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Relationships between Morphostructural/Geological Framework and Landslide Types: Historical Landslides in the Hilly Piedmont Area of Abruzzo Region (Central Italy)

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Abstract: Landslides are a widespread natural phenomenon that play an important role in landscape evolution and are responsible for several casualties and damages. The Abruzzo Region (Central Italy) is largely affected by different types of landslides from mountainous to coastal areas. In particular, the hilly piedmont area is characterized by active geomorphological processes, mostly represented by slope instabilities related to mechanisms and factors that control their evolution in different physiographic and geological–structural conditions. This paper focuses on the detailed analysis of three selected case studies to highlight the multitemporal geomorphological evolution of landslide phenomena. An analysis of historical landslides was performed through an integrated approach combining literature data and landslide inventory analysis, relationships between landslide types and lithological units, detailed photogeological analysis, and geomorphological field mapping. This analysis highlights the role of morphostructural features on landslide occurrence and distribution and their interplay with the geomorphological evolution. This work gives a contribution to the location, abundance, activity, and frequency of landslides for the understanding of the spatial interrelationship of landslide types, morphostructural setting, and climate regime in the study area. Finally, it represents a scientific tool in geomorphological studies for landslide hazard assessment at different spatial scales, readily available to interested stakeholders to support sustainable territorial planning.

Keywords: historical landslides; multitemporal analysis; geomorphological mapping; GIS analysis; piedmont area; Abruzzo Region

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1. Introduction

Landslides are considered, worldwide and in Italy, as one of the most important and frequent natural hazards [1–5] as their occurrence can directly impact humans, infrastructures, economic activities, and the social and environmental systems [6–8]. Landslides are a landscape modelling process inducing geomorphological changes on slopes in mountainous, hilly, and coastal areas. Their occurrence is generally controlled by predisposing factors (i.e., morphology, lithological and structural setting, vegetation cover, land use, climate, etc.) and triggering ones (e.g., heavy rainfall and snowfall events, snow melting, earthquakes, wildfires, human activity, etc.) [9–13]. Many of the triggering factors are only sufficient conditions for the occurrence of landslides, which are occasional and spasmodic. Therefore, it is essential to pay attention to predisposing factors in landslide analyses to set an organic correlation between climate regime, morphostructural/geological framework, and slope instability phenomena [14,15].

Many theories and methods have been proposed about the spatial relationship between landslides and causative factors [16–22] to perform landslide hazard assessment studies [23]. However, the type, extent, magnitude, and direction of the geomorphological processes and the location, abundance, activity, and frequency of landslides in a changing environment are still under debate. Establishing a relationship between climate change and its potential effects on the occurrence of landslides remains an open issue [24]. The role played by projected climate changes in modifying the response of single slopes or entire catchments, the frequency and extent of landslides, and the related variations in landslide hazard, remain to be discussed and understood [25–27]. Most of the current landslides in the Central Apennines are the reactivation by pre-existing ones, which have occurred in periods of climatic and geomorphological conditions different from those of the present. Most dormant slides and/or paleolandslides, in which the strength parameters are reduced to values close to the residual ones, can be reactivated and/or modified by natural causes, such as rainfall or snowmelt, as well as man-made disturbance [28,29].

Geomorphological mapping is a common and fundamental tool for the representation and the comprehension of the spatial and temporal development of landslides. Recent and new methods developed in the last decades have improved landslide analysis with multidisciplinary approaches including (i) morphometric analysis using very-high-resolution Digital Elevation Models (DEMs), (ii) interpretation and analysis of satellite images, including Synthetic Aperture Radar (SAR) images, and (iii) the use of new tools to facilitate field mapping [30–35]. Moreover, the investigation of geomorphological processes and dynamics, in different and complex morphostructural domains, became necessary for the assessment of the areas prone to landslides with reference to the predisposing and/or triggering factors.

According to national and regional inventories [36,37], the Abruzzo Region (Central Italy) is acknowledged as an area highly exposed to landslide hazards and risks. It is located in the central–eastern part of the Italian peninsula, and it is characterized by a landscape that is the result of a complex cyclic evolution that occurred in succeeding stages with the dominance either of morphostructural factors, linked to the conflicting tectonic activity (compressive, strike–slip, and extensional tectonics) and regional uplift, or morphosculptural factors, linked to drainage network linear down-cutting and slope gravity processes [14,38,39].

For developing the present study, the analysis of historical landslides was carried out following an integrated approach that incorporates literature and landslide inventory analysis, relationships between landslide types and lithological units, detailed photogeological analysis, and geomorphological field mapping. The paper focuses on selected slope instabilities to highlight the multitemporal geomorphological evolution and the interplay between morphostructural/geological framework and landslide dynamics in the hilly piedmont area of Abruzzo Region. The work shows an effective integrated approach in geomorphological studies for landslide hazard modelling at different spatial scales, readily available to interested stakeholders. Furthermore, it could provide a scientific basis for the implementation of sustainable territorial planning and loss-reduction measures in a changing environment.

2. Study Area

The study area is located in the central–eastern part of the Italian peninsula along the hilly piedmont area of Abruzzo Region, between the Apennine chain and the coastal area (Figure 1a). It includes the lower part of the main SW–NE to W–E fluvial valleys (i.e., Vomano, Pescara, and Sangro rivers), and the small tributary catchments of the main rivers and those incising the coastal slopes.

The Apennine chain area is characterized by a mountainous landscape (with reliefs up to 2900 m.a.s.l. high) interrupted by longitudinal and transversal valleys and wide intermontane basins (i.e., Fucino Plain, Sulmona Basin). It is made up of carbonate lithological sequences pertaining to different Meso-Cenozoic palaeogeographical domains. Carbonate shelf limestones, slope limestones, basin limestone, and marls represent the carbonate backbone of the main ridges of the Abruzzo Apennines, and allochthonous pelagic deposits are widespread in the southern sectors featuring a chaotic assemblage on clayey–marly–limestone units. The main tectonic features are represented by NW–SE to

N–S-oriented thrusts, which affected the chain from the Late Miocene to the Early Pliocene. Compressional tectonics was followed by strike–slip tectonics along mostly NW–SE to NNW–SSE-oriented faults that were poorly constrained in age and largely masked by later extensional tectonic events since the Early Pleistocene [40,41].

The hilly piedmont area is a low relief area (heights ranging from ~100 to 800 m.a.s.l.) characterized by a cuesta, mesa, and plateau landscape and a gently NE-dipping homocline, locally cut by fault systems (NW–SE, SW–NE) with low displacement [42–44]. Bedrock lithologies pertain to Neogene sandy-pelitic turbidites and Plio-Pleistocene marine clayey–sandy and conglomeratic deposits. The geological and structural setting is related to the Pliocene–Quaternary evolution of the Adriatic foredeep and the related regional uplifting processes. Since the Middle Pleistocene, the geomorphological evolution has primarily comprised the incision of major dip river valleys (WSW–ENE-oriented), characterized by fluvial deposits arranged in flights of at least four orders of terraces (Middle Pleistocene–Holocene) [44,45]. Quaternary continental deposits are widely present in the alluvial valleys, alluvial plains, and coastal slopes. They can be referred to fluvio-lacustrine, travertine, sandy shore, and eluvial–colluvial deposits (Figure 1b).

The geomorphological framework is mainly related to fluvial and slope processes. Fluvial processes affect the main rivers, alternating between channel incisions and flooding. The slope processes due to running water mostly affect the clayey and arenaceous-pelitic areas of piedmont and coastal sectors, generating minor landforms such as rills, gullies, and mudflows [46,47]. The area is extensively affected by different types of landslides (e.g., mostly rotational–translational slides, earth flows, rockfalls, complex slides), mostly characterizing the hilly piedmont and the chain area and, locally, the coastal area [3,48].

The present-day regional tectonic setting is dominated by extensional tectonics still active in the axial part of the chain, which is characterized by intense seismicity and strong historical earthquakes (up to M 7.0; [49]). The piedmont area is characterized by moderate uplifting and moderate seismicity, while the Adriatic Sea is affected by subsidence and by moderate compression and strike–slip related seismicity, as also documented by the recent seismicity [50] (Figure 1b).

Climatically, the study area belongs to temperate sub-littoral regime with scarce annual rainfall, mainly autumnal, and medium temperatures [51]. It is largely affected by the orographic setting, changing from a Mediterranean type with maritime influence along the coasts and the piedmont area to more continental-like in the inner sectors [52]. The hilly piedmont area is characterized by a maritime Mediterranean climate [53]. The average annual precipitation is 600–800 mm/year, with occasional heavy rainfall events (>100 mm/d and 30–40 mm/h). The mean annual temperature ranges between 12 and 16 °C in the coastal part of the region, with mild winters and hot summers, and from 8 to 12 °C in mountain areas, with more severe (low) temperatures, especially in the winter season [54,55].

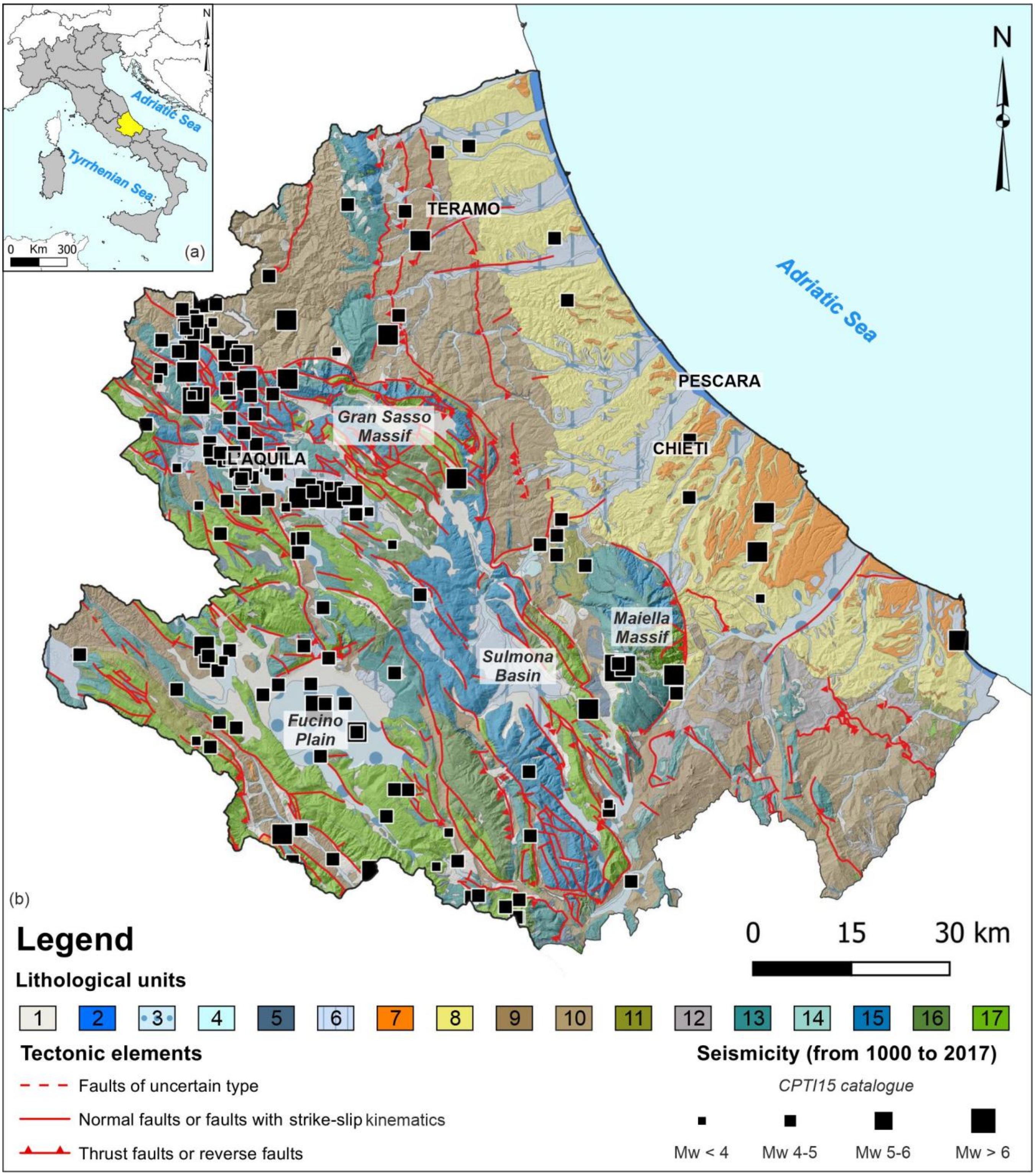


Figure 1. (**a**) Location map of the Abruzzo Region in Central Italy; (**b**) geolithological map of the Abruzzo Region (modified from [56,57]). Legend: (1) eluvial–colluvial deposits; (2) sandy shore deposits; (3) recent fluvio-lacustrine deposits; (4) travertine deposits; (5) morainic deposits; (6) old fluvio-lacustrine deposits; (7) conglomeratic deposits; (8) clayey–sandy deposits; (9) sandy turbidites; (10) pelitic turbidites; (11) carbonate deposits in conglomeratic and calcarenitic facies; (12) allochthonous pelagic deposits; (13) carbonate ramp limestones; (14) basin limestones and marls; (15) slope limestone; (16) open carbonate shelf-edge limestones; (17) carbonate shelf limestones and dolomites. Seismicity derived from [49].

3. Materials and Methods

Landslide analysis was achieved through an integrated approach based on the combination of literature data, landslide inventory analysis, statistical analysis of the relationships between landslide types and lithological units, detailed photogeological analysis, and geomorphological field mapping, supported by multidisciplinary analysis and GIS–based techniques.

3.1. Landslide Inventory Maps and Database Analysis

Landslide inventories and databases represent an important tool to document the extent of landslide phenomena in a region, to investigate the distribution, types, pattern, recurrence, and statistics of slope failures, to determine landslide susceptibility, hazard, and risk, and to study the evolution of landscapes dominated by mass-wasting processes [58].

A preliminary GIS-based analysis was performed to store, organize, and manage available data recorded in four different databases and catalogues, briefly described as follows. The IFFI database (Italian Landslide Inventory—[59,60]) supplies a detailed picture of the distribution of landslide phenomena within Italy. As of today, the IFFI database holds 620,793 landslide phenomena, covering an area of approximately 23,000 km^2, which is equivalent to 7.9% of the Italian territory [37]; for the Abruzzo Region, the database is updated to 2007. The compilation of the catalogue was structured in several phases: (i) collection of bibliographic cartographic data useful to identify areas subject to landslides; (ii) verification by aerial photo interpretation and cartographic transposition; (iii) verification through field-based analysis; (iv) digitization. A total of 6557 events (categorized as rockfalls, lateral spreading, complex landslides, translational and rotational slides, debris flows, earth flows, DSGSDs, and soil creep areas) were included in the inventory used in this study. The CEDIT catalogue (Italian catalogue of earthquake-induced ground failures—[61]) includes more than 150 earthquakes and almost 2000 earthquake-induced effects, which involved almost 1100 localities; the catalogue is updated to the 2016–2017 Central Italy seismic sequence [62,63]. The catalogue implies detailed research of historical documents and reports as well as of already published scientific papers. The analysis of reported seismically induced effects infers that most of them are landslides, which account, alone, for about half of the total (44%). Among all these earthquake-induced landslides, only seven events are located in the hilly piedmont area, and they were selected, recognized, and integrated into the analysis in terms of georeferenced location and detailed information. The EEE catalogue (Earthquake Environmental Effects catalogue—[64]) is aimed to collect in a standard format the wealth of information of environmental/geological effects induced by a seismic event; the catalogue contains tables that include information at site of each EEE, including detailed characteristics on the type of earthquake. The database is updated to the 2016–2017 Central Italy seismic sequence. Among all the documented seismic-induced effects, only landslides (six events falling within the study area) were selected and included in the analysis. The FraneItalia catalogue [65] contains information retrieved from online news sources (especially Google Alerts and Italian Civil Protection press reviews) on landslides that occurred in Italy. It contains all the landslide events reported since 2010 (January 2010–December 2017), not only the ones that caused direct consequences to people or major damage; it is structured as a geo-referenced open-access database containing information on a variety of landslide features and consequences. For this study, all the landslides (162 events falling in the study area) for which it was possible to univocally define the location and the type of movement were selected and included in the inventory.

Available data (i.e., georeferenced location and detailed information) from the above-mentioned catalogues were merged to completely define the landslides' spatial distribution over the Abruzzo Region (Figure 2).

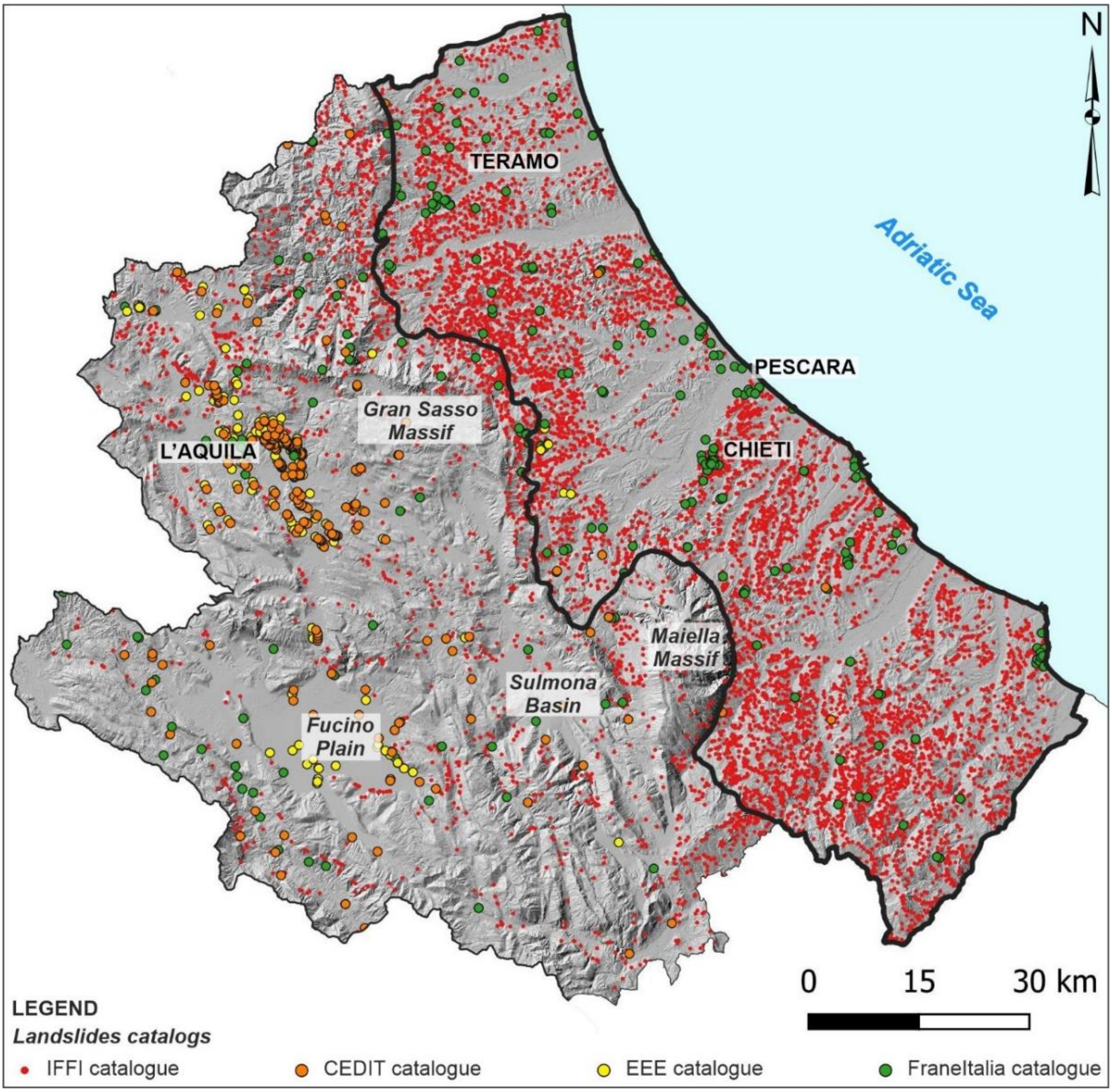


Figure 2. Landslide spatial distribution over the Abruzzo Region. This graphical representation includes the georeferenced location of rockfalls, landslides (lateral spreading, complex landslides, translational and rotational slides), debris flows, earth flows, DSGSDs, and soil creep areas. This general labelling derives from all historical documents, technical reports, and detailed information included in available inventories and databases, such as the Italian Landslide Inventory (IFFI) catalogue [60]; the Italian earthquake-induced ground failures (CEDIT) catalogue [61]; the Earthquake Environmental Effects (EEE) catalogue [64]; the FraneItalia catalogue [65]. The black line represents the study area.

Even if the landslide spatial distribution over the Abruzzo Region is related to rockfalls, landslides (lateral spreading, complex landslides, translational and rotational slides), debris flows, earth flows, DSGSDs, and soil creep area, landslides located in the study area and used for this analysis were categorized and selected according to the type of movement into four categories: rotational and translational slides, complex landslides, earth flows, and rockfalls. This specific labelling was followed to highlight the most characterizing and frequent mass movement types, according to geological–structural setting, location and abundance of landslides. Then, the spatial distribution of each category was evaluated through the creation of density maps, generated using the QGIS (version 3.10, 2019, "A Coruña") HeatMaps (Kernel Density) tool, which calculates a magnitude-per-unit (1 km^2) area from a point or polyline features using a kernel function to fit a smoothly tapered surface to each point. Landslide density maps generally show a synoptic view of landslide distribution for large regions or entire nations in order to portray the first-order overview of landslide abundance. Density is a clearly definable and easily comprehended quantitative measure of the spatial distribution of slope failures. These maps derive from the georeferenced location of each initiation point of landslides (defined as the center of the main headscarp) and assume that landslide density is continuous in space, which may not be the case everywhere.

3.2. Statistical Analysis of the Relationships between Landslides and Lithological Units

Lithology shows a great influence on landslide development since different lithological units may be affected by different landslide types. Moreover, soil cover deposits, mostly exposed to weathering, may influence land permeability and the landslide type, as known from thematic literature [66,67].

In order to stress the role played by lithological units on the development of landslides and build up a statistical relationship with the spatial distribution of landslide type, a vector lithological map (previously categorized into 17 lithological units according to the sedimentation environment and the lithological features of the outcrops) was spatially overlapped with the landslide distribution layer, derived from the selected inventories and databases.

A GIS-based overlay between the georeferenced location of the initiation points of landslides (defined as the center of the main headscarp) and lithological units was performed to understand the influence of lithologies on landslides. This correlation was carried out for different types of landslides (rotational and translational slides, complex landslides, earth flows, and rockfalls) recorded in the hilly piedmont area.

3.3. Detailed Multitemporal and Multidisciplinary Analysis

Multitemporal and multidisciplinary analyses were performed to outline the mass movement types and evolution mechanisms that characterize the different morphostructural domains of the study area. Selected case studies (one for landslide type; about rockfalls, according to a moderate to low spatial distribution, no landslide events have been identified as clearly representative of this mass movement type in the study area, so no case study was reported) have undergone several main movements from the 18th century onwards. These are intended to be representative of the most characterizing and frequent mass movement type, showing significant features useful for understanding the relationships between landslide types, lithologies, and morphostructural setting.

Multitemporal geomorphological analysis was based on detailed analysis of historical maps and literature data, stereoscopic air-photo interpretation, and field mapping. Air-photo interpretation was performed using 1:33,000, 1:20,000, 1:13,000, and 1:5000 scale stereoscopic air-photos (Flight GAI 1954, Flight CASMEZ 1974, Flight Abruzzo Region 1981–1987, and Flight Abruzzo Region 2018–2019), 1:5000-scale orthophoto color images (Flight Abruzzo Region 2010), and Google Earth imagery; this analysis was also supported using high-resolution Digital Elevation Models (DEMs). Field mapping was carried out at an appropriate scale (1:5000–1:10,000), according to international guidelines [68], Italian geomorphological guidelines [69] and the thematic literature concerning geomorphological mapping, fieldbased and numerical analysis [70–73]. It was focused on the definition of lithological and morphostructural features, superficial deposit cover, and the type and distribution of geomorphological landforms with reference to the main landslides affecting the study area.

Rainfall data analysis was carried out to outline the distribution of the climatic parameters and conditions in the hilly piedmont area. The analysis was based on a rainfall dataset obtained from a network of 51 gauges (data provided by the Functional Center and Hydrographic Office of the Abruzzo Region, Pescara, Italy). Using the ArcGIS Kernel Interpolation function, the variation of the distribution of rainfall in the study area was derived for a 65-year time record (1950–2015).

To support the geomorphological dynamic of the area and improve the knowledge of spatial and temporal evolution of landslides, an interferometric analysis (InSAR) was implemented. The approach used is the so-called Persistent Scatterers Interferometry (PSInSAR), which is based on the information achieved by pixels of the SAR images characterized by high coherence over long time intervals [74]. Generally, constructed structures, such as buildings, bridges, dams, railways, pylons, or natural elements, such as outcropping rocks or homogeneous terrain areas, can represent good Persistent Scatterers (PSs). However, these techniques are also affected by some limitations. First, because only objects which are good "radar reflectors" can be analyzed, they cannot attain information over highly vegetated areas. This aspect is not secondary, as landslides often involve non-urban areas [75]. For the present study, we performed analyses of past displacements using data-stacks from the ESA archive ranging in the period 1992–2010. Specifically, Envisat data were selected from the 2003–2010 period, providing quantitative data (i.e., the detection of targets affected by displacements) about displacement information present in both the ascending and descending geometries.

4. Results

4.1. Density Maps (Heatmaps) of Landslide Types over Abruzzo Hilly Piedmont Area

Heatmaps of various slope instability processes over the Abruzzo hilly piedmont area (Figure 3) were produced using GIS technology. These maps allowed us to outline the spatial distribution of landslide phenomena. For this kind of analysis, landslides data were labelled according to the type of movement (rotational and translational slides, complex landslides, earth flows, and rockfalls). Colored areas represent the sites with a higher density of slope instability processes in each category. In the current study, a heterogeneous spatial distribution of landslide types was identified, reflecting the physiographic, geological–structural, and geomorphologic setting of the hilly piedmont area.

The analysis allowed us to identify that (i) rotational and translational slides are most widespread in central and southern sectors (Figure 3a) with high density in correspondence of the mesa-plateau landscape on clayey–sandy and conglomeratic deposits and the incision of the main rivers; (ii) complex landslides are heterogeneously widespread in the study area, with the highest density in the southern sectors following the complex rough topography developed on allochthonous pelagic deposits (Figure 3b); (iii) earth flows mainly characterize the northernmost sectors of the study area reflecting the physical landscape on sandy-pelitic turbidites (Figure 3c). Rockfall density map (Figure 3d) shows a moderate to low spatial distribution as the result of episodic and localized slope instability processes related to the morphostructural setting in the inner sectors [76] and cliff recession processes combined with wavecut and gravity-induced slope processes in coastal areas [77]. Regarding this latter case, no landslide events have been identified as clearly representative of this mass movement type in the study area. In detail, we selected the following case studies intended to be representative of the most characterizing and frequent slope instability processes:

(A). San Martino sulla Marruccina landslide;
(B). Roccamontepiano landslide;
(C). Montebello sul Sangro landslide.

The georeferenced location of selected case studies is graphically shown in Figure 3 with capital letters in white circles.

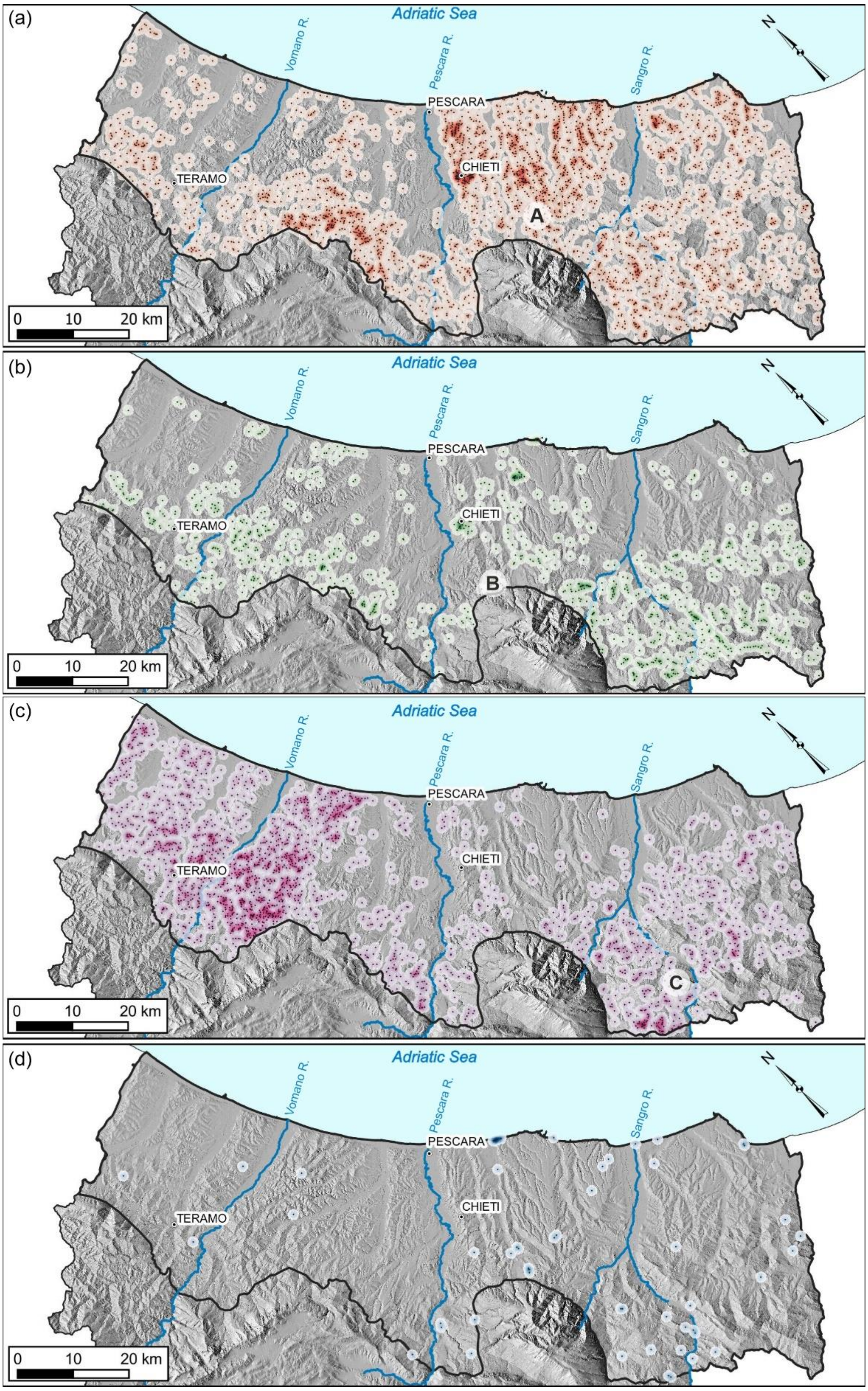


Figure 3. Density maps (heatmaps) of various slope instability processes over the Abruzzo hilly piedmont area: (**a**) rotational and translational slides; (**b**) complex landslides; (**c**) earth flows; (**d**) rockfalls. Colored areas represent the sites with a higher density of slope instability processes in each category (black dots). Capital letters in white circles locate the selected case studies. The black line represents the study area.

4.2. Relationship between Lithology and Spatial Distribution of Landslide Types

A detailed landslide analysis allowed us to differentiate landslide types in order to define the role played by lithological units on landscape development and build up a statistical relationship with the spatial distribution of landslide type.

Preliminary GIS-based analysis of the data derived from available databases (i.e., georeferenced location and detailed landslide information) allowed us to recognize the presence of a large number of landslide phenomena in the study area, reaching 5605 recorded events. In order to promote a relationship between mass movements and lithological units outcropping in the area, recorded landslides were classified according to their typology of movement (e.g., rotational and translational slides, complex landslides, earth flows, and rockfalls). Then, a spatial overlapping between the landslide distribution layer and the vector lithology layer was performed, and a new table of attributes was built (Figure 4).

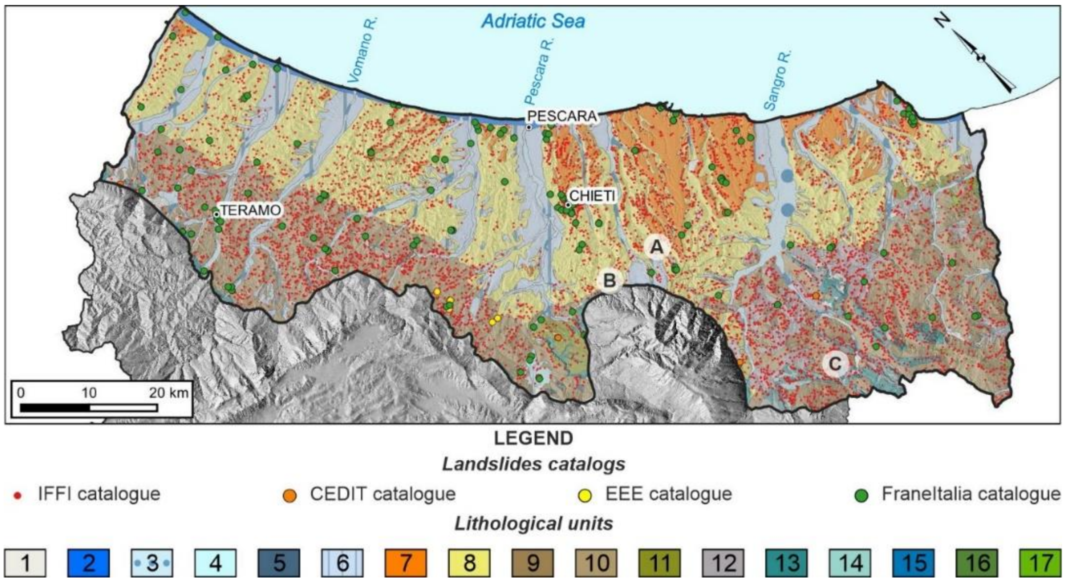


Figure 4. Lithological sketch map of the Abruzzo hilly piedmont area (modified from [56,57]) and spatial landslides distribution [60,61,64,65]. Legend: (1) eluvial–colluvial deposits; (2) sandy shore deposits; (3) recent fluvio-lacustrine deposits; (4) travertine deposits; (5) morainic deposits; (6) old fluvio-lacustrine deposits; (7) conglomeratic deposits; (8) clayey–sandy deposits; (9) sandy turbidites; (10) pelitic turbidites; (11) carbonate deposits in conglomeratic and calcarenitic facies; (12) allochthonous pelagic deposits; (13) carbonate ramp limestones; (14) basin limestones and marls; (15) slope limestone; (16) open carbonate shelf-edge limestones; (17) carbonate shelf limestones and dolomites. Capital letters in white circles locate the selected case studies. The black line represents the study area.

The area of each landslide was obtained from this estimation so that the area ratio of the distribution of landslides in each lithology was derived.

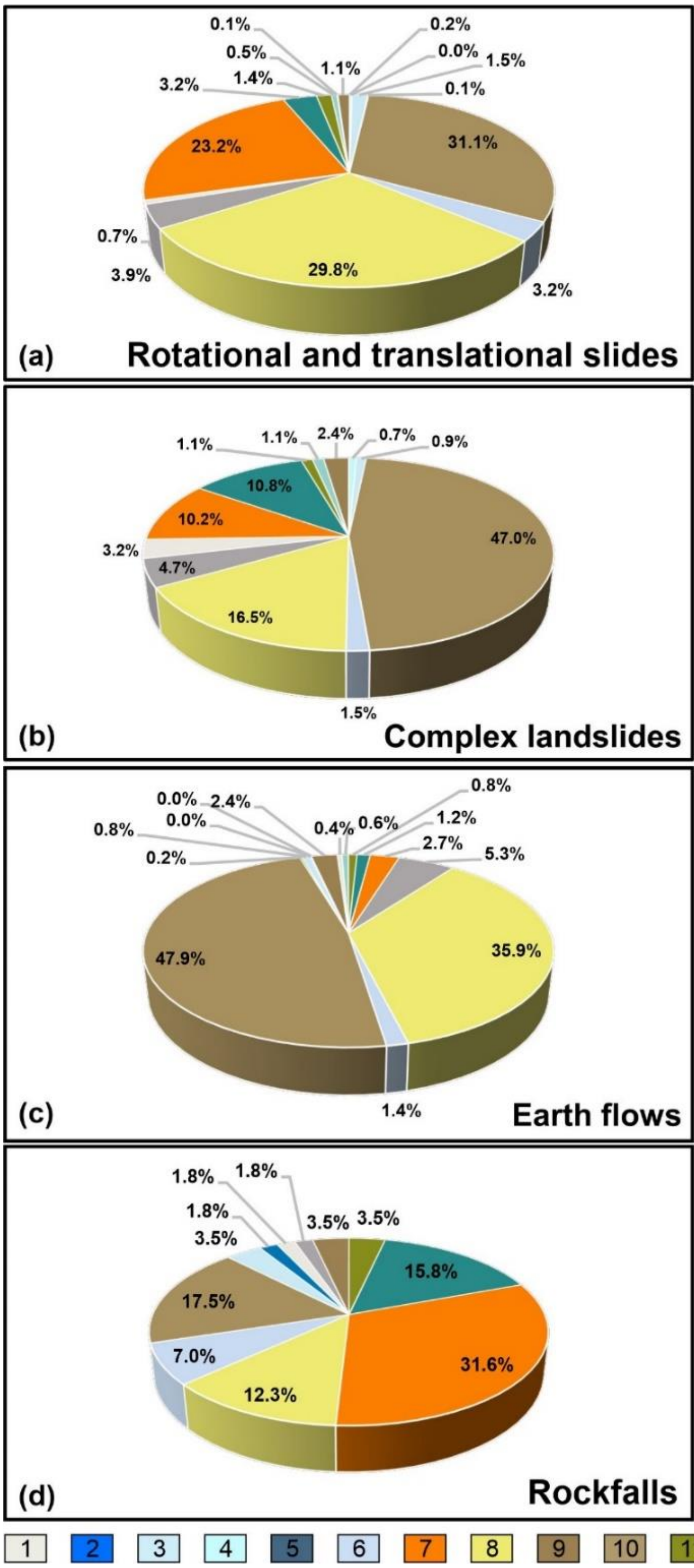
The spatial overlapping allowed us to quantitatively estimate the extension of each lithological unit in the study area in terms of area (km^2) and percentage (Table 1). This GIS-based technique was useful to define the major lithological abundance (both in percentage and area) of clayey–sandy deposits and pelitic turbidites over the study area. Then, the analysis of spatial distribution compared to the outcropping lithologies was carried by comparing the percentage and number of landslides (rotational and translational slides, complex landslides, earth flows, and rockfalls) on each lithological unit as graphically shown by the pie charts and tables in Figure 5.

This overlapping process shows a heterogeneous relationship between lithological units and the distribution of different types of landslides in the Abruzzo hilly piedmont area. Landslides on Quaternary continental deposits were mostly small flows and slides located along the scarp edge of fluvial terraces. Landslides affecting the cuesta and mesa reliefs on the sands and conglomerates on high gradient slopes or else along structural scarps are represented by rapid earth flows affecting surface colluvial cover; falls and topples affecting the edge of structural scarps on sandstones and conglomerates; rotational and translational sliding, which was less frequent but developed for a long time after the event due to deep water infiltration in the permeable conglomerates and sandstones laying on impermeable clays. Landslides on the hilly slopes and cuesta and mesa slopes affecting clayey–sandy deposits were mostly earth flows, from the small to the very wide. Landslides on the arenaceous-pelitic and marly rocks of the turbiditic succession consisted of mostly rapid surface flows and sliding, affecting the eluvial and colluvial cover, particularly where it is more clay-rich. Landslides on the slopes and isolated reliefs on allochthonous pelagic deposits outcropping in the southernmost sectors were mostly flows and complex landslides occurring on all the slopes with a low gradient due to its complex geological–structural setting.

Table 1. Extension of each lithological unit in the study area.

Lithological Unit	Unit Description	Area (km^2)	% of Area
1	Eluvial–colluvial deposits	57.998	1.310
2	Sandy shore deposits	49.622	1.121
3	Recent fluvio-lacustrine deposits	347.175	7.842
4	Travertine deposits	11.571	0.261
5	Morainic deposits	2.333	0.053
6	Old fluvio-lacustrine deposits	464.892	10.501
7	Conglomeratic deposits	380.776	8.601
8	Clayey–sandy deposits	1450.528	32.763
9	Sandy turbidites	38.679	0.874
10	Pelitic turbidites	1228.908	27.757
11	Carbonate deposits in conglomeratic and calcarenitic facies	53.939	1.218
12	Allochthonous pelagic deposits	189.460	4.279
13	Carbonate ramp limestones	125.675	2.839
14	Basin limestones and marls	13.672	0.309
15	Slope limestone	2.127	0.048
16	Open carbonate shelf-edge limestones	0.000	0.000
17	Carbonate shelf limestones and dolomites	9.976	0.225

The study area is characterized by 2694 rotational and translational slides, 851 complex landslides, 2003 earth flows, and 57 rockfalls. In detail, rotational and translational slides mostly develop on pelitic turbidites (31.1%), clayey–sandy deposits (29.8%), and conglomeratic deposits (23.2%), with a higher number of events recorded (839) on pelitic turbidites. Complex landslides mostly develop on pelitic turbidites (47.0%), clayey–sandy deposits (16.5%), carbonate ramp limestones (10.8%), conglomeratic deposits (10.2%), with the higher number of events recorded (400) on pelitic turbidites. Earth flows develop on pelitic turbidites (47.9%) and clayey–sandy deposits (35.9%), with a higher number of events recorded (959) on pelitic turbidites. Rockfalls develop on conglomeratic deposits (31.6%), pelitic turbidites (17.5%), carbonate ramp limestones (15.8%), and clayey–sandy deposits (12.3%) with 18 recorded events on conglomeratic deposits. This latter relationship shows a moderate to low distribution as the result of episodic and localized processes related to morphostructural setting in the inner sectors and cliff recession processes combined with wavecut and gravity-induced slope processes in coastal areas.



Lithological unit	N° of event
1	18
2	-
3	40
4	6
5	2
6	86
7	626
8	802
9	29
10	839
11	38
12	106
13	85
14	14
15	1
16	-
17	2
Total	2694

Lithological unit	N° of event
1	27
2	-
3	8
4	6
5	-
6	13
7	87
8	140
9	20
10	400
11	9
12	40
13	92
14	9
15	-
16	-
17	-
Total	851

Lithological unit	N° of event
1	9
2	1
3	16
4	-
5	-
6	29
7	55
8	720
9	49
10	959
11	16
12	107
13	25
14	12
15	1
16	-
17	4
Total	2003

Lithological unit	N° of event
1	1
2	-
3	2
4	-
5	-
6	4
7	18
8	7
9	2
10	10
11	2
12	1
13	9
14	-
15	1
16	-
17	-
Total	57

Figure 5. Relationships between lithological units and the distribution of different types of landslides in the Abruzzo hilly piedmont area. (**a**) Pie chart and table showing the percentage and number of rotational and translational slides on each lithological unit; (**b**) pie chart and table showing the percentage and number of complex landslides on each lithological unit; (**c**) pie chart and table showing the percentage and number of earth flows on each lithological unit; (**d**) pie chart and table showing the percentage and number of rockfalls on each lithological unit. Numbers and colors refer to legend in Table 1 and Figure 4.

4.3. Selected Landslide Case Studies

4.3.1. San Martino Sulla Marruccina Landslide

The case study area is located in the central-eastern hilly area of the Abruzzo Region with heights ranging from 200 to 450 m.a.s.l.; this landscape is interrupted by the S–N-oriented Dendalo River valley, where lower altitudes (up to 200 m.a.s.l.) are reached. The study area shows a homogeneous slope distribution (about 5°–15°), with some peaks (>20°) especially in correspondence with the main steep scarps and along the secondary slopes.

From a lithological standpoint, bedrock lithology is composed of a thick marine succession, composed of arenaceous-pelitic and pelitic-arenaceous deposits, known in the literature as the *Mutignano Formation* [78,79]. This succession is composed of clays and silty clays alternated with gray to yellow sands in the lower part, and by gray to yellow sands in medium layers with frequent intercalations of fine-grained sandstone, in the upper part. Quaternary continental deposits include landslide, alluvial, and eluvial–colluvial deposits mainly observed along fluvial incisions and slopes. Strength features of the outcropping rocks are considerably complex, being linked not only to the lithological and structural setting (sub-vertical fracture-sets NNW–SSE to E–W-oriented) but also to the alteration, rearrangement, and loosening processes during complex gravitational phenomena [80]. The landslide phenomenon covers an area of about 2.5 km^2 extending between 400 and 300 m.a.s.l.; it presents a medium length of about 750 m and a significant width of surface rupture area. It is characterized by the main crown of about 2.5 km long, which is locally more than 20 m high. Multitemporal analysis of air-photos, technical cartography, and dendrochronological analysis reveals the first signs of activity in the second half of the 1960s, causing the definition of the first slopes and causing huge damage to roads, buildings, and crops [79,81]. These geomorphological effects, definable in the timespan 1968–1981, are represented by complex landslide bodies with related scarps in the northernmost areas and rotational–translational landslide bodies in the central sector. Nowadays, the movements recorded by the monitoring network are due to a residual activity, but the central sectors are currently affected by a significant local instability due to retrogressive evolution (Figure 6a). Currently, landslides mainly show a rotational and translational sliding surface, as highlighted by counterslopes, counterscarps, and formation of ponds and peatbogs recognized in landslide bodies; smaller instability phenomena are represented by complex landslides and earth flows. Landslide scarps (Figure 7) have different morphological and geomorphological characteristics: where the pelitic deposits outcrop, they are highly degraded, while where sandy deposits are present, they are fresh and evident. The geometrical development of the main and the subordinate crowns are influenced by the spatial disposition of the structural landforms. The planimetric development of the scarps, corresponding in part to the disposition of the families of faults, shows how the geomorphologic processes have been conditioned by the structural setting. The area that surrounds the currently active landslide also presents an old and generalized familiarity with the slope instability processes. Relict shapes and quiescent minor instability phenomena have been observed owing to detailed field surveys and stereoscopic observations [80].

The geomorphological cross-section (Figure 6b) shows how the landslides are in close connection with each other, often presenting several coalescent bodies, also involving landslides activated in the previous time frame. These landslides are characterized by deep failure surfaces, often in the range of several tens of meters. The geometry of the sliding surfaces shows a strong structural control, mainly connected to fault zones and bedding planes; in fact, most of the main landslide scarps and flanks coincide with inferred faults, while the geometry of the sliding surfaces, especially in the middle and lower part of the landslide body, is conditioned by the bedding of the pelitic sequences.

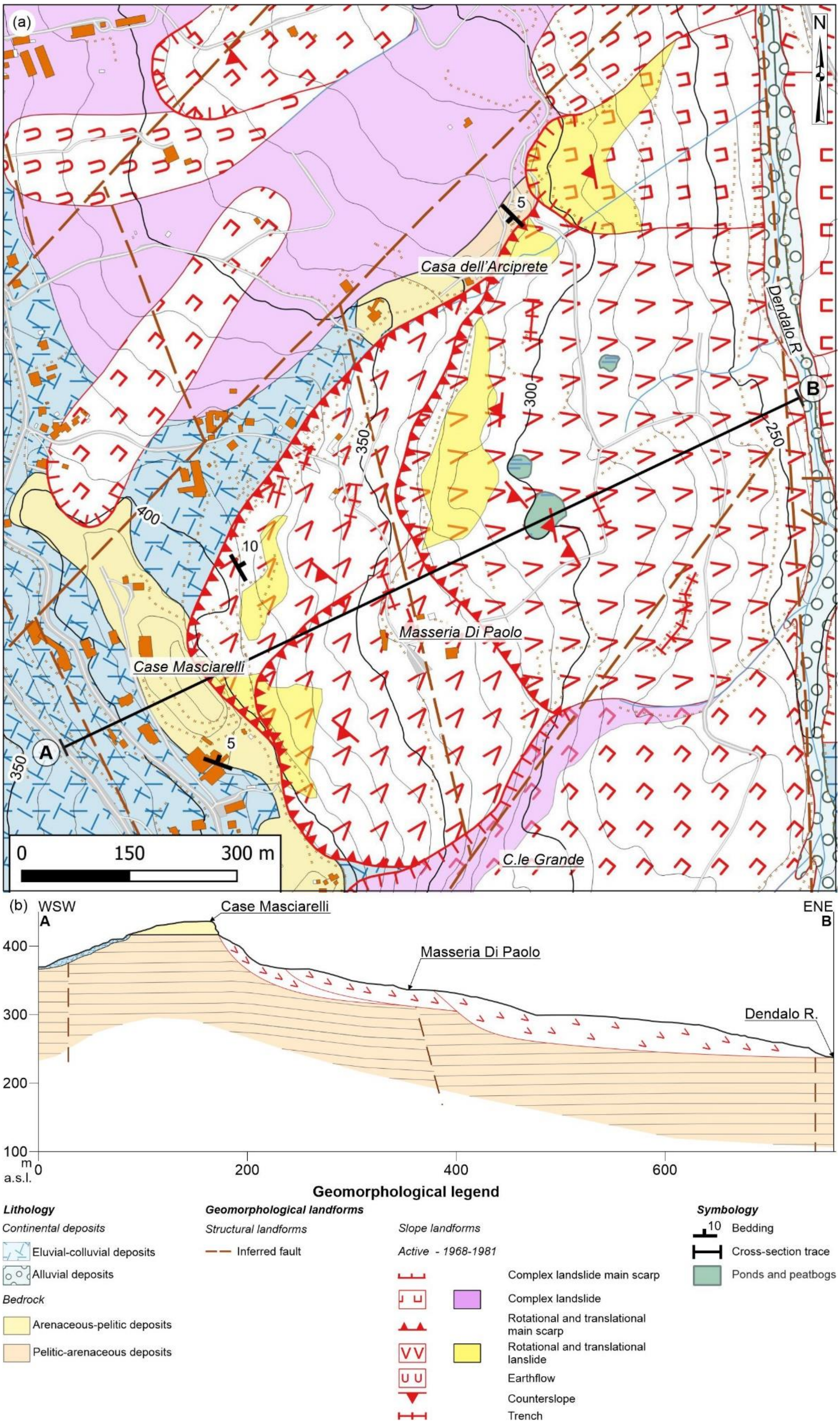


Figure 6. San Martino sulla Marruccina: (**a**) multitemporal geomorphological map (derived from unpublished data and modified and updated from [79–81]); (**b**) geomorphological cross-section.

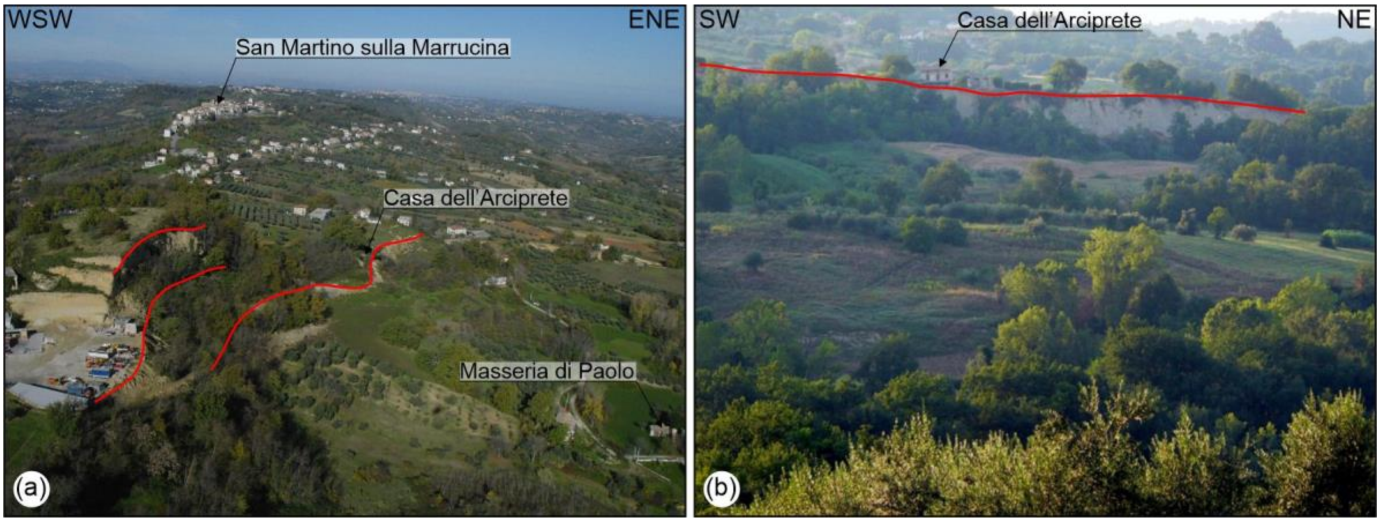


Figure 7. Photo documentation of geomorphological features of San Martino sulla Marruccina landslide. (**a**) Aerial view of the landslide area; (**b**) panoramic view of the landslide scarp of Casa dell'Arciprete. Red lines show the planimetric development of main landslide scarps.

The complex landslide system could be divided into fairly regular "blocks", dislocated from each other and generally prismatic in form, originally created by the intersection of tectonic fracturing and faulting systems. The main direction of the landslide mass movement is SW–NE, that is, obliquely to the slope.

4.3.2. Roccamontepiano Landslide

The case study area is located next to the northeastern front of the Maiella Massif. It is characterized by the presence of a pseudo-rectangular-shaped travertine plateau (Montepiano) which dominates both topographically and morphologically the landscape of the area. Montepiano is a flat tabular relief 610–650 m.a.s.l. high, with a maximum length of about 2.3 km (along NW–SE direction). It generally dips gently north-east with an average gradient of about 5%, and it is bounded by vertical cliffs and scarps up to 30 m high [82,83]. Furthermore, the landform is cut by a series of small SW–NE-oriented fluvial incisions that raise the relief values along the slopes.

From a lithological standpoint, the area is characterized by an approximately 40 m thick travertine layer that overlies arenaceous-pelitic and pelitic-arenaceous deposits, with thin conglomerate layers in between, pertaining to the *Mutignano Formation* [78]; also, these bedrock layers are gently dipping towards the NE. Physical–mechanical parameters show a significant variability in terms of rock resistance and behavior according to lithological nature (travertine layer and arenaceouspelitic lithotypes) and subsequent loosening and weathering phenomena [84]. Quaternary continental deposits include eluvial–colluvial deposits mainly observed along the southwestern flank of the plateau. The landslide phenomenon covers a wide area (~4 km^2) with high slope gradients (seldom less than 30%) and high variability in width and thickness due to repeated historical landslide events (Figure 8a). The maximum width of more than 2 km can be found downstream of the Ripa Rossa, whilst the maximum thickness of more than 20 m is located immediately above Roccamontepiano village. From historical sources, the first landslide events that occurred in the area took place on 24 June 1765, causing severe damage to the village and 2000 casualties [82,85].

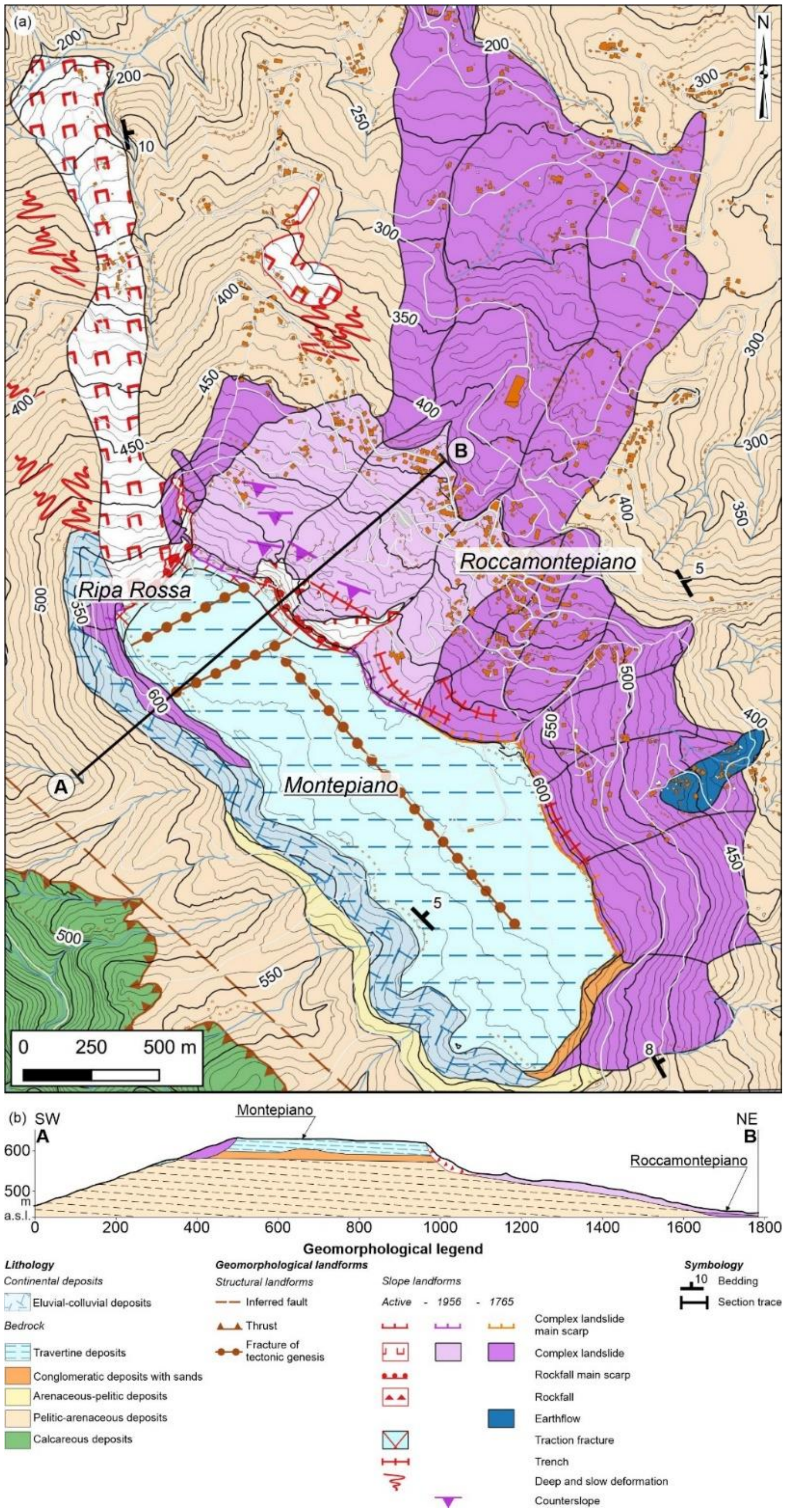


Figure 8. Roccamontepiano landslide: (**a**) multitemporal geomorphological map (derived from unpublished data and modified and updated from [82,83]); (**b**) geomorphological cross-section.

Therefore, the relief is almost surrounded by wide complex landslide bodies and related scarp, which characterize most of the area south of Roccamontepiano village. Other historical movements occurred in the second half of the 1950s, reactivating pre-existing ones and causing extensive damage to the village of Roccamontepiano but this time without the report of victims [86]. Evidence of this second historical event is represented by wide counterslopes located at ~500 m.a.s.l. Actually, the landslide body is formed by a thick heap (up to 17 m) of travertine blocks and fragments with secondarily reworked sandstone-conglomerate deposits, active especially in the northeastern and northern part of the Montepiano plateau (Figure 9a). The overall mechanism could be referred to a complex landslide system, including lateral spreading with rockfalls, rotational, and translational movements.

Figure 9. Photo documentation of geomorphological features of Roccamontepiano landslide. (**a**) Panoramic view of the landslide area. Red lines show the planimetric development of main landslide scarps, red circles show travertinous blocks in the landslide body; (**b**) detail of NE–SW trending traction fractures (red lines) in the travertine cliff scarp near Ripa Rossa.

The geomorphological cross-section (Figure 8b) shows how the landslides are strictly connected with the structural framework of the study area; the mechanism implies the involvement of the plastic clays that underlie the travertines in the mass movement.

The presence of a thick layer of massive rocks over plastic lithologies leads to tension stresses along the edge of the travertine layer and the progressive opening of preexisting fractures. The travertine layer exhibits NW–SE and NE–SW trending fracture systems, probably caused by tectonic activity (Figure 9b). Fracture of tectonic genesis up to 10 m wide and in different stages of evolution are sub-parallel to the plate edge and the major fracture systems all along the cliff scarps. When these fractures reach the clays, large blocks of travertine are isolated over the plastic materials, and lateral spreading accelerates, defining sliding surfaces; the movement evolves as a complex landslide.

4.3.3. Montebello sul Sangro Landslide

The case study area is located in the transition zone between the central Apennines chain front and the piedmont area on the left side of the middle Sangro River valley. It is on a narrow-faulted anticline ridge, more than 900 m.a.s.l. high, trending N–S. The landscape outlines a strongly asymmetric calcareous hogback ridge, with a gentler eastern slope and a steeper western one, resulting from the erosion of the anticline flank; northwards the ridge is deeply incised and separated by a second hogback ridge on which the Pennadomo village is located.

From a lithological standpoint, bedrock lithology is made of rocks pertaining to allochthonous pelagic deposits. Clayey deposits with embedded terrigenous siliciclastic deposits (*Argille varicolori formation*) outcrops in the western side of the ridge; alternating calcareous-marly and calcirudite rocks (*Tufillo formation*) represent the backbone of the ridge; pelitic-arenaceous deposits (*Flysch of Agnone formation*) mostly outcrop in the eastern side of the ridge [39,87]. Physical–mechanical properties of chaotic marly–clayey deposits reflect the great amount of lithological variability within them, and consequently the rock behavior is not constant. Moreover, detailed analysis showed that outer area of the scree slope deposits appears plasticized, and the most superficial zones are at yield in tension [87]. Quaternary continental deposits include eluvial–colluvial and scree deposits mainly observed along fluvial incisions and slopes.

The landslide phenomenon covers an area of ~1.1 km^2, and it is affected by strong variations in the state of activity. Large landslides (mostly dormant and/or abandoned) and small landslides (generally more recent and active) constitute the wide and complex landslide system. Historical documents and chronicles show multiple activations of the main event, involving the western side of the Montebello hogback and spreading out on the eastern side (Figure 10a). These worrying geomorphological dynamics are testified by the involvement of the Montebello village. The first evolution of events occurred in the second half of 1800 (1864, 1891, and 1899); after that, the new village of Montebello sul Sangro was reconstructed in a more western site [86–88]. It was characterized by a complex dynamic including earth flows, complex landslides, rotational and translational landslides, and localized rockfalls. Another significant landslide event occurred in 1971 [89], and it was mainly characterized by earth flows due to the activation of several small mass movements composing the large one. Nowadays, a principal earth flow is present, and the activity of this movement is demonstrated by a range of surface expressions such as irregular mounds, landslip troughs, and several tension fractures that opened both longitudinally and transversely to the main landslide. The main landslide is characterized by a mass that flows down along a narrow channel and then spreads out in a wide accumulation lobe, with depressions and undulations. Thrust features in the accumulation area point out at least three overlapped flows, suggesting an intermittent movement (Figure 11). Moreover, the geomorphological complexity of the area is evidenced by the presence of several families of rotational and translational landslides, complex landslides, and rockfalls, present especially along the steep western side of the hogback.

The geomorphological cross-section (Figure 10b) shows that the landslide movements are strictly controlled by the geological and morphostructural setting of the carbonate hogback (east overturned faulted anticline trending from N–S to NNW–SSE) and chaotic clay rocks; the main earth flow is influenced by the progressive involvement of the clay units in the landslide movement, and the rockfalls in the upper part of the ridge are linked to fractures and jointing in the calcareous strata. The scarp area involves the steep western calcareous slope of the ridge down to the gentle lower slope on clay units; the regressive enlargement of the landslide scarp, close to the Montebello village, involves the western side of the calcareous ridge, with systems of tension fractures and reverse slope areas, affecting the Montebello village (Figure 11b).

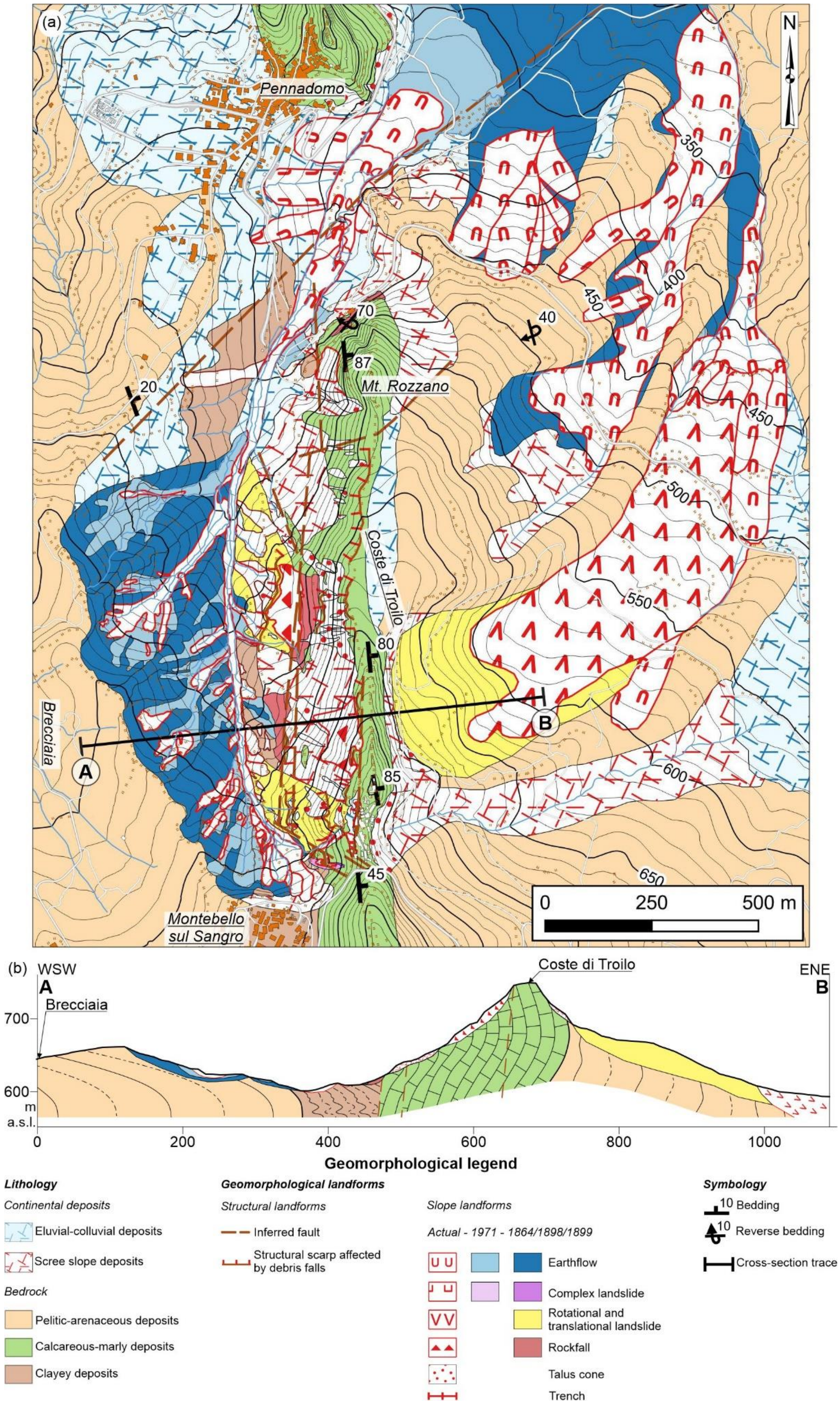


Figure 10. Montebello sul Sangro landslide: (**a**) multitemporal geomorphological map (derived from unpublished data and modified and updated from [87]); (**b**) geomorphological cross-section.

Figure 11. Photo documentation of geomorphological features of Montebello del Sangro landslide. (**a**) Panoramic view of the main earthflow; (**b**) detail of allochthonous pelagic deposits involved in the landslide phenomenon, with regressive enlargement of the landslide scarp near the Montebello sul Sangro village.

5. Discussion

Landslides have been widely considered as principal mass-wasting agents in areas experiencing varied influence of several causative factors (i.e., lithology, geological setting, climate regime, etc.). However, patterns of landslides are rarely addressed as a surface manifestation of interrelationships between morphostructural setting, lithology, and climate. Here, we have attempted to understand such interrelationships in the context of landslide distribution patterns in the hilly piedmont area of Abruzzo Region. Historical landslides analysis allowed us to understand that the distribution, mechanisms, and types of mass movements in the study area strictly correlate with the different physiographic, lithological, and geological–structural settings. The work mostly focuses on three landslide case studies analyzed with the aim of highlighting the multitemporal evolution of the landslide phenomena, emphasizing the role of lithological and morphostructural features on landslide types and the interplay between such processes and the geomorphological evolution. Landslide density maps, directly combined with the inventories and databases from which they were obtained, allowed us to define and graphically show different sectors in the study area. In each sector, we have outlined the landslide types and the mechanisms that mostly determine the slope instability reflecting the geological–structural and geomorphological setting. Selected case studies are representative of the most characterizing and frequent slope instability processes over the hilly piedmont area, showing different influences on geomorphological dynamics according to the physiographic and litho-structural setting. In the northern and central sectors, landslide phenomena affect a gently hilly area made of clayey–sandy deposits (with sandstone-conglomerate sequence on top), gently dipping towards the northeast or horizontal. In the southernmost sector, landslide phenomena affect a landscape derived from exogenous processes (fluvial and slope processes) on mostly chaotic marly–clayey deposits or chaotic succession of calcareous-marly deposits.

Several previous studies in the Abruzzo Region [48,79,90,91] analyzed and described the widespread slope geomorphic processes, showing an organic correlation between the morphostructural/geological setting and landslide types as the result of the dynamic interaction between morphostructural factors, linked to the conflicting tectonic activity and regional uplift, and morphosculptural factors, linked to drainage network linear down–cutting and slope gravity processes. The slope evolution is mainly related to the interplay of different landslide types referable to lateral spreading, rockfall, earth flow, rotational and translational sliding, evolving into complex movements and systems.

In this framework, local features such as lithology and morphostructural framework should be noted to control the occurrence and distribution of landslides. Nonetheless, interrelationships of these factors have been rarely associated with spatiotemporally varying landslide distribution patterns. However, there are many limitations to infer temporally varying landslide distribution, such as delineation of individual failure events on the reactivated landslide, loss of landslide scarp caused by the successive mass movement, etc. Different predisposing and triggering factors can influence the stability of slopes and can cause landslides, among which heavy rainfall events are intended to be a significant one. It is well known that extreme and localized heavy rainfalls constitute the main triggering causal factor of landslides. Rainfall pattern is strongly controlled and influenced by climate regime and its variations. Therefore, it is to be expected that climate changes could influence slope stability at different temporal and geographical scales. The frequency and the intensity of heavy rainfall events are also increasing, although both at local and regional scale the average annual rainfall is not showing significant changes. The assessment of the effects of climate change on the natural environment is an open issue for the scientific community trying to establish a relation between climate change and its potential effects on the occurrence, or lack of occurrence, of landslides. However, the effects of changes in climate regimes on landslides (as on other geo-hydrological hazards) remain difficult to quantify and predict.

This work represents a useful source for investigating landslide behaviors in terms of spatial and temporal distribution, as well as for analyzing and attempting correlation between climate regime, historical landslides, and present-day geomorphological activity.

In order to understand and quantify how climate regime and its variability could affect landslides, a climatic analysis was performed using a 65-year period rainfall gauges data. Figure 12a shows the spatial distribution of annual average rainfall in the study area, with minimum values (~700 mm/year) recorded along with the coastal areas and the southeastern sector of the Maiella Massif; these rainfall values are gradually increasing, moving towards the innermost areas, where the maximum values (about 1150 mm/year) are reached. Similarly, the analysis of the annual average rainfall diagram from 1950 to 2015 shows values ranging from ~530 to ~1130 mm/year, with a clear decreasing trend over the examined period (Figure 12b).

Taking into account the spatial distribution (landslide heatmaps), the location and abundance of landslides, and the geomorphological features of selected case studies, the landscape dynamics and activity of the hilly piedmont area have also been confirmed by the interferometric analysis. Considering that movements recorded by interferometric data can be due to different causes acting at different scales (i.e., uplift, subsidence, landslide, etc.), the PSInSAR technique was here used as a tool for systematic monitoring of ground deformation related to slope instability. The presence and temporal persistence of clusters of anomalies within the main landslide body act as the most important parameters that show present-day landscape changes linked to temporal landslide dynamic. Figure 12c shows the total number of persistent anomalies detected over the period 2002–2010, clipped by landslide bodies (green polygons) mapped by the IFFI project [59,60] over the hilly piedmont area of Abruzzo Region. Analyzed data show a spatial distribution of negative movements (lowering) and positive movements (raising), which reflect the extension of the investigated landslide phenomena with the highest values located in the central-southern sectors and locally in the northernmost coastal slopes.

Moreover, in order to attempt a general correlation between long-term rainfall trends and trends in landslide occurrence, a statistical analysis of the annual distribution of landslides was carried. This kind of analysis was completed collecting data from historical sources, technical reports, and updated catalogues [60,65,86] containing a variety of historical, geographical, geomorphological, and bibliographical information on landslides.

Reported diagram (Figure 12d) stores information regarding dates of occurrences of several landslides, starting from the year 1950 until the present, with non-homogeneous rates of recorded landslides per year. A detailed analysis shows that the frequency remains under the value of 10 landslides per year starting from 1950 to 1990, with unique exception years (i.e., 1954, 1956, 1986). Subsequently, growth rates, from 1991 onwards, clearly increase. Even if the variance of the number of reported landslides over time is also due to the different availability of sources of information and not necessarily linked to the real frequency of landslide occurrences [92], it is possible to consider this analysis a reasonably true reflection of reality for the period 1950–2018. Despite the presence of a timespan with a lack of suitable and univocal data (i.e., year, day, hour, etc.) on landslides' activation–reactivation in the period 2002–2009, it is possible to note that the annual landslide distribution ranges from ~5 to ~75 individual events. Considering the complete distribution of the number of landslides during the years covered, the annual landslide distribution during this period shows different periods of landslide activity and abundance. It is possible to note a nearly stable trend in the first 20-year time record (1950–1970), followed by a general increasing trend in the 1970–2000-time record, also supported and corroborated by a weak increasing trend in the last decade (2010–2018). The identified trend should be considered in relation to both the incremental data availability and the rise in mass-wasting processes, as directly shown by historical information on past and current landslides. Moreover, regarding the study area, it is not correct to conclude that a lack of reported landslides in a given time interval would be due to a minor activity of gravitational mass wasting or to a gap in the documental source, as marked by the present-day geomorphological activity testified by the temporal persistence anomalies of movement related to slope instability (Figure 12c).

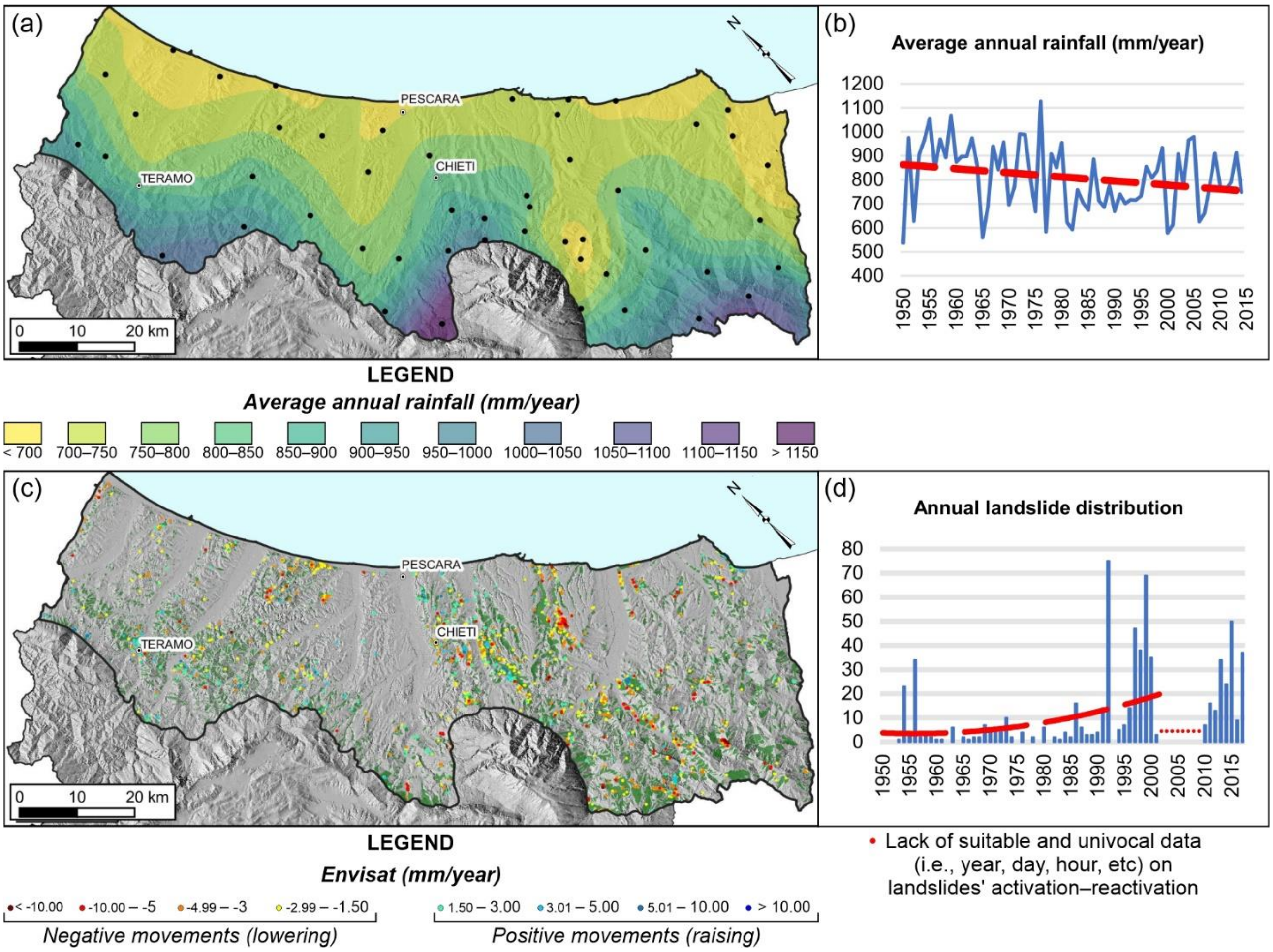


Figure 12. (**a**) Average annual rainfall map. Black dots represent rainfall gauges. (**b**) Average annual rainfall diagram from a 65-year time record (1950–2015). (**c**) InSAR observations for the selected area over the hilly–piedmont area. Mean line-of-sight (LOS) velocity for the period 2002–2010 from Envisat descending track. Only the Persistent Scatterers (PSs) that fall within the landslide areas (dark green polygons) have been selected and are represented as colored dots. Positive values represent the motion of the ground toward the satellite (raising), and negative values represent the motion away from the satellite (lowering). Green polygons represent landslide bodies detected by the IFFI Project [60]. (**d**) Distribution of annual landslide occurrences over the 1950–2015 period (derived from [60,65,86]).

The final combination and overlapping between the spatial and temporal landslide distribution pattern, the mismatch between landslide areas and sectors characterized by high rainfall density, the lack of correspondence between decreasing annual average rainfall trend and the increasing annual landslide distribution allowed us to highlight the interplay between the morphostructural/geological framework and landslide dynamics in the hilly piedmont area of Abruzzo Region. The present study allowed us to better characterize the present-day landscape setting of the study area, confirming that it is characterized by active geomorphological processes, mostly represented by slope instabilities (i.e., rotational and translational slides, complex landslides, earth flows, and rockfalls). This was obtained from historical information on past and current landslides. Currently, geomorphological activity and landslide dynamics are testified and supported by interferometric data (clusters of persistent anomalies, detected over the period 2002–2010, and clipped by landslide' polygons) with negative movements (values between -10 and -2) and positive ones (values between 2 and 10) heterogeneously distributed over the hilly piedmont area. Detailed multitemporal geomorphological analysis on selected case studies (San Martino sulla Marruccina, Roccamontepiano, and Montebello sul Sangro) show multiple activations of the main event since the 18th century onwards with large landslides (mostly dormant and/or abandoned) and small landslides (generally more recent and active) constituting the wide and complex landslide systems and reflecting the physiographic, geological–structural, and geomorphologic setting.

In conclusion, by summarizing data obtained from multitemporal and multidisciplinary, it is possible to suggest that landslide occurrence and the dynamics of the hilly piedmont area of Abruzzo Region are not directly linked to climate regime variations, but the most influential factors are represented by the lithological and morphostructural setting. These predisposing factors are strictly related to a cuesta, mesa, and plateau landscape in which it is possible to outline the landslide types and the mechanisms that mostly determine the slope morphogenesis and are characterizing of the specific geological–structural setting. To these characterizing landslide types are obviously associated and sometimes super-imposed a set of landslides secondary or however controlled by local conditions, single factors (i.e., extreme heavy rainfall events), and not by the whole morphostructural setting. Moreover, considering the historical landslide events and the geomorphological activity of the area, most of the recorded landslides could be considered as reactivations of pre-existing ones (dormant slides and/or paleolandslides), which have occurred in periods of climatic and geomorphological conditions different from those of the present, evolving in complex movements and systems because of the absence of sustainable land planning and appropriate landslide hazard mitigation measures.

6. Conclusions

This paper presents detailed analyses of the occurrence and distribution of landslides over the hilly piedmont area of Abruzzo Region (Central Italy) in relation to mechanisms and factors that control their evolution in different orographic, lithological, and geological–structural conditions. Historical landslides analysis, supported by GIS-based techniques, was performed through an integrated approach combining literature data and landslide inventories analysis, relationships between landslide types and lithological units, detailed photogeological analysis, and geomorphological field mapping. In detail, the work focuses on three landslide case studies that have undergone several main movements since the 18th century onwards, intending to highlight the multitemporal geomorphological evolution of phenomena and the interplay between morphostructural/geological framework and landslide dynamics. The main landslide cases analyzed and discussed in this paper consist of rotational and translational slide in a complex landslide system on clayey–sandy deposits, characterized by a very rough topography documenting the activity of long-term landslide processes (San Martino sulla Marruccina landslide case); complex landslide system including lateral spreading with rockfalls, rotational and translational movements, characterized by a travertine layer that overlies arenaceous-pelitic and pelitic-arenaceous deposits (Roccamontepiano landslide case); main earth flow on chaotic allochthonous pelagic deposits with several families of rotational and translational landslides, complex landslides, and rockfalls (Montebello sul Sangro landslide case).

A multidisciplinary and multitemporal analysis allowed us to better characterize the present-day landscape setting of the study area, deriving data from historical information on past and current landslides. Furthermore, this work represents an attempt for the understanding of spatial interrelationship of landslide types, morphostructural setting, and climate regime in the study area. It gives a contribution about the location, abundance, activity, and frequency of landslides in a changing environment, by means of the analysis of historical events and a comparison between the long-term rainfall trends and the distribution of annual landslide occurrences, which shows that landslide dynamics are not directly linked to climate regime variations, but that the most influential factors are represented by the lithological and morphostructural setting. Finally, the work could represent a scientific tool for any study in the future concerning susceptibility, hazard, and risk assessment at different spatial scales, readily available to interested stakeholders for sustainable territorial planning and loss-reduction measures.

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Conflicts of Interest: The authors declare no conflict of interest.

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