operations in ArcGIS 10.0 software included the following (Table 1): (i) hillshade maps, (ii) slope map, and (iii) contour maps. Hillshade maps were generated with sun azimuth angles of 315° and 45°, and a sun elevation angle of 45°. They were analyzed both individually and in combination to optimize the visualization of different slope segments in the study area. Contour maps were created with contour intervals of 1 m, 2 m, and 5 m.

3.2. Visual interpretation of high-resolution LiDAR DTM morphometric derivatives

Discernible topographic characteristics remaining after a landslide occurrence, i.e., topographic signatures (Guzzetti, 2006) were visually analysed on LiDAR DTM morphometric derivatives. The main landslide features, i.e. landslide crowns, and landslide foots, have enabled the recognition of landslides based on the specific: (a) shape; (b) morphometric characteristics; (c) texture; (d) appearance; and (e) size (**Figure 3**). Landslides were first searched on the hillshade map, because the hillshade map most clearly reflects the pseudo three-dimensional effect of a surface (Guzzetti et al., 2012). However, topography of landslide features for a certain amount of landslide phenomena in the study area is not clearly expressed on the hillshade map (Jagodnik et al., 2020b). Hence, a semilunar crown (pointed with black arrows in **Figure 3**) could have been, in most cases, easily recognized on the slope map. A hummocky appearance, rough texture and frequent changes of curvature, which are specific for the landslide foot (pointed with blue arrows in **Figure 3**), can be as well recognized on the slope map, for almost all detected landslides.

Landslides were manually mapped using polygons (**Figure 4**). The identification of landslide features was carried out by examining LiDAR-derived datasets at scales ranging from 1:5,000 to 1:800, depending on the size of the landslides. Precise delineation was conducted at significantly larger scales, typically between 1:500 and 1:300. The boundaries of individual landslide features were drawn separately on various LiDAR morphometric derivatives, depending on their visibility in each dataset. These individual lines were then merged into a single polygon representing the landslide using *ArcGIS 10.0* tools.

Table 1. LiDAR DTM morphometric datasets derived from the 1 x 1 m LiDAR Digital Terrain Model.

Morphometric dataset	Description	Visualisation
Hillshade map 315°/45°	A pseudo-three-dimensional representation of the terrain surface, most often used for the visual interpretation of morphological characteristics (Guzzetti et al., 2012). It is created by simulating illumination conditions defined by the light source azimuth ranging from 0° to 360° and the angle of incidence of light rays ranging from 0° to 90°. Each raster cell takes on a specific surface illumination value ranging from 0 to 255, depending on the direct exposure of the surface to the given illumination conditions. Two shaded relief maps with illumination parameters 315°/45° and 45°/45° were derived from the DEM. To achieve a more uniform shading of the relief, i.e., optimal quality for the interpretation of surface morphology (Schulz, 2004), the maps were additionally overlaid, specifically the 45°/45° shaded relief map at 35% transparency over the 315°/45° shaded relief map.	
Hillshade map 45°/45°		
Slope map	Representation of the spatial distribution of slope angles ranging from 0° to 90°, using a selected colour scale for different slope classes. Typically, steep slopes are represented by shades of warm colours, i.e., red, orange, and yellow, while gentler slopes and flat terrain are shown in shades of cool colours, most often green.	
Contour map e = 2 m	Significant for the visual interpretation of surface morphology when combined with a shaded relief map and a slope map (Ardizzone et al., 2007), as it often clearly reflects the specific morphology of individual landslide elements. From the Digital Elevation Model (DEM), three contour maps were derived, with contour intervals of 2, 4, and 10 meters	
Composite display of morphometric derivatives used for the visual interpretation and landslide inventory mapping	A composite display of morphometric derivatives was used for detailed visual interpretation, i.e. delineating individual landslides. The derivatives were overlapped as follows: the contour map over the transparent slope map (65% transparency), over the transparent hillshade map 45°/45° (35% transparency), over the hillshade map 315°/45°.	

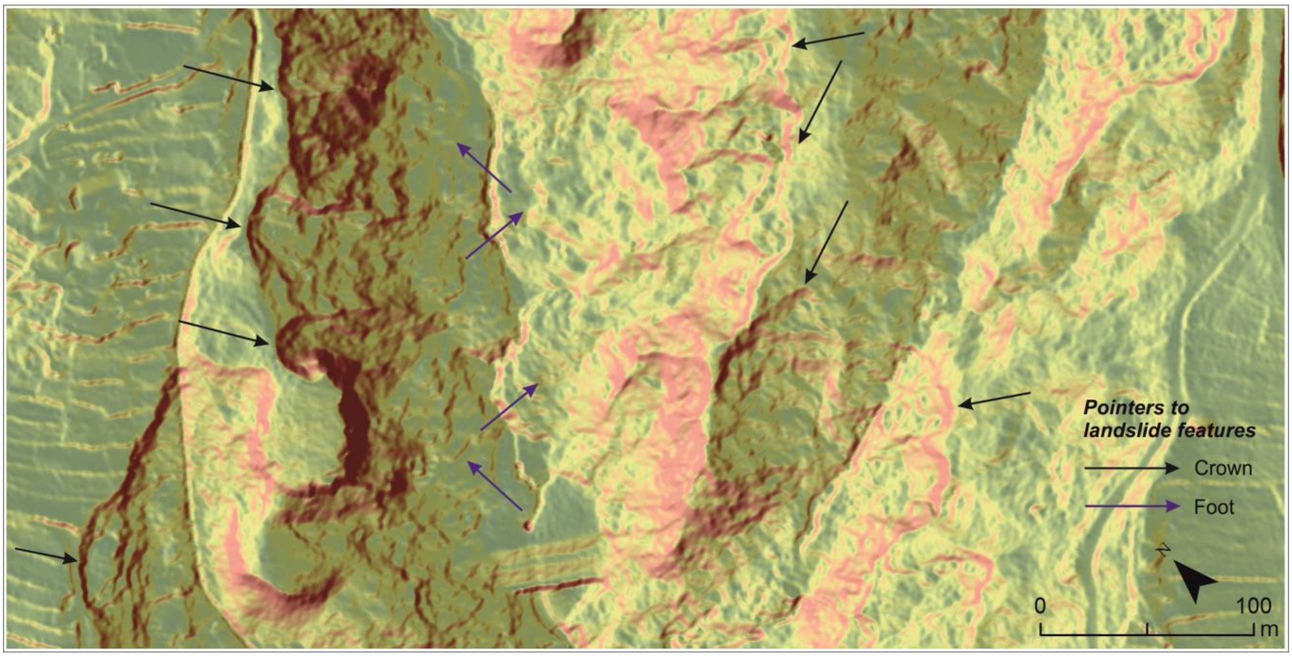


Figure 3. Landslide features topography (i.e., crowns and foots) visible on HR LiDAR topographic derivatives.

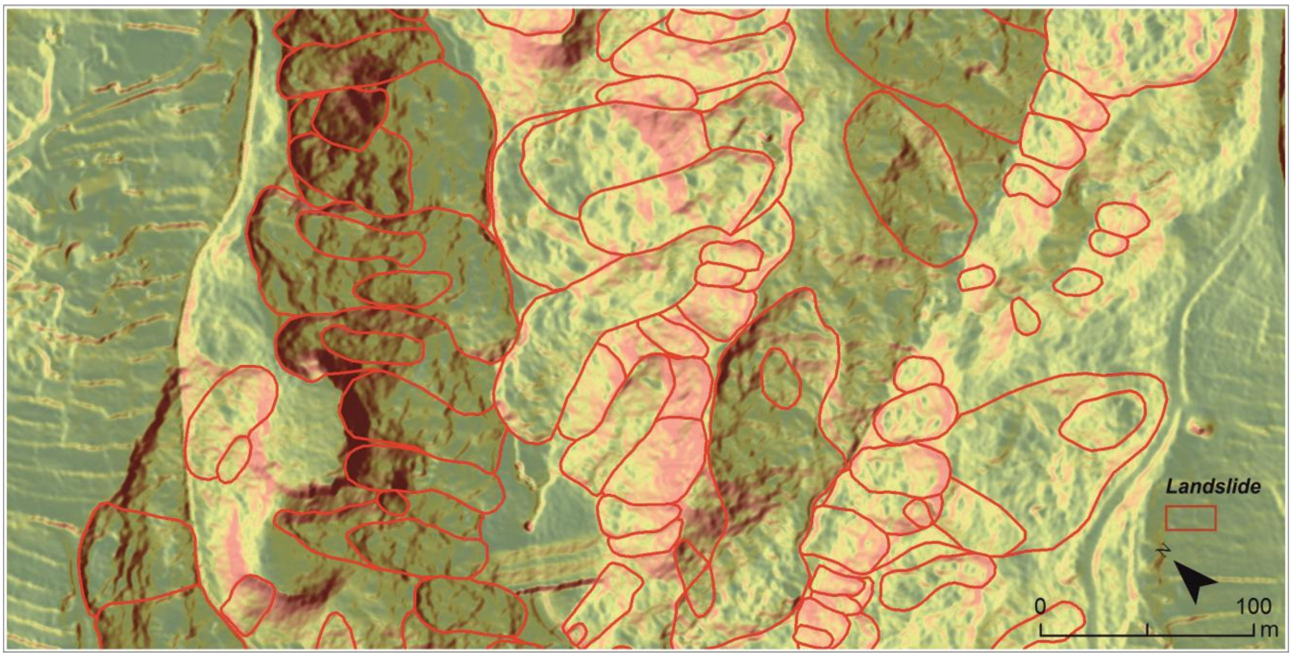


Figure 4. Landslide polygons manually delineated based on the visual interpretation of LiDAR topographic derivatives.

3.3. Classification of landslide types

In the final **Landslide inventory map at a scale 1:10.000 for the pilot area in the Municipality of Vinodol**, the landslide will be classified based on the following criteria: (i) type of movement (Varnes, 1978; Cruden & Varnes, 1996), (ii) relative age (McCalpin, 1984; Keaton & DeGraff, 1996), (iii) size (ICL, 2013), and (iv) estimated depth (van Schalkwyk & Thomas, 1991).

Landslide types according to these criteria will be assigned as attributes to the leach landslide polygons in the GIS attribute table.

A unique identification code (ID) will be assigned to each landslide polygon in the attribute table.

Landslide area will be calculated in square meters using the standard Calculate Geometry tool in ArcGIS.

Named landslide attributes will present the landslide database accompanying the Landslide inventory map at a scale 1:10.000 for the pilot area in the Municipality of Vinodol.

Based on the visual interpretation of LiDAR morphometric derivatives in progress, two landslide types according to the type of movement (Varnes, 1978; Cruden & Varnes, 1996) have been identified in the pilot area:

(i) slide type landslides (**Figure 5a**), and
(ii) slide-flow type landslides (**Figure 5b**),

clearly reflected by the shapes of landslide polygons.

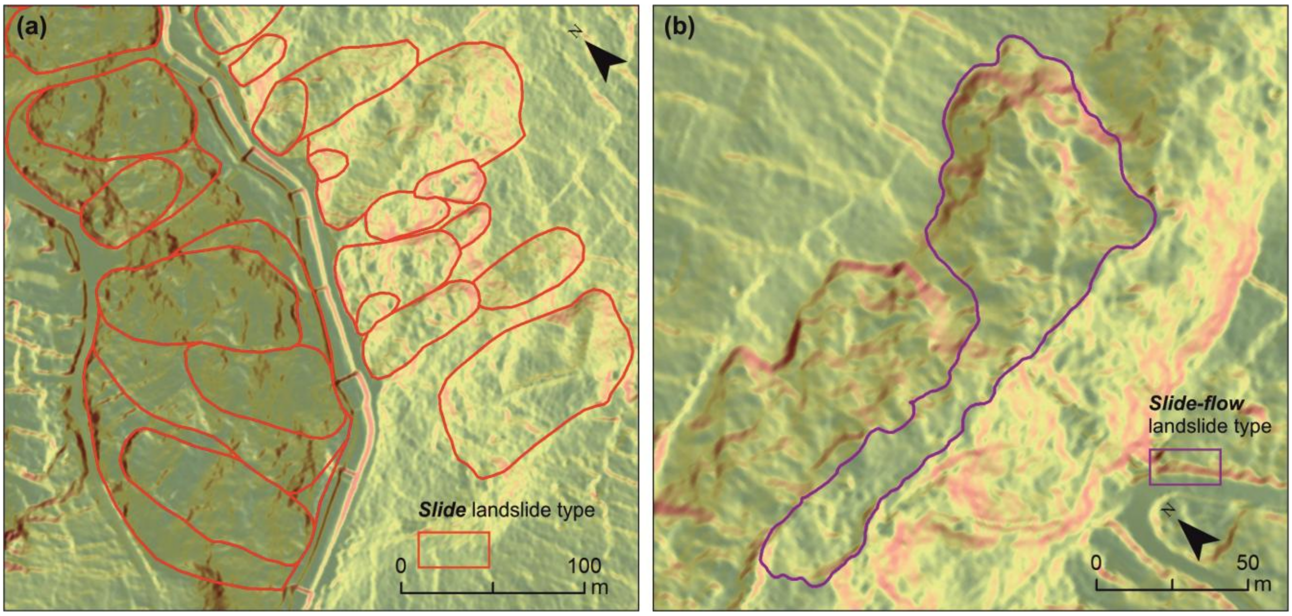


Figure 5. Landslide types identified in the pilot area: (a) ***slide*** type landslide, and (b) ***slide-flow*** type landslide.

4. Landslide inventory map

In this phase of the research, the draft version of the **Landslide inventory map at a scale 1:10.000 for the pilot area in the Municipality of Vinodol** includes a total of **822 landslides**.

Details from the draft landslide inventory are presented in **Figure 6a** for the Dubračina River Basin, and in **Figure 6b** for the Suha Ričina River Basin.

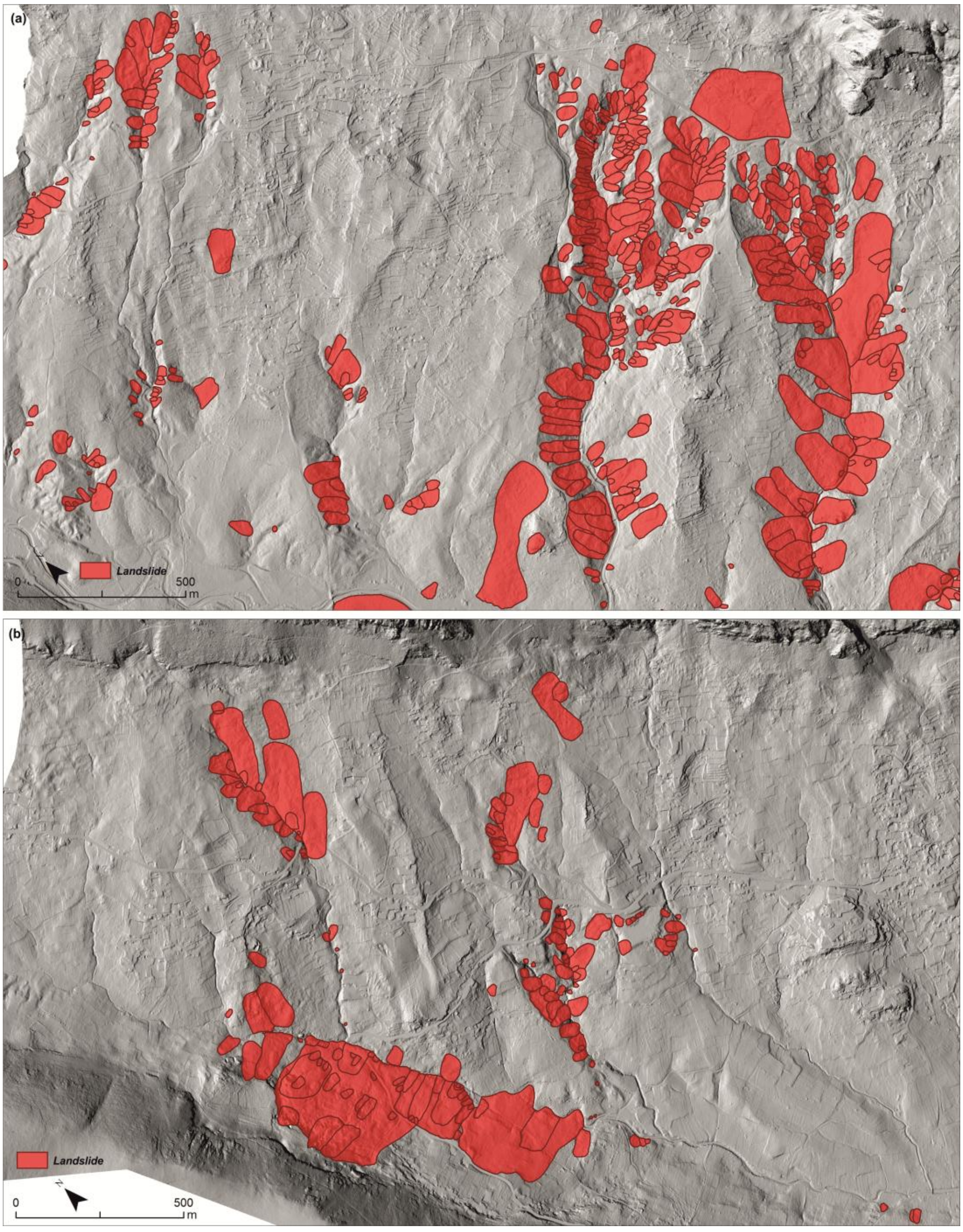


Figure 6. Details from the draft landslide inventory map of the pilot area, presenting landslides in: (a) Dubračina River Basin; (b) Suha Ričina River Basin.

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Rijeka,

11.4.2025.

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Climate RESiliEnt Coastal planning in Adriatic

Programme: (Interreg VI-A) Italy- Croatia

D1.4.2. Inventory of Landslides

Pilot area: Nuova Pescara
(Pescara, Montesilvano and Spoltore municipalities)

Report and map

Benificiary: UNICAM-SAAD
Deadline: January 2026

In collaboration with the University "G. d'Annunzio" Chieti-Pescara (Ud'A-TEMA)
Prof. E. Miccadei, Dr. Giorgio Paglia, Dr. Giovanni Santucci

Interreg Co-funded by the European Union

Italy – Croatia

CRESCO Adria

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Introduction

This report details the activities conducted within the framework of Deliverable D1.4.2, aimed at creating an inventory of landslide phenomena within the study area and producing the associated thematic cartography. Landslide inventories are fundamental tools for documenting the extent of landslides at regional and local scales. They are based on the accurate collection and standardization of data derived from geomorphological field surveys and various bibliographic sources (thematic maps, scientific articles, historical archives, technical documentation, chronicles, newspapers, etc.). These inventories can be compiled using different techniques, applied individually or in combination (van Den Eeckhaut et al., 2009). The choice depends on the purpose of the inventory, the extent of the study area, the resolution and characteristics of the available cartographic data (e.g., aerial photos, satellite imagery, etc.), the experience of the surveyors, and the bibliographic sources available.

1.Sources and scientific references

Thematic maps and products represent an essential scientific reference for the analysis of spatial distribution, typology, triggering mechanisms, frequency, and statistical characteristics of landslide phenomena. They are also vital for landslide hazard assessment and the study of landscape evolution controlled by gravitational instability processes (Guzzetti et al., 2012). The first examples of inventories date back to the notable works of Almagià (1907; 1910), which consist of a detailed report on the main landslides occurring in Italy between 1100 and 1908. In 1957 and 1963, the Ministry of Public Works produced national landslide inventories (Ministry of Public Works, 1965). Also noteworthy is the bibliographic review by Guida et al. (1979) on landslides in Italy from 1900 to 1978. Benedini and Gisotti (1985) published a list of major floods and landslides occurring in historical times across the national territory. More recently, a comprehensive report on natural disasters in Italy (including landslides, floods, groundwater pollution, earthquakes, and volcanic eruptions) between 1945 and 1990 was published by the National Geological Service (Catenacci, 1992).
Historical and recent analyses, along with the design and implementation of inventories, have been developed at scales ranging from national and regional to site-specific levels (e.g., AVI archive; SICI project; IFFI inventory; Basin Plans; ISPRA reports; CNR-Polaris initiative; FraneItalia; LAND-deFeND database – Canuti et al., 2001; Guzzetti et al., 1994; Guzzetti & Tonelli, 2004; Calvello & Pecoraro, 2018; Napolitano et al., 2018). In recent years, the systematic collection of data regarding geomorphological hazards across Italy has been promoted by the IdroGEO web platform. This platform allows for the navigation, sharing, and downloading of data, maps, and risk indicators (Iadanza et al., 2021). It serves as a tool for communication and information dissemination, supporting land-use planning decisions, intervention planning, risk mitigation policies, civil protection emergency management, and environmental impact assessments.

The temporal coverage of landslide occurrences in the inventory ranges from 1116 to 2020. This inventory is maintained by the Italian Institute for Environmental Protection and Research (ISPRA) and by the Regions and Autonomous Provinces (Trigila et al., 2010). National mosaics of landslide hazard zones are produced by ISPRA based on data provided by the District Basin Authorities. The landslide hazard zones of the basin plans (Hydrogeological Setting Plans – PAI) include, in addition to existing landslides, areas of possible evolution and areas where new landslides may potentially occur (Trigila et al., 2015; Corominas et al., 2014). Landslide hazard assessment has been carried out by District Basin Authorities adopting different methodological approaches (e.g., geomorphological, statistical, and/or matrix-based methods). Consequently, some cartographic inhomogeneities have been identified, mainly due to the different methods used (Trigila et al., 2021). ISPRA has harmonized all available data into 5 different classes (P4, P3, P2, P1, AA). The total area of these zones is 59,981 km² (19.9% of the national territory). Considering the highest hazard classes (P3 - high and P4 - very high), the area amounts to 25,410 km² (8.4%).

2. Characteristics of the study area

In this context, the study area, located in the central-eastern sector of the Italian peninsula between the foothill belt and the coastal zone, is recognized as highly prone to geomorphological hazards. It has been affected by landslide phenomena in historical and recent times, resulting in significant morphological changes and risk conditions (Trigila et al., 2021; Paglia et al., 2024). To observe, identify, and catalog the landslide phenomena, the analysis was conducted starting from the landslide areas identified in the geomorphological map of the Hydrogeological Setting Plan (PAI) developed by the Central Apennine District Basin Authority (AUBAC, 2025). This served as the main cartographic reference, as it represents the technical-regulatory instrument for planning soil conservation and environmental protection.

In the study area, slope movements are widespread and show marked spatial and typological heterogeneity, strictly correlated to lithological conditions, structural characteristics, and the mechanical behavior of the outcropping geological units. In particular, the surveyed landslides were subjected to a detailed classification, based on both the type of movement and the state of activity, to provide a comprehensive interpretive framework. This approach allowed for the integration of morphogenetic and kinematic aspects, which are fundamental for understanding slope processes and for subsequent hazard analyses.

Based on movement characteristics, six main types of landslides were recognized: flows, rockfalls and topplings, complex landslides, rotational slides, translational slides, and slopes affected by slow surface deformations. In parallel, landslide phenomena were distinguished by their state of activity: active (recent or ongoing movement), quiescent (no current signs of activity but potentially reactivatable), and inactive (stabilized or relict processes).

A total of 169 landslide movements were surveyed. Their classification, obtained by integrating movement type and state of activity in accordance with the PAI legend, allowed these phenomena to be divided into twelve distinct classes, as shown in Table 1:

Table 1 – Typology, state, and number of landslides in the study area

TYPE	ACTIVITY STATUS	FE NUMBER
Landslide	Activate	6
Landslide	Inactive	1
Landslide	Quescient	13
Collapse and overturning landslide	Activate	1
Landslide of complex genesis	Activate	3
Landslide of complex genesis	Quescient	1
Rotational sliding landslide	Activate	4
Rotational sliding landslide	Inactive	7
Rotational sliding landslide	Quescient	12
Translational sliding landslide	Activate	1
Slope affected by slow surface deformations	Active	43
Slope affected by slow surface deformations	Quescient	77

Landslide movements are distributed in a markedly heterogeneous manner, with a clear concentration in the inland hilly sectors and a progressive reduction towards the urbanized coastal strip. Three main sectors were identified:

- North-central sector (Montesilvano): Landslides are predominantly located along the hilly slopes behind the urbanized area. There is a widespread presence of slopes affected by slow surface deformations (active and quiescent), generally associated with gently dipping slopes. Rotational slides (mostly inactive) and complex landslides (predominantly quiescent) are also present.
- South-western sector (Spoltore): This area has the highest concentration of active landslide phenomena, including rotational slides, complex landslides, and numerous slow surface deformations.
- South-eastern sector (San Silvestro): Some rotational slides (mostly quiescent) were identified, alongside both active and quiescent slow surface deformations.

Overall, the spatial distribution confirms the decisive role played by local morphology and geology in controlling slope instability, with the most significant phenomena concentrated in the inland hills.

3. Conclusions

Deliverable D1.4.2 has resulted in the creation of thematic cartography for the study area aimed at inventorying landslide phenomena, based on the AUBAC (2025) geomorphological map. This cartographic product identifies the main landslide movements, distinguished by type and activity state. The spatial distribution is heterogeneous, with a prevailing concentration in hilly areas, where geological and morphological conditions are most conducive to gravitational instability.

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Annex 1: Landslides Map

Interreg
Co-funded by the European Union
Italy – Croatia
CRESCO Adria

Output D.1.4.2 Inventory of landslides

Abruzzo Region

with the support of

ete Srl

environmental, territorial and economic

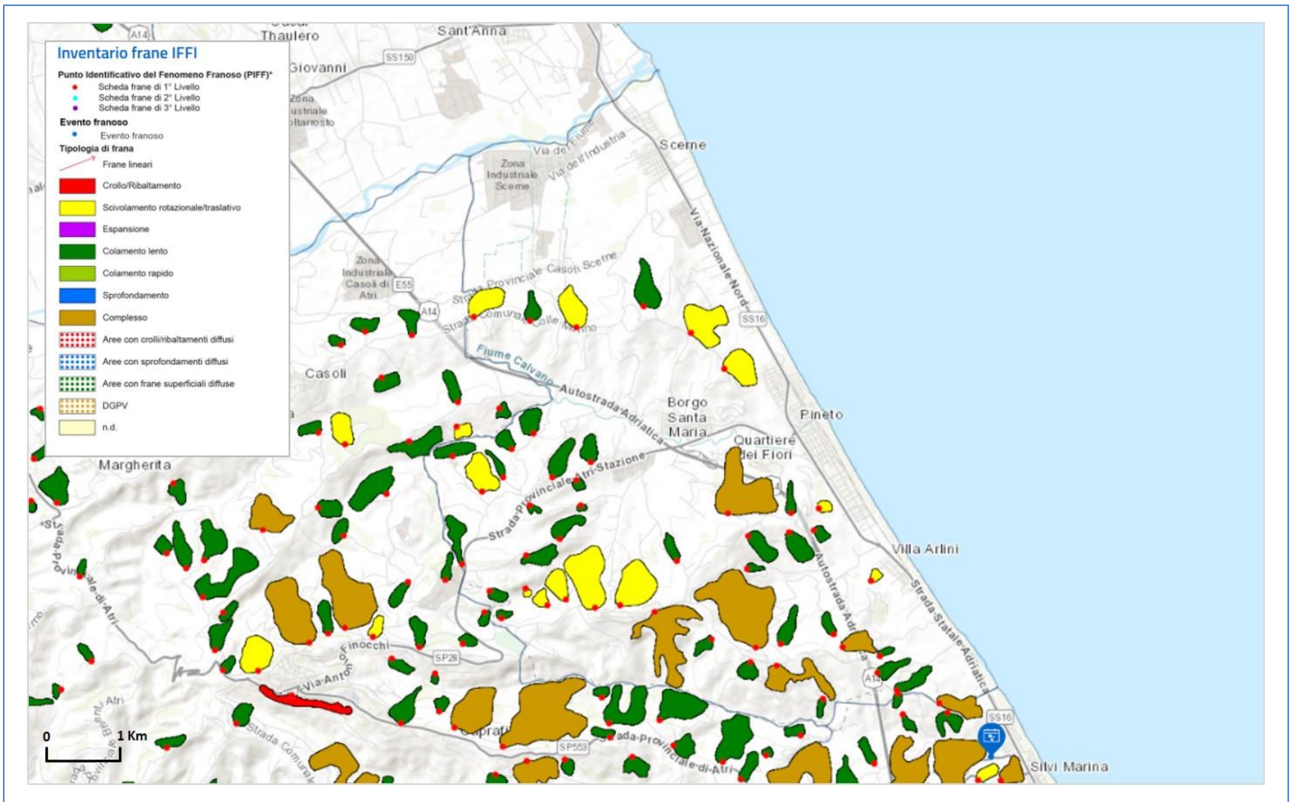
research and consulting

Inventory of Landslide Phenomena in the Pineto Area

Based on information available in the Inventory of Landslides in Italy, there are 49 landslides in the Municipality of Pineto, classified by type of movement: 63.3% are slow-moving, 24.5% are rotational/translational slides, and 12.2% are complex movements.

The landslides recorded in the Municipality of Pineto are not monitored.

Figure 1. Landslide Inventory IFFI (ISPRA 2024) - Comune di Pineto



Source: ISPRA – National platform IdroGEO (https://idrogeo.isprambiente.it/app/iffi/c/67035?@=42.61080204224305,14.056008891239204,12)