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**Perception and assessment of geodiversity and
cultural heritage to promote geotourism in the
Irpinia area crossed by the disused Avellino-
Rocchetta S. Antonio railway line**

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che ha creduto in me anche quando io faticavo a farlo,
e alla mia famiglia,
per avermi dato le basi su cui costruire questo cammino.*

La Terra ha memoria scritta nelle rocce
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ABSTRACT

This research provides a comprehensive analysis of the geodiversity, geomorphodiversity, and cultural heritage along the decommissioned Avellino–Rocchetta S. Antonio railway line. The study area spans 1,589 km² along the inner margin of the Southern Apennines and includes regions in Campania (80.64%), Apulia (18%), and Basilicata (1.29%). This region forms a geo-cultural corridor of strategic importance. The inactive railway traverses an area with significant geological, geomorphological, and landscape diversity, where volcanic systems, carbonate massifs, fluvial basins, and terrigenous complexes coexist, alongside a rich array of historical, cultural, and productive elements.

The primary goal of this research is to create a multidisciplinary model that characterises the physical, environmental, and anthropogeographical aspects of the study area. This study will employ quantitative methods to assess geodiversity and geomorphodiversity, and interpret the findings in the context of socio-economic dynamics and the potential to enhance geoheritage. The specific objectives include constructing an integrated geodatabase, applying quantitative indices to measure geo-lithological, hydrogeological, pedological, land-use, and geomorphological variety, defining landscape units, and evaluating territorial, cultural, and geotouristic implications.

The methodology integrates GIS analysis, morphometric processing, thematic classifications, photointerpretation, and quantitative modelling applied on a 1×1 km grid. This approach allows for systematic representation of the physical variability in the study area, enabling comparisons across geographical sectors and among different landscape units.

Results indicate that geodiversity predominantly displays low to medium values, whereas geomorphodiversity shows greater complexity, with medium to high values found in terrigenous hilly areas, lithological transition zones, and along major river corridors. Correlations among indices suggest that lithology significantly influences geodiversity, whereas geomorphodiversity is more closely associated with morphometry and drainage density. Differences between the western and eastern sectors confirm a more complex geomorphological structure within the Ofanto basin, aligning with the tectonic framework and the presence of Plio-Pleistocene and volcanic successions.

The decommissioned railway represents a promising opportunity for regional planners and tourism developers to create innovative, sustainable geotourism experiences that can enhance local identity and stimulate economic development.

The proposed geotouristic itinerary illustrates how quantitative analyses combined with landscape and cultural interpretation can effectively promote geoheritage. This approach encourages stakeholders to adopt integrated conservation strategies and foster sustainable tourism development.

INTRODUCTION

AIMS AND GOALS OF THE RESEARCH

Until relatively recent times, the prospect of developing a project aimed at enhancing geodiversity within an area crossed by a railway line, even if decommissioned or in the process of being decommissioned, would have required, as its only indispensable premises, at least the acknowledgement of the socio-economic obsolescence of the infrastructure and/or its irreversible underutilization. At the same time, however, the demand for a form of “travelling” tourism has progressively emerged and differentiated, increasingly oriented toward the discovery of new landscape and cultural scenarios to be shared also in emotional terms. Within this framework, the natural variability of the area or territory traversed by a railway line lends itself particularly well to fulfilling this mission, in which the role of the infrastructure is reinterpreted and valorized within a socio-touristic, cultural, and historical new deal, embedded in the broader context of territorial specificities.

It is in this spirit that the research presented in this doctoral dissertation was initiated, taking advantage of the fact that, in the inner Apennine region, already characterized by high geo-naturalistic and historical-cultural value, various public infrastructures are currently in deep crisis or have become unproductive, with significant repercussions on the socio-economic system and on the associated management or decommissioning costs.

Within this context, the Avellino–Ponte Santa Venere railway section, more commonly known as the Avellino–Rocchetta Sant’Antonio line, constitutes a genuine strategic geo-cultural corridor, where landscape systems and geological frameworks of considerable importance converge and intersect, including: the volcanic complex of Monte Vulture, the karstic reliefs of the Monti Picentini, the plains and fluvial terraces of the Ofanto, Calore, and Sabato rivers, the erosional phenomena characterizing the Ofanto valley slopes, the complex lithological variability, the geo-morpho-tectonic evolution of the area, and more. This ensemble of elements generates, with high frequency and within a relatively restricted spatial domain, an intriguing environmental and landscape variability, further enriched by significant historical, cultural, and anthropogenic vicissitudes which, as in many other inner Apennine areas, still await full valorization.

A substantial and diverse body of national and international scientific literature (Merciu et al., 2022, Peira et al., 2022, Kosykh et al., 2023, Quattrini et al., 2023, Wang et al., 2023, Ristić et al., 2024, Duarte et al., 2025) is dedicated to this topic, in which infrastructural lines, generated by rapid and often unregulated anthropization, are now in profound crisis and are being reconsidered within a perspective of geo-environmental enhancement of the territories they traverse. In line with these scientific orientations, the present research aims to:

- develop an integrated mapping of the geological, geomorphological, climatic, and anthropogenic features of the territory affected by the decommissioned Avellino–Rocchetta S. Antonio railway line,
- apply quantitative models to assess the geodiversity and geomorphodiversity of the area crossed by the infrastructure,

- situate this study within the contemporary debate on geoconservation and on the valorization of anthropized territories within a sustainable development framework.

The thesis is structured as follows:

The first part is dedicated to analysing the meaning and scientific value of the “Landscape” considered as a geological and cultural “asset”, highlighting aspects related to geodiversity and geomorphodiversity. The in-depth examination of these concepts allows the recognition of the “Landscape” as natural heritage and, consequently, supports the need for its conservation and protection (geoconservation).

The second part describes the geographical, geological, and geomorphological characteristics of the study area, systematically outlining its various anthropogenic components related to agri-food, enogastronomic, and historical-cultural systems. Particular attention is devoted to the history of the decommissioned Avellino–Rocchetta Sant’Antonio railway line, in order to highlight its strategic role in the past and the potential it still holds for a future oriented toward sustainable development.

The third part presents the methods used for analysing territorial data and for their classification and cartographic representation, as well as the theoretical models and procedures adopted for the qualitative-quantitative assessment of geodiversity and geomorphodiversity.

The fourth part concerns the survey, analysis, and processing of data related to the anthropo-geographical, geo-lithological, and geomorphological framework of the study area. Several morphometric and land-use datasets were employed for the characterization of landscape units and for the semi-quantitative determination of Geodiversity and Geomorphodiversity within the study area.

The fifth part examines the results of the geoprocessing procedures and their comparison for the purpose of determining the indexed qualitative-quantitative values of geodiversity and geomorphodiversity for both the entire study area and the individual landscape units identified.

The sixth part is dedicated to the discussion and contextualization of the results obtained through this research and of the performance of the models employed, which made it possible to highlight the relationships between physical diversities and the socio-economic and cultural diversities present in the examined territory. Particular emphasis is placed on the implications that such diversities have had, currently have, or may have in the future on the specificities of the territory. Such a territorial profile thus emerges as strongly identity-defining and therefore deserving of attention in terms of valorization and geoconservation of geoheritage.

The concluding section aims to foster a deeper and more systematic understanding of the potential uses of the examined territory and of its characteristics in relation to geoconservation, territorial management, and sustainable development.

PART I

GEO-ENVIRONMENTAL SIGNIFICANCE OF LANDSCAPE ELEMENTS

In the following pages, the meaning and scientific value of the “Landscape” as a geological and cultural “asset” will be examined, emphasizing the elements attributable to geodiversity and geomorphodiversity. The definition and analysis of these concepts make it possible to recognize the “Landscape” as natural heritage and to orient, consequently, conservation and protection practices (geoconservation).

1.1 THE CONCEPT OF GEOLOGICAL HERITAGE

Within the framework of geosciences applied to the protection of natural heritage, the concept of a “Geological Asset” constitutes a fundamental element in the paradigm of geoconservation, as it represents a tangible expression of geodiversity and a material testimony of the Earth’s evolutionary memory. Its formalization reflects the progressive maturation of conservationist thought, which, alongside the safeguarding of biodiversity, acknowledges the value of lithological, geomorphological, and paleontological evidence for their epistemic, educational, aesthetic, and identity-related significance (Reynard & Brilha, 2018).

According to the canonical definition proposed by Wimbledon (1996), subsequently refined by Strasser et al., 1995, Poli, 1999, Wimbledon et al., 1995, 1999, Bertacchini et al., 1999, Panizza, 2001, Panizza & Piacente, 2003, Reynard & Panizza, 2005, Reynard et al., 2009, a “geological asset” is understood as “...a geosite... (as) an entity of the geosphere relevant for the study of terrestrial evolutionary dynamics, recognizable and morphologically distinctive with respect to the surrounding geological context.” This broad and inclusive definition has been adopted by the “Geosites Project” of the International Union of Geological Sciences (IUGS), which aims to harmonize nomenclature and promote a shared semantic framework at the global scale.

The term “geosite”, a linguistic synthesis of “site of geological interest”, is now widely appreciated for its communicative effectiveness and for the conceptual flexibility that makes it suitable for various disciplinary applications. Among its principal articulations are geomorphosites, that is, landforms to which landscape, cultural, socio-economic, or scientific value may be attributed (Panizza, 2001, Reynard, 2009). Furthermore, the identification, cataloguing, and protection of geosites transcend mere scientific interest, constituting strategic tools for the development of resilient territorial policies and for fostering collective awareness of landscape value.

In outlining the rigorous and standardized criteria necessary to transform the abstract concept of a geological asset into a concrete entity, namely the Geosite, recognizable and scientifically definable, the classification proposed by Vai (1999) (Table 1) identifies four fundamental dimensions through which a geological object or condition may acquire geosite status:

Dimensions	Description of Geosite Status
Historical	Geology constitutes the natural archive of the Earth, and every rock formation narrates a chapter of its history.
Scientific	Geological objects that enable the interpretation of rare processes are irreplaceable assets, and their loss would erase unique information.
Documentary	Geological features that possess exemplary value in representing geohistorical processes and events.
Normative-Communicative	The lithological type (e.g., andesite) and/or the type locality in which it occurs (e.g., the Andes Range) serve as scientific and historical references for the classification of geological formations.

Table 1 - Fundamental dimensions of a geosite (Vai, 1999).

Within this conceptual framework, a geological object or condition (e.g., an outcrop, a mineral, a landform) becomes a geosite when a value, whether scientific, aesthetic, cultural, or otherwise, is attributed to it, and it may be considered a resource when it is accessible and usable for educational, touristic, or conservation purposes (Figs. 1–2).

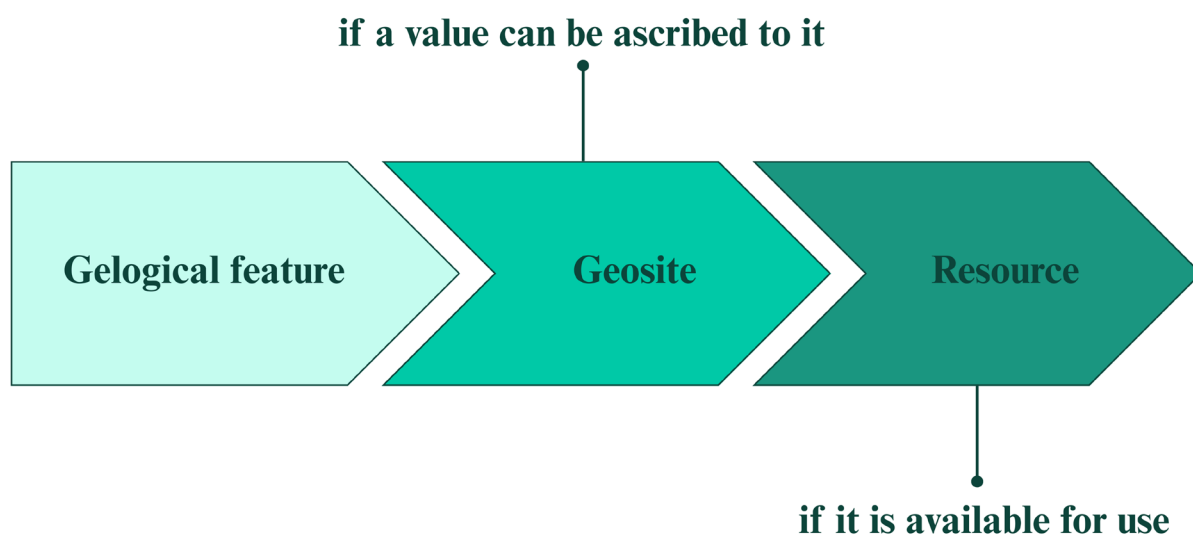


Figure 1 - Process of definition and valorization of the geological object.



Figure 2 - Global value of a geosite.

The identification and systematic assessment of a geosite require an interdisciplinary approach capable of integrating geosciences with spatial planning and cultural heritage protection. In this perspective, the objective criteria of the natural sciences merge with symbolic and value-based indicators derived from the human and social sciences.

To characterize and enhance a geosite, it is essential to adopt a methodology that considers not only scientific aspects but also perceptual and functional dimensions (Panizza & Piacente, 1999; Reynard et al., 2003), with particular attention to:

- landscape quality,
- historical and educational relevance,
- touristic usability,
- ecological vulnerability,
- sustainability and participatory management.

This approach requires advanced technical expertise, such as geomorphology and sedimentology, integrated with a semiotic analysis of the socio-cultural value of geological features, an indispensable component for a comprehensive evaluation (tab. 2).

Assessment domain	Assessment parameter	Parameter description
Scientific Value	Rarity	Degree of uniqueness relative to similar regional geosites.
	Representativeness	Extent to which the site typifies local geodiversity.
	Integrity	Conservation status and structural cohesion.
	Geological History	Contribution to reconstructing geoevolutionary dynamics.
	Geodiversity	Range of features and processes compared to the broader area.
	Scientific Documentation	Volume and quality of research outputs.
	Stratigraphic Referencing	Benchmark relevance for geoscientific disciplines.
	Research Constraints	Impediments to scientific access or utility.
Ecological Value	Ecological Functionality	Role in habitat formation and endemic species presence.
Aesthetic Value	Protection Status	Legal and ecological safeguards in place.
	Visual Accessibility	Distribution of scenic viewpoints (>1 km spacing).
	Scenic Quality	Aesthetic appeal of geological forms.
	Morphological Contrast	Visual distinction from surrounding landscape.
Cultural Value	Landscape Context	Integration with natural scenery and absence of anthropogenic impact.
	Spiritual Significance	Religious or mythological value.
	Historical Affiliation	Connections to historical or archaeological narratives.
	Artistic Integration	Representation in regional cultural expressions.
Functional Value	Societal Relevance	Alignment with customs, ethics, and identity.
	Accessibility	Infrastructure supporting site access.
	Natural Adjacency	Nearby geosites or natural assets within 5 km.
	Anthropogenic Proximity	Presence of cultural or infrastructural elements nearby.
	Environmental Pressure Zones	Influence from nearby urban or industrial zones.
	Transportation Connectivity	Proximity to major road networks.
Economic Value	Tourist Footfall	Annual visitors relative to tourism metrics.

Educational Potential	Attractiveness Index	Importance as a destination at various scales.
	Demographic Accessibility	Nearby student populations or educational institutions.
	Didactic Suitability	Compatibility with curricula and academic use.
	Cognitive Accessibility	Interpretability by non-specialists.
	Supportive Infrastructure	Availability of services like lodging, sanitation, info centers.
	Observational Conditions	Visual clarity of geological elements.
	Safety Compliance	Risk evaluation for visitors.
	Use Restrictions	Recreational or instructional limitations.
Touristic Potential	Anthropogenic Vulnerability	Risk of site degradation due to human activity.
	Resilience Threshold	Capacity to withstand visitor impacts.
	Socioeconomic Environment	Local income levels influencing tourism.
	Accommodation Facilities	Lodging options near the site.
	Guided Engagement	Frequency and quality of interpretive visits.
	Promotional Activity	Availability of outreach materials.
	Adjacency to Tourist Hubs	Presence of complementary attractions.
	Catering Services	Nearby dining establishments.
Degradation Risk	Interpretive Staffing	Competency of guides in languages and geology.
	Infrastructure Provisioning	Trails, seating, signage, waste disposal, restrooms, etc.
	Visitor Center Proximity	Distance to interpretive/management facilities.
	Geological Fragility	Natural and anthropogenic susceptibility.
	Anthropogenic Stressors	Proximity to activities threatening site integrity.
	Legal Protection Framework	Legal instruments governing conservation.
	Access-Induced Threats	Risk from uncontrolled public access.
	Demographic Pressure	Impact from local population density and misuse.

Table 2 - Multidimensional parameters for the characterization and assessment of geosites.

From the examination of Table 2, the need for a multidimensional approach becomes evident in order to define the complexity of a geosite in both natural and cultural terms (Pereira et al., 2007; Vujičić et al., 2011; Coratza et al., 2011; Fassoulas et al., 2012; Pica et al., 2015; Brilha, 2016; Suzuki & Takagi, 2018; Kubaliková et al., 2021). In this perspective, the geosite represents the dimensional synthesis of various sensitivities, geoscientific, educational, touristic and anthropogenic, which fundamentally require a comprehensive understanding of the territory.

1.2 THE CONCEPT OF GEOTOURISM

Within the broader debate concerning the strategies for enhancing geological heritage, geotourism emerges as a specialized dimension of the relationship between society and the geosphere, in which tourist experience becomes a privileged means for understanding Earth processes and the landforms derived from them (Hose, 1995, 2000). The plurality of definitions found in the literature reflects the progressive maturation of geographical and conservationist thought. As observed by Stueve et al. (2002), geotourism is situated within a wide spectrum of geographical, socioeconomic, and cultural contexts. Similarly, Frey et al. (2002) interpret geotourism as an instrument for social and community development, in continuity with the geopark model.

Over time, the very concept of geotourism has undergone significant evolution. Early formulations, more closely aligned with geological tradition, focused on the scientific observation of landforms, rocks, and fossils, attributing to the geosite a primarily documentary and educational value (Hose, 2012). With the diffusion of geoparks and the incorporation of more explicitly geographical perspectives, attention expanded to include the relationships between geological heritage, local communities, territorial identity, and tourism practices (Zouros, 2004, UNESCO, 2016). The geological approach, oriented toward the description of physical processes and the protection of natural elements, has thus been complemented by a more integrated geographical approach, which interprets geotourism as a complex territorial phenomenon capable of generating sustainable development and enhancing the landscape in both its natural and cultural dimensions (Newsome & Dowling, 2010, Farsani et al., 2011). This evolution has contributed to transforming geotourism from a specialist practice into an interdisciplinary tool, in which scientific knowledge interacts with educational, economic, and social needs (Ólafsdóttir & Tverijonaite, 2018).

In the sense adopted here, the prefix *geo* refers to geology, geomorphology, and the ensemble of natural resources that compose the landscape: landforms, fossiliferous deposits, rocks, minerals, and sedimentary materials. The focus is placed on understanding the processes that generate these elements, processes that express the dynamic nature of the Earth through phenomena such as volcanic eruptions, fluvial activity, landslides, and sediment transport and deposition. Direct observation made possible through visits to geosites allows one to grasp the evolutionary dimension of the planet and to develop a critical awareness of the mechanisms that shape the territory (Dowling, 2011).

Landscapes of geotouristic interest encompass a wide variety of contexts: mountain chains, rift valleys, major escarpments, volcanoes, karst environments, and arid regions. Within them, characteristic landforms or complex assemblages of geomorphological elements may be identified, as occurs in mountainous areas that preserve traces of both glacial modelling and fluvial dynamics. The hierarchy of elements of interest may extend from individual landforms to geological materials, rocks, sediments, and fossils, forming a mosaic of evidence that documents the local geological history (Gray, 2004).

Superimposed on this natural dimension is the anthropic one, represented by the modes of tourist use. Visits to geosites may take very different forms: bus tours, boat excursions, scenic flights, self-guided itineraries, hiking routes, or stops at panoramic viewpoints. Sites intended for geotourism may be equipped with accommodation facilities, dedicated infrastructures, visitor centres, and interpretive services, including geotours and virtual routes, as highlighted by Newsome et al. (2002). Although many activities take place in natural environments and share certain traits with ecotourism,

geotourism is distinguished by the centrality attributed to the geosite, which may be a landscape, an assemblage of landforms, a single outcrop, or a fossiliferous deposit. This focus allows it to be differentiated from other forms of nature-based tourism, while acknowledging that many visitors also attribute value to geosites for aesthetic, recreational, or hiking-related motivations.

Geotourism may extend to the study of ancient evolutionary processes, particularly when fossils documenting the history of life and human or animal evolution are involved. In this sense, visiting geosites assumes an educational and cultural significance. Alongside scientific values, many landscapes and geosites also possess aesthetic, cultural, historical, and even adventurous relevance. Geological tourism may indeed focus on elements of built heritage, such as buildings constructed with local stone materials, or on mining sites that testify to the interaction between geology and society. Particularly significant are abandoned extraction sites, where the influence of geology on human life becomes immediately perceptible, as noted by Pretes (2002). Former gold mines, for example, represent emblematic places where historical memory, territorial identity, and reflections on environmental degradation intersect.

Like all forms of tourism, geotourism generates impacts, both positive and negative. Recreational activities carried out in geological environments may produce disturbances of various kinds, sometimes permanent: graffiti, erosion of friable rocks, damage to sensitive elements such as karst formations, or deterioration caused by hammering, digging, and fossil collection. As early as Mathieson & Wall (1982), the scarcity of studies on the effects of tourism on geology was highlighted, noting that rock formations and caves were vulnerable to amateur collectors, professional souvenir gatherers, and vandalism in heavily visited sites. With the increase in visitor numbers in natural areas, also observed by Newsome et al. (2002), the potential for negative impacts becomes more complex and variable, with significance depending on environmental sensitivity, cumulative pressures, and the effectiveness of management measures. What constitutes a significant impact in one context may not represent a problem elsewhere, making management calibrated to local specificities essential.

From this perspective, geotourism emerges as a synthesis of multiple sensitivities, scientific, educational, cultural, and recreational, which require a deep understanding of the territory and careful management of its natural and anthropic components. Its full valorization implies an integrated approach, capable of recognizing in the geosite not only an object of interest, but a strategic resource for building awareness, identity, and sustainability.

1.3 THE CONCEPT OF “LANDSCAPE”

The “landscape” can be defined, from a broad and interdisciplinary perspective, as “... *the visible and perceptible expression of the dynamic interaction among natural processes, geological structures, landforms, ecosystems and human activities, resulting in a territorial configuration endowed with identity, meaning and cultural value*” (European Landscape Convention, 2000; Farina, 2000; Antrop, 2005). It therefore represents a comprehensive synthesis in which biophysical components and sociocultural dimensions intertwine inseparably to give rise to a new entity, the Landscape.

Within this interpretative framework, the concept of landscape assumes a particularly articulated meaning, yet one that is ultimately applicable to the aims of various scientific disciplines, including ecology, geography, visual arts and architecture. However, in the field of Earth Sciences, the term is still scarcely adopted or even overlooked, despite its transversal relevance. Indeed, Reynard (2009) notes its absence from most geological dictionaries, with the sole exception of the *Penguin Dictionary of Geology* (Kearey, 2001), where the expression *landscape marble* appears, used to describe polished limestone lithotypes characterized by chromatic patterns reminiscent of landscape representations. Conversely, the term is clearly defined in the *Dictionary of Physical Geography* (Whittow, 1984), which specifies that *landscape* derives from the Dutch *landschap* and, in modern usage, designates the entire surface morphology of a geographical area, encompassing both natural and anthropogenic elements, and thus representing both natural and cultural landscapes.

In response to the Davisian geomorphological approach to landscape (Davis, 1899), Sauer (1925) highlighted the inadequacy of an interpretation limited exclusively to landforms and geological structures. In his article *The morphology of landscape*, he proposed a broader and more inclusive conception in which climate, vegetation, hydrology and meteorology play equally important roles and, together with the anthropogenic component, contribute to the formation of the cultural landscape. This framework, which integrates physical and cultural dimensions, is still widely adopted (Erikstad et al., 2015; Mùcher et al., 2010) and aligns with Article 1, letter a, of the European Landscape Convention (2000), which, by adding a perceptual dimension, states that landscape is defined as a portion of territory perceived by populations, whose identity derives from the reciprocal interaction between natural and/or anthropogenic factors.

According to Olwig (2002), the term *Landschaft* assumes a meaning that merges geographical, political and social dimensions. From another perspective, landscape may also be understood as a dialectical synthesis between economic-territorial function (land management) and aesthetic-artistic representation (particularly within the pictorial tradition), constantly oscillating between tangible elements and intangible components such as emotions, symbolic codes, cultural aesthetics and sensory perceptions. In this sense, landscape simultaneously takes shape as a physical object and as an experiential or cultural subject (Reynard, 2009; Luginbühl, 2012).

Examples of cultural landscapes are described by Droste et al., 1995 and highlighted by UNESCO (2003), such as terraced vineyards found in many countries, where the geological and geomorphological value of the territory is inseparable from its identity-forming, aesthetic and productive significance. Numerous Italian examples also exist, where the landscape embodies the interpenetration of natural history and human history, such as the terraced slopes of Liguria and the

Amalfi Coast, the traces of Roman centuriation in extensive plains and the hilltop villages perched and fortified across the countryside.

1.4 THE CONCEPT OF GEODIVERSITY

The origin of the term is not univocal, and it is plausible that several scholars developed it as a natural complement to the concept of biodiversity. Gray (2008) reconstructed the early developments of the term, highlighting how the fundamental principles of geological diversity and geoconservation were already present in the scientific literature.

Beginning in the 1990s, the term *geodiversity* was introduced into geological and geomorphological literature to describe the variability of the abiotic components of the lithosphere, that is, the differences in geological, geomorphological, pedological and hydrological characteristics that structure terrestrial environments (Gray, 2013). The concept emerged as a critical response to the persistent imbalance in environmental policies, historically oriented toward biodiversity conservation and often insufficiently attentive to abiotic elements, despite their decisive role in the equilibrium and functionality of ecosystems.

The first documented use of the term *geodiversity* dates to 1993 (Wiedenbein, 1993), followed in the same year by a contribution from Sharples in Tasmania (Sharples, 1993), where it assumed a central role in environmental and conservation planning (Kiernan, 1994, 1996, 1997; Dixon, 1995, 1996a, 1996b).

According to these authors, geodiversity may be understood in a value-based sense as intrinsic, ecological and anthropocentric, each corresponding to different ethical, scientific and social perspectives. Intrinsic value is attributed to physical elements that bear witness to natural processes. Ecological value concerns ecosystems in which abiotic components constitute the structural, functional and resilient foundation of natural systems, forming an indispensable condition for sustaining biodiversity. Finally, anthropocentric value refers to human society, particularly to the cultural, educational, aesthetic, identity-forming and socio-economic aspects that are regarded as non-exhaustible resources and essential components of natural heritage.

Through these values, geodiversity emerges as a defining feature of human–territory relationships, a context that, similarly to biodiversity, supports geosciences through spatial planning, environmental education and forms of sustainable tourism within a systemic vision that is indispensable for conservation policies.

1.5 THE CONCEPT OF GEOCONSERVATION

Geoconservation refers to the set of practices aimed at the protection, interpretation and enhancement of geological and geomorphological elements and processes of scientific, educational, cultural, aesthetic and ecosystemic relevance (Prosser, 2013; Crofts & Gordon, 2014). It currently represents an emerging pillar within environmental sustainability policies, which, from a conservationist perspective, have historically followed biocentric trajectories often subordinated to the protection of biodiversity alone (Brilha, 2002; Gray, 2013; Crofts, 2014).

In Europe, interest in geological heritage emerged between the eighteenth and nineteenth centuries, a period characterized by a new aesthetic sensibility, the so-called “romantic gaze” (Urry, 1990), which permeated artistic and literary works, travel guides and explorers’ accounts, contributing to the construction of a new collective imagination that was less materialistic and more symbolic and sacred (Reynard et al., 2011; Gordon & Baker, 2016; Hose, 2016; Vasiljević et al., 2016). This vision, which dematerializes the human being as an integral part of the ecosystem, was soon adopted in many countries culturally distant from the Western world, such as Japan (Bernbaum & Price, 2013; Kiernan, 2015; Feary et al., 2015).

In the name of geoconservation, the last fifty years have witnessed, at both local and international scales, the proliferation of inventories of geological heritage (geosites and geomorphosites), protected areas, and the increasing number of UNESCO Global Geoparks, culminating in the recognition of geoheritage within the World Heritage Convention and the activation of outreach programs by the IUCN (International Union for the Conservation of Nature) (Crofts & Gordon, 2014; Prosser, 2013).

Despite these developments, in the early years of the new millennium geoconservation was still frequently relegated to a secondary role compared to disciplines focused on flora and fauna (Gray, 2004), effectively equating “nature conservation” with the sole “conservation of biodiversity.” Such marginalization inevitably leads to conflicts of competence in the formulation of conservation strategies for natural heritage (Pemberton, 2001).

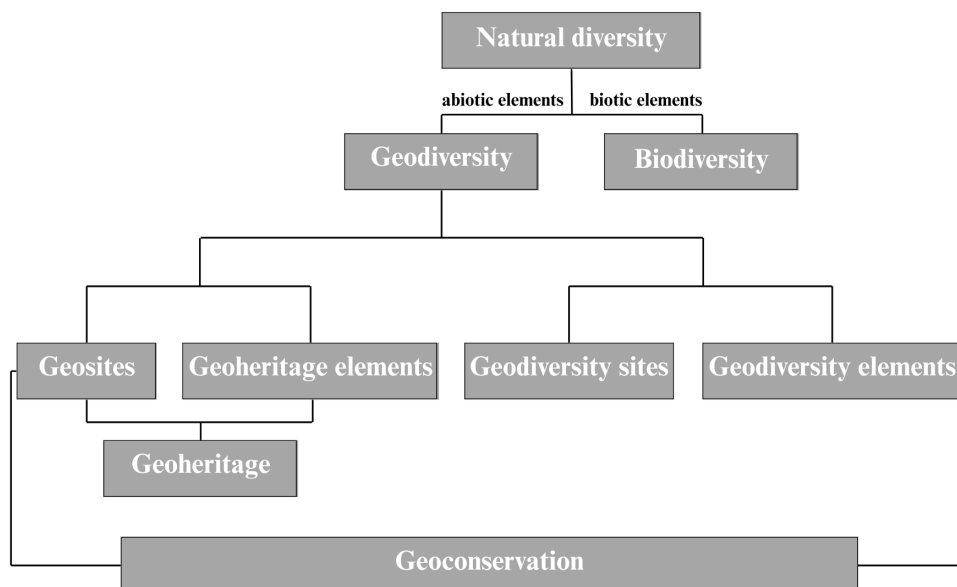


Figure 3 - Hierarchical scheme of geoconservation (Brilha, 2016, redrawn).

To address these critical issues, Brilha (2016) proposed a conceptual model (Fig. 3) that synthesizes the components, objectives and operational tools of geoconservation, highlighting the need for systematic evaluative criteria for the identification and management of geosites (Brilha, 2005). This approach underscores the urgency of recognizing equal environmental dignity for both abiotic and biotic components, a perspective in which ecological space represents the domain where species distribute themselves in relation to physical conditions and available resources (Beier et al., 2015; Lawler et al., 2015). Indeed, lithological and pedological variability modulates nutrient accessibility (Anderson & Ferree, 2010), while landform morphology influences habitat dynamics and, consequently, the structure of biological communities. Likewise, water resources condition species survival and diversification (Konar et al., 2013). These combinations form the basis of the bio-geodiversity relationship which, over geological time, has contributed to shaping present-day biogeographic patterns (Hoorn et al., 2010; Gill et al., 2015; Antonelli et al., 2018).

Name	Region	Province	Resident Population [ISTAT 2023]	Area (km ²)	Population Density (inhab./km ²)
Aiello del Sabato	Campania	Avellino	4,000	10.82	369.79
Andretta	Campania	Avellino	1,678	43.38	38.68
Aquilonia	Campania	Avellino	1,462	55.78	26.21
Atella	Basilicata	Potenza	3,654	87.87	41.58
Atripalda	Campania	Avellino	10,367	8.55	1212.66
Avellino	Campania	Avellino	52,198	30.40	1717.26
Bagnoli Irpino	Campania	Avellino	3,027	68.41	44.25
Bisaccia	Campania	Avellino	3,534	101.52	34.81
Cairano	Campania	Avellino	275	13.72	20.04
Calitri	Campania	Avellino	4,243	100.40	42.26
Candida	Campania	Avellino	1,101	5.32	206.92
Caposele	Campania	Avellino	3,245	41.04	79.08
Capriglia Irpina	Campania	Avellino	2,262	7.45	303.61
Cassano Irpino	Campania	Avellino	945	13.00	72.68
Castelfranci	Campania	Avellino	1,766	11.62	151.93
Castelgrande	Basilicata	Potenza	818	34.67	23.59
Castelvetero sul Calore	Campania	Avellino	1,486	17.08	87.02
Cesinali	Campania	Avellino	2,552	3.71	688.44
Chiusano di San Domenico	Campania	Avellino	2,089	24.47	85.36
Contrada	Campania	Avellino	2,950	10.26	287.56
Conza della Campania	Campania	Avellino	1,270	51.32	24.75
Fontanarosa	Campania	Avellino	2,870	16.61	172.76
Frigento	Campania	Avellino	3,462	37.82	91.53
Gesualdo	Campania	Avellino	3,234	27.18	118.98
Grottolella	Campania	Avellino	1,793	7.09	252.90
Guardia Lombardi	Campania	Avellino	1,515	55.54	27.28
Lacedonia	Campania	Avellino	2,048	81.56	25.11
Lapio	Campania	Avellino	1,428	15.17	94.16
Lioni	Campania	Avellino	5,934	46.24	128.34
Luogosano	Campania	Avellino	1,082	6.04	179.28
Manocalzati	Campania	Avellino	3,019	8.70	347.00
Melfi	Basilicata	Potenza	17,092	204.79	83.46
Mirabella Eclano	Campania	Avellino	6,640	33.77	196.60
Montefalcione	Campania	Avellino	3,092	15.21	203.23
Montefredane	Campania	Avellino	2,108	9.40	224.30
Montefusco	Campania	Avellino	1,192	8.20	145.44
Montella	Campania	Avellino	7,291	82.50	88.38
Montemarano	Campania	Avellino	2,610	33.82	77.17
Montemiletto	Campania	Avellino	5,070	21.52	235.58
Monteverde	Campania	Avellino	695	39.30	17.68
Morra De Sanctis	Campania	Avellino	1,124	30.23	37.18
Muro Lucano	Basilicata	Potenza	4,931	125.36	39.33
Nusco	Campania	Avellino	3,899	53.29	73.16
Parolise	Campania	Avellino	637	3.20	198.95
Paternopoli	Campania	Avellino	2,143	18.32	116.95
Pescopagano	Basilicata	Potenza	1,659	69.39	23.91

Pietradefusi	Campania	Avellino	1,916	9.19	208.41
Prata di Principato Ultra	Campania	Avellino	2,696	10.94	246.55
Pratola Serra	Campania	Avellino	3,592	8.80	408.31
Rapone	Basilicata	Potenza	865	29.31	29.51
Rionero in Vulture	Basilicata	Potenza	12,496	53.15	235.09
Rocca San Felice	Campania	Avellino	781	14.33	54.51
Rocchetta Sant'Antonio	Puglia	Foggia	1,687	72.00	23.43
Ruvo del Monte	Basilicata	Potenza	995	32.40	30.71
Salza Irpina	Campania	Avellino	720	4.93	145.95
San Fele	Basilicata	Potenza	2,600	97.04	26.79
San Mango sul Calore	Campania	Avellino	1,093	14.51	75.34
San Michele di Serino	Campania	Avellino	2,414	4.44	543.34
San Potito Ultra	Campania	Avellino	1,477	4.51	327.19
Santa Lucia di Serino	Campania	Avellino	1,383	3.91	353.46
Santa Paolina	Campania	Avellino	1,157	8.39	137.89
Sant'Andrea di Conza	Campania	Avellino	1,406	7.00	200.88
Sant'Angelo all'Esca	Campania	Avellino	730	5.43	134.43
Sant'Angelo dei Lombardi	Campania	Avellino	3,832	54.78	69.95
Santo Stefano del Sole	Campania	Avellino	2,055	10.72	191.63
Serino	Campania	Avellino	6,695	52.22	128.20
Sorbo Serpico	Campania	Avellino	530	8.06	65.75
Taurasi	Campania	Avellino	2,161	14.33	150.76
Teora	Campania	Avellino	1,447	23.07	62.73
Torella dei Lombardi	Campania	Avellino	1,952	26.42	73.89
Torre Le Nocelle	Campania	Avellino	1,201	9.99	120.24
Venticano	Campania	Avellino	2,274	14.08	161.48
Villamaina	Campania	Avellino	911	8.99	101.39
Volturara Irpina	Campania	Avellino	2,963	32.24	91.89

Table 4 - Demographic data for the 74 municipalities included within the study area (source: ISTAT, 2023).

As shown by the data in Table 4, as many as 64 municipal territories fall under the administration of the Campania Region, particularly within the Province of Avellino. The remaining municipalities include 9 within the Province of Potenza (Basilicata) and 1 within the Province of Foggia (Puglia). Moreover, the municipality with the largest resident population is Avellino, the provincial capital, with 52,198 inhabitants, whereas the least populated municipality is Cairano, with only 274 residents. In terms of territorial extent, the largest municipality is Melfi (Province of Potenza), covering an area of 204.79 km² with a population density of 83 inhabitants/km², while the smallest is Parolise (Province of Avellino), with an area of only 3.20 km².

2.2 PHYSICAL-GEOGRAPHICAL FEATURES

The analysed area lies within the central sector of the Campanian Apennines and is bounded to the north by the Frigento ridge, to the south by the reliefs of the Monti Picentini range, to the east by the volcanic complex of Monte Vulture and to the west by the fluvial valleys of the Sabato and Calore rivers. It straddles the Tyrrhenian–Adriatic watershed, defined by the line separating the hydrographic basin of the Calore River (a Tyrrhenian tributary) from that of the Ofanto River (an Adriatic tributary) (Fig. 5).

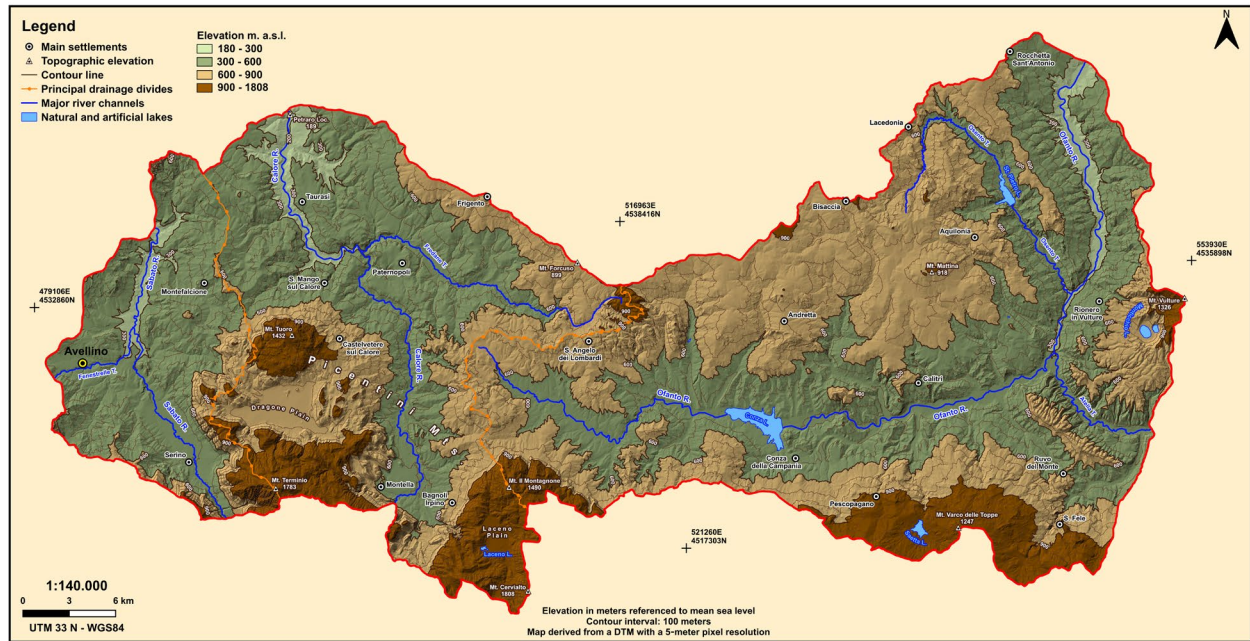


Figure 5 - Altimetric and hydrographic framework of the study area (see Plate 2).

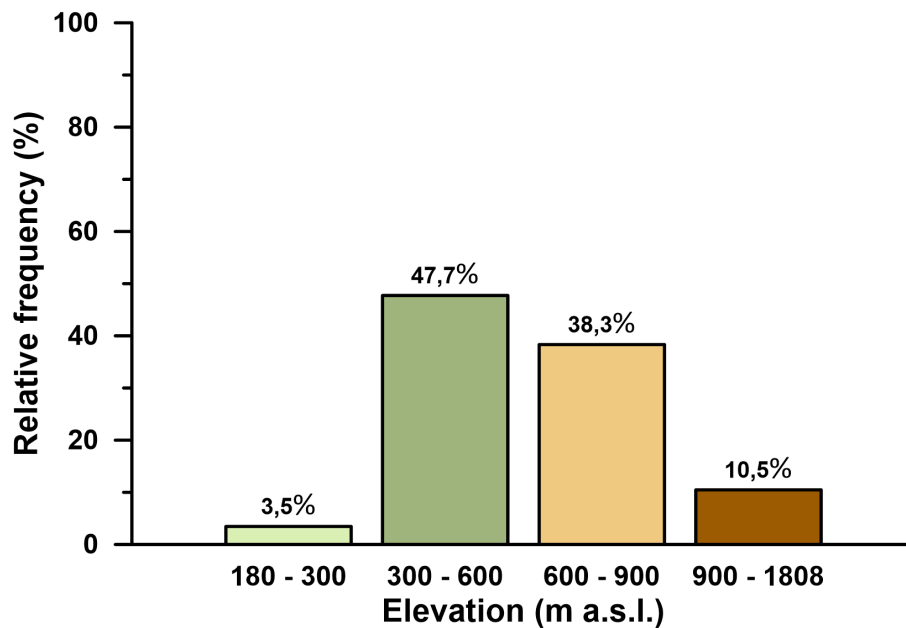


Figure 6 - Distribution of elevation classes.

From an altimetric perspective, the territory is topographically organized into four elevation belts (Fig. 6):

- The belt between 180 and 300 m a.s.l. represents a marginal portion of the territory, amounting to 3.5% of the total surface, and is located within valley-floor sectors, particularly along the middle reaches of the Sabato and Calore rivers, where some agricultural areas and the main urban settlements are concentrated.
- The belt between 300 and 600 m a.s.l. is the most extensive, covering 47.7% of the territory. These intermediate elevations host the majority of urban settlements and the agricultural areas typical of mid-hill environments.
- The belt between 600 and 900 m a.s.l. occupies 38.3% of the surface and is characterized by hilly and sub-mountain reliefs with forest cover and agro-silvo-pastoral practices.
- Finally, the highest belt, between 900 and 1,800 m a.s.l., covers 10.5% of the territory and is predominantly represented by mountainous reliefs with high naturalness and low anthropic pressure.

Throughout the study area, the highest reliefs, excluding those of volcanic origin, exceed 1,000 m a.s.l. and belong to the Picentini Mountains. Arranged along a NW–SE structural alignment, these mountain elevations include:

- **Mount Cervialto (1,808 m)**, the highest peak of the group, characterized by high-altitude environments and marked naturalness, with the presence of priority habitats protected at the European level.
- **Mount Terminio (1,783 m)**, the most representative relief of the western sector, known for its extensive beech forests and for its ecological role in regulating local water resources.
- **Mount Tuoro (1,432 m)**, situated within an elevated hilly landscape, plays an important role in ensuring ecological connectivity among forested areas.
- **Il Montagnone (1,490 m)** and **Mount Varco delle Toppe (1,249 m)**, located in the eastern sector, act as watershed divides between the Calore and Ofanto river basins.

The Picentini Mountains (Fig. 5) host numerous springs, including those of the Sele, Calore, and Sabato rivers, which are essential for the water supply of the Campania and Puglia regions. They include the Picentini Mountains Regional Park, established for the conservation of biodiversity and the enhancement of mountain landscapes. **Mount Vulture (1,380 m)**, by contrast, is the only volcanic relief within the study area. **Mount Forcuso (899 m a.s.l.)**, located along the Frigento ridge in the northern sector of the study area, contributes significantly to the definition of the local orographic framework and plays a strategic hydrographic role, acting as a watershed between the valleys of the Calore River, the Ufita River, the Calaggio Stream, and the Ofanto River.

The flat areas within the study area include:

- **The Piana del Dragone**, located at 671 m a.s.l. in the municipality of Volturara Irpina (Province of Avellino), appreciated for its landscape value, the tranquility of its natural setting, and the presence of environmental features of high interest, making it an ideal destination for hiking and environmental education.
- **The Laceno Plateau**, located at 1,052 m a.s.l. within the municipality of Bagnoli Irpino, renowned for its recreational and touristic vocation, particularly due to the presence of

accommodation facilities and sports infrastructures that make it a reference point for mountain tourism in Irpinia.

The hydrographic network of the study area (Fig. 5) includes three main watercourses: the Ofanto, Calore, and Sabato rivers.

The **Ofanto River** crosses the study area for a total length of 71.11 km (41.59% of its total course). Its source is located in the locality of Valle, within the municipality of Torella dei Lombardi, at an elevation of 703 m a.s.l. The river flows into the Adriatic Sea between Margherita di Savoia and Barletta. Within the study area, it receives the following tributaries: Torrente Isca, Torrente Sarda, Torrente Orato, and Torrente Osento (left bank), and Torrente Fiumicello, Torrente Lucido, Torrente Arso, Torrente Ficocchia, Torrente Lento, and the Fiumara di Atella (right bank). Beyond its hydrological function, the Ofanto also plays a significant administrative role, marking the boundary between the Campania and Basilicata regions, as well as between Puglia and Basilicata.

The **Calore River** flows through the study area for 40.54 km (18.28% of its total length). It originates on Mount Accellica (1,660 m) and exits the study area before joining the Volturno River at Fiumara, near the municipality of Amorosi. Within the study area, the Calore receives the following tributaries: Valle Vuccolo, Valle delle Grotti, Acquavivola, and Vallone Uccello (left bank), and Torrente Lacinolo, Valle l'Avella, Valle Gargone, Torrente Pacione, Vallone Faitano, and Torrente Fredane (right bank).

The **Sabato River** crosses the study area for 25.55 km (39.56% of its total length). Its source lies outside the study area, at Colle Finestra (1,060 m), a pass on Mount Accellica, and it also terminates outside the area, flowing into the Calore River near the town of Benevento. Within the study area, the Sabato receives only one tributary, the Torrente Fenestrelle, from the left bank.

Of particular hydrological and environmental interest within the study area are the lacustrine water bodies, both natural and artificial. Among the natural lakes are:

- **Lake Laceno**, located on the homonymous plateau in the municipality of Bagnoli Irpino at approximately 1,050 m a.s.l., a karst lake characterized by strong seasonal variability linked to the permeability of the carbonate substrata. It is situated within a high-value environmental context and represents an important naturalistic and touristic resource.
- **Lake Saetta**, a small basin located in the Province of Avellino, characterized by seasonality and shallow depth. Its genesis is linked to local tectonic and subsidence processes.
- **The Monticchio Lakes**, two volcanic lakes located within the crater of Mount Vulture in Basilicata. They are important for the biodiversity associated with water quality and geological features, and are surrounded by dense riparian and woodland vegetation with high ecotouristic value.

Among the artificial lakes are:

- **Lake Conza**, an artificial reservoir created along the Ofanto River, with a fundamental role in flood regulation and water storage for agricultural and industrial purposes. It is regulated by a dam and plays a strategic role in water resource management in the northeastern sector of Campania.
- **Lake San Pietro**, an artificial accumulation basin fed mainly by meteoric waters and by the Osento Stream. It is used for irrigation and features riparian vegetation that has contributed, in recent decades, to the formation of secondary wetland habitats.

Finally, from a climatic perspective, according to the parameters adopted by Köppen (1936) in his classification, the study area falls within Group C, specifically the Csa subtype, corresponding to warm temperate (mesothermal) Mediterranean climates, where the mean temperature of the coldest month ranges between -3°C and 18°C , summer is dry (s), and the warmest month has a mean temperature above 22°C (a). More specifically, the area exhibits a mean monthly temperature of 13.5°C and an average annual precipitation regime of 953.27 mm.

2.3 LAND-USE CHARACTERISTICS IN THE STUDY AREA

The main land-use within the study area is represented by agricultural crops, both temporary and permanent, together with non-irrigated arable land, which collectively occupy more than 56% of the total surface (Figs. 7 and 8). These agricultural domains are distributed between 200 and 800 m of elevation, in accordance with the geographical framework outlined by Bonapace (1977). This condition enables the agricultural sector to exert a significant influence on the local economy.

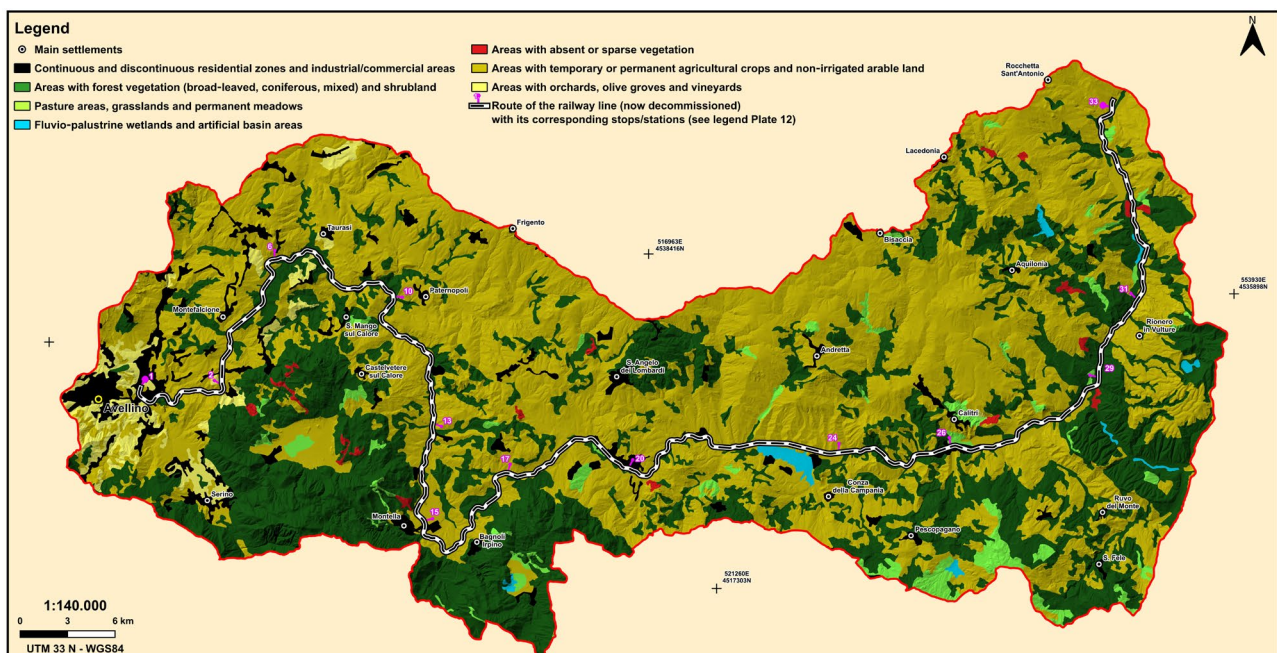


Figure 7 - Land-use map of the study area (source: Corine Land Cover, 2018, modified) (see Plate 11).

Elevations above 800 m a.s.l., which account for approximately 34% of the study area, are characterized by forest and shrubland cover. These vegetational ecosystems perform relevant ecological functions, including the conservation of biological diversity, the modulation of the local microclimate, and the stabilization of environmental processes. Specialized crops, such as orchards,

olive groves, and vineyards, occupy only 2% of the study area, yet they represent a distinctive component of the local landscape, shaped by traditional agricultural practices that produce varietal specificities linked to the regional pedoclimatic context.

Finally, 1% of the study area is occupied by surfaces used as pastures, permanent grasslands, or sparsely vegetated areas, as well as by wetland environments. Although these surfaces cover a comparatively smaller extent, they play an important role in shaping the landscape, as they reflect the presence of an extensive livestock production system, primarily associated with dairy cattle and sheep farming.

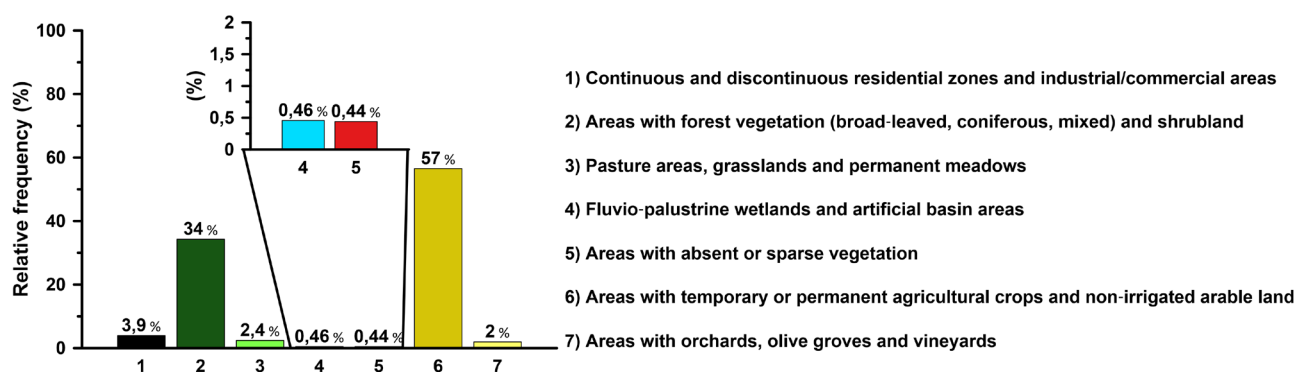


Figure 8 - Percentages of land-use classes within the study area.

The settlement component, corresponding to residential, productive, and tertiary areas, accounts for approximately 4% of the total extent of the study area. It is predominantly distributed within valley floors and morphological depressions (e.g., the Avellino Basin), and to a lesser extent along ridge-top locations (e.g., Bisaccia, Sant'Angelo dei Lombardi, Cairano), delineating a polycentric settlement pattern conditioned by the underlying morphology. This limited spatial incidence highlights non-intensive land-occupation dynamics and suggests a relatively low level of anthropic pressure.

2.3.1 High-value agricultural crops and traditional agro-food productions in the study area

Among the various crops present in the territory, viticulture plays a particularly prominent role, characterized by DOC (Controlled Designation of Origin) and DOCG (Controlled and Guaranteed Designation of Origin) labels (Figs. 9a, 10a), while olive cultivation is associated with DOP (Protected Designation of Origin) certifications. Furthermore, the area hosts several high-value certified agro-food products (Figs. 9b, 9c, 10b, 10c), such as *Caciocavallo Silano* DOP and *Pecorino di Filiano* DOP, as well as IGP (Protected Geographical Indication) products linked to fruit cultivation, including *Mela Annurca Campana*, *Castagna di Montella*, *Marrone di Serino*, and *Lucanica di Picerno*.

In addition, the study area hosts numerous food specialties classified as PAT (Traditional Agri-food Products), an intangible heritage resulting from long-established local knowledge and artisanal practices rooted in rural contexts (e.g., *Pecorino di Carmasciano*, *Muffletto* and *Matasse di Caposele*, *Cannazze Calitrane*, etc.) (Fig. 11 and Tab. 5).

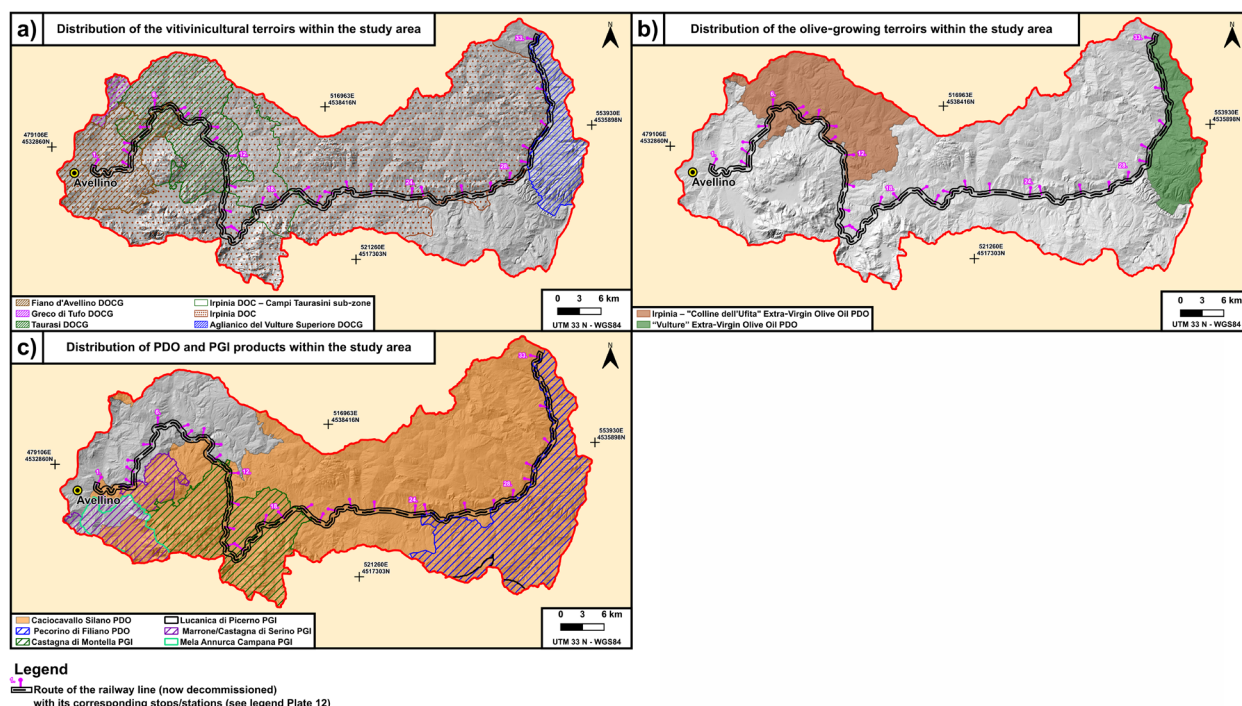


Figure 9 - Production areas of high-value crops within the study area:
a) Viticultural terroirs, b) Olive-growing terroirs, c) PDO and PGI products
(<https://www.masaf.gov.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/15117>) (see Plate 9).

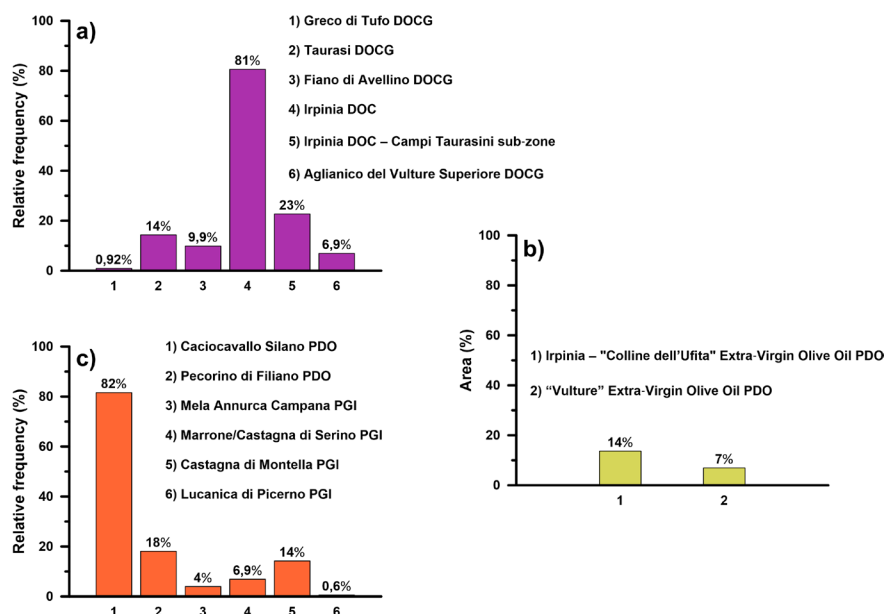


Figure 10 - Percentage distribution: a) Viticultural terroirs, b) Olive-growing terroirs, c) PDO and PGI products.

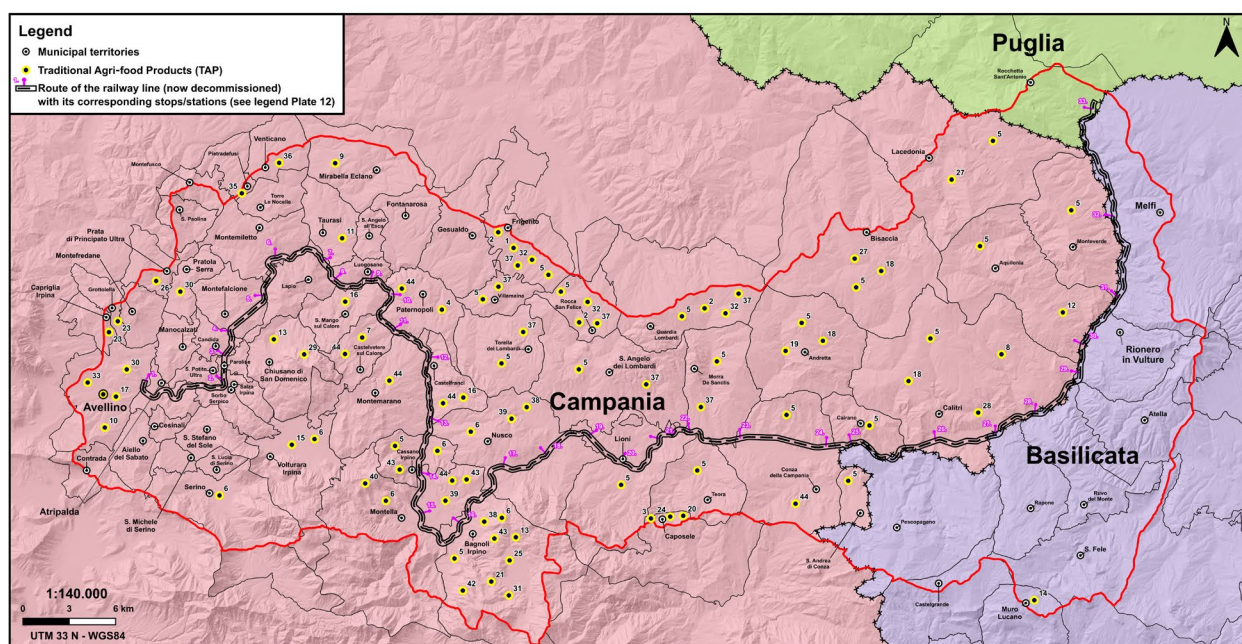


Figure 11 - Distribution of Traditional Agri-Food Products (TAP) within the study area (see Plate 10).

Id	Product name	Category
1	Aglione dell'Ufita	TAP - SLOWFOOD PRESIDIO
2	Agnello di Carmasciano	TAP
3	Amaretto di Caposele	TAP
4	Broccolo Aprilatico di Paternopoli	TAP - SLOWFOOD PRESIDIO
5	Caciocavallo irpino di grotta	TAP
6	Caciocavallo podolico dei Monti Picentini	TAP
7	Caciocavallo Silano DOP	TAP
8	Cannazze	TAP
9	Cicatielli col pulieio	TAP
10	Cicci di Santa Lucia	TAP
11	Ciliegia Maiatica	TAP
12	Corresce re cocozza janca	TAP
13	Fagioli tabacchini / quarantini	TAP - SLOWFOOD PRESIDIO
14	Fagiolo di Muro Lucano	TAP
15	Fagiolo di Volturara Irpina	TAP - SLOWFOOD PRESIDIO
16	Fico di San Mango	TAP
17	Fusillo Avellinese	TAP
18	Guanciale del Formicoso	TAP
19	Lardello di Andretta	TAP
20	Le Matasse	TAP
21	Liquore al tartufo nero	TAP
22	Lucanica di Picerno	TAP
23	Mela bianca di Grottolella	TAP
24	Muffletto di Caposele	TAP
25	Nnogleia di maiale	TAP
26	Nocciola camponica	TAP
27	Oliva masciatia	TAP
28	Pane di Calitri	TAP
29	Pane di Iurmano	TAP

30	Pantorrone	TAP
31	Pecorino Bagnolese	TAP
32	Pecorino di Carmasciano	TAP - SLOWFOOD PRESIDIU
33	Pizza chiena	TAP
34	Pomodorino seccagno di Gesualdo	TAP
35	Prosciuttella della bassa Valle del Calore	TAP
36	Prosciutto di Venticano	TAP
37	Ricotta di Carmasciano	TAP
38	Ricotta di pecora bagnolese	TAP
39	Ricotta Mantéca di Montella	TAP
40	Scamorza di Montella	TAP
41	Sedano di Gesualdo	TAP - SLOWFOOD PRESIDIU
42	Tartufo nero di Bagnoli	TAP
43	Torrone di castagna	TAP
44	Treccia di Montella	TAP
45	Uva Coda di Volpe Rossa	TAP

Table 5 - List of Traditional Agri-Food Products (TAP) present within the study area.

2.3.2 Protected areas and sites of geological interest in the study area

Within the study area, surfaces of naturalistic relevance and protected areas subject to specific legislative constraints (parks, nature reserves, Natura 2000 sites, etc.) hold particular scientific and socio-cultural significance. Specifically, five sites are classified as parks and nature reserves, and sixteen areas fall within the European ecological network Natura 2000 (Fig. 12, Tab. 6).

Protected areas and nature reserves extend over a total surface of 202.07 km², corresponding to 12.71% of the territory under examination (Fig. 13c). Of this surface, 170.45 km² (10.72%) fall within the Campania Region, 27.50 km² (1.73%) belong to the Basilicata Region, and 4.11 km² (0.25%) to the Puglia Region (Fig. 13a).

The protected areas included in the Natura 2000 Network cover a surface of 354.20 km². Of this, 330.21 km² (20.78% of the total area analysed) are located in Campania, while 10.03 km² (0.63%) are situated in Puglia and 13.96 km² (0.88%) in Basilicata (Fig. 13b).

Name	Official List of Protected Areas (EUAP)	Region	Category	Area [km ²]
Parco Regionale “Monti Picentini”	EUAP0174	Campania	Regional Park	170.32
Parco Naturale Regionale del Vulture	—	Basilicata	Regional Nature Park	23.32
Riserva Naturale Lago Piccolo di Monticchio e Patrimonio Forestale Regionale	EUAP0253	Basilicata	Regional Reserve	1.98
Riserva Naturale Orientata Grotticelle	EUAP0035	Basilicata	State Reserve	2.19
Parco Naturale Regionale del Fiume Ofanto	EUAP1195	Puglia	Regional Nature Park	4.11
Picentini	IT8040021	Campania	Special Protection Area	161.76
Monte Tuoro	IT8040012	Campania	Site of Community Importance	21.88
Piana del Dragone	IT8040014	Campania	Site of Community Importance	6.86

Monte Terminio	IT8040011	Campania	Site of Community Importance	48.80
Monte Cervialto e Montagnone di Nusco	IT8040010	Campania	Site of Community Importance	52.86
Alta Valle del Fiume Ofanto	IT8040003	Campania	Site of Community Importance	5.90
Querceta dell'Incoronata (Nusco)	IT8040018	Campania	Site of Community Importance	13.62
Boschi di Guardia dei Lombardi e Andretta	IT8040004	Campania	Site of Community Importance	29.19
Bosco di Zampaglione (Calitri)	IT8040005	Campania	Site of Community Importance	95.14
Lago di S. Pietro – Aquilaverde	IT8040008	Campania	Site of Community Importance	6.04
Lago di Conza della Campania	IT8040007	Campania	Site of Community Importance, Special Protection Area	12.14
Valle Ofanto – Lago di Capaciotti	IT9120011	Puglia	Special Area of Conservation	10.02
Monte Vulture	IT9210210	Basilicata	Special Area of Conservation, Special Protection Area	10.53
Grotticelle di Monticchio	IT9210140	Basilicata	Special Area of Conservation	3.42
Bosco di Montefusco Irpino	IT8040020	Campania	Site of Community Importance	0.01

Table 6 - List and characteristics of Park Areas and protected sites belonging to the Natura 2000 Network.

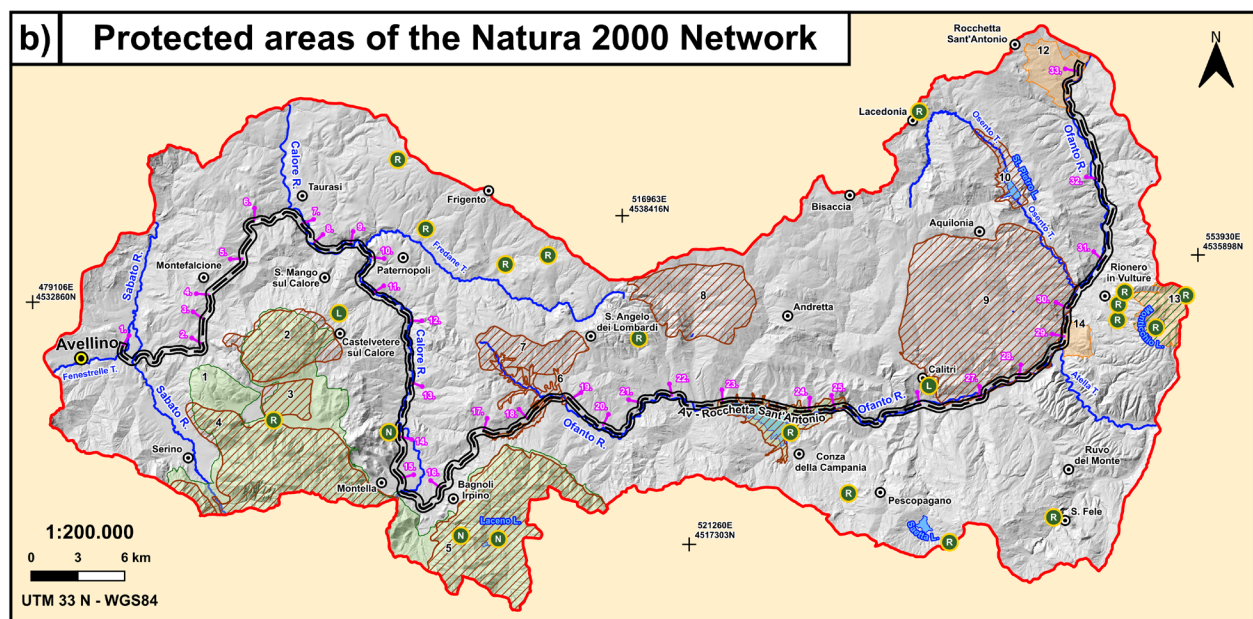
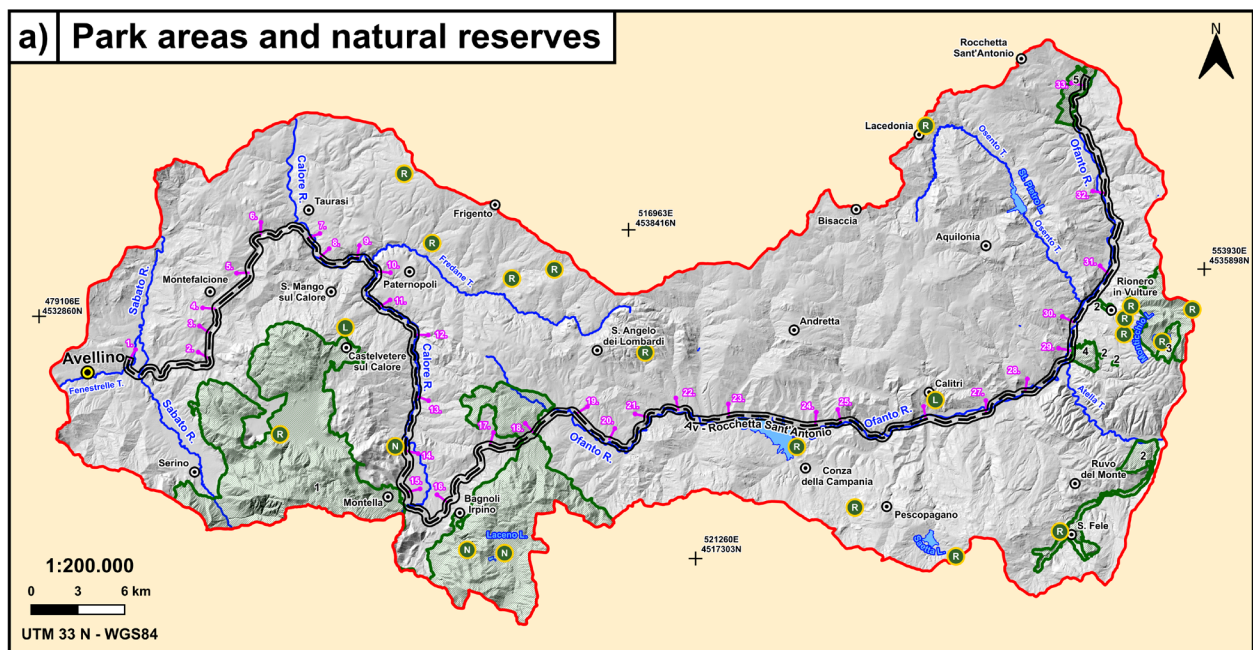


Figure 12 - a) Park areas within the study area, b) Protected areas belonging to the Natura 2000 Network (see Plate 8).

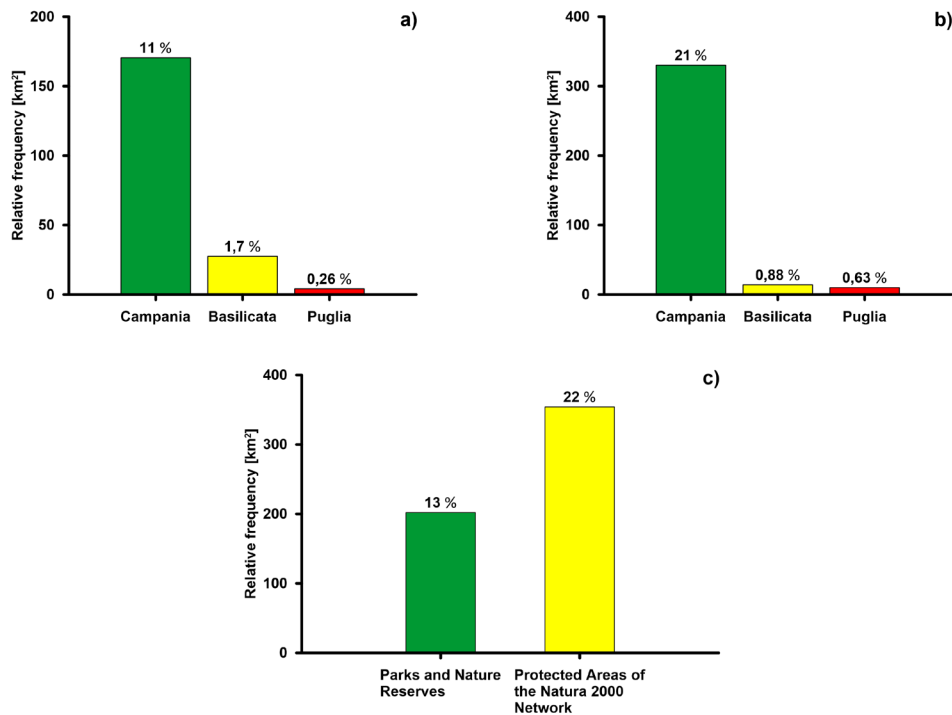


Figure 13, Percentages of the surface areas of Park Areas and protected sites belonging to the Natura 2000 Network: a) Regional percentages of the surface areas of Park Areas, b) Regional percentages of protected areas included in the Natura 2000 Network, c) Total percentages.

Among these protected areas, those of greatest relevance include:

- **The Monti Picentini Regional Park:** The area, extending over approximately 62,200 ha between Avellino and Salerno, is characterized by carbonate reliefs culminating at 1,810 m on Mount Cervialto. Classified as IUCN Category V, it encompasses temperate-montane forest ecosystems with high naturalness and hosts species of community interest. It is part of the Natura 2000 Network, including both SCIs and SPAs.
- **The Monte Vulture Regional Natural Park:** Established in 2017, the park (57,500 ha) encompasses the volcanic complex of Mount Vulture and the Monticchio Lakes. Classified as IUCN Category V, it is included within the Natura 2000 Network and comprises montane woodlands and rocky habitats.
- **The Special Area of Conservation (SAC) Monte Tuoro:** The site (2,188 ha) includes Mount Tuoro (1,424 m). Vegetation is dominated by extensive beech forests and hosts amphibians, reptiles, and breeding bird species of high conservation interest.
- **SAC/SPA Conza della Campania Lake:** The Conza Lake site (1,214 ha) is designated as SAC, SPA, and Ramsar site. It includes alluvial wetland environments with priority habitats such as reed beds and hygrophilous woodlands.

Of particular scientific relevance are also the 21 geosites identified within the study area (Fig. 12, Tab. 7). Among these, eight are listed in the ISPRA National Inventory of Geosites, while thirteen are included in the Regional Geosite Catalogue (CA.ReGeo) of the Campania Region. In terms of scientific value, the area comprises three geosites of national interest, seventeen of regional interest, and one of local significance.

Geosite	Inventory	Scientific value	Province
Olistiti carbonatici di Castelgrande	ISPRA	Regional	Potenza
Anticlinale di San Fele	ISPRA	Regional	Potenza
Sorgente Crocco	ISPRA	Regional	Potenza
Cava di Piana Ferriera	ISPRA	Regional	Potenza
Valle dei Grigi	ISPRA	Regional	Potenza
Laghi di Monticchio	ISPRA	Regional	Potenza
Monte Vulture	ISPRA	Regional	Potenza
La mefite nella Valle d'Ansanto	ISPRA	Regional	Potenza
Piano Laceno	Ca.ReGeo.	National	Avellino
Frana di Calitri	Ca.ReGeo.	Regional	Avellino
Vallone Remolise Flysch di Castelvetero	Ca.ReGeo.	Local	Avellino
Conza della Campania	Ca.ReGeo.	Regional	Avellino
Cava di Pietra di Fontanarosa	Ca.ReGeo.	Regional	Avellino
Lacedonia	Ca.ReGeo.	Regional	Avellino
I Sintemi del Pliocene nella Valle dell'Ofanto	Ca.ReGeo.	Regional	Avellino
S. Andrea di Conza	Ca.ReGeo.	Regional	Avellino
Le Terme di San Teodoro	Ca.ReGeo.	Regional	Avellino
Bocca del Dragone - Piana di Volturara	Ca.ReGeo.	Regional	Avellino
Grotta di Caliendo	Ca.ReGeo.	National	Avellino
Sorgenti di Cassano Irpino	Ca.ReGeo.	National	Avellino
Cava di Alabastro Cotognino	Ca.ReGeo.	Regional	Avellino

Table 7 - List of the 21 geosites located within the study area.

Alongside the officially recognised geosites, the territory also includes a series of sites which, although not formally listed in institutional inventories, play a significant role in reconstructing the geomorphological and cultural evolution of the area (Tab. 8).

Potential geological heritage site	Province
La rupe di Cairano	Avellino
La fumara di Atella	Potenza
L'olistolite carbonatico di "Cacariavule"	Foggia
L'affioramento calcareo di "Piesco re lo Riavolo"	Avellino
I dolmen "Casa dell'Orco" di Pratola Serra	Avellino
Aquilonia	Avellino

Table 8 - List of sites of potential geological interest.

They constitute key indicators of the local geological evolution, as well as tangible expressions of the traditions, belief systems, and socio-cultural identity of both current and past communities inhabiting the area.

2.4 GEOLOGICAL-STRUCTURAL AND TECTONIC FEATURES OF THE CAMPANIA–LUCANIA SEGMENT OF THE APENNINE CHAIN

The study area lies within the Campania–Lucania portion of the northern sector of the Southern Apennine orogen. Geological data (D’Argenio et al., 1973) indicate that this orogenic system began to develop from the late Miocene as a consequence of the collision between the Eurasian and African plates. The orogenic structure of this Apennine sector results from multiple compressive tectonic phases that produced the superposition and stacking, in the form of thrust sheets, of several tectonic units, each representing the deformation of older palaeogeographic domains that once occupied the Tethyan realm between the two converging major plates.

The resulting mountain chain became emergent and morphologically expressed mainly from the late Pliocene throughout the Pleistocene, within a still active geodynamic context characterized by the presence of a back-arc basin, corresponding to the Tyrrhenian margin of the Peninsula, and a stable foreland in the Apulian–Gargano sector along the Adriatic front.

Thus, in an ideal palaeogeographic framework (Fig. 14), from west to east, the following palaeogeographic domains were progressively involved in the deformation, and today constitute the structural backbone of the Southern Apennines (Brancaccio et al., 1984, Mostardini and Merlini, 1986, Vitale and Ciarcia, 2018):

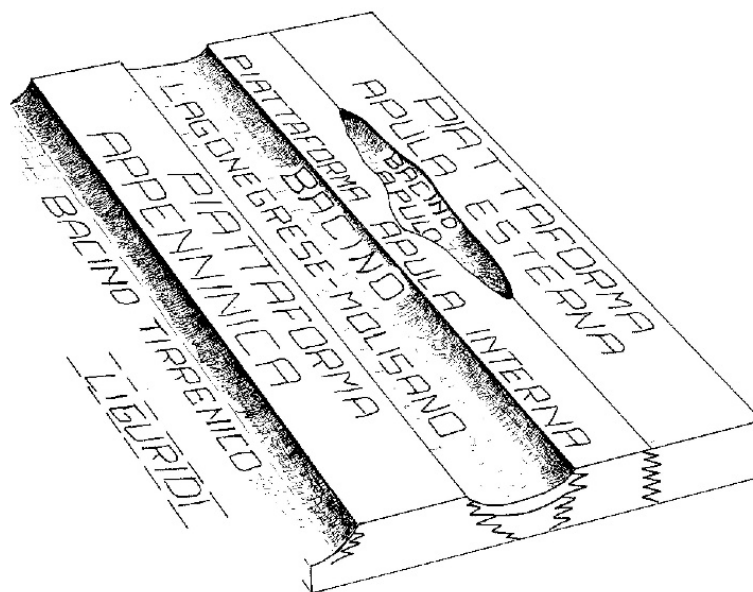


Figure 14 - Pre-orogenic palaeogeographic framework of the Southern Apennines (Mostardini & Merlini, 1986).

Tyrrhenian Basin: a basin depression, likely representing remnants of the ancient Tethys Ocean, corresponding to the western or internal margin of the Chain. It is filled with flysch-type sedimentary accumulations known as the Liguride/Sicilide Units of Mesozoic age, overlain, in unconformity, by Cenozoic deposits referred to as the Cilento Flysch (Bonardi et al., 2009).

Apenninic Platform: reliefs composed of Mesozoic carbonate successions in neritic facies (Bahamas-type carbonate platform) (D’Argenio et al., 1973).

Lagonegrese–Molise Basin: a basin depression filled with predominantly flysch-type sediments attributable to two superposed stratigraphic-structural units. The lower unit, of Middle Triassic–Lower Cretaceous age, consists of a calcareous-siliceous-marly succession (Scandone, 1967). The upper unit, of Upper Cretaceous–Lower Miocene age, is composed of flysch deposits and Scaly Clays (Sicilide Complex) (Bonardi et al., 2009).

Internal Apulian Platform: reliefs composed of Meso-Cenozoic carbonate successions in neritic facies (Bahamas-type carbonate platform; D’Argenio et al., 1973) (Mostardini and Merlini, 1986).

Apulian Basin: a basin depression located between the two Apulian platforms, detectable only in seismic sections due to crustal discontinuities. It is filled with a siliciclastic-carbonate succession of Late Mesozoic–Cenozoic age (D’Argenio et al., 1986).

External Apulian Platform: reliefs composed of Late Meso-Cenozoic carbonate successions in neritic facies (Bahamas-type carbonate platform; D’Argenio et al., 1973) (Mostardini and Merlini, 1986). It represents the foreland of the Apennine orogen, only partially deformed (Ortolani, 1978).

The outcropping units within the study area faithfully reflect the described geodynamic configuration of the Campania–Lucania Apennines, as the area lies within the axial portion of this orogenic sector (Fig. 15). Being also crossed by the Tyrrhenian–Adriatic watershed (Mazzanti and Trevisan, 1978), this allows the study area to be subdivided into two sectors, an internal or western one and an external or eastern one.

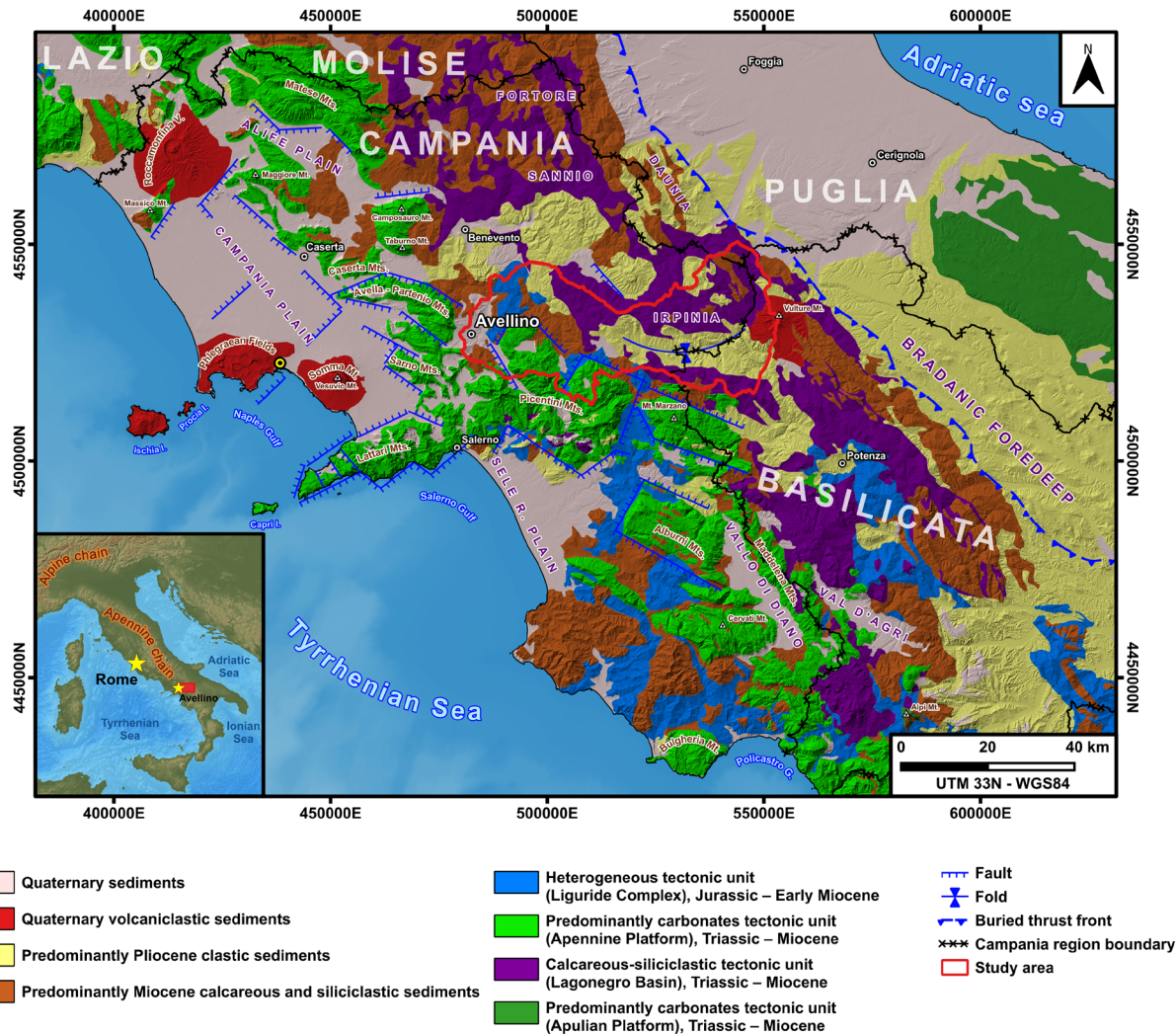


Figure 15 - Schematic general geological map of the Campania–Lucania sector of the Apennines (redrawn from Valente, 2009), with the study area outlined in red.

Therefore, as shown in Fig. 15, the following tectonic and stratigraphic units crop out within the study area:

- **Quaternary sediments:** these deposits crop out mainly in the Sabato and Calore valleys and within intramontane depressions (Brancaccio et al., 1991, Brancaccio et al., 1994, Brancaccio et al., 1995, Santangelo et al., 2017, Valente et al., 2019).
- **Quaternary volcanic deposits:** they crop out on the right-hand side of the Ofanto River near Rionero in Vulture and are related to the volcanic edifice of Mount Vulture (Beneduce and Giano, 2024, La Volpe and Principe, 1994, Principe et al., 2004, Schiattarella et al., 2005).
- **Predominantly Pliocene clastic sediments:** these deposits crop out mainly in the Calore valley between the towns of Luogosano, Paternopoli, and Taurasi, as well as in the Ofanto and Osento valleys near Lacedonia (Ascione, 2012, Chiocchini et al., 1992, Di Celma et al., 2016, Giannandrea, 2014, Vitale and Ciarcia, 2013).
- **Predominantly Miocene calcareous and siliciclastic sediments:** located at the base of the main carbonate ridges, they crop out extensively in the Calore and Sabato valleys and locally near the towns of Rocchetta Sant'Antonio and Lioni (Bonardi et al., 2009, Vitale and Ciarcia, 2018).

- **Heterogeneous tectonic unit (Liguride Complex):** these terrains crop out within the Sabato valley between Santa Paolina, Montemiletto, and Montefalcione, as well as near Teora. They also crop out within the Montella–Bagnoli plain at the foothills of the Picentini Mountains (Bonardi et al., 2009, Ferranti et al., 2024, Patacca and Scandone, 2007, Vitale and Ciarcia, 2018, Vitale et al., 2019).
- **Predominantly carbonates tectonic unit (Apenninic Platform):** this unit crops out in the southern portion of the sector, forming the imposing carbonate reliefs of the Picentini Mountains (D'Argenio et al., 1973, Mostardini and Merlini, 1986, Patacca and Scandone, 2007, Vitale and Ciarcia, 2018).
- **Calcareous–siliciclastic tectonic unit (Lagonegro Basin):** this unit crops out in the northern part of the Fredane stream valley and is widely distributed throughout the upper Ofanto valley at elevations above 500 m a.s.l. (Bonardi et al., 2009, Ferranti et al., 2024, Patacca and Scandone, 2007, Vitale and Ciarcia, 2018, Vitale et al., 2019).

In this highly complex geological framework, a fundamental role in reconstructing and interpreting the evolutionary history and in perceiving the geodiversity of the study area is played by the 21 geosites and geomorphosites described in section 2.3.2.

2.4.1 Geology and geomorphology as drivers for the perception of geodiversity in the study area

The Apennine watershed, which transects the study area (Fig. 16), constitutes a key morphological element, as it separates the study area into two sectors, each characterised by geologically distinct landscapes and by contrasting deformational styles and geodynamic regimes (Amato et al., 1995, Mazzanti and Trevisan, 1978): the western sector, drained by the Calore River hydrographic basin, and the eastern sector, drained by the Ofanto River hydrographic basin.

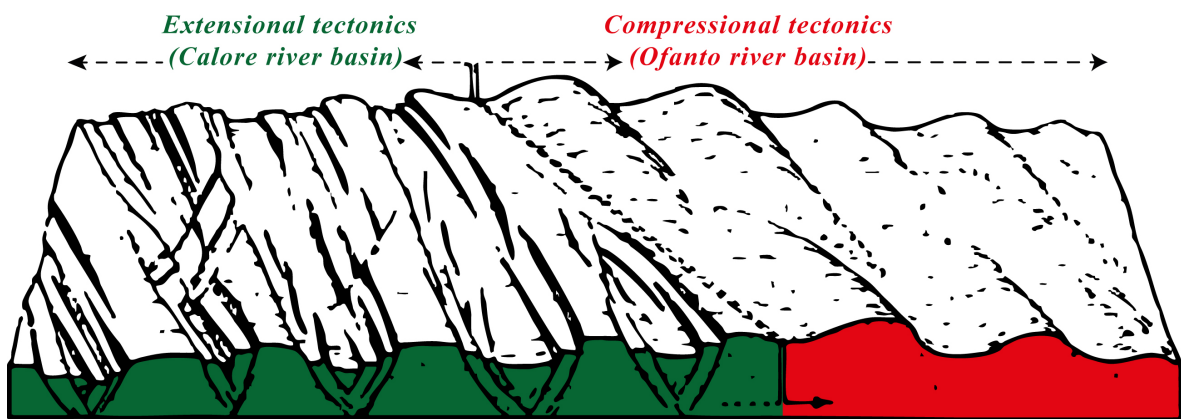


Figure 16 - Schematic geodynamic model of the deformational styles characterising the study area. The Apennine watershed separates the area into two geologically and landscape-wise distinct sectors, drained by the Calore and Ofanto hydrographic basins (from Mazzanti and Trevisan, 1978, modified).

In the western sector (Figs. 17a, b), drained by the Sabato and Calore rivers, an extensional tectonic regime has prevailed since the late Tortonian. The crustal thinning generated by this tectonic style produced, at the surface, the development of horst and graben systems (Di Bucci et al., 2006, Magliulo et al., 2007, 2013, Massa and Zuppetta, 2009, Santangelo et al., 2016, Amato et al., 2018). The interaction between tectonic exhumation and fluvial incision affecting

carbonate lithologies contributes to shaping a landscape morphology deeply dissected by a hierarchically organised hydrographic network.

Limestones and dolomites forming the main reliefs of the study area, exhumed during the extensional phase through low-angle faulting, favour the development of karst aquifers, springs, and chemical dissolution processes which, combined with the mechanical action of fluvial systems, generate a landscape exceptionally rich in predominantly longitudinal water resources.

Karst processes and vertical tectonics are the primary controls on the surface and subsurface morphology of this sector, expressed through striking epigean landforms (poljes, dolines, karren fields, etc.) and hypogean features (karst caves, shafts, speleothems, etc.), associated with an extensive underground drainage network often discontinuous with surface water pathways.

The fluvial terraces flanking the Calore valley represent significant morpho-stratigraphic evidence of Plio-Pleistocene sedimentary cycles, in which phases of valley incision, triggered by tectonic uplift or by glacio-eustatic variations in base level (Santangelo et al., 2016, Amato et al., 2018), alternated with phases of aggradation.



Figure 17, a, b) Typical landscape features of the Calore River basin, c) Typical landscape feature of the Ofanto River basin.

The landscape of this sector is, overall, markedly disarticulated in terms of elevation (with relief differences up to approximately 1,700 m), featuring deeply incised valleys and steep slopes produced by tectonic uplift, which also influences the spatial arrangement of both surface and, possibly, subsurface drainage networks. Karst macroforms (poljes, dolines, karren fields, etc.) dominate only the surface of the main carbonate massifs. Land-use includes moderately extensive forest and shrub formations, accompanied by wide agricultural areas dominated by vineyards, olive groves, and orchards; in karst poljes, perennial herbaceous species and grasses adapted to saturated soils and relatively cold climates prevail.

In the eastern sector (Fig. 17c), drained by the Ofanto River, a compressive tectonic regime prevails, responsible for the formation of fold structures (Amato et al., 1995). The outcropping terrains are largely clastic sedimentary deposits belonging to the Pliocene marine-transitional formations known as the “Ofanto Basin”, a typical piggy-back basin (Ori and Friend, 1984) developed atop a tectonic thrust sheet advancing toward the Apennine orogenic front (Giannandrea, 2003). The thrust surface, located within ductile levels such as clays and marls, favours the creation of the accommodation space required for the formation of a syn- and post-orogenic depocentre, where terrigenous sediments accumulate in fluvial, deltaic, and turbiditic environments (Patacca and Scandone, 2007). The resulting syn-orogenic stratigraphy displays cycles of conglomerates, sands, and clays that reflect variations in depositional energy and the dynamics of the orogenic front (Giannandrea, 2003). Subsequent Plio-Pleistocene subsidence allowed the preservation of two main depositional cycles, characterised by alternating erosive phases and periods of relative stability (Schiattarella et al., 2003).

This tectono-sedimentary framework is further complicated by the presence of volcanic products from the Vulture massif: pyroclastic layers and lava flows generate marked lithological contrasts, influencing surface water circulation, fluvial morphogenetic processes, and the generally hilly morphology of the area (Beneduce and Giano, 2024, Beneduce and Schiattarella, 1997, Schiattarella et al., 2005). The sector exhibits a regular, Davisian-mature landscape, with wide open spaces and limited relief (maximum 500 m), dissected by broad, open valleys with extensive alluvial plains bordered by fluvial terraces. Land-use is dominated by arable fields, accompanied by olive groves, orchards, and vineyards, while forest cover is almost absent; the main settlements, characterised by low population density, are located along the crests of major ridges.

Given the characteristics of the two identified sectors, the succession of different geological substrates and the variety of landforms make the geodiversity of the study area immediately perceptible. Moreover, differences in structural settings, lithologies, and morphogenetic dynamics produce diversified geomorphological responses; thus, it is appropriate to recognise the existence of a geomorphodiversity that is reflected both in the distribution of relief surfaces and in the geometry of hydrographic networks. The route of the abandoned Avellino–Rocchetta Sant’Antonio railway, which traverses the study area, allows one to appreciate the various nuances of this geodiversity, both in the diversity of geo-lithological units and in the physiographic variability expressed by the different landscape units.

2.5 ROAD NETWORK, COMMUNICATION ROUTES AND NATURE TRAILS

The study area is characterised by a dense network of communication routes that develop both transversely and longitudinally, creating a mosaic of pathways within it. This network provides easy access to all the naturalistic and landscape features of the territory (Fig. 18).

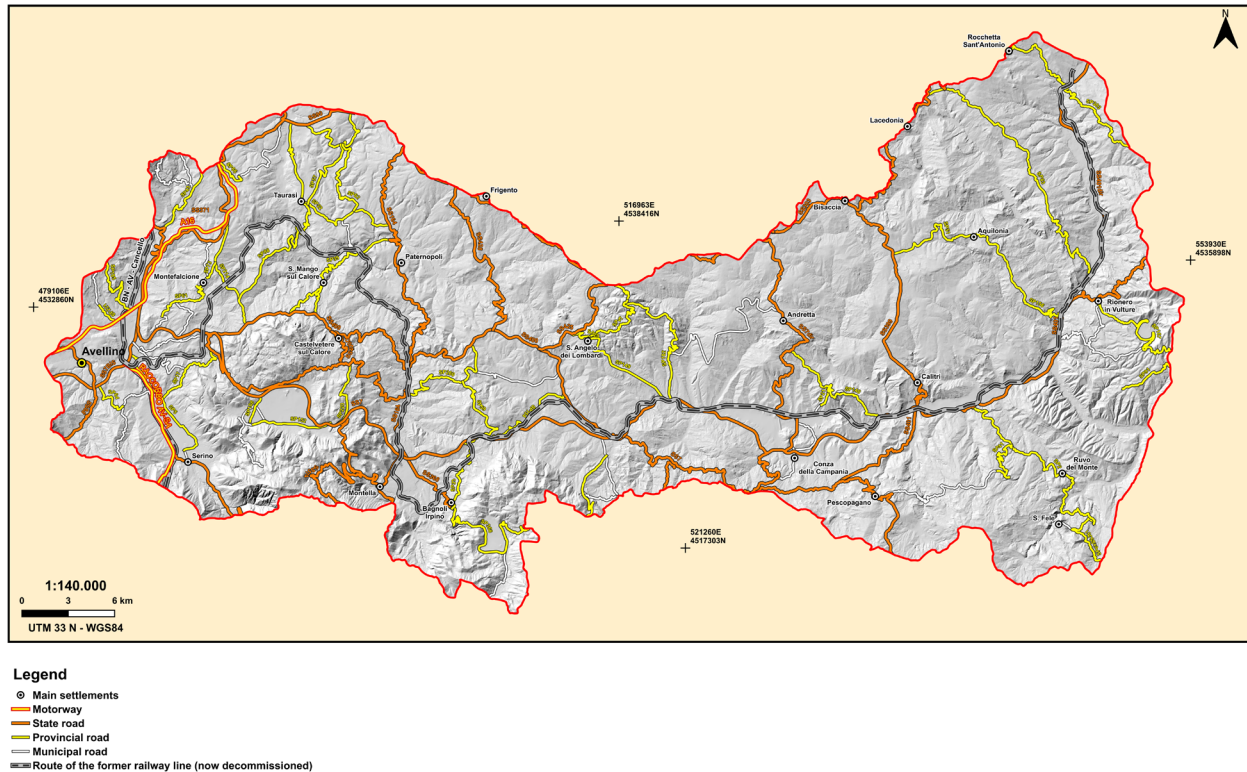


Figure 18 - Map of the road network and anthropogenic features (see Plate 3).

The road infrastructure system is dominated by the state road network, which accounts for 47.07% of the entire system, with more than 400 km of routes. This is followed by the provincial road network, covering 35.45% of the system with approximately 300 km. Primary municipal roads and the motorway network represent, respectively, 14.26% (about 100 km) and 3.22% (about 30 km) of the total (Fig. 19).

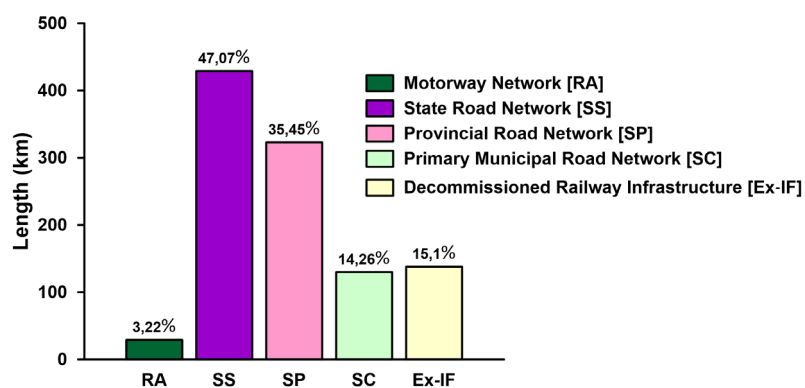


Figure 19, Percentage distribution of the road network within the study area.

The main communication arteries within the study area are:

- **A16 Motorway Naples–Canosa:** it crosses the northern sector of Irpinia, following within the study area the valleys of the Clanio, Acqualonga, Sabato, Calore, and Fiumarelle rivers. Along its route, it skirts Avella and Mugnano del Cardinale, crosses the Monteforte Irpino Pass, and connects directly to the urban area of Avellino. It then continues toward the main centres of northern Irpinia, including Grottaminarda, Ariano Irpino, and Trevico, eventually reaching the eastern sector near Bisaccia and Lacedonia.
- **State Road 7 “Ofantina”:** this route connects Avellino to Melfi, crossing southern Irpinia. From the Bellizzi junction, it reaches Montemarano, Montella, and Nusco, then follows the Ofanto valley with exits for Sant’Angelo dei Lombardi, Lioni, and Caposele. It skirts Lake Conza and, through the connection with SS91, reaches Calitri, the SS401 to Melfi, and continues toward the A2 Salerno–Reggio Calabria motorway.
- **State Road 303 of Formicoso:** SS303 originates at the Mirabella Pass and follows the central ridge of the Frigento plateau, passes Guardia dei Lombardi, and crosses the Formicoso plateau, reaching Bisaccia and Lacedonia before turning toward Melfi. The route partially retraces the ancient Roman Via Appia, whose persistence is evidenced by the basalt outcrop known as the “Frigento Diabase” (locally called *preta spaccata*), located east of Frigento.

Finally, the railway network represents only 15.1% of the transport infrastructure and extends for more than 120 km.

- **Avellino–Rocchetta Sant’Antonio Railway Line:** the Avellino–Rocchetta Sant’Antonio railway, supported by Francesco De Sanctis and inaugurated in 1892, played a crucial role in mobility and territorial cohesion, as it connected the provincial capital of Irpinia with the inland towns along the Calore and Ofanto valleys up to the strategic junction of Ponte Santa Venere, part of the “Ofanto railway system”, linking Campania, Lucania, and Apulia.

The railway route (Fig. 19), although tortuous and penalising in terms of travel times (<https://www.lestradeferrate.it/>), made the line a testing ground for innovative technical solutions, requiring the adoption of complex engineering works that involved the construction of fifty-eight bridges and nineteen tunnels (<https://www.lestradeferrate.it/>, Panzone, 2003). These structures were built to overcome significant elevation differences, gradients reaching up to 25%, frequent valley depressions, and the complex geo-lithological nature of the traversed territory (clays, schists, alluvial deposits, etc.) (<https://www.lestradeferrate.it/>, Pane, 2020). These peculiarities also contributed to its technical and cultural relevance until its definitive decline and abandonment in 2010 (Pane, 2020, Panzone, 2003), further accelerated by the construction of the “Ofantina Bis” state road, which rendered the railway no longer competitive.

Nevertheless, the suspension of passenger services resulted from a combination of converging negative factors, including demographic decline in the Apennine inland areas, infrastructure degradation, road competition, lack of integrated strategies, inadequate governance, and insufficient innovation.

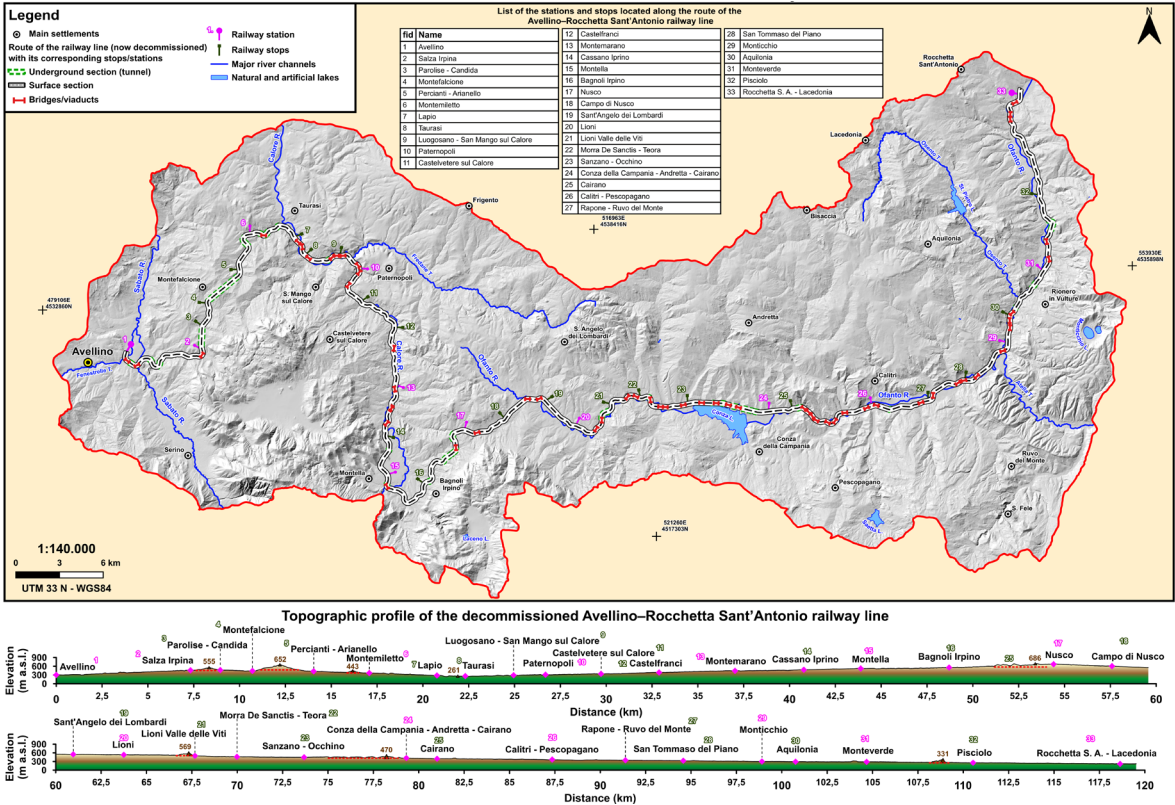


Figure 19 - Route and topographic profile of the decommissioned Avellino–Rocchetta Sant’Antonio railway line (see Plate 12).



Figure 20 - a) and b) views of the Milano Bridge, c) and d) views of the Ponte Principe.

Today, only the railway track remains, awaiting reconversion for tourism and cultural purposes rather than logistical use (<https://www.lestradeferrate.it/>, Panzone, 2003, Pane, 2020). Among the most significant engineering works are the curved “Milano” viaduct over the Sabato River (225 m) and the oblique bridge over the Calore River near San Mango (104 m). Also noteworthy is the 340-m-long, three-span metal structure of the “Ponte Principe” near Lapio (Fig. 20).

After 2010, the decommissioned railway line became the focus of an articulated preservation movement thanks to the work of the association *InLocoMotivi* (2009), which promoted awareness-raising initiatives and demonstrative journeys, helping to keep public attention alive. Furthermore, the *Fondazione FS Italiane*, through the programme “Binari senza tempo” (2014), included this route among the lines eligible for reactivation for tourism purposes, launching the first historic trains in 2016 in collaboration with the *SponzFest* (<https://www.sponzfest.it>).

The railway was recognised as a cultural asset in 2016 following studies conducted by the Department of Architecture of the University of Naples Federico II and was reopened in 2018 for tourist services. Although structural and managerial criticalities persist, the interpretative framework offered by the principles of the Faro Convention (Council of Europe, 2005, <https://www.coe.int>), which conceives heritage as a community resource and promotes active community participation, reinforces the interpretation of the line as shared heritage. Within this framework, the area retains significant environmental, historical, and tourism development potential, still largely unexpressed.

Of particular relevance are the numerous nature trails that cross the study area, revealing a territorial framework rich in historical-artistic, environmental, and landscape points of interest (Fig. 21). A total of 79 elements have been surveyed, variously distributed across the area and classified into eight categories: geosites, panoramic viewpoints, historic villages (<https://borghipiubelliditalia.it/>), FAI “Luoghi del Cuore” sites (FAI – Luoghi del cuore), ghost towns, ski areas, thermal springs, and hiking, trekking, and cycling routes.

The twenty-one geosites, classified according to their degree of scientific interest following the proposal by Coratza et al. (2021) at national, regional, and local scales, highlight the geological value of the area and confirm its relevance for research and dissemination activities (sit.regione.campania.it/geoportale, isprambiente.gov.it, Cusano et al., 2022, Sisto et al., 2020, Sisto et al., 2022a, 2022b).

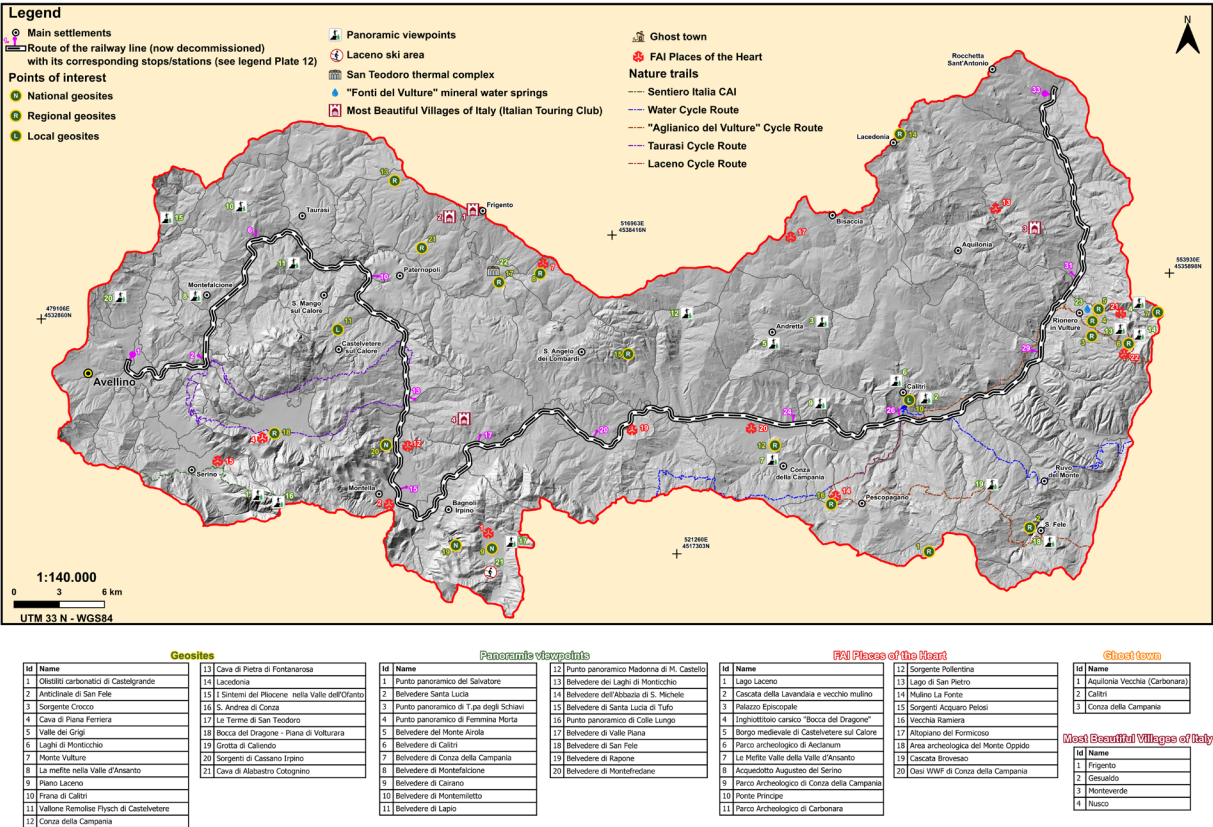


Figure 21 - Distribution of points of interest and nature trails within the study area (see Plate 13).

The network of panoramic viewpoints and cycle-pedestrian routes (viefrancigene.com, Rumiz, 2016, Montaruli, 2023) contributes to the enhancement of the landscape by offering opportunities to observe the diversified morphology of the territory, within which the settlements are embedded, including villages of recognised architectural and historical value (ghost towns) (Moccia, 2014, Tesei and Calloni, 2018, derivesuburbane.it, paesifantasma.it, isprambiente.gov.it). These constitute tangible testimonies of the socio-economic transformations that have shaped the territory over time, rooted in the local rural context, where they represent a stratified cultural heritage of considerable significance.

2.6 HISTORICAL, ARCHITECTURAL AND SOCIO-CULTURAL FEATURES OF THE STUDY AREA

The study area is also known for its high density of historical sites and events, socio-cultural initiatives (e.g., local festivals), and various expressions of local popular traditions (religious celebrations, commemorative events, folkloric manifestations, food festivals, etc.) (Cusano et al., 2022, Touring Club Italiano, 2013, sistemairpinia.provincia.avellino.it), distributed throughout the year and associated with different thematic domains.

Out of a total of 228 surveyed events, food festivals (*sagre*) constitute the largest segment, accounting for 24.1%, followed by patronal feasts (19.3%) and traditional religious celebrations and rites (18.4%). Religious festivities and artistic festivals (musical, theatrical, or cinematic) each represent 13.2%, whereas historical re-enactments (5.3%) and traditional festivities (4.8%) show a lower incidence, although they maintain a significant presence in the annual calendar. Fairs account for 1.3% of the total events, and sporting events for 0.4% (Figs. 22 and 23).

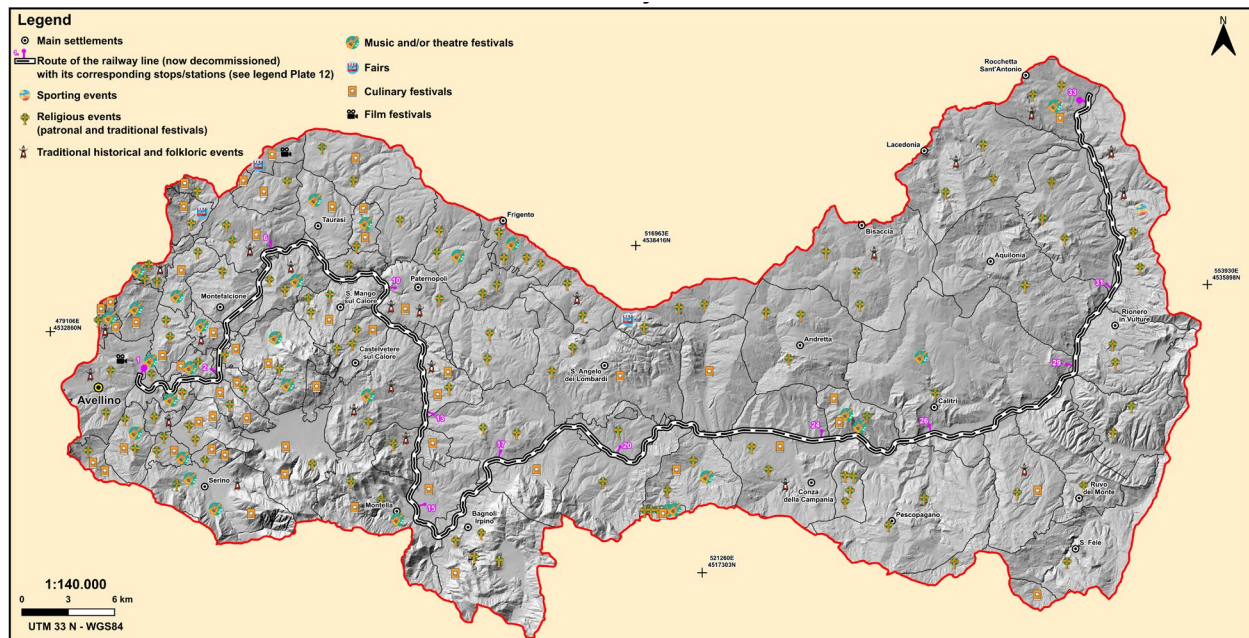


Figure 22 - Map of traditional events (religious, cultural, folkloric festivals, food festivals, etc.) documented within the study area (see Plate 14).

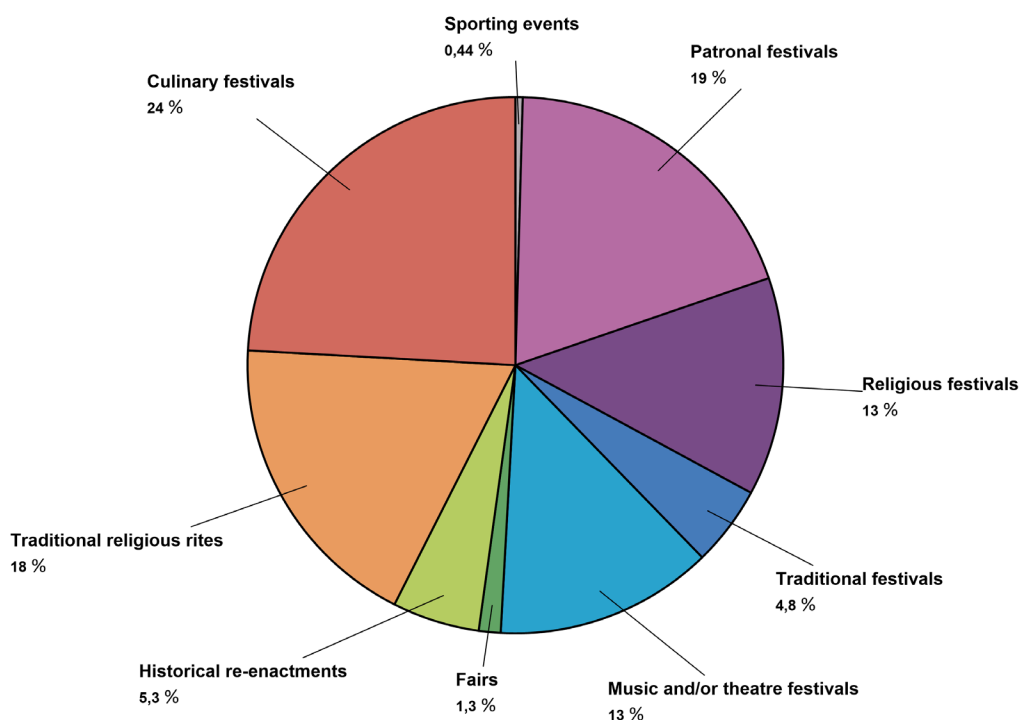


Figure 23 - Percentage distribution of traditional events.

These events highlight the extraordinary richness and diversity that characterise the forms of social aggregation expressed in various ways throughout this territory, as well as their distribution across the entire year, with a significant concentration during the spring and summer months, particularly in correspondence with major liturgical festivities that attract substantial tourist flows and confirm the intense and deeply rooted social vitality of the area.

Within the study area, the numerous religious buildings (churches, convents, monasteries, sanctuaries, etc.), places of worship, and sacred monuments are also of considerable interest, as they hold significant historical-cultural as well as tourism value (chiesacattolica.it, beweb.chiesacattolica.it). A total of 63 worship sites have been surveyed and classified into ten architectural and functional categories (Figs. 24 and 25). The most significant datum concerns the predominance of parish churches, amounting to 35 units (55.56%). These structures, typically located in strategic points of the urban or rural fabric, represent the core of local religious life and the historical continuity of liturgical practices.

Particularly significant is also the presence of 11 sanctuaries (17.46%) and 4 cathedrals (6.35%), which indicate a deeply rooted spiritual vocation associated with specific cults and pilgrimage phenomena, fulfilling a devotional function that is symbolically meaningful for the local communities.

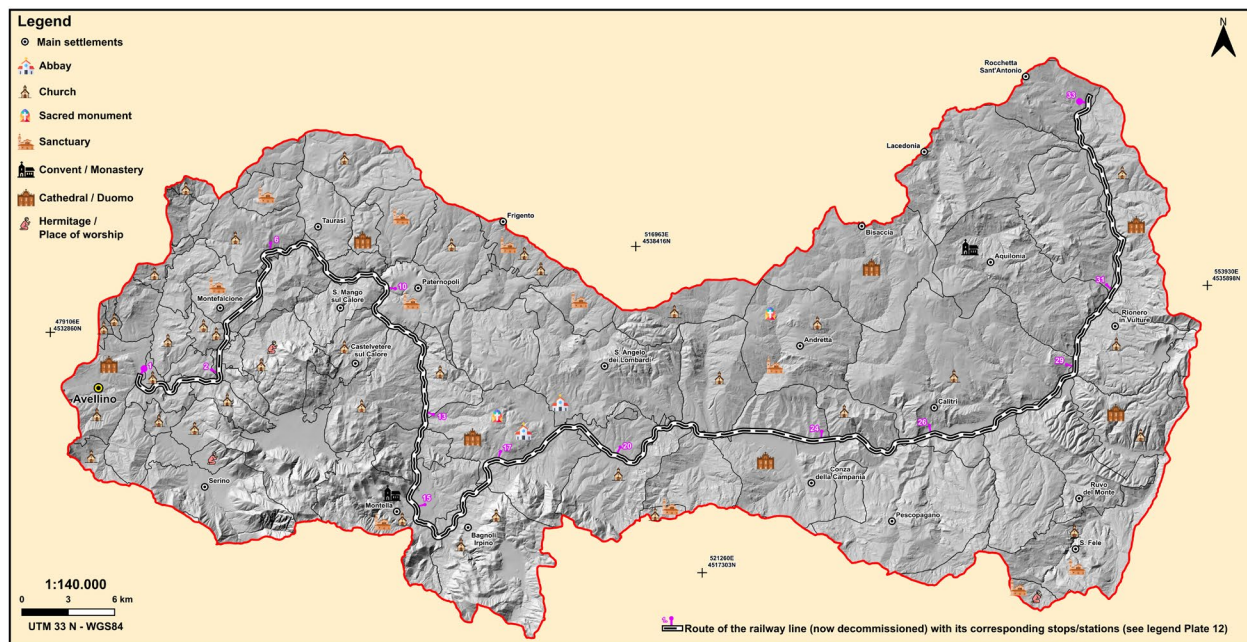


Figure 24 - Religious buildings (churches, convents, monasteries, sanctuaries, etc.), places of worship, and sacred monuments of significant historical-cultural and tourism interest present within the study area (see Plate 15).

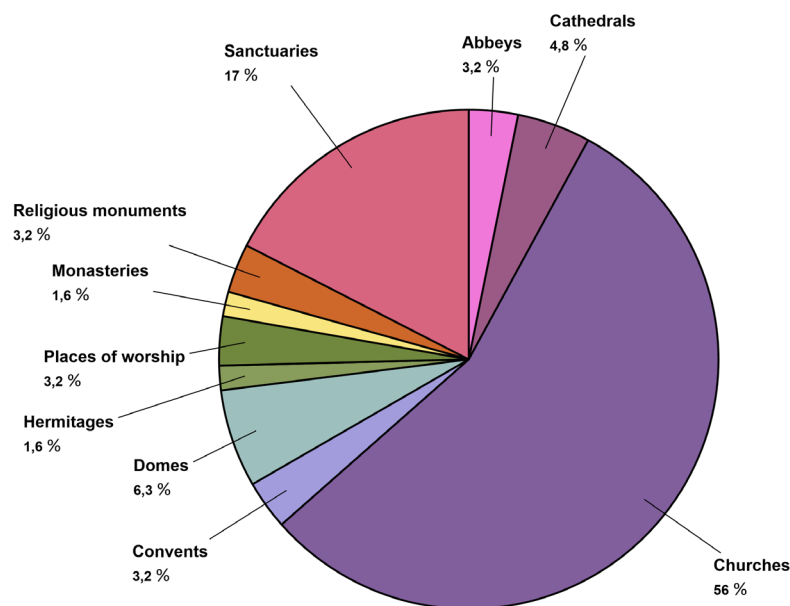


Figure 25 - Percentage distribution of religious buildings, places of worship, and sacred monuments of significant historical-cultural and tourism interest present within the study area.

Cathedrals (3 units, corresponding to 4.76%), abbeys, convents, generic places of worship, and sacred monuments (each with 2 buildings, corresponding to 3.17%), together with monasteries and hermitages (1 site each, corresponding to 1.59%), complete the framework of a stratified and composite sacred heritage that is embedded within a heterogeneous landscape context, of which it represents the spiritual component endowed with strong identity value.

The historical-artistic and architectural heritage comprises 127 sites distributed throughout the study area (cultura.gov.it, musei.beniculturali.it). This heritage is classified into five typological categories (Figs. 26 and 27). The most significant datum concerns the predominance of historic

buildings (historic palaces and villas, castles, towers, fortresses, etc.), amounting to 63 units (49.61% of the total), distributed across both urban centres and rural areas. These structures constitute loci of collective memory and express the continuity of settlement patterns and the socio-cultural dynamics embedded within the landscape.

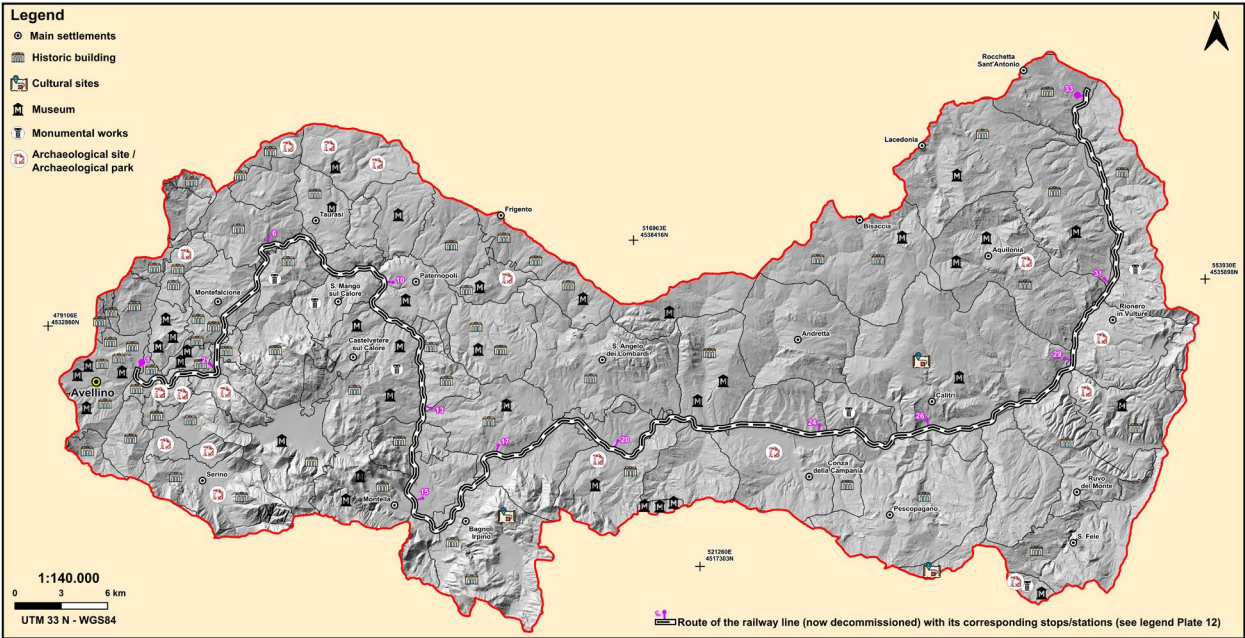


Figure 26 - Historic buildings, monumental structures, cultural sites, museum centres, and archaeological parks or sites of significant historical-cultural and tourism interest present within the study area (see Plate 16).

The 38 museums (29.92%) surveyed reflect a strong inclination of the territory toward cultural fruition. They are often housed in repurposed historic buildings, with which they jointly reinforce local identity values while also supporting a wide range of educational experiences.

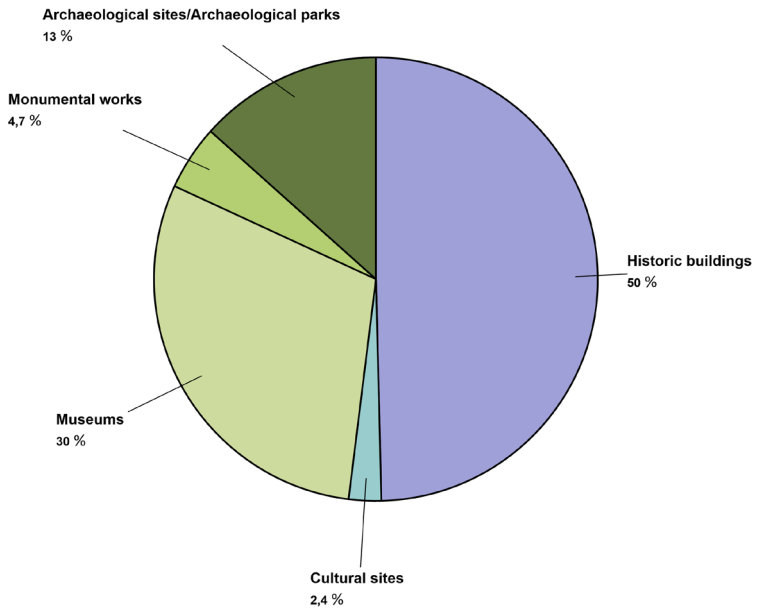


Figure 27 - Percentage distribution of historic buildings, monumental structures, cultural sites, museum centres, and archaeological parks or sites of significant tourism interest.

The 17 archaeological sites and parks surveyed (13.39%) document key moments in the local settlement evolution. Located either in peripheral areas or integrated within the urban fabric, they represent fundamental resources for historical reconstruction and for the enhancement of ancient heritage, providing concrete tools for understanding territorial stratification.

The 6 monumental works (4.72%) and the 3 cultural sites (2.36%) complete the framework of built heritage intended for commemorative or artistic functions, assuming a symbolic role within the urban layout. Cultural sites (libraries, art galleries, historical archives, civic centres, etc.) operate across the territory as custodians of knowledge and intellectual life, actively contributing to the participatory dimension of the area.

Overall, the typological and functional variety of the surveyed sites outlines an integrated cultural system in which historical heritage, museum spaces, and knowledge infrastructures collectively contribute to defining a territorial model grounded in the widespread dissemination of cultural value.

PART III

MATERIALS, METHODS, INSTRUMENTS AND TECHNIQUES

The following pages describe the materials, methods, instruments and techniques employed for the production and analysis of the data required to achieve the objectives of the present research. *Materials* refers to the set of raw data, whose origin (derived or directly measured), nature and provenance are specified. The collected data were used to construct a geodatabase in which each datum, appropriately georeferenced, is associated with a unique piece of information. *Methods* refers to the ensemble of methodological procedures, whether specific or standard, adopted for the processing, elaboration and rendering of the raw data. Finally, *instruments and techniques* denotes the means and approaches, primarily mathematical-statistical and geoinformatic, through which the data were acquired, refined and represented, as well as the results of their interpretation within models already tested and validated in other contexts documented in the scientific literature.

3.1 MATERIALS

The data employed in the present research are heterogeneous in origin, nature and provenance, therefore it was necessary to classify them, according to their typology, into four distinct domains, each of which enabled the construction of a specific geo-database:

- **Geo-naturalistic domain:** includes territorial, geo-lithological, morpho-topographic data, natural resources, vegetation cover, climatic characteristics, land-use, hydrography, springs and infrastructures,
- **Administrative-demographic domain:** includes political-administrative and socio-economic information related to the anthropization of the examined territory,
- **Tourism domain:** includes information on the tourism offer, accommodation facilities, routes and documented visitor flows within the study area,
- **Agri-food and enogastronomic domain:** includes information related to agricultural production, agri-food supply chains, local culinary traditions and typical territorial products.

The database of each domain is composed of the following three categories of data or information, also expressed in percentage terms:

- **Raster data (26%):** each pixel is associated with a numerical value, Digital Number (DN), containing qualitative information (e.g., colour) or quantitative information (e.g., elevation of a point),
- **Vector data (32%):** the data are expressed through different geometries (e.g., point, linear, polygonal) and defined by sequential points or vertices,
- **Textual data (42%):** the data consist of textual information referring to a georeferenced point (e.g., description of a monument, of an agricultural product, etc.).

All acquired data were geolocated and organized into structured layers to be managed as vector-format information levels within a GIS environment, and subsequently rendered as cartographic documents at a scale of 1:140,000 in the EPSG:32633 reference system. The integration of data obtained from the various sources used enabled a systemic interpretation of the rural

landscape, in which diverse information is combined to uniquely define the identity and value of the landscape, a fundamental aspect for achieving the scientific and cultural objectives of the present research.

3.1.1 Geo-naturalistic domain

The geo-naturalistic data concerning the study area were collected through an integrated approach, based on their provenance from authoritative and open-source repositories, and selected according to typology, quality, territorial coverage and scientific reliability. This procedure enabled the construction of a multidisciplinary and multifunctional geodatabase with a robust informational framework capable of illustrating the physical complexity of the territory in its geo-lithological, morpho-topographic, hydrographic, climatic and infrastructural components. All data were digitized and georeferenced for implementation within a GIS environment.

For example, the topographic configuration of the study area derives from raster and vector data provided by **TINITALY 1.1** (Tarquini et al., 2023, TINITALY DEM – INGV: <https://tinitaly.pi.ingv.it/>), with a spatial resolution of 10 metres, complemented by DTM data from NASA's **Shuttle Radar Topography Mission (SRTM)**, with a spatial resolution of 30 metres (NASA Earthdata – SRTM: <https://www.earthdata.nasa.gov/>).

Vector topographic data (contour lines and spot heights) were extracted from the **Regional Technical Map (CTR)** at a scale of 1:5,000, available for the regions of Campania (Geoportale Campania: <https://sit2.regione.campania.it/>), Basilicata (Regione Basilicata – CTR: <https://www.regione.basilicata.it/>), and Puglia (SIT Puglia – CTR: <https://www.sit.puglia.it/>).

Geological data derive from the **Geological Map of the Southern Apennines** at a scale of 1:250,000 (Bonardi et al., 1988) and from the **Geological Map of Italy** at a scale of 1:100,000 produced by the Italian Geological Survey (ISPRA – Carta Geologica 1:100.000: <https://www.isprambiente.gov.it/>).

Raster and vector data relating to the hydrographic network and springs of the study area originate from the **National Hydrographic Network** (Geoportale ISPRA – Reticolo Idrografico: <https://www.isprambiente.gov.it/>), from the hydrographic dataset of the Campania Region at a scale of 1:25,000 (Geoportale Campania: <https://sit2.regione.campania.it/>), from the **OpenStreetMap** platform (<https://www.openstreetmap.org/>), as well as from the digitization of the **Topographic Map of Italy** produced by the Military Geographic Institute (IGM) at scales 1:25,000 (1954) and 1:50,000 (1987), from the **Hydrogeological Map of the Province of Avellino** at a scale of 1:100,000 (Aquino et al., 2008) (IRIS UniSannio: <https://iris.unisannio.it/>), and from the **Hydrogeological Map of Southern Italy** at a scale of 1:250,000 (Allocca et al., 2007).

Land-use data derive from the **CORINE Land Cover (2018)** dataset, developed within the European **Copernicus Land Monitoring Service** (Copernicus – CLC 2018: <https://land.copernicus.eu/>), structured into 44 classes with a spatial resolution of 100 metres.

The boundaries of protected natural areas and **Natura 2000** sites were obtained from regional Open Data catalogues: for Campania (Open Data Campania – Natura 2000: <https://dati.regione.campania.it/>), for Basilicata (Regione Basilicata – Natura 2000:

<https://www.regione.basilicata.it/>), and for Puglia (Open Data Puglia – Natura 2000: <https://dati.puglia.it/>).

Meteoclimatic data were extracted from the historical series of 34 thermo-pluviometric stations located within the study area and made available online by the following regional services: **Centro Funzionale Multirischi** (Centro Funzionale Campania: <https://centrofunzionale.regione.campania.it/>), **Centro Agrometeorologico Regionale Campano**, **Centro Funzionale Decentrato Pugliese** and **ARIF Puglia**, **Centro Funzionale Regionale** (Centro Funzionale Basilicata: <https://centrofunzionale.regione.basilicata.it/>), and **ALSIA Basilicata**. These data were integrated with those from stations managed by the **National Environmental Information System (SINA)** (ISPRA – SINA: <https://www.isprambiente.gov.it/>).

Finally, regarding historical and contemporary infrastructure (roads, highways, railways, etc.), vector data were obtained from the **OpenStreetMap** platform (<https://www.openstreetmap.org/>) and from the **Open Data Catalogue of the Campania Region** (<https://dati.regione.campania.it/>).

3.1.2 Administrative-demographic domain

The structured and georeferenced data concerning the administrative-demographic framework of the study area derive from official institutional sources, also available as open-source datasets.

In vector format, the following elements were acquired and geolocated: administrative boundaries, provided by the Italian National Institute of Statistics (ISTAT) (*ISTAT – Confini amministrativi*: <https://www.istat.it/>), and municipal centroids, obtained from the Open Data Catalogue of the Campania Region (*Geoportale Campania – Centroidi comunali*: <https://sit2.regione.campania.it/>).

Demographic data referring to the resident population and all other socio-economic variables originate as textual information from the official statistics of ISTAT (*ISTAT – Statistiche demografiche*: <https://www.istat.it/>), although they were subsequently processed and converted into vector format for integration within the geographic information system.

3.1.3 Tourism domain

The data concerning the tourism appeal of the study area also originate from heterogeneous sources (institutional bodies, thematic associations, open-source platforms, etc.), and primarily relate to the cultural, landscape and recreational resources present within the territory. These structured and georeferenced data were likewise implemented in a GIS environment to enable spatial management.

More specifically, information regarding *I Borghi più belli d'Italia* and geosites was acquired in textual format, and subsequently converted into vector format, from the official portal of the association (<https://borghipiubelliditalia.it/>), from the Geoportal of the Campania Region (<https://sit.regione.campania.it/geoportale> ([sit.regione.campania.it in Bing](https://sit.regione.campania.it/geoportale))), and from the National Inventory of Geosites of ISPRA (<https://www.isprambiente.gov.it> ([isprambiente.gov.it in Bing](https://www.isprambiente.gov.it))). Detailed information on the latter is provided in paragraph 2.3.2. Panoramic viewpoints were identified using the Topographic Map of Italy produced by the Military Geographic Institute (IGM), at scales 1:25,000 and 1:50,000.

Abandoned villages, the so-called *ghost towns*, were surveyed and implemented as textual datasets derived from various thematic sources and editorial projects, such as *Le Belle Addormentate* (Mocciola, 2014), the *Derive Suburbane* project (<https://derivesuburbane.it>), the *Paesi Fantasma* portal (<https://paesifantasma.it>), and the *Ghost Cities* project of ISPRA (<https://www.isprambiente.gov.it> ([isprambiente.gov.it](https://www.isprambiente.gov.it) in Bing)). The “Luoghi del cuore” promoted by FAI were acquired as a vector layer, georeferenced and adapted to the visualization scale, from the official website (FAI – Luoghi del cuore: <https://fondoambiente.it/luoghi>).

Information concerning thermal facilities and ski resorts was extracted from OpenStreetMap (<https://www.openstreetmap.org>) and from the Open Data Catalogue of the Campania Region, in vector format and using the EPSG:32633 reference system. The hiking and cycle-tourism network was extracted, in raster and vector format, from the *Carta dei Tratturi* at a scale of 1:100,000 (IGMI, 1959), and integrated with the route of the Via Francigena (<https://www.viefrancigene.com>), the itinerary of the Via Appia (Rumiz, 2016), the *Sentiero Italia CAI* described in the homonymous series (<https://ideamontagna.it>), and the *Strade del Vino*, promoted by National Geographic across various regional itineraries (National Geographic, 2025, <https://www.nationalgeographic.com>).

Traditional events were obtained from textual sources and editorial projects such as the study *Geotourism, traditions and typical products of Avellino Province* (Cusano et al., 2022, <https://doi.org/10.1080/17445647.2021.2004941>), the institutional portal *Sistema Irpinia* (<https://sistemairpinia.provincia.avellino.it> (sistemairpinia.provincia.avellino.it in Bing)), and the guide *Le terre del Greco e del Fiano. Tra boschi e castelli nella verde Irpinia, sulle strade del Taurasi, del Greco di Tufo e del Fiano di Avellino* (Slow Food, 2013, <https://touringclubstore.com>).

Finally, data relating to religious buildings, places of worship and sacred monuments were acquired from official sources of the Catholic Church (<https://www.chiesacattolica.it>) and from the BeWeb portal (<https://beweb.chiesacattolica.it>). Archaeological sites, monumental works, museums and buildings or sites of historical-artistic interest were derived from the database of the Ministry of Culture (<https://cultura.gov.it>), and in particular from the platform of the Directorate-General for Museums.

3.1.4 Agri-food and enogastronomic domain

The data concerning the agri-food and enogastronomic system present within the study area were obtained through the consultation of thematic repertoires and institutional archives. These consist of textual data relating to typical products and high-value agricultural areas, selected according to their geographical location and subsequently processed into vector format. These data originate from local institutional websites, such as the *Guida ai prodotti tipici del territorio* of GAL Irpinia (GAL Irpinia, n.d., <http://www.galirpinia.it>), from specialist publications, such as *Le terre del Greco e del Fiano* (Slow Food Editore, 2013), and from the *National List of Traditional Agri-food Products* available on the website of the Ministry of Agriculture, Food Sovereignty and Forests (MASAF).

Data relating to traditional regional products were obtained from the official archives of the regions of Campania (https://agricoltura.regione.campania.it/Tipici/prodotti_tradizionali.htm), Basilicata (<https://www.regione.basilicata.it>), and Puglia (<https://www.patpuglia.it>).

From the same regional sources derive the georeferenced datasets concerning the delimitation of high-value agricultural areas: Campania (<https://dati.regione.campania.it>), Basilicata (<https://dati.regione.basilicata.it>), and Puglia (<https://dati.puglia.it>).

3.2 METHODS

The data collected or produced through the procedures previously described were used to construct a complex and diversified territorial dataset managed within a GIS (Geographic Information System), following the procedures outlined by Burrough (1996). The geodatabase created not only enabled the quantification of the distinctive features of the examined territorial heritage, but also allowed the availability of multiple simple information layers, each corresponding to a specific queried variable, with the possibility, by appropriately exploiting the functions offered by the software used, of generating more complex and advanced data layers. In this way, territorial data were integrated with demographic, socio-economic and historical-cultural information, thereby achieving an important objective of the present research: the quantification of the diversity characterizing the study area.

This paragraph illustrates the methods, practices and procedures adopted to analyse, process, render and represent the collected or produced data.

3.2.1 Topographic and hydrographic characterization of the study area

The topographic data (contour lines and spot heights) and hydrographic data relating to the study area (see Fig. 5 – Plate 2) were imported into a GIS environment, where they were subjected to geospatial analyses and processing using the *TopoToRaster* tool, as recommended by Hutchinson et al. (2011), in order to obtain a high-resolution Digital Terrain Model (DTM) with a pixel size of 5 metres. The level of detail, density and informational quality of the data provided a solid basis for the three-dimensional cartographic modelling of the examined territory.

The resulting DTM was subsequently imported into QGIS 3.44, where it underwent an altimetric reclassification using the *r.reclass* plugin of the GRASS GIS module. The four altimetric classes identified effectively represent the orographic structure of the study area, and on this basis it was possible to delineate watershed boundaries and major hydrographic lines, densifying the hydrographic network through comparison with available IGMI cartographic sources and with high-resolution satellite imagery available on Google Earth. The data were exported in shapefile format.

3.2.2 Characterization of morphometric parameters

The morphology of the territory was characterized through the analysis of four morphometric parameters: slope, aspect, drainage density and relief energy (Fig. 28). These data were likewise imported and processed within a GIS environment, reclassified and exported in shapefile format in order to obtain qualitative and quantitative representations of the physiographic characteristics of the relief that influence the socio-environmental dynamics of the study area.

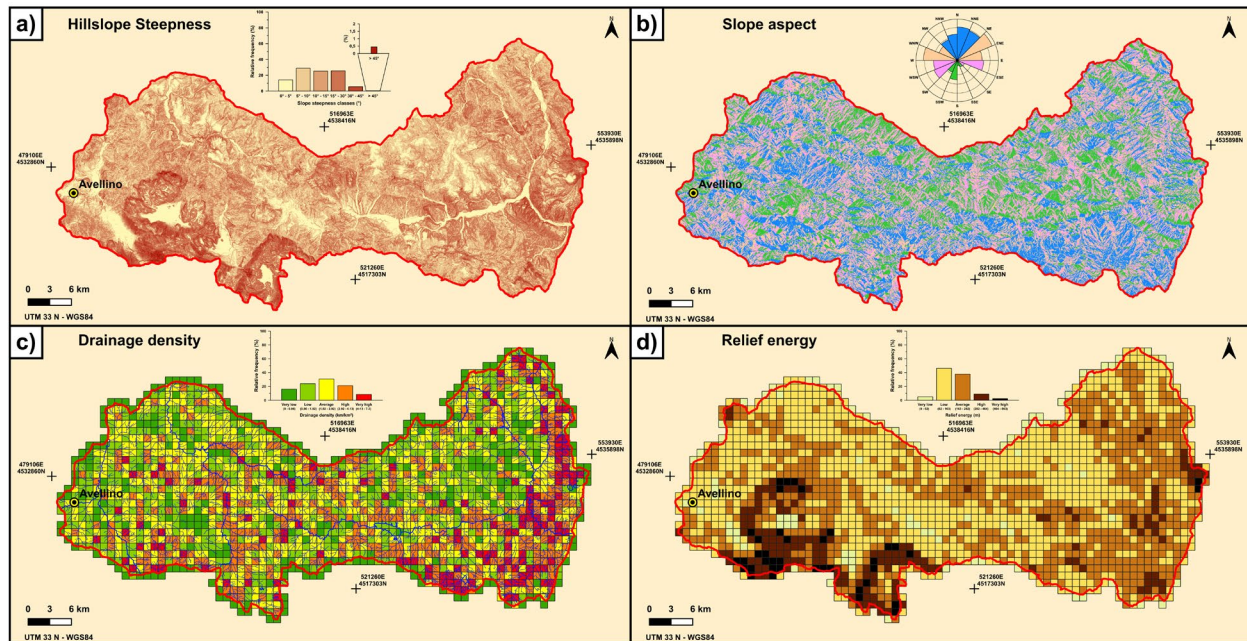


Figure 28 – Morphotopographic parameters characterizing the study area: a) Hillslope Steepness; b) Slope aspect; c) Drainage density; d) Relief energy (see Plate 4).

The **hillslope steepness parameter** (Billi et al., 1987) was obtained and processed within a GIS environment using the *Slope* tool (Hickey et al., 1994, Dunn & Hickey, 1998), an algorithm included in the ESRI Spatial Analyst extension suite. The thematic reclassification performed with the *r.reclass* plugin of the GRASS GIS module made it possible to obtain six slope classes, which effectively describe the morpho-topographic variations of the relief within the study area (Fig. 28a).

The **slope aspect parameter** (orientation) describes the azimuthal direction toward which a slope surface is inclined with respect to geographic north (Billi et al., 1987). It is a key morphometric parameter influencing solar radiation, surface temperature, soil moisture and vegetation distribution. For the calculation of aspect, the data extracted from the DTM were imported into a GIS environment and processed using the *Aspect* tool included in the Spatial Analyst suite. The *Aspect* tool computes, in sexagesimal degrees measured clockwise from geographic north, the azimuthal orientation (downslope direction) for each cell of the elevation raster, typically a Digital Elevation Model (DEM). The resulting data, appropriately reclassified using the *r.reclass* plugin of the GRASS GIS module following the criteria indicated by Billi et al. (1987), yielded 16 aspect classes relative to geographic north. These were exported in shapefile format and graphically represented through a rose diagram produced with Golden Software Grapher 23 (Fig. 28b).

The **drainage density (D)**, defined by Horton (1945) as the ratio between the total length of stream channels (l) and the area they drain (A),

$$D = \frac{\sum l}{A}$$

depends on several factors: slope gradient, rock resistance to erosion, permeability of outcropping materials and vegetation cover. It was calculated in a GIS environment by subdividing the study area, through the *Create Grid* function, into a grid of square cells with 1-km sides. Within each square cell, the total length of stream segments was determined using the *Sum line lengths* function (Fig. 28c) (Centamore et al., 1996).

The **relief energy** parameter is defined as the altimetric difference within a specific spatial unit, and it highlights areas potentially subject to more or less intense erosive processes (Castiglioni, 1979, Ciccacci et al., 1988). This parameter was calculated (Lupia Palmieri et al., 1995, 1998) in a GIS environment by subdividing the study area, through the *Cell statistics* function, into a grid of square cells with 1-km sides. Within each square cell, using the DTM, the difference between the maximum and minimum elevation contained within the reference polygon was determined (Fig. 28d).

3.2.3 Characterization of climatic parameters

The meteoroclimatic and bioclimatic framework of the study area was obtained by processing thermo-pluviometric data from 34 meteorological stations (Fig. 29a), referring to the twenty-year period 2003–2022. The homogeneous distribution of the stations across the study area ensured adequate territorial coverage, mitigating potential local anomalies in climatic gradients. The raw datasets were first interpolated and subsequently subjected to a normalization process. From the climatic series of each station, the main thermal parameters (minimum, mean and maximum temperatures, annual and monthly values, and mean annual thermal excursion) and pluviometric parameters (minimum, mean and maximum rainfall, annual and monthly values) were extracted using standard statistical methods. From these parameters, the following climatic and bioclimatic indices were derived according to the procedures established by their respective authors.

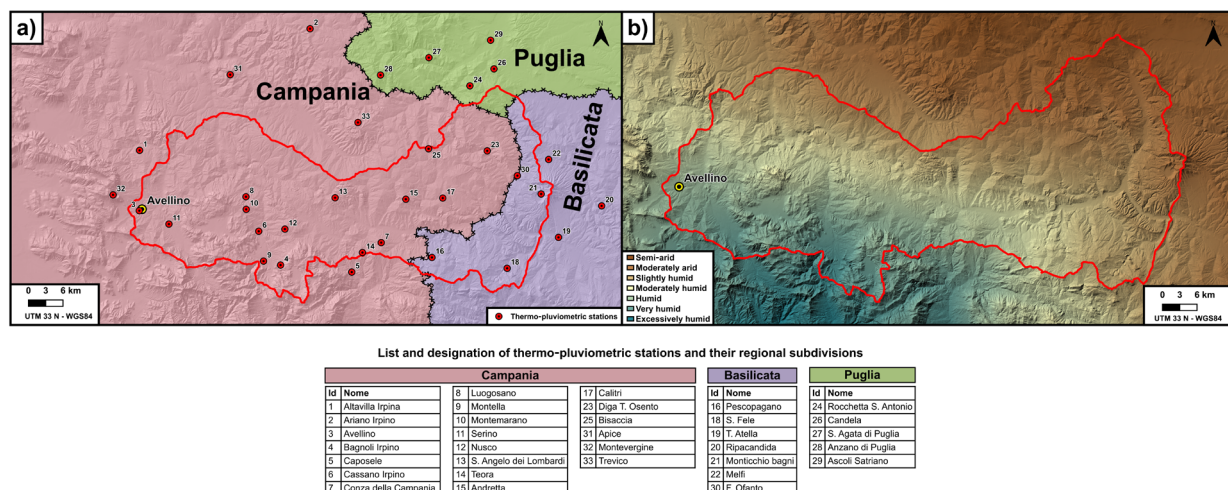


Figure 29 - Climatic parameters characterizing the study area: a) Map of the 34 thermo-pluviometric stations, b) De Martonne aridity index (see Plate 7).

The **aridity index** is a numerical indicator of the degree of climatic dryness at a given location, and it allows the classification of climate types based on water availability. It was calculated using the procedure proposed by De Martonne (1926) (Fig. 29b).

To obtain an accurate climatic modelling of the study area, the thermo-pluviometric data (Fig. 29) were processed in R and subsequently spatialized using altitude, derived from the DTM, as an explanatory variable, applying geostatistical methods and techniques (Ordinary Kriging, Webster & Oliver, 2001, Regression-Kriging, Hengl et al., 2004). Furthermore, for each thermo-pluviometric station, the distance from the highest peak in the study area, Monte Cervialto, was calculated in a GIS environment using the *Euclidean Distance* tool, in order to interpret the spatial distribution of precipitation.

3.2.4 Land-use characterization

As previously mentioned, land-use within the study area (see Fig. 7) was characterized using the Corine Land Cover 2018 dataset (scale 1:100,000), produced by the Copernicus Land Monitoring Service and imported into QGIS 3.44. In an initial phase, the data underwent spatial harmonization: originally georeferenced in ETRS89-extended/LAEA Europe, they were subsequently reprojected into the UTM-WGS84 Zone 33N system (EPSG:32633) using the *Reproject layer* function.

The imported Corine Land Cover (CLC) classes were aggregated to obtain new land-use macro-categories, following the procedures adopted by Panagos et al. (2015) and Magliulo et al. (2022) (Tab. 9), aimed at simplifying the CLC classification structure by grouping classes into homogeneous categories according to their response to erosive processes. The aggregation criterion adopted was the **C-Factor** (Cover and Management Factor) of the USLE model (Bazzoffi, 2007, Wischmeier & Smith, 1978, Panagos et al., 2015), a dimensionless coefficient expressing the combined effect of vegetation cover, crop residues and management practices on soil susceptibility to erosion: high C values indicate greater susceptibility, whereas low values reflect more effective protection.

The aggregation of CLC classes into macro-categories with similar or identical C-Factor values enabled a more functional representation of the territory in relation to the identification of areas potentially subject to erosion risk and requiring targeted soil-conservation interventions.

CLC 2018 Code	Corine Land Cover 2018 Description	Land-use classes (Magliulo et al., 2022)	C-Factor
311	Broad-leaved forests	Forest and shrub vegetation areas (broad-leaved, coniferous, mixed)	0.0012
312	Coniferous forests	Forest and shrub vegetation areas (broad-leaved, coniferous, mixed)	0.0012
313	Mixed forests	Forest and shrub vegetation areas (broad-leaved, coniferous, mixed)	0.0012
324	Transitional woodland-shrub	Forest and shrub vegetation areas (broad-leaved, coniferous, mixed)	0.0012
231	Pastures	Natural grasslands, pastures and permanent meadows	0.0520
321	Natural grasslands	Natural grasslands, pastures and permanent meadows	0.0520
323	Sclerophyllous vegetation	Natural grasslands, pastures and permanent meadows	0.0520
211	Non-irrigated arable land	Temporary or permanent crops and non-irrigated arable land	0.1869
241	Annual crops associated with permanent crops	Temporary or permanent crops and non-irrigated arable land	0.1869

242	Complex cultivation patterns	Temporary or permanent crops and non-irrigated arable land	0.1869
243	Agricultural areas with significant natural spaces	Temporary or permanent crops and non-irrigated arable land	0.1869
221	Vineyards	Orchards, olive groves and vineyards	0.2231
222	Fruit trees and berry plantations	Orchards, olive groves and vineyards	0.2231
223	Olive groves	Orchards, olive groves and vineyards	0.2231
131	Mineral extraction sites	Areas with absent or sparse vegetation	0.2652
333	Sparsely vegetated areas	Areas with absent or sparse vegetation	0.2652
334	Burnt areas	Areas with absent or sparse vegetation	0.2652
111	Continuous urban fabric	Residential, industrial and commercial areas	N.A.
112	Discontinuous urban fabric	Residential, industrial and commercial areas	N.A.
121	Industrial, commercial and public facilities	Residential, industrial and commercial areas	N.A.
122	Road and rail networks and associated land	Residential, industrial and commercial areas	N.A.
331	Beaches, dunes and sand plains	Fluvial-palustrine wetlands and artificial water bodies	N.A.
411	Inland marshes	Fluvial-palustrine wetlands and artificial water bodies	N.A.
512	Water bodies	Fluvial-palustrine wetlands and artificial water bodies	N.A.

Table 9 - Aggregation scheme of the various CLC 2018 classes.

3.2.5 Characterization of the Cultural Heritage

The characterization of the cultural heritage of the study area (see Figs. 22, 24, 26) was developed through two methodological phases: (1) **documentary screening**, and (2) **data spatialization**.

In the screening phase, an in-depth bibliographic analysis was conducted on heterogeneous sources, followed by a validation process aimed at verifying their relevance, reliability and consistency with the research objectives. The subsequent phase involved transforming documentary information into georeferenced data using QGIS 3.44, assigning point coordinates to the identified entities. In the case of museum facilities, for example, geolocation was obtained through cross-checks on digital platforms such as Google Earth Pro and Google Maps.

This process made it possible to construct a coherent geospatial database, functional for the visualization, querying and cartographic interpretation of cultural heritage within a systemic framework.

3.2.6 Geo-lithological Characterization

The geo-lithological characterization of the study area was developed through a structured and integrated methodological process. In an initial phase, the official geological sheets at a scale of 1:100,000 provided by ISPRA (Tab. 10) were acquired, selected for their adequate spatial coverage and geological representativeness. These documents were subsequently validated through field

surveys, which confirmed the overall consistency of the cartographic data and made it possible to identify sectors exhibiting greater geological complexity.

Number	Sheet name	Scale	Year	Producing institution
173	Benevento	1:100,000	1970	Geological Survey of Italy
174	Ariano Irpino	1:100,000	1963	Geological Survey of Italy
175	Cerignola	1:100,000	1963	Geological Survey of Italy
186	Salerno	1:100,000	1969	Geological Survey of Italy
186	S. Angelo dei Lombardi	1:100,000	1970	Geological Survey of Italy
187	Melfi	1:100,000	1970	Geological Survey of Italy

Table 10 - Geological map sheets used and their main characteristics.

The subsequent phase involved the georeferencing and digitization of the geological sheets within a GIS environment (QGIS 3.44). Since they lacked digital georeferencing, the sheets were initially aligned to the original Roma 40 reference system using Ground Control Points and affine transformation, and were then reprojected into the UTM-WGS84 Zone 33N system to ensure full integration with the other thematic layers.

The georeferenced sheets were then digitized in vector format, organizing the geological information into three geometric typologies: points (attitudes, springs, toponyms), lines (faults, lineaments, lithological contacts) and polygons (lithological units). The digitization, carried out using the QGIS Editing Tool, was followed by a validation and database-cleaning phase aimed at removing incorrect or incomplete geometries.

The final phase consisted of synthesizing the digitized lithological units, which were subsequently aggregated into 12 lithological complexes (Tab. 11), thereby creating a coherent, reliable and fully operational geological database for subsequent geospatial analyses.

Code	Geo-lithological complexes
Q₁	Quaternary detrital complex
Q₂	
Q₃	
Q₄	
Q_v	Quaternary volcanic complex
P	Pliocene conglomeratic-sandy-argillaceous complex
PM	Miocene carbonate-gypsum-sulphur-bearing complex
M	Miocene carbonate-siliceous-clastic complex
FN	Miocene molassic-quartzarenitic complex
AV	Varicoloured Clays Complex (Auct.), Meso-Paleogene
CSM	Mesozoic-Tertiary carbonate-siliceous-marly complex
CD	Mesozoic carbonate-dolomitic complex

Table 11 - Geo-lithological complexes.

The aggregation criterion adopted was multidimensional, based on four fundamental parameters that ensure genetic, environmental, lithological and chronostratigraphic coherence among the grouped units. These parameters are summarized in the following table:

Level	Criterion	Description
I	Genesis	Origin of the material: detrital-clastic, volcanic, carbonate, mixed.
II	Depositional environment	Sedimentary context: continental, marine (shallow/deep), volcanic.
III	Dominant lithology	Prevalent rock types: gravels, sands, clays, limestones, tuffs, flysch, breccias, etc.
IV	Geological age	Predominant chronostratigraphic interval: Holocene, Pleistocene, Miocene, etc.

Table 12 - Classification scheme of the geo-lithological complexes.

The approach adopted made it possible to aggregate lithologies belonging even to different formations, yet characterized by sedimentological, environmental and chronostratigraphic affinities. The resulting classification provides an organic representation of the geological evolution of the territory and constitutes an effective interpretative tool, capable of relating heterogeneous lithological complexes through unifying criteria.

3.2.7 Landscape Characterization

The landscape characterization of the study area was developed through a multitemporal and photointerpretative analysis based on high-resolution orthophotos derived from Google Earth, LandSat and Copernicus. This preliminary phase made it possible to identify the main morphological features and the geo-environmental typologies of the landscapes present within the study area.

The import of the data into a GIS environment (QGIS 3.44) enabled the management and interrogation of morpho-topographic, geological, climatic, pedological and agri-food information, supporting a systemic interpretation of the landscapes and of the interactions between natural and anthropogenic components.

Code	Landscape Units
LU 1	Mountain landscape of the calcareous reliefs of the Campanian Apennines
LU 2	Landscape of the intermontane depressions
LU 3	Volcanic landscape of Mount Vulture
LU 4	Landscape of the arenaceous-argillaceous-marly hills
LU 5	Landscape of the sandy-conglomeratic and clayey hills
LU 6	Landscape of the valley floors and floodplains

Table 13 - Landscape Units.

Six Landscape Units (LUs) (Tab. 13) were thus defined, identified according to geomorphological and lithological criteria, integrated with environmental and anthropogenic variables. Each LU was characterized on the basis of a coherent set of factors: altitudinal belts (mountain areas, valley floors, etc.), slope gradients and aspect, dominant lithology, climate and drainage density. Soils and

vegetation, which are closely linked to the geological substrate, further contribute to the definition of the LUs, with pedological types ranging from andosols to luvisols and land-cover classes varying from forests and grasslands to intensive croplands. Land-use and settlement distribution complete the framework, distinguishing units with low rural density from those containing urban centres and peri-urban areas.

Each LU was also associated with typical agri-food productions (e.g., *Aglianico del Vulture*, *Fiano di Avellino*, *castagne di Montella*, etc.), often protected by PDO or PGI labels, and closely connected to local pedoclimatic conditions.

3.2.8 General Considerations on Geodiversity Assessment Methods

Geodiversity of a territory refers to the variety of geological, geomorphological, pedological and hydrological elements present within an area and recognized as fundamental components for environmental conservation (Sharples, 1993, 1997, 2002a; Dixon, 1996; Eberhard, 1997). From this perspective, the abiotic diversity of the landscape is valued as a key factor in ecosystem processes and in the interactions between the physical substrate and biological dynamics.

Therefore, the assessment of Geodiversity is a multidisciplinary process that integrates ecological, geomorphological, geological and cartographic criteria, with significant operational implications for sustainable land management, targeted conservation and environmental decision-making. Systematic classification and organization procedures of abiotic elements are necessary for Geodiversity assessment (Johnston, 1976), which entails the development and testing of analytical, classificatory and evaluative methods aimed at objectively defining the Geodiversity of a territory.

In the scientific literature, numerous and diverse analytical methods exist for the assessment and representation of Geodiversity, generally grouped into two categories: qualitative methods and quantitative methods. The former rely on expert experience, adopt a descriptive approach and are based on the analysis of nominal data and numerical levels, varying in scale and detail (Sharples, 1995; Kiernan, 1997; Gray, 2008, 2012, 2013, 2018; Gray et al., 2013; Panizza, 2009; Holt-Wilson, 2010; Gordon, 2012; Bradbury, 2014; Seijmonsbergen et al., 2014; Kale, 2015). Overall, however, qualitative methods present several limitations, such as excessive subjectivity, limited comparability between areas with different morphological characteristics (Zwoliński, 2010) and difficulties in verifying results, which are often not easily translatable into objective or rigorously validated data.

Quantitative methods, on the other hand, rely on measurable, updated and high-resolution data, and on rigorous analytical procedures (field surveys, thematic maps, satellite imagery, etc.), often supported by GIS tools, mathematical models and geographic databases (or geospatial datasets). For this reason, they are the most scientifically consolidated, as they produce objective, replicable and comparable results.

Quantitative methods employ numerous discrete and continuous parameters describing the physical, geological, geomorphological and climatic characteristics of an area. Among the most common indicators is the index proposed by Serrano and Ruiz-Flanó (2007), which quantifies Geodiversity using the formula:

$$Gd = \frac{Eg \times R}{\ln(S)}$$

where Eg is the number of distinct geophysical elements, R the roughness coefficient, S the surface area of the analysis unit and $\ln$ the natural logarithm. Although widely applied, the index presents some important limitations, for which several variants have been proposed (Pereira et al., 2013; Zwoliński et al., 2018). Another widely used approach is map algebra, which applies mathematical and logical operations to raster or vector information layers, combining factors such as lithology, morphology and land-use to produce synthetic geodiversity maps. Within this framework also falls the *point bonitation* method, based on assigning scores to individual factors and subsequently summing them in a weighted manner.

3.2.8.1 Method Used for the Assessment of Geodiversity in the Study Area

For the purpose of assessing Geodiversity within the study area, a quantitative model previously and successfully applied by Ferrando et al. (2021) was implemented. The model is based on the analysis of four main indices, each designed to quantify a distinct component of geodiversity.

The methodological approach adopted is expressed by the following mathematical formulation:

$$Gd_i = Geo_i + Geom_i + Hydro_i + Slu_i$$

where:

- **Geo_i (Geological Index):** quantifies the lithological variety of the investigated territory,
- **Geom_i (Geomorphological Index):** quantifies the morphological variety of the investigated territory,
- **Hydro_i (Hydrogeological Index):** measures the variety of hydrographic complexes present in the investigated territory,
- **Slu_i (Soil-Land-use Index):** quantifies the variety of land-use types within the investigated territory.

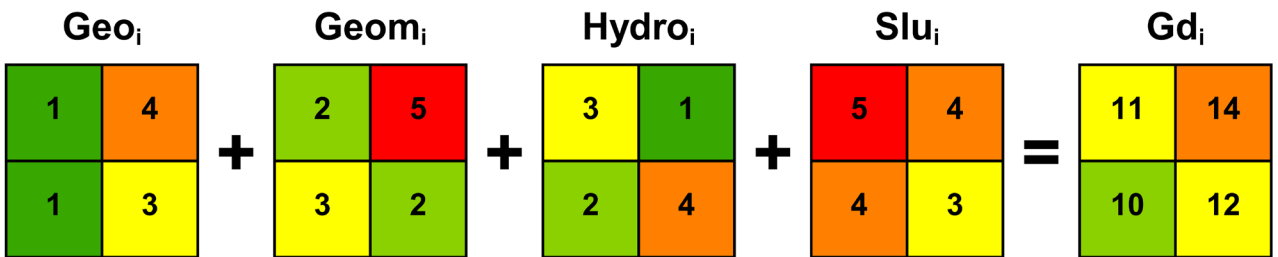


Figure 30 - Representation of Geodiversity estimation through the unweighted algebraic sum of four thematic matrices (Geo_i, Geom_i, Hydro_i, Slu_i) using map algebra operations. The final output (Gd_i) synthesises the spatial distribution of geodiversity across the analysed territory.

The analysis, as illustrated in the formula and in Fig. 30, is based on the use of an unweighted algebraic sum of the indices corresponding to the four components of geodiversity, a methodological choice aimed at ensuring neutrality and consistency in the overall assessment. This approach, widely documented in the relevant scientific literature (Araujo & Pereira, 2018; Carrión-Mero et al., 2022), was adopted to minimize any form of subjectivity in the overall estimation of Geodiversity.

Of the four indices used to quantify the respective components of Geodiversity, three can be classified as fundamental indices, **Geo_i**, **Hydro_i** and **Slu_i**, as they provide a direct measure of geological, hydrological and land-use diversity within the analysed territory. The fourth index, **Geom_i**, should instead be considered a composite or derived index, since it represents the sum of the diversities identified through five specific subcomponents, each related to a distinct aspect of the territory's morphometry.

To estimate the parameters required for the assessment of geodiversity in the study area, the territory was subdivided using a regular grid. The cell size, equal to 1×1 km, was defined through an iterative trial-and-error procedure aimed at balancing spatial resolution and the quality of the available data (Fig. 31). The adoption of 1×1 km cells proved methodologically robust. Given the relatively limited extent of the area (1589 km²), this resolution allowed an adequate representation of the variability of the four Geodiversity indices analysed, ensuring consistency among the different information layers and good cartographic readability.

Since geodiversity represents a continuous property of the territory, an interpolation was applied to the geodiversity index map using ordinary kriging with Gaussian fitting (Araujo & Pereira, 2018), resulting in the geodiversity gradient map. This configuration also facilitated the integration of geological, hydrographic, geomorphological and land-use data, contributing to the construction of a robust and scientifically grounded interpretative model.

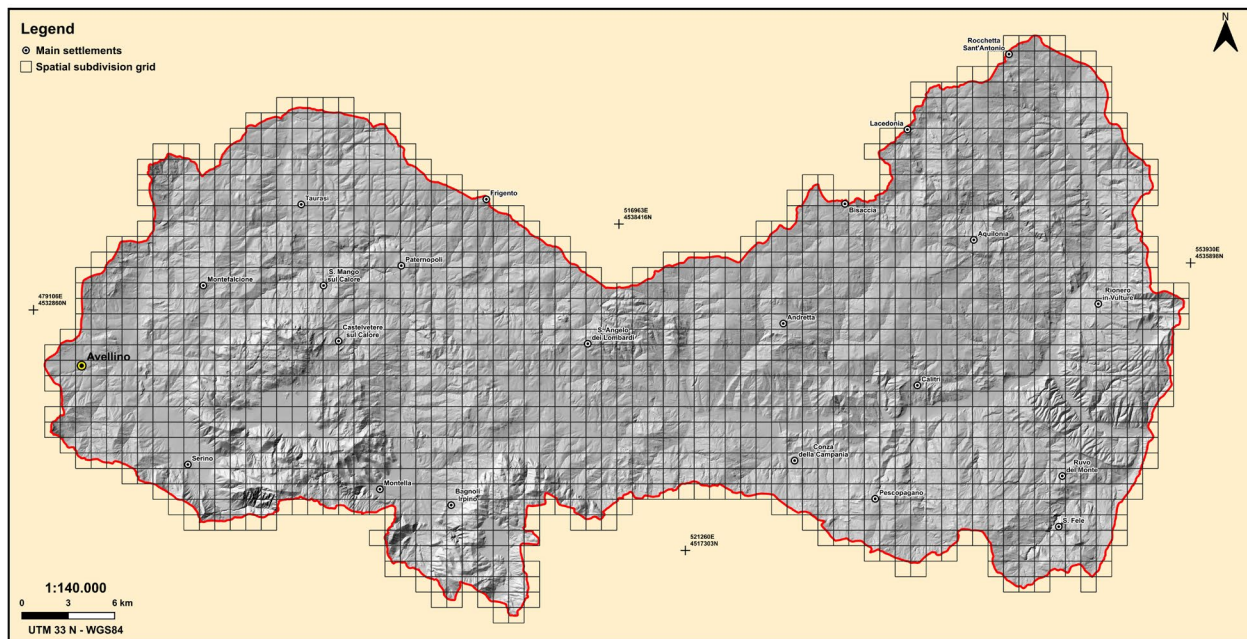


Figure 31 - Definition of the spatial grid.

3.2.8.2 Estimation of the geo-lithological variety index (Geo_i)

This is a spatial indicator that quantifies the variety of geo-lithological complexes present within a given portion of territory, and therefore represents a useful tool for describing the geological complexity of the study area.

For the calculation of this important index, the geo-lithological data previously collected and mapped, as described in the geo-lithological complexes map, were used. These data were imported

into the geodatabase and subsequently extracted in raster format using the *Rasterize* tool in QGIS 3.44. A regular grid composed of square cells with 1 km sides was then superimposed, suitable for geospatial processing and analysis.

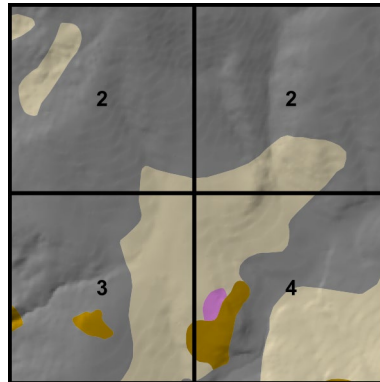


Figure 32 - Scheme used for the evaluation of the geo-lithological index within a 1×1 km grid

On the raster thus obtained, the statistical analysis performed using the *Zonal Statistics* function made it possible to quantify, for each cell, the number of geo-lithological complexes falling within it (Fig. 32), providing an objective and replicable measure of local geo-lithological heterogeneity (Fig. 33).

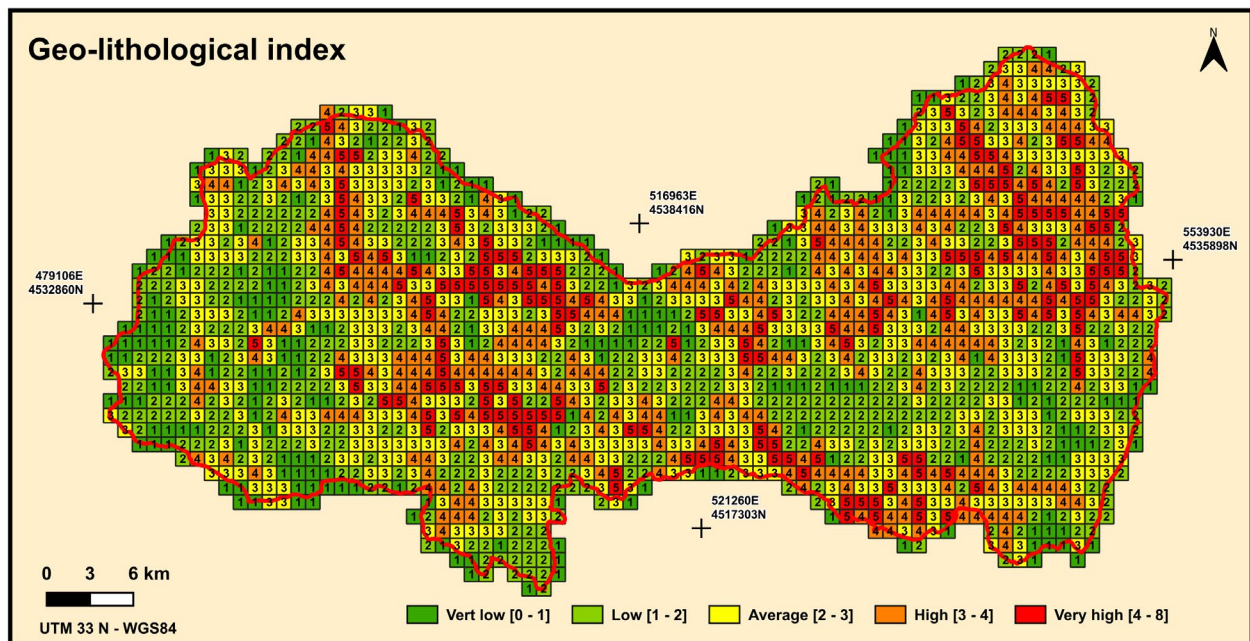


Figure 32 - Map of the Geo-lithological Index.

The resulting values were then reclassified into five classes (Tab. 14) using the Jenks algorithm (1976), in order to gradually highlight the areas characterized by higher or lower geo-lithological diversity and to facilitate both cartographic interpretation and comparison with other environmental indicators.

Geo-lithological index classes	
Class	Range
Very low	0-1
Low	1-2
Average	2-3
High	3-4
Very high	4-8

Table 14 - Classification of the Geo-lithological Index

3.2.8.2 Estimation of the hydrogeological variety index (Hydro_i)

The Hydrogeological Variability Index (Hydro_i), calculated in the same cell-based manner as the previous index (Fig. 34), quantifies the variety of hydrogeological complexes present within regular portions of the territory. Its distribution across the study area was analysed by classifying the values into five ordinal classes: very low, low, medium, high and very high.

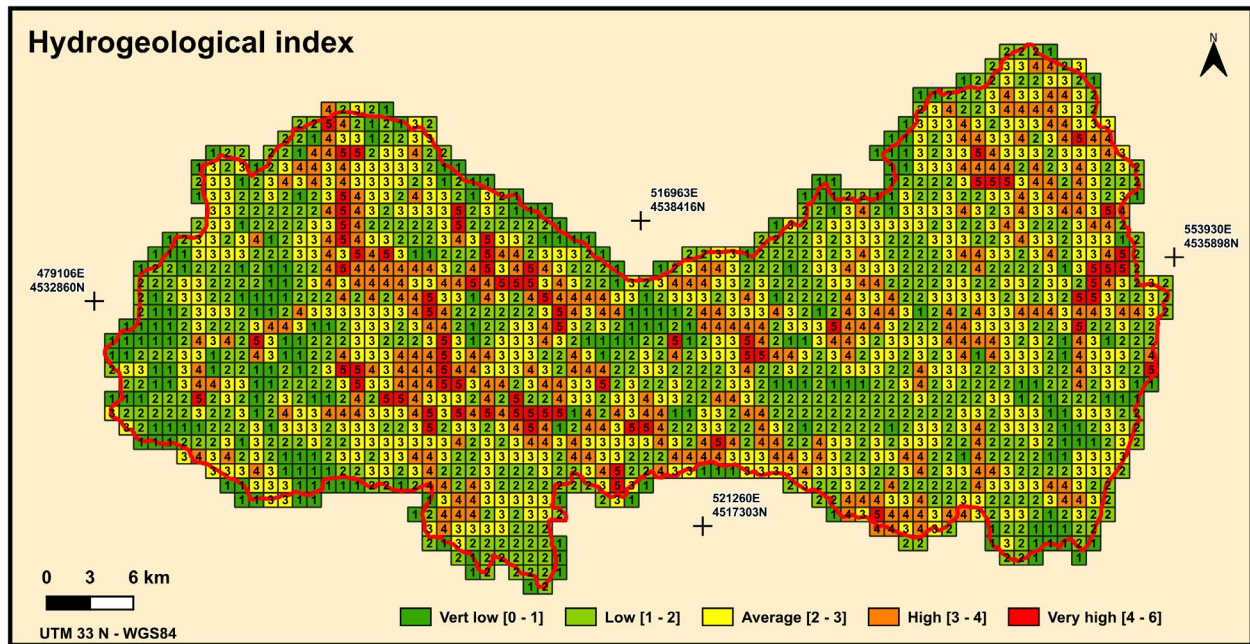


Figure 34 - Map of the Hydrogeological Index.

3.2.8.3 Estimation of the soil land-use variety index (Slu_i)

This index is an indicator of the combined variability of pedological characteristics and land-use patterns. Its geospatial distribution within the study area, as for the previous indices, is illustrated in the map shown in Fig. 35.

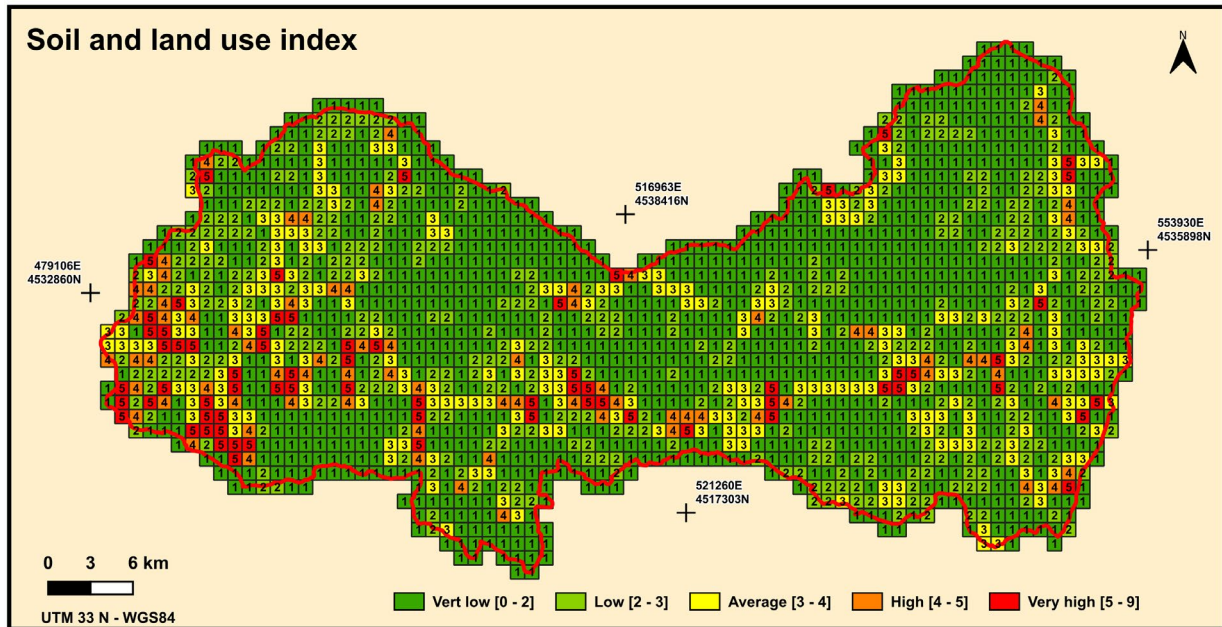


Figure 35 - Map of the Soil and Land-use Index.

3.2.8.4 Estimation of the geomorphological variety index ($Geom_i$)

The Geomorphological Index ($Geom_i$) represents a synthetic indicator of the morphological variability of an area, obtained through the integration of five quantitative sub-indices:

- **Drainage Density:** index used to estimate drainage density,
- **Topographic Roughness Index** (Riley et al., 1999): index used to estimate terrain roughness, based on the altimetric variation between adjacent cells of a Digital Terrain Model (DTM),
- **Topographic Position Index** (Weiss, 2001): index used to describe the relative altimetric position of a point with respect to the surrounding relief,
- **Landform Category Index** (Jasiewicz & Stepinski, 2013): index used for the automatic classification of landforms, based on a computer-vision approach,
- **Relief Energy** (Ciccacci et al., 1988): index used to estimate the energy of the relief.

Each parameter contributes to describing specific aspects of the morphology and of the topographic and hydrographic configuration, enabling a spatially distributed assessment of geomorphological variability. Its geospatial distribution within the study area, as for the previous indices, is illustrated in the map shown in Fig. 36, obtained by processing in a GIS environment the geospatial data associated with the five indices described above.

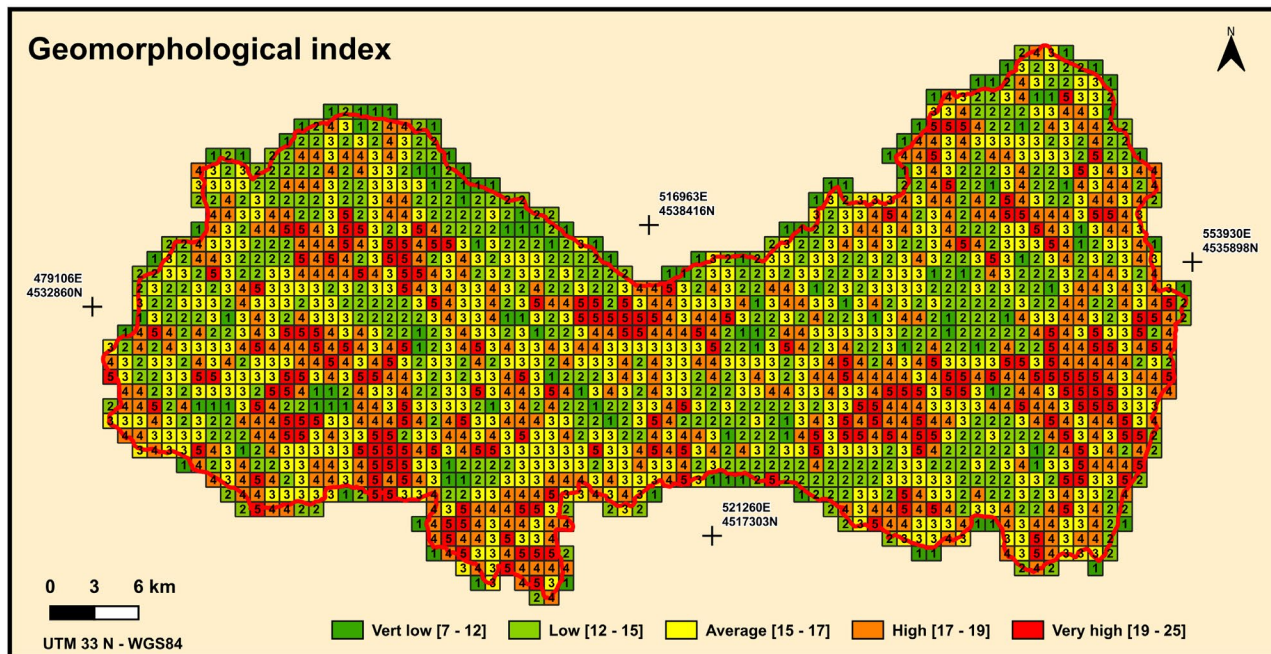


Figure 36 - Map of the Geomorphological Index.

3.2.9 General considerations on geomorphodiversity assessment methods

Geomorphodiversity is situated within the theoretical framework of Geodiversity, understood as the variety of abiotic elements of the Earth's surface (Gray, 2013). It represents the diversity of landforms and of the processes that generated them, serving as a valuable indicator of geomorphological variability, environmental complexity and the evolutionary history of a territory (Reynard & Coratza, 2013). Its analysis requires approaches capable of integrating quantitative dimensions, such as the number, distribution and typology of landforms, and qualitative dimensions, related to the aesthetic, scientific and cultural values of the landscape (Panizza, 2001; Coratza & Hobléa, 2018).

Geomorphodiversity can be assessed from two perspectives:

- **extrinsic**, based on the comparison between territories in terms of morphostructures, morphoclimatic conditions, lithology and active processes (Goudie, 2006),
- **intrinsic**, focused on the internal morphological diversity of an area and its spatial organization.

In both cases, the scale of observation is crucial, as it influences the perception and quantification of geomorphological diversity (Gerasimov, 1946; Tricart, 1965). Additional complexities arise from the need to assign objective value to landforms that may be poorly represented in certain contexts, yet contribute significantly to the geomorphological identity of those territories (Reynard et al., 2016).

The assessment of Geomorphodiversity requires an integrated methodological framework, grounded in detailed geomorphological mapping, statistical tools and expert interpretation. The quantitative methodological approach is based on the use of ecological indices adapted to the geomorphological context, which provide a balanced and quantitative measure of landform diversity (Gray, 2013; Serrano & González-Trueba, 2009). The qualitative methodological approach, instead, relies on the selection of geomorphosites, evaluated according to multidisciplinary criteria such as rarity, representativeness, vulnerability and educational value (Panizza, 2001; Reynard et al., 2016).

Finally, the scale of landform analysis profoundly influences the interpretation of a territory's Geomorphodiversity: local studies highlight micro-variations and morphological details, whereas regional or global analyses allow broader patterns to be identified. The integration of quantitative and qualitative approaches, and of multiple scales, is essential for a comprehensive understanding of Geomorphodiversity.

3.2.9.1 Method Used for the Assessment of Geomorphodiversity in the Study Area

For the quantitative assessment of Geomorphodiversity within the study area, the analytical model proposed by Burnelli et al. (2023) was adopted. The choice of this methodological approach was motivated by the results of a series of preliminary exploratory tests, which highlighted a high degree of compatibility between the structure of the model and the distinctive geomorphological characteristics of the analysed territory.

The model by Burnelli et al. (2023) functions as a quantitative tool, analogous to the one employed for the estimation of Geodiversity, and is based on the unweighted algebraic sum of four thematic matrices (Sp, Gm, Dd, Li) obtained through map algebra operations:

$$GmI = Sp_{var} + Gm_{var} + Dd_{var} + Li_{var}$$

- **Slope index (Sp):** quantifies the distribution of slope gradients within regular portions of the territory,
- **Landforms index (Gm, Jasiewicz & Stepinski, 2013):** index used for the automatic classification of landforms, based on a computer-vision approach,
- **Drainage density index (Dd):** index used to measure the distribution of drainage density within regular territorial units,
- **Geo-lithological index (Li):** quantifies the lithological diversity of the investigated territory.

This approach ensures a transparent and replicable methodological structure, facilitating comparison between different geographical areas.

The operational workflow adopted for the application of the model is illustrated in the diagram shown in Fig. 37, where the phases of acquisition, processing and synthesis of geomorphological data are detailed. The use of this framework ensured methodological consistency and scientific rigor throughout the entire analytical process.

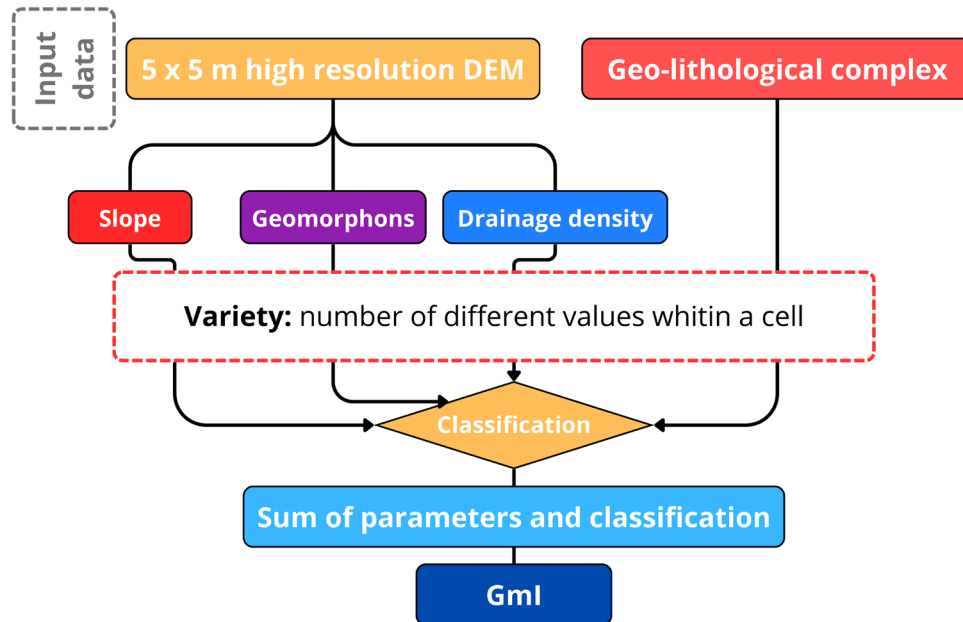


Figure 37 - Workflow used for estimating the Geomorphodiversity of the study area (modified from Burnelli et al., 2023).

As with the estimation of Geodiversity, the spatial quantification of Geomorphodiversity was carried out using a regular grid composed of square cells of 1×1 km (see Fig. 29), selected as a methodological compromise between local-scale detail and computational manageability of the dataset, while ensuring homogeneous coverage of the study area.

This structure made it possible to subdivide the territory into uniform spatial units, used as the reference framework for calculating the diversity values of geomorphological parameters. The approach provided a solid basis for quantitative analysis, enabling the systematic detection and comparison of the variability, intensity and distribution of morphometric parameters.

The use of the same spatial resolution adopted for the estimation of Geodiversity also allowed for a direct comparison between the two indicators, facilitating the integrated analysis of the relationships between geological and geomorphological diversity within the study area. This made it possible to highlight potential correspondences, divergences or overlaps between the structural and morphogenetic components of the landscape.

The choice of resolution is consistent with previous studies in geomorphological and environmental research, in which grids of similar dimensions have proven effective in representing landscape complexity, avoiding excessive generalization or analytical fragmentation.

The quantification of the diversity of individual geomorphological parameters within each grid cell was performed using the “Zonal Statistics” function available in the GIS software QGIS, version 3.44. Furthermore, since geomorphodiversity represents a continuous property of the territory,

an interpolation was applied to the geomorphodiversity index map using ordinary kriging with Gaussian fitting (Araujo & Pereira, 2018), resulting in the geomorphodiversity gradient map.

3.2.9.2 Estimation of the slope variety index (Sp)

This index constitutes a spatial tool designed to quantify the distribution of slope gradients within regular portions of the territory. Its geospatial distribution across the study area, as with the previous indices, is illustrated in the map shown in Fig. 38.

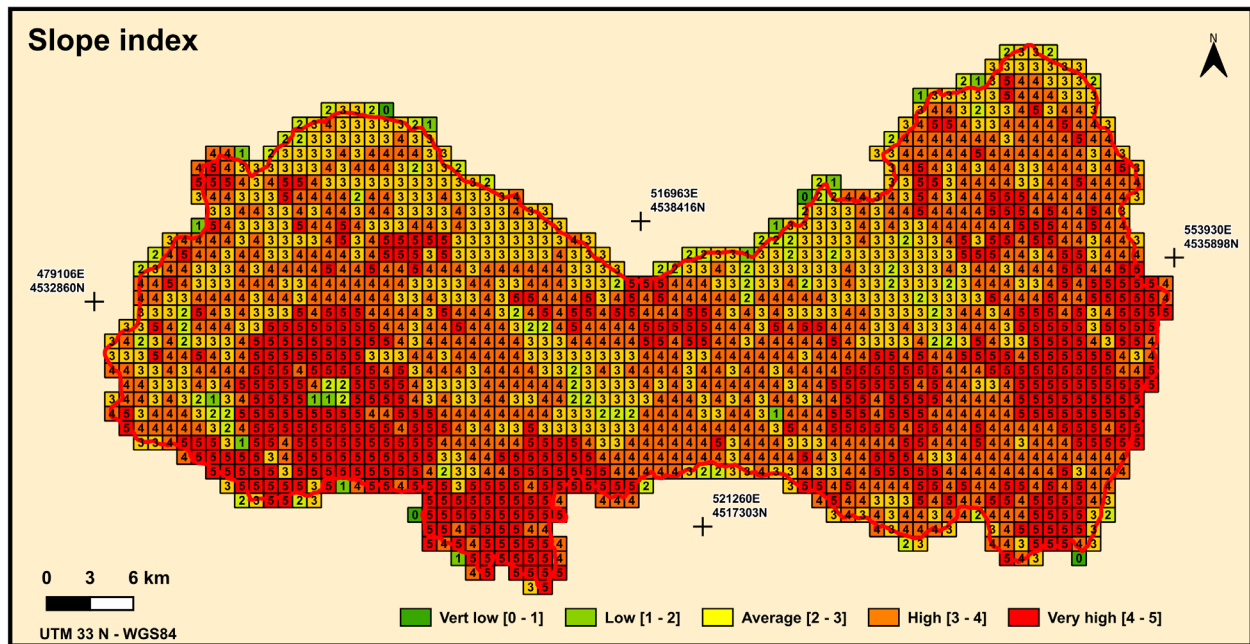


Figure 38 - Map of the Slope Index.

3.2.9.3 Estimation of the geo-lithological and morphological variety index (Li, Gm)

The estimation of the geo-lithological variability index (Geo-lithological index – Li) and of the landscape-form variability index (Landforms Index – Gm) was conducted using the same methodological approach and the same dataset employed for the evaluation of the Lithological Index (Geo_i) and the Geomorphological Index (Geom_i) used in the assessment of Geodiversity. In view of this correspondence between parameters, reference is made to Sections 3.2.8.2 and 3.2.8.4.

3.2.9.4 Drainage Density Variability Index (Dd)

The fourth and final indicator used to assess geomorphodiversity is the Drainage Density Index (Dd), a spatial index designed to measure the distribution of drainage density within regular portions of the territory. Its geospatial distribution across the study area, as with the previous indicators, is illustrated in the map shown in Fig. 39.

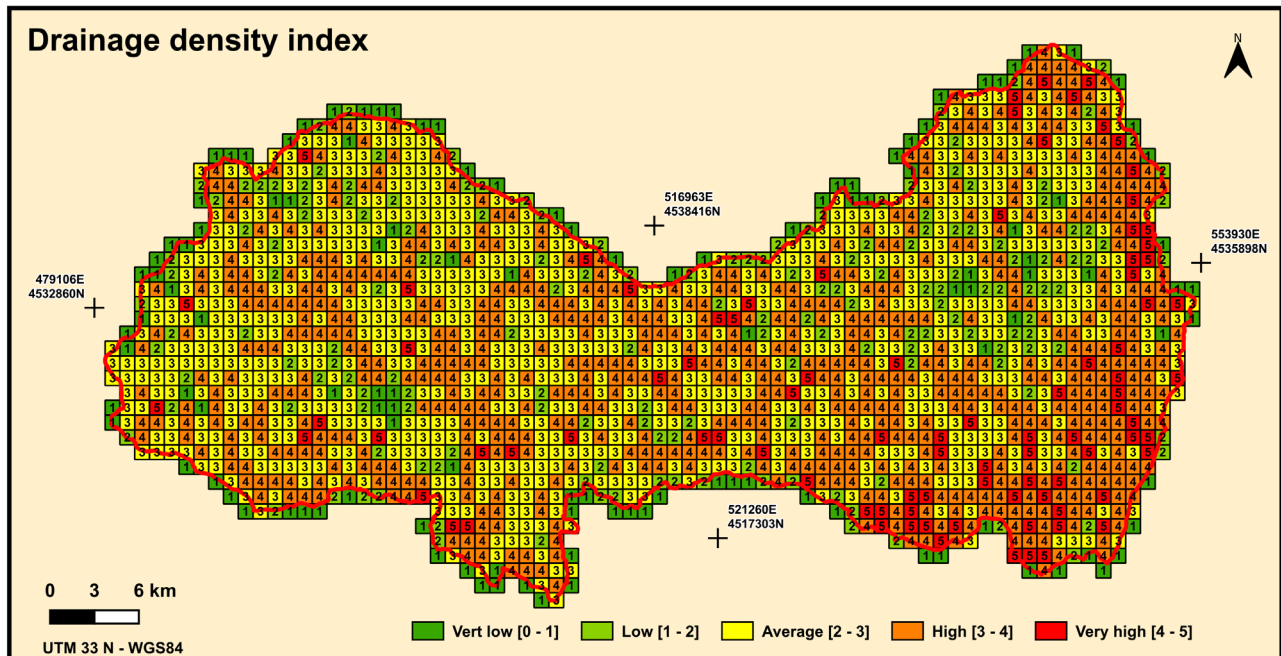


Figure 39 - Map of the Drainage Density Index.

3.3 TOOLS AND TECHNIQUES

For the execution of geospatial and statistical analyses aimed at characterizing the study area, several software tools were employed, both commercial and open source, specifically designed for digital cartography, spatial modelling and advanced statistical processing. Cartographic elaborations were carried out using the commercial GIS software ArcGIS 10.5.8, developed by ESRI, and the open-source GIS software QGIS 3.44 – Solothurn, which were used for the management of geographic databases, the production of thematic maps and the execution of procedures such as raster analysis, spatial interpolations, buffering, overlay operations and the calculation of morphometric indices.

Mathematical-statistical and geostatistical analyses were conducted within the open-source development environment R 4.4.2, integrated with dedicated packages such as *sf*, *terra*, *gstat* and *tidyverse*, used for exploratory data analysis (EDA), variogram modelling, ordinary kriging and multivariate regressions. In parallel, the commercial software Golden Software Grapher 24.1 was employed for advanced graphical representation of datasets, the construction of interpretative diagrams and the analysis of statistical distributions, thereby supporting the validation and communication of the obtained results.

Furthermore, for a more detailed characterization of the Landscape Units (UdP), both classical and satellite photointerpretation techniques were adopted. Classical photointerpretation involved the observation and analysis of recent and historical landscapes through the visualization of aerial

stereopairs using Topcon MS-3 stereoscopes. Satellite photointerpretation, on the other hand, involved the observation and analysis of the landscape through satellite orthophotos, acquired and processed within the GIS software previously described, as well as multispectral images processed using remote-sensing techniques (decorrelation stretching, cluster analysis, stacking, etc.) within the Exelis ENVI 5.3 software.

PART IV

DATA ANALYSIS AND PROCESSING

The following pages describe the procedures and analytical elaborations applied to the dataset collected and presented in the previous sections, as well as the results, albeit partial, derived from these analyses through the application of the methods outlined in Part Three. Data processing was carried out, as previously described, using the tools and functionalities provided by the software employed and the subsequent integrations. For geo-lithological and geomorphological data, both direct field verification and indirect validation through photointerpretation were required.

First, the analytical procedures and elaborations concerning climatic data are presented, as these are essential for a correct interpretation of the geomorphic processes active within the study area. Subsequently, the main morphometric parameters characterizing the morpho-topographic and hydrographic structure of the study area are examined. Finally, the geo-lithological features of the terrains and the landscape units that define the study area are described.

4.1 ANALYSIS AND PROCESSING OF CLIMATIC DATA

In order to understand the climatic regime of the study area, the thermo-pluviometric series for the twenty-year period 2003–2022 were analysed, derived from 34 thermo-pluviometric stations (Tab. 15) distributed homogeneously so as to cover the entire study area (Fig. 40a).

Id	Station name	Region	Latitude	Longitude	Elevation [m a.s.l.]	Sensor
1	Altavilla Irpinia	Campania	41°00'21.96"N	14°47'00.96"E	364	T,Rg
2	Ariano Irpino	Campania	41°11'46.68"N	15°08'08.88"E	633	T
3	Avella	Campania	40°57'33.91"N	14°35'42.58"E	185	Rg
4	Avellino	Campania	40°54'42.84"N	14°46'59.88"E	351	T,Rg
5	Bagnoli Irpino	Campania	40°49'37.92"N	15°04'27.84"E	730	T,Rg
6	Caposele	Campania	40°48'57.96"N	15°13'14.88"E	413	T,Rg
7	Cassano Irpino	Campania	40°52'48.00"N	15°01'45.84"E	457	T,Rg
8	Conza della Campania	Campania	40°51'42.84"N	15°16'53.76"E	769	T,Rg
9	Luogosano	Campania	40°56'02.04"N	15°00'11.16"E	618	T,Rg
10	Montella	Campania	40°50'00.24"N	15°02'21.48"E	540	T,Rg
11	Montemarano	Campania	40°54'51.12"N	15°00'12.96"E	867	T,Rg
12	Serino	Campania	40°53'27.96"N	14°50'39.84"E	325	T,Rg
13	Nusco	Campania	40°52'59.99"N	15°04'59.99"E	796	T,Rg
14	S. Angelo dei Lombardi	Campania	40°55'55.60"N	15°11'12.60"E	880	T,Rg
15	Teora	Campania	40°50'47.60"N	15°14'34.30"E	763	T,Rg
16	Andretta	Campania	40°55'46.20"N	15°19'57.50"E	895	T,Rg
17	Pescopagano	Basilicata	40°50'18.50"N	15°23'09.50"E	883	T,Rg
18	Calitri	Campania	40°55'51.90"N	15°24'31.50"E	721	T,Rg
19	S. Fele	Basilicata	40°49'15.30"N	15°32'26.20"E	880	T,Rg
20	T. Atella	Basilicata	40°52'07.08"N	15°38'48.24"E	398	T,Rg
21	Ripacandida	Basilicata	40°55'02.20"N	15°44'10.00"E	635	T,Rg
22	Monticchio Bagni	Basilicata	40°56'11.50"N	15°36'41.90"E	724	T,Rg
23	M. Vulture	Basilicata	40°57'11.82"N	15°37'47.10"E	1281	Rg

24 Melfi	Puglia	40°59'25.20"N 15°37'39.20"E	558	T,Rg
25 Diga T. Osento	Campania	41°00'15.90"N 15°30'03.50"E	463	T,Rg
26 Rocchetta S. Antonio	Puglia	41°06'21.80"N 15°27'57.40"E	675	T,Rg
27 Bisaccia	Campania	41°00'29.20"N 15°22'47.80"E	907	T,Rg
28 Candela	Puglia	41°07'56.30"N 15°30'57.40"E	456	T,Rg
29 S. Agata di Puglia	Puglia	41°09'01.30"N 15°22'53.10"E	669	T,Rg
30 Anzano di Puglia	Puglia	41°07'24.50"N 15°16'52.60"E	847	T,Rg
31 Ascoli Satriano	Puglia	41°10'38.40"N 15°30'33.36"E	219	T,Rg
32 Apice	Campania	41°07'27.84"N 14°58'13.80"E	635	T
33 Trevico	Campania	41°02'58.37"N 15°14'03.82"E	1053	T,Rg
34 Mercogliano	Campania	40°55'12.11"N 14°43'54.91"E	627	T,Rg

Table 15 - General characteristics of the thermo-pluviometric stations distributed across the study area (T = Thermometric station, Rg = Rain gauge).

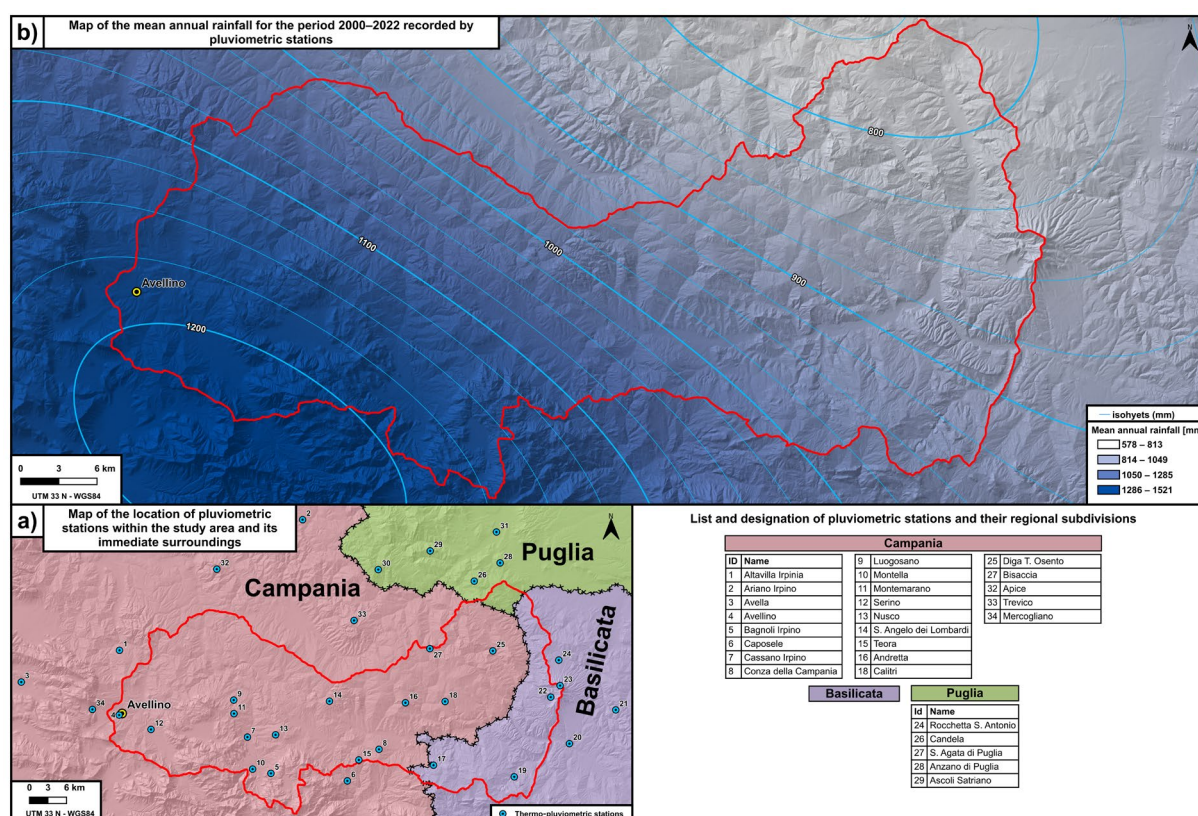


Figure 40 - a) Location and spatial distribution of the thermo-pluviometric stations within the study area, b) Map of mean annual precipitation for the period 2003/2022.

The statistical analysis, carried out through the normalization of pluviometric data, made it possible to exclude null or missing values for each year and for each station, and to derive a set of synthetic climatic indicators specific to each monitoring site. The processing of these indicators within a GIS environment enabled the production of the Mean Annual Precipitation Map (Fig. 40b).

When overlaid onto the DTM, this map highlights, as expected, a clear correlation between elevation and mean annual precipitation values. Indeed, the stations located along the Apennine ridge (e.g., Caposele, Cassano Irpino, Bagnoli Irpino) exhibit high rainfall, with values ranging from 1348

mm to over 1500 mm. Conversely, the stations situated in valley floors and hilly lowlands (e.g., Candela, Ascoli Satriano, Rocchetta Sant'Antonio) show mean annual precipitation rates of 700–800 mm or even lower. This pattern suggests the presence of a negative gradient (Figs. 40c, 41), meaning that precipitation decreases with increasing distance from the reliefs, a phenomenon known in the literature as *orographic rainfall* (Pinna, 1977). In this context, the Apennine reliefs act as natural barriers capable of intercepting humid air masses arriving from the Tyrrhenian sector, leaving the inland areas in the rain shadow and affected only by drier air masses.

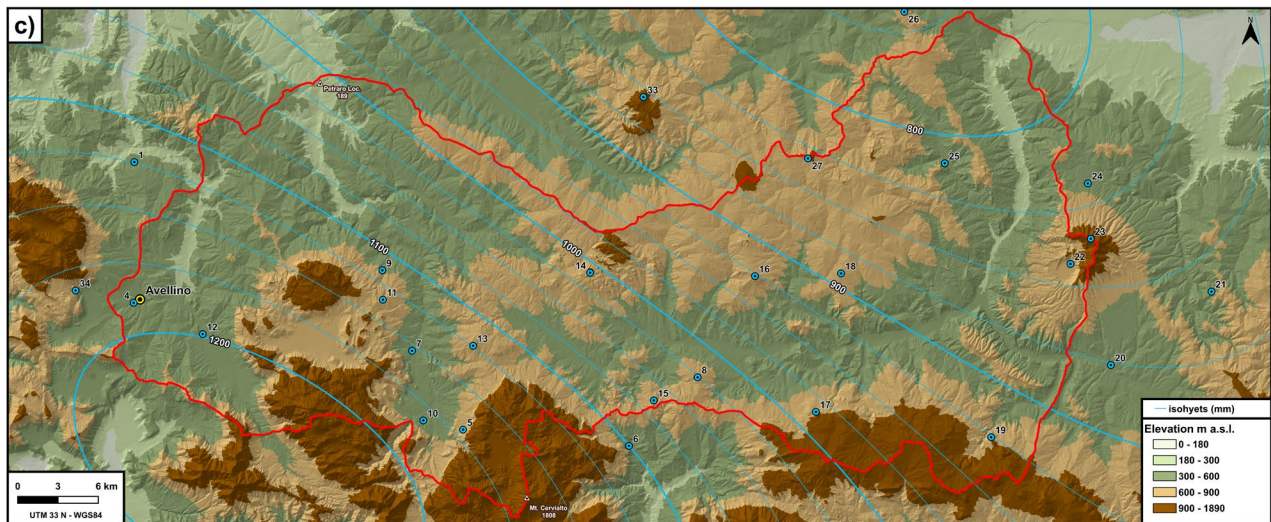


Figure 40c - Illustrative map of *orographic rainfall* within the study area.

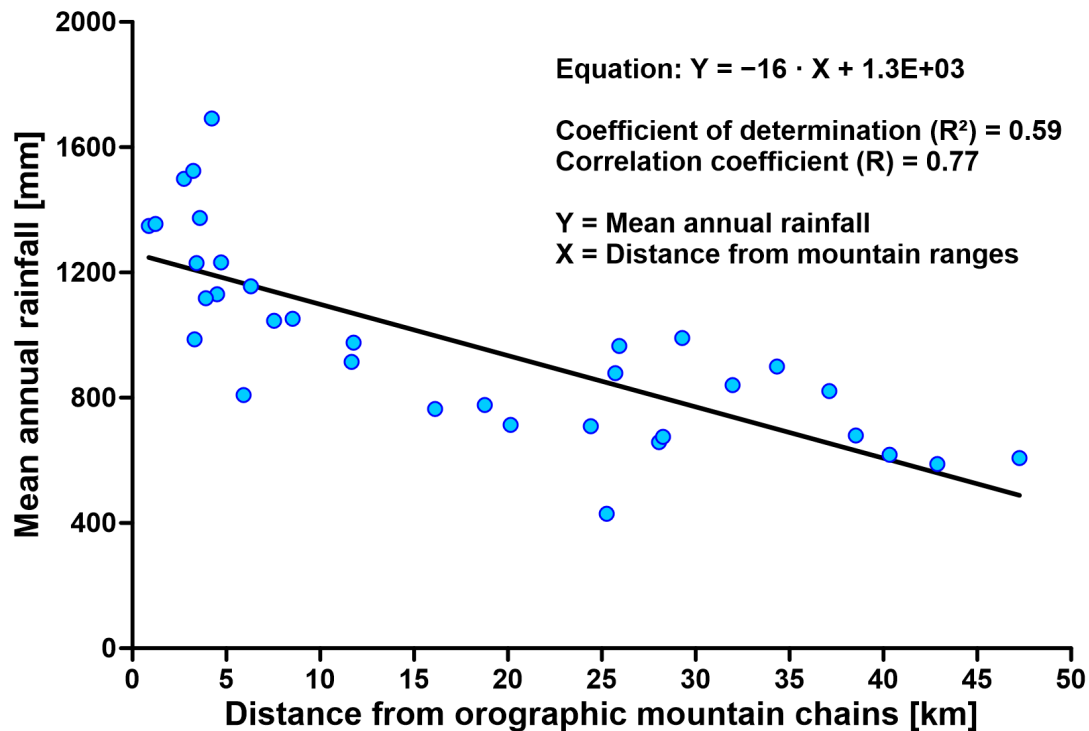


Figure 41 - Relationship between mean annual precipitation and distance from the reliefs.

The analysis of pluviometric data shows that the study area is characterized by a spatial variability strongly controlled by topography, in which mountainous and sub-mountain sectors are more humid than hilly and lowland areas. It is reasonable to expect that the effects of the pluviometric gradient may have negative implications for agriculture and water supply.

Conversely, the stations located at lower elevations (e.g., Serino, Fiume Ofanto, Cassano Irpino, Avellino, Montella and Diga T. Osento) record maximum mean annual temperatures between 20.82°C and 22°C, mean temperatures exceeding 13°C and thermal excursions often surpassing 13°C. The data reveal a strong amplification of both diurnal and seasonal thermal variability, with cold winters and very hot summers, caused by higher solar radiation, reduced ventilation and more stable atmospheric conditions.

Figure 42, a) Location and spatial distribution of the thermometric stations within the study area, b) Map of the mean annual maximum temperatures, c) Map of the mean annual minimum temperatures, d) Map of the mean annual thermal excursion.

From the examination of the graphs in Fig. 43, the mitigating effect of altitude on ambient temperature clearly emerges, suggesting a reduced diurnal and seasonal radiative amplitude.

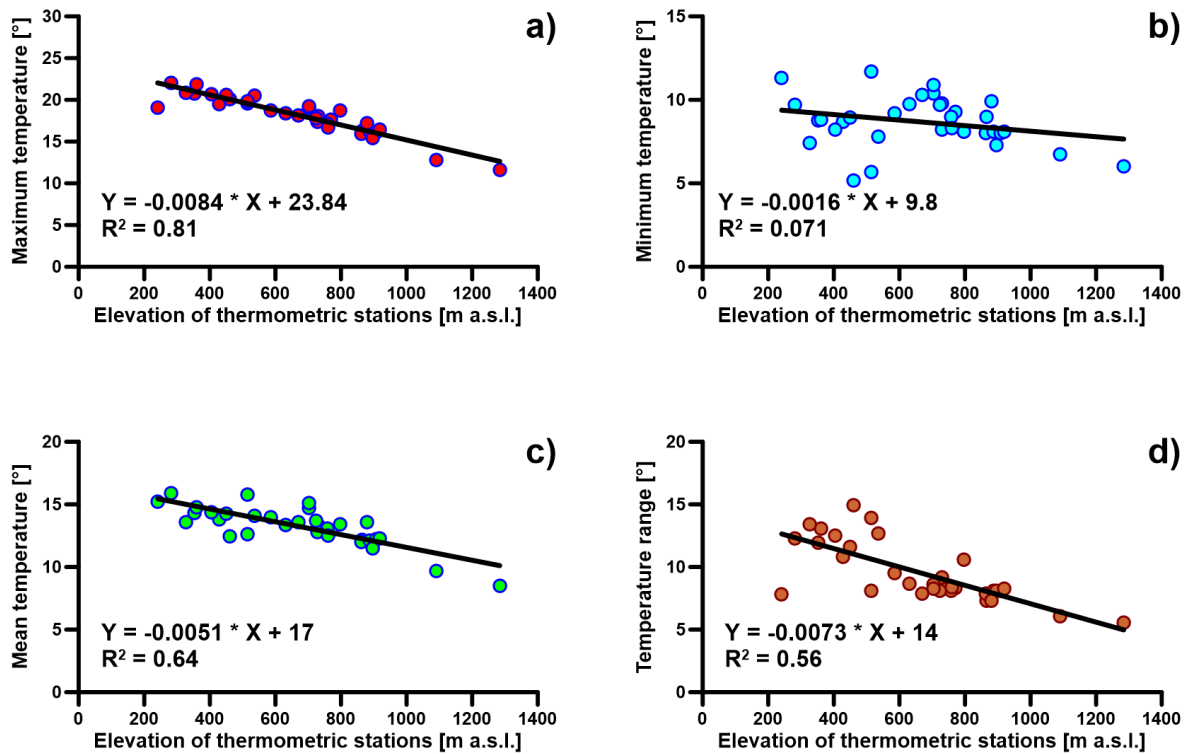


Figure 43 - a) Correlation between mean annual maximum temperatures and station elevation, b) Correlation between mean annual minimum temperatures and station elevation, c) Correlation between mean annual mean temperatures and station elevation, d) Correlation between mean annual thermal excursion and station elevation.

The dataset as a whole therefore indicates a certain degree of climatic continentality within the study area, characterized by marked seasonal energy variations whose environmental implications may be of the following types:

- **Agro-climatic** – areas subject to strong thermal excursions are more vulnerable to radiative frost and thermal stress, with negative impacts on sensitive crops,
- **Ecological** – mountainous areas, characterized by greater thermal stability, favour habitats suitable for microthermal species. Valleys, on the contrary, host more adaptable mesothermal species, although they are also more exposed to environmental stress conditions.

The thermo-pluviometric data also made it possible to calculate and manage, within a GIS environment, the Aridity Index (De Martonne, 1926) (see § 3.2.2, Fig. 26), highlighting a significant variability between semi-arid and sub-humid areas in relation to elevation within the study area.

Overall, the relationship between altitude and thermo-pluviometric data proves to be decisive for defining the climate of the study area, as demonstrated by the behaviour of the climatic gradients (Fig. 44).

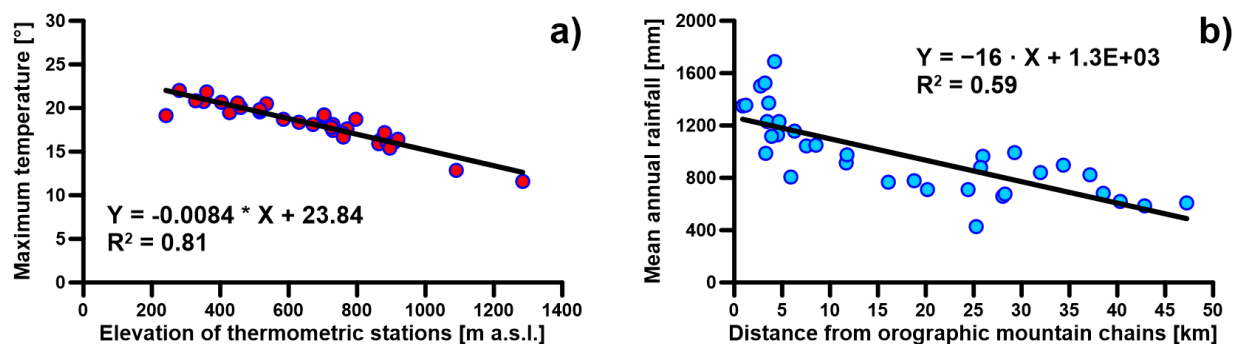


Figure 44 - a) Correlation between mean annual maximum temperatures and station elevation, b) Correlation between mean annual precipitation and distance from the reliefs.

4.2 ANALYSIS AND PROCESSING OF MORPHOMETRIC DATA

To quantitatively characterize the physiographic framework of the study area, an in-depth analysis of the main morphometric parameters of the relief was conducted using the DTM. The processing, carried out through geoprocessing techniques within a GIS environment, focused on the following parameters: slope and aspect of the hillslopes, surface drainage density and the potential energy of the relief, whose relevance has already been extensively described in the previous section (see § 3.2.2). Each of these parameters is represented areally through its own thematic map (see § 3.2.2, Fig. 28) and through quantitative data, also expressed as percentages, graphically illustrated by means of histograms.

The DTM data already provided an Elevation Band Map (see § 2.2, Fig. 5), from which it is evident that, from an altimetric perspective, the study area is predominantly hilly, with low and high hill sectors occupying 81.45% of the total 1,589 km² of the study area. These hills, due to the geo-lithological characteristics of the terrains that compose them (mainly arenaceous-marly-argillaceous clastic sediments), exhibit hillslopes with gradients (slope angles) ranging between 5° and 30°.

By comparing the Slope Map (see § 3.2.2, Fig. 28a) with the graph in Fig. 45, it becomes clear that the lowest slope classes (0°–5°), accounting for 14.09% of the surface, are concentrated in the flat valley-floor areas of the main fluvial systems (Ofanto, Calore, Sabato) and, at higher elevations, on sub-planar karst surfaces such as the Piana del Dragone and the Piano Laceno. Slope classes exceeding 30° occupy a total of 2.41% of the area and are restricted to the most rugged morphological sectors. Hillslopes with gradients between 30° and 45° (2.23% of the area) characterize the slopes of the calcareous reliefs of the Monti Picentini and those of the volcanic edifice of Monte Vulture, whereas slopes steeper than 45° (only 0.18% of the area) are limited to short, particularly steep segments, such as along the Fiumara di Atella. This framework, in which slope classes within the 5°–30° interval cover approximately 80% of the study area, confirms the high degree of maturity of the hilly slopes, while the steeper segments occur only locally and are likely linked to geo-lithological structure.

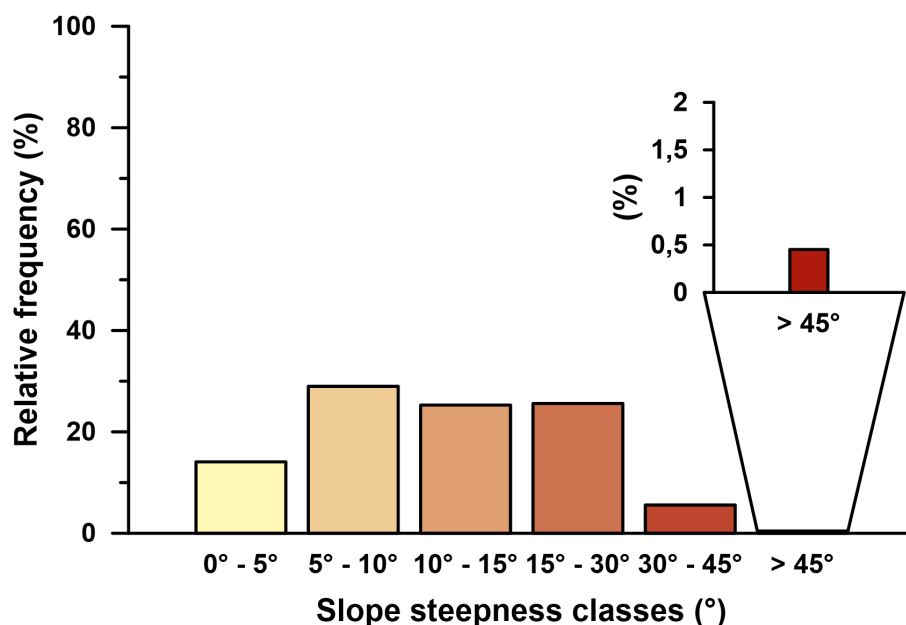


Figure 45 - Statistical distribution of slope classes.

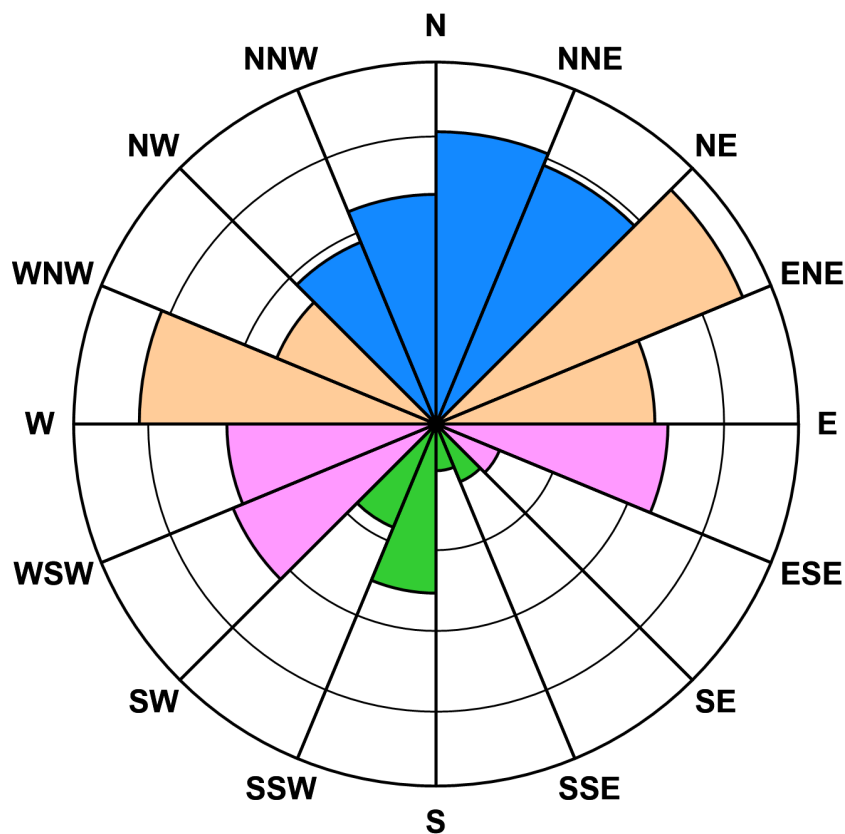


Figure 46 - Rose diagram of the statistical distribution of aspect classes.

With regard to the Aspect parameter, the data geoprocessed in the GIS environment produced the map shown in Fig. 28b (see § 3.2.2, Fig. 28b), in which the distribution of directional classes, illustrated in the rose diagram in Fig. 46, appears overall evenly distributed, with values ranging between 5.52% and 6.91% of the total surface area. The most frequent aspects, North-East (6.91%), West (6.74%) and North (6.72%), reflect the structural configuration of the territory, which is strongly conditioned by NE–SW-oriented tectonic lineations that have influenced the orientation of both the

reliefs and the fluvial valleys within the study area. It is well known (Billi et al., 1987, Pinna, 1977) that the Aspect parameter affects microclimatic and vegetation processes, and it can therefore be assumed that, within the study area, these aspect configurations exert similar influences. Consequently, north-facing and north-eastern slopes, receiving less solar radiation during the central hours of the day, exhibit lower temperatures, higher soil moisture and cooler, shaded microclimates, which favour mesophilous vegetation and the persistence of snow cover, with implications for hydrological stability.

Western-facing slopes, which receive greater solar radiation in the afternoon, exhibit more pronounced thermal excursions and conditions favourable to heliophilous arboreal crops, whereas southern and south-eastern aspects, more sun-exposed during the morning hours, develop warm and arid microclimates characterized by reduced water retention, higher susceptibility to desiccation and a predominance of xerophilous vegetation.

With regard to the Drainage Density parameter, the data geoprocessed in the GIS environment produced the map shown in Fig. 28c (see § 3.2.2, Fig. 28c), in which the distribution of density classes, illustrated in the graph in Fig. 47, shows the predominance of the medium class (1.92–2.92 km/km²), covering 30.62% of the territory, followed by the low (23.91%) and high (21.03%) classes. The very low and very high classes, on the other hand, account for 16.06% and 8.38% of the total surface area, respectively.

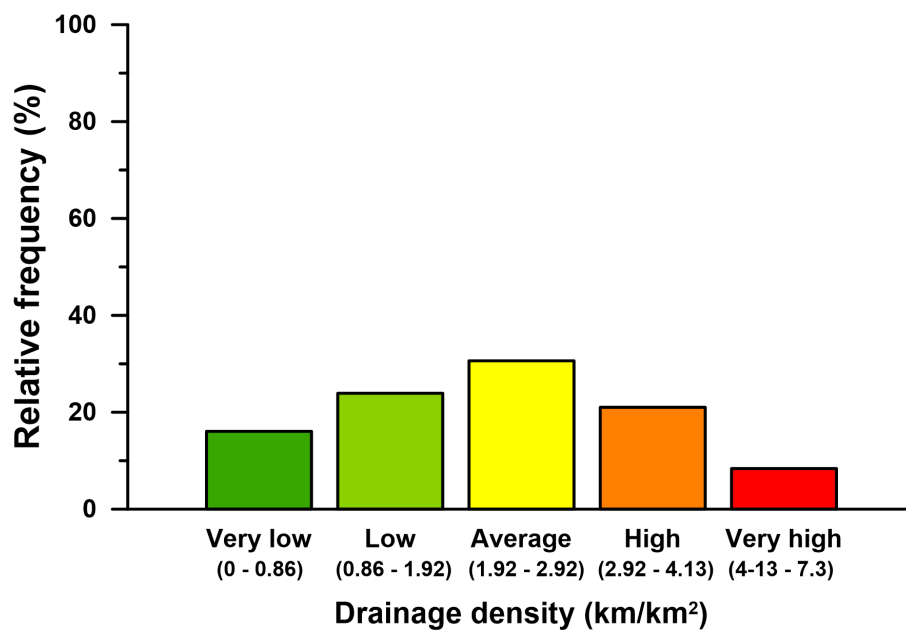


Figure 47 - Statistical distribution of drainage density classes.

The predominance of the medium class, according to Horton (1945) and Strahler (1956, 1957), indicates a relief morphology that is substantially mature in the Davisian sense, characterized by an efficient and moderately articulated hydrographic network, with moderate slopes developed on a heterogeneous lithological substrate. These conditions favour a limited linear erosive response to meteorological events.

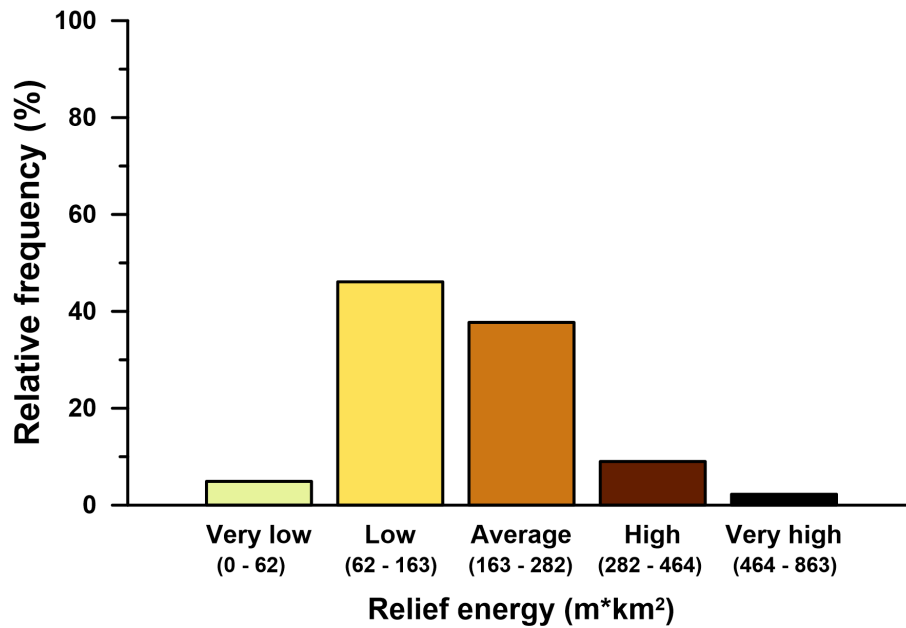


Figure 48 - Statistical distribution of potential energy classes.

Areas characterized by low and very low drainage density (together accounting for 39.97% of the total surface area) are plausibly associated with flat or sub-planar zones with limited surface runoff. Conversely, areas with high and very high drainage density, which collectively represent only 29.40% of the total surface area, correspond to more closely spaced drainage networks developed on steep slopes and lithological substrates with low permeability and a strong linear erosive response (e.g., badland sectors).

The distribution of Relief Energy, illustrated by the map in Fig. 28d (see § 3.2.2, Fig. 28d), obtained through GIS-based geoprocessing, confirms the pronounced morphological and energetic variability of the analysed landscape. The graph in Fig. 48 shows the percentage distribution of energy classes within the study area. Notably, the low-energy class prevails over all others, occupying 37.40% of the examined surface. This class identifies hilly reliefs with gentle slopes and limited incision. The medium-energy class covers 30.61% of the area and corresponds to sectors with steeper hillslopes and more rapid runoff.

4.3 ANALYSIS AND PROCESSING OF GEO-LITHOLOGICAL DATA

As illustrated in the previous section (see § 3.2.6), the geo-lithological framework of the study area was primarily derived from information reported in the official geological maps (Servizio Geologico Nazionale, 1967a, 1967b, 1971a, 1971b, 1975), complemented by direct field observations and, indirectly, by photointerpretation. This work led to the production of the **schematic map of the geo-lithological complexes of the study area** (Fig. 49).

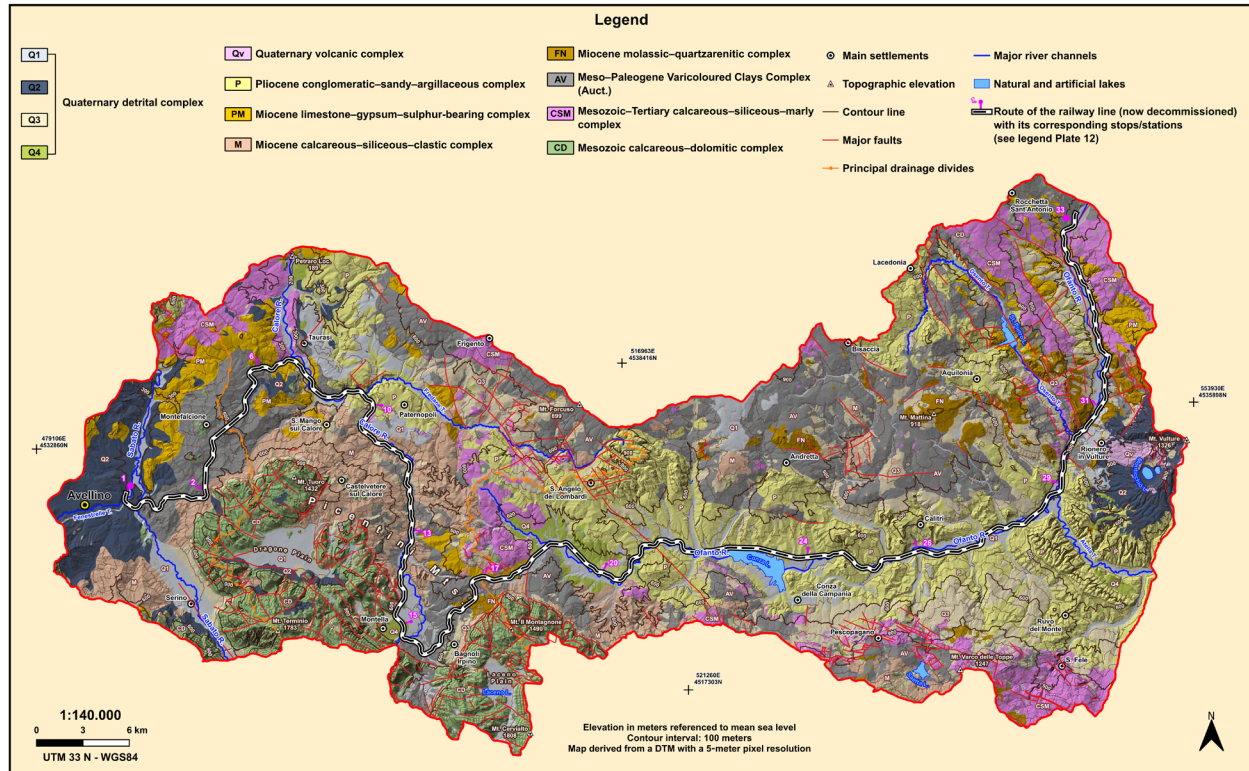


Figure 49 - Map of the geo-lithological complexes present within the study area (see Plate 17).

It reports the 12 geo-lithological complexes (previously described in Tab. 9), obtained through the aggregation of digitized data processed within the GIS environment. It is worth reiterating that the adopted grouping or aggregation criterion was multidimensional, as it was based on four fundamental parameters that ensure, for the grouped units, genetic, environmental, lithological and chronostratigraphic coherence.

From this map, it is evident that the study area represents a geological context characterized by high geosstructural and lithostratigraphic complexity, the result of geodynamic processes—still active—that, since the late Miocene (Bonardi et al., 2009, Ferranti et al., 2024, Patacca & Scandone, 2007, Vitale & Ciarcia, 2018, Vitale et al., 2019), have contributed to the construction of the present orogenic framework of this sector of the Apennines.

The geo-lithological complexes identified and illustrated in Fig. 42 are, in fact, the synthesis of the grouped morpho-sedimentary and geo-tectonic units recognized within the study area, which clearly represent environments and sedimentary complexes belonging to palaeogeographic settings now preserved within the successions forming the orogenic relief of the study area. These are listed below:

- Sedimentary complexes in flysch and turbidite facies, attributable to deep-marine basins (M, FN, AV, CSM),
- Sedimentary complexes in carbonate facies, attributable to predominantly neritic environments of the Mesozoic carbonate platform (CD),
- Volcaniclastic sedimentary complexes in primary and secondary facies (Qv),
- Clastic sedimentary complexes attributable to continental environments, predominantly fluvio-lacustrine and limno-palustrine (Q1–Q4),
- Clastic sedimentary complexes attributable to transitional marine-deltaic environments (P and PM).

Furthermore, the analysis of the lithofacies reveals that the genesis and emplacement history of these lithological complexes is highly diversified, as they document syn- and post-orogenic geodynamic processes reflecting tectonic, volcanic and sedimentary dynamics. A detailed description of each geo-lithological complex, together with its corresponding abbreviation, is provided below, and Fig. 50 illustrates their quantitative distribution.

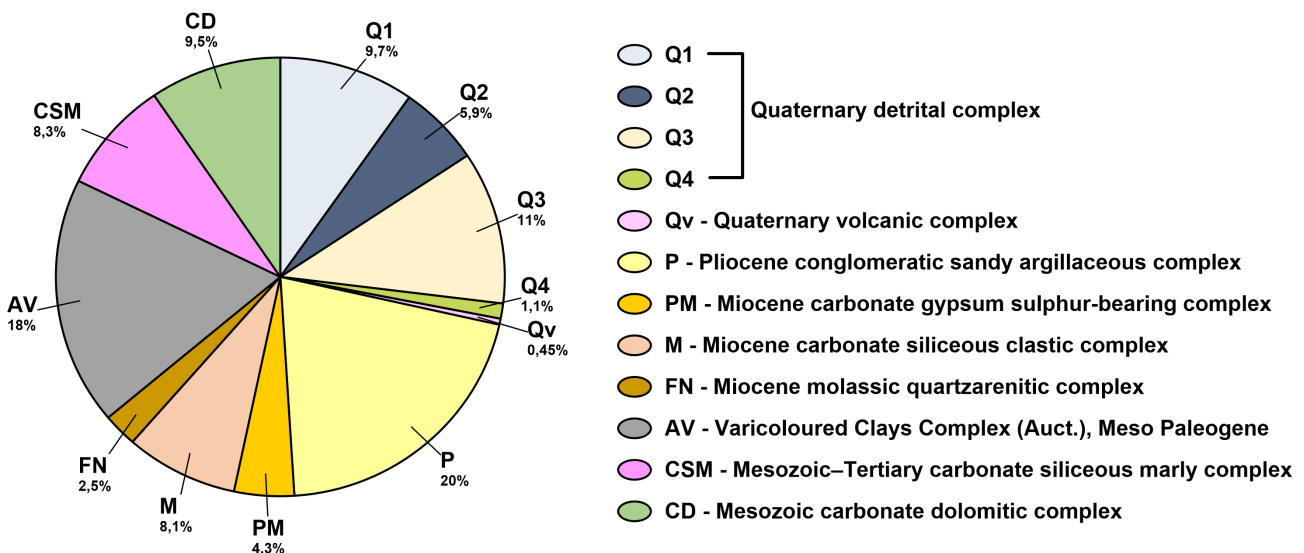


Figure 50 - Areal composition of the geo-lithological complexes.

4.3.1 Descriptive characteristics of the geo-lithological complexes

Q1 – Holocene to Late Quaternary detrital–clastic complex

Q1 represents a Quaternary stratigraphic unit, predominantly attributed to the Holocene, characterized by marked lithological heterogeneity and by a significant continental environmental imprint. This complex is composed of detrital-clastic deposits with variable grain size, arranged in stratified successions that include fluvial and alluvial gravels, clayey-silty sediments, cineritical-sandy-lapilli volcanoclastics and colluvial levels derived from surface wash processes.

The volcaniclastic sediments are attributable almost exclusively to the explosive Phlegraean–Vesuvian activity of the last 30 ka (Di Girolamo et al., 1984, Rolandi et al., 2003, Santacroce et al., 2008, Di Vito et al., 1999). They consist of reworked cinerites, sands and lapilli arranged in

discontinuous or lenticular layers that record syn-eruptive and post-eruptive depositional phases in continental environments.

The clastic sedimentary sequence, in contrast, exhibits generally thin and discontinuous stratification, with thicknesses ranging from a few metres to several tens of metres. Grain-size textures are extremely variable, spanning from coarse gravels to fine silty-clayey deposits. Fluvial and alluvial gravels, sometimes arranged in degraded terraces (Brancaccio, 1969, Labella & Giannandrea, 2012), are frequently associated with in-situ colluvial deposits indicative of active gravitational processes along unstable slopes. They are occasionally associated with lignite lenses, sandy calcareous crusts, red and black clayey soils and travertine deposits, all of which indicate sedimentation in limno-palustrine environments, typically developed within intermontane basins or tectonic depressions where water stagnation also favours the development of hydromorphic soils and carbonate precipitation. The scarce fossil content, with rare gastropods and plant remains, suggests episodic sedimentation influenced by climatic oscillations (humid and arid phases) and distal volcanic events.

The geomorphological context in which the Q1 complex develops is characterized by intermontane basins or closed depressions, and clastic infill of valley depressions (Sabato River Valley, Calore River Valley, Piana del Dragone, Upper Ofanto Valley), often controlled by extensional tectonic lineaments and active faults. The colluvial and slope deposits indicate strong geomorphological instability, with accelerated erosion and gravitational transport processes, sometimes triggered by seismic events or abrupt hydroclimatic variations (Brancaccio & Cinque, 1988a).

Q2 – Coherent and semi-coherent pyroclastic complex

Q2 is of considerable relevance for understanding volcanic processes. It consists predominantly of coherent and semi-coherent pyroclastic deposits, mainly cineritic-sandy tuffs, basaltic scoriae and welded and unwelded ignimbritic levels of Middle–Upper Pleistocene age. These deposits are attributed to the volcanic districts of Campania (Campi Flegrei, Vesuvius, Roccamonfina) and to the Monte Vulture volcanic complex. Among the Campanian ignimbritic deposits, the most notable is the *Tufo Grigio Campano* (also known as the Campanian Ignimbrite), dated to approximately 39 ka, which represents a key stratigraphic marker within the Pleistocene continental successions of Campania (Di Girolamo et al., 1984, Rolandi et al., 2003, De Vivo et al., 2001). Less well known but equally important are the Vulture ignimbrites, dated between 740 ka and 130 ka (Beneduce & Giano, 2024, La Volpe & Principe, 1994). These are often associated with lahars and explosion breccias, which record episodes of crater collapse and syn-eruptive reworking, as well as with scoriaceous levels and welded lapilli deposited at high temperature (La Volpe & Principe, 1994, Santacroce et al., 2008, Schiattarella et al., 2005). Clayey reddish-brown palaeosols frequently intercalated within the volcanic sequences testify not only to more or less prolonged eruptive pauses but also to geomorphological and climatic stability (Schiattarella et al., 2005).

Q3 – Gravitational sedimentary complex of Quaternary piedmont environments

Q3 represents a gravitational sedimentary unit typical of Quaternary piedmont environments. It is composed mainly of massive or weakly stratified calcareous breccias deposited at the base of tectonically unstable carbonate slopes. In these settings, the interaction between gravitational processes, local seismicity and hydroclimatic variations promotes the detachment, transport and accumulation of heterometric materials (Brancaccio et al., 1978, Brancaccio et al., 1979). The breccias exhibit coarse textures with angular to subangular clasts embedded in a poorly cemented sandy or clayey matrix. Their internal structure, generally chaotic and lacking preferential orientation, indicates rapid transport dynamics and high-energy depositional conditions. Locally, pseudostratified facies occur, with alternations of finer levels and sandy-silty intercalations, interpretable as multiple depositional episodes linked to intense rainfall events or local reactivations.

The presence of landslide bodies, rockfall deposits and debris flows confirms active slope dismantling, particularly along carbonate reliefs. Downslope, the gravitational deposits gradually transition into gravelly-sandy conglomerates of alluvial fan systems, characterized by greater grain-size selection and more rounded clasts, indicative of prolonged fluvial transport. Sandy and clayey intercalations, sometimes containing pyroclastic layers and palaeosols, document quieter depositional phases and pedogenetic development under subaerial conditions (Brancaccio et al., 1969).

Q4 – Coarse detrital–clastic sedimentary complex

Q4 consists of coarse detrital-clastic sedimentary deposits dominated by polygenic gravelly-sandy conglomerates with subangular to subrounded clasts of diverse petrographic composition, embedded in a moderately to well-sorted sandy matrix. The internal structure displays large-scale pseudostratification and cross-bedding, typical of high-energy depositional environments subject to rapid variations in discharge and hydraulic regime.

Qv – Quaternary Volcanic Complex

This geo-lithological complex crops out exclusively in the Monte Vulture area, where it represents the expression of a monogenetic volcanism of Early Pleistocene age, developed within an active tectonic setting along the eastern margin of the southern Apennine chain (Beneduce & Schiattarella, 1997, Schiattarella et al., 2005). The lithologies of the complex include a variety of lava and welded or fumarolized pyroclastic products, such as tephritic lavas, trachytes, trachy-phonolites, welded ignimbrites, welded scoriae and lapilli, cinerites and lahar deposits. These volcanic facies delineate crater and peri-crater environments characterized by pronounced geological instability and by alternating effusive and explosive activity. The presence of explosion breccias, welding structures and fumarolized levels indicates high-temperature depositional conditions and rapid consolidation, consistent with short-lived but high-intensity surface volcanic activity (Beneduce & Giano, 2024, La Volpe & Principe, 1994, Principe et al., 2004).

P – Pliocene Conglomeratic-Sandy-Clayey Complex

This geo-lithological complex forms a Pliocene sedimentary succession that crops out mainly in the upper Ofanto Valley (D'Argenio et al., 1975). The stratigraphic succession—clays, sandy sandstones and conglomerates—shows a clear regressive trend typical of the closing stages of syn-orogenic basins in the Apennines (Ascione et al., 2012, Chiocchini et al., 1992). At the top of the succession, polygenic conglomerates and puddingstones occur, with well-rounded and oriented clasts, predominantly of calcareous-marly composition. These deposits indicate fluvio-deltaic environments consistent with the regressive evolution of the basin (Vitale & Ciarcia, 2013).

PM – Miocene Calcareous-Gypsiferous-Sulphur-Bearing Complex

This geo-lithological complex consists of a polygenic sedimentary succession of Late Miocene age, with predominant development during the Messinian and partial extension into the Early Pliocene. It crops out in discontinuous patches along the Apennine front and in more internal sectors of the Campanian Apennines, with a particularly significant expression in the Altavilla Irpina area (Avellino), from which its conventional name derives (Ippolito et al., 1974). Sedimentation of this complex occurred within an intra-Apennine marine basin established on stratigraphic-structural units previously deformed during Early Miocene tectonic phases (Di Nocera et al., 1981).

From a lithostratigraphic perspective, the PM complex exhibits marked lithological heterogeneity, with alternations of pelitic, arenaceous, evaporitic and clastic sediments reflecting variable and transitional depositional environments. The main lithofacies include: silty clays, grey-green marls and varicoloured clays re-sedimented in open-marine to deep-marine settings (Di Nocera et al., 1981). Typical lithofacies of this complex also include polygenic puddingstones and quartz-rich sandstones, but above all the marine-lacustrine facies composed of evaporitic levels with selenitic gypsum, gypsarenites, diatomites and evaporitic limestones, sometimes containing sulphur lenses, attributable to the *Formazione gessoso-solfifera Auct.* (Ippolito et al., 1974).

M – Miocene Calcareous-Siliceous-Clastic Complex

This geo-lithological complex consists of polygenic sedimentary successions predominantly in flysch and wildflysch facies, deposited within a syn-orogenic deep-marine basin known as the Irpinian Basin s.l. (Cocco et al., 1972). Sedimentation began in the Early Miocene (Langhian) and continued until the Late Miocene (Tortonian), during the tectogenetic phases that led to the construction of the southern Apennines (D'Argenio et al., 1973, Bonardi et al., 2009, Vitale & Ciarcia, 2018).

From a lithological perspective, the M complex is composed as follows (Pescatore, 1988):

- **Castelvete–Caiazzo Formation:** predominantly arenaceous, consisting of conglomeratic lenses, sandstones, marls and clays arranged in turbiditic structures, locally containing carbonate olistoliths (wildflysch). It crops out mainly in the internal sector of the chain in the Campanian area (Irpinia and Sannio), with thicknesses of several hundred metres.
- **Gorgoglione, Serra Palazzo and S. Bartolomeo Formations:** alternation of sandstones and clays with intercalations of marls and conglomeratic beds. These formations crop out in Basilicata and along the Molise–Apulia boundary, with thicknesses exceeding 1000 m.

- **Faeto Flysch Formation:** alternations of centimetric layers of calcarenites, marly limestones and clays. It crops out in the external sector of the chain along the Irpinia–Apulia boundary, with thicknesses greater than 1000 m.

FN – Miocene Molassic-Quartzarenitic Complex (Numidian Flysch)

This sedimentary complex, in flysch facies (Numidian Flysch), is characterized by a succession dominated by turbiditic quartzarenites, associated with medium- to coarse-grained sandstones (molasse) of quartz-feldspar-mica composition, typically yellow-grey in colour. Layers of marly clays and whitish marls are also present, while greenish clay-schists and small breccias containing calcareous and siliceous elements occur locally. The overall thickness of the series is variable, ranging from several hundred metres to approximately one thousand metres. The depositional environment corresponds to a deep syn-orogenic foredeep basin. The age of the deposits is Miocene, with a predominance of levels attributable to the Early Miocene (Aquitania–Langhian) (Ogniben, 1960, Patacca et al., 1992).

AV – Meso-Paleogene Varicoloured Clay Complex Auct.

This polygenic sedimentary complex, mostly in basinal facies and locally in flysch facies, consists of stratified alternations of fossiliferous varicoloured clayey rocks, calcareous-clastic and siliceous-marly units, with rare clay-schist, siltstone, quartzarenite and chert levels (Guerrera et al., 1993). Locally, isolated blocks (olistoliths) of Cretaceous neritic limestones or Cenozoic quartzarenites are embedded within the succession. The complex is subdivided locally into several formations with similar lithological characteristics but different names. Average thickness reaches several hundred metres. Depositional environment: deep-marine to foredeep basin (Sicilide Basin s.l.). Age: Meso-Cenozoic (mainly Cretaceous–Paleogene).

CSM – Mesozoic–Tertiary Calcareous-Siliceous-Marly Complex

This polygenic sedimentary complex is mostly in basinal facies (Lagonegro Basin) and calcareous-siliceous-clastic flysch facies (Galestrino Flysch–Red Flysch) (Scandone, 1967, 1972). Average thickness reaches several hundred metres. Depositional environment: deep-marine to foredeep basin. Age: predominantly Paleogene. Locally, it is subdivided into formations with distinct lithological and chronological characteristics.

1. **Calcareous-Siliceous-Marly Series:** siliceous limestones, siliceous clay-schists and cherts, claystones, marls and siliceous calcilutites. Age: Triassic–Cretaceous.
2. **Red Flysch:** cherts and varicoloured claystones often alternating with quartzarenites, calcarenites and turbiditic calcilutites associated with marls and silty clays, pink and whitish calcareous marls, small calcareous breccias and fossiliferous white limestones. Age: Cretaceous–Miocene.

CD – Mesozoic Calcareous-Dolomitic Complex

This sedimentary complex is predominantly carbonate, mostly in platform facies and neritic depositional environments. It includes dolomites, dolomitic limestones and fossiliferous limestones (algae, bryozoans, gastropods, bivalves, planktonic foraminifera, etc.), whitish, buff or greyish in colour, compact and massive or arranged in layers and beds of variable thickness, frequently

fractured. Organogenic limestones (bioherms and biostromes) and bioclastic limestones are also present, along with detrital and microcrystalline or saccharoidal limestones. Calcareous breccias and oolitic limestones occur locally. Conglomeratic levels, greenish marls and fossiliferous marly limestones may also be associated. In some areas, the complex forms isolated blocks (olistoliths) incorporated within other geo-lithological complexes. Total thickness reaches several thousand metres. Age: predominantly Mesozoic, with stratigraphic gaps extending the succession into the Miocene (D'Argenio et al., 1973, Mostardini & Merlini, 1986).

4.4 ANALYSIS AND PROCESSING OF GEOMORPHOLOGICAL DATA

The study area exhibits a marked morphological heterogeneity, the result of geodynamic and morphoevolutionary processes that have shaped this sector of the Campanian–Lucanian Apennines from the late Miocene to the present day (Brancaccio & Cinque, 1988a). The outcome of these processes is a mosaic of diverse morphoscapes and terrains arranged, within a limited spatial domain, along variable altitudinal gradients that generate unique landscapes capable of eliciting in the observer a kaleidoscope of contrasting sensations and emotions within a short temporal span.

To define the specific characteristics of these landscapes, geomorphological field observations were conducted with the aim of identifying their differentiated genesis, environmental dynamics, territorial vocations, and settlement patterns. As anticipated in the previous section, the analysis carried out made it possible to identify, within the study area and particularly along the route of the former Avellino–Rocchetta Sant'Antonio railway line, six Landscape Units (UdP) (Di Gregorio & Piras, 2005, Coltorti et al., 2011). These units, shown in Fig. 51, are illustrated and described in detail below.

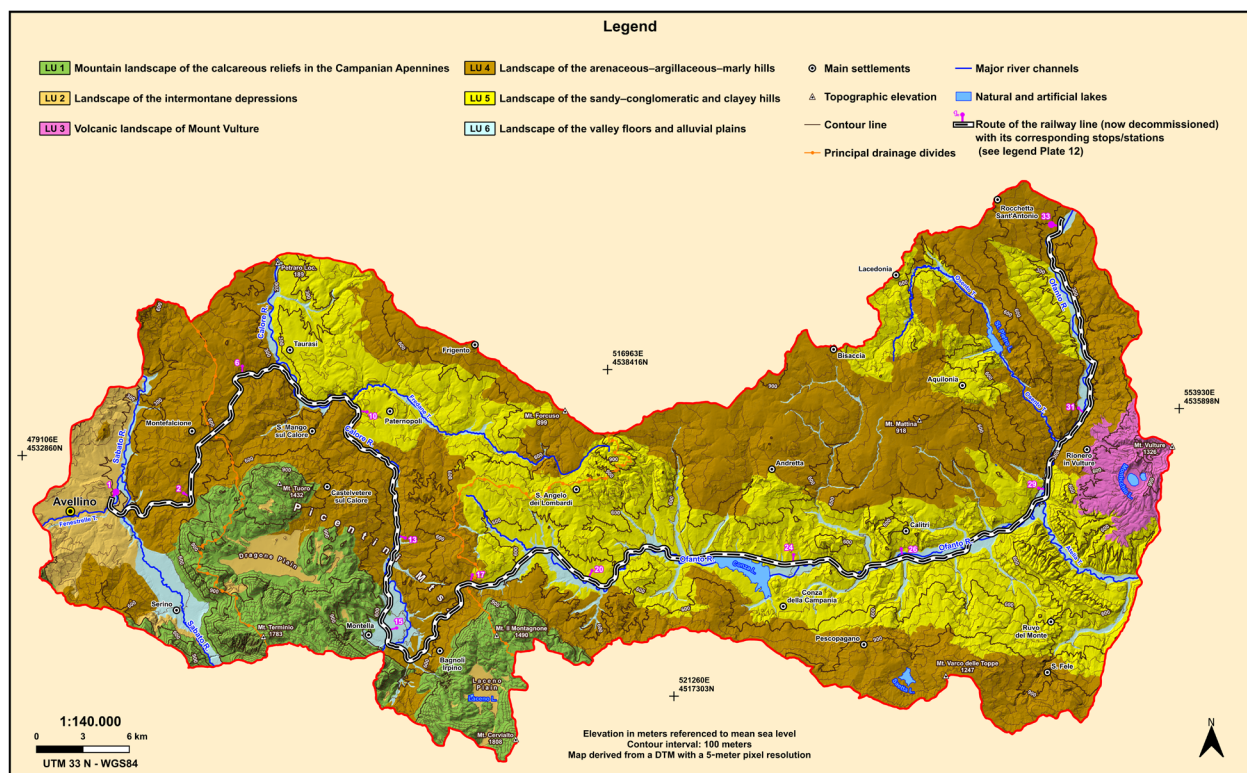


Figure 51 – a) Map of the Landscape Units in the study area (see Plate 17).

Each Landscape Unit was delineated into homogeneous areas by extracting information from the pre-established Geodatabase within a GIS environment. As a result, each Unit encompasses specific combinations of geological, geomorphological, climatic, environmental, and land-use factors that give rise to distinct environmental georesources and settlement configurations capable of expressing different territorial potentials in socio-economic and cultural terms, which are easily accessible and usable by stakeholders (e.g., tourists, occasional and interested travellers, etc.).

Fig. 52 shows a chart illustrating the percentage distribution of the areas of the UdP relative to the total extent (1588.791 km²) of the study area. The chart clearly indicates that the study area is predominantly occupied by UdP 4 and 5, whereas all the others cover only relatively small or marginal sectors, thereby accentuating the contrast among the various UdP.

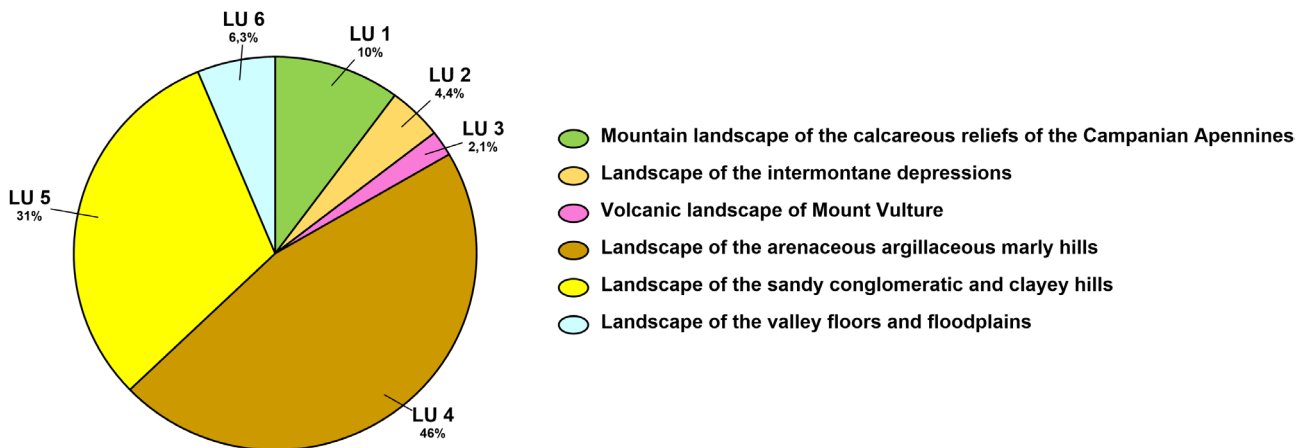


Figure 52 – b) Areal extent (percentage) of the Landscape Units within the study area.

4.4.1 Descriptive characteristics of the Landscape Units

UdP 1 - Mountain Landscape of the Calcareous Ridges of the Campanian Apennines

This UdP includes the main mountain reliefs that define the orography of the study area, whose characteristics can nonetheless be extended at the regional scale throughout the Southern Apennines (Fig. 53, 54).

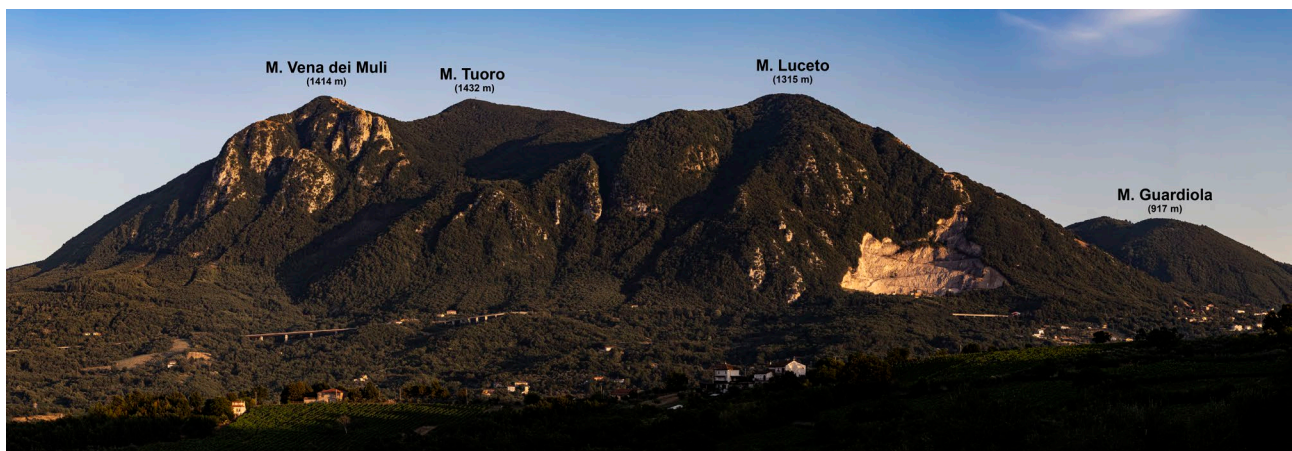


Figure 53 - Panoramic view of the north-western slope of the Monti Picentini, taken from Provincial Road 88 between the towns of Lapio and Montefalcione.

Within the study area, these reliefs are distributed along a wide altitudinal gradient, ranging from 600 to 1800 meters above sea level, delineating an articulated morphology that reflects the complex tectonic evolution of the southern sector of the Apennine Chain. The mountain landforms are characterized by extensive summit surfaces of erosional origin, strongly karstified (Brancaccio & Cinque, 1988a), which stand out sharply with respect to the surrounding valley floors. This pronounced morphological offset is controlled by the presence of particularly steep fault scarps, with slopes ranging between 30° and 45°, often rectilinear and predominantly oriented toward the northern quadrants.

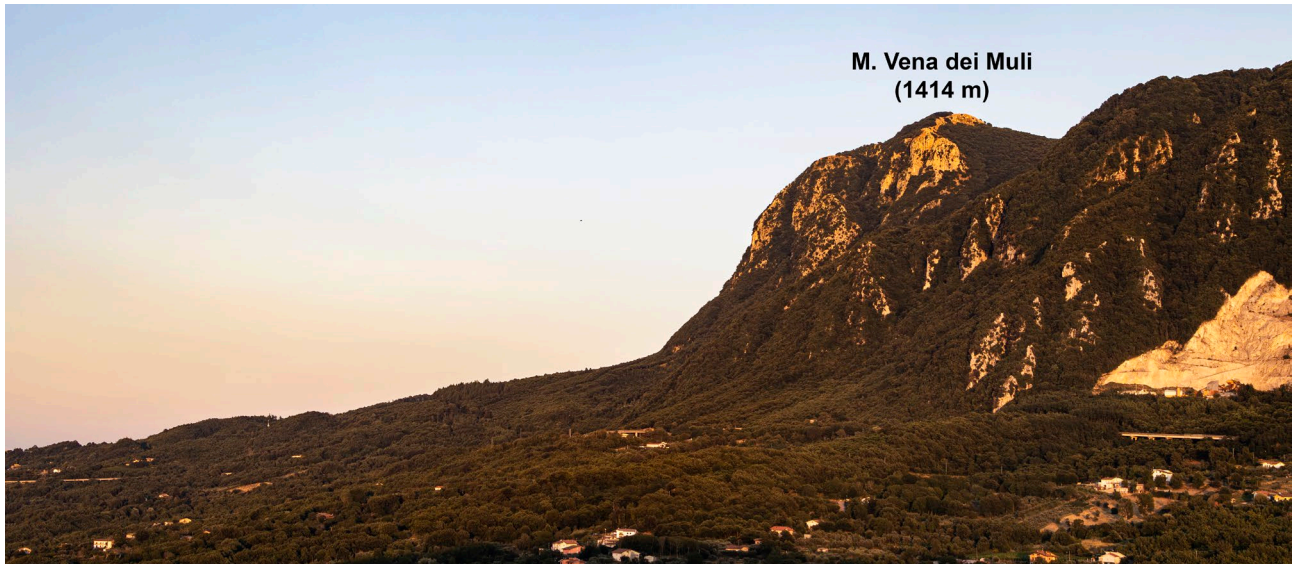


Figure 54 - Fault-line slope of Mt. Vena dei Muli (detail of the previous photograph).

Lithologically, the bedrock is composed almost exclusively of Mesozoic carbonate rocks (Figs. 55, 56), belonging to the calcareous–dolomitic succession of the Campanian Apennines, with thicknesses reaching several thousand meters (Mostardini & Merlini, 1986, Vitale & Ciarcia, 2018).



Figure 55 - Cretaceous rudist limestones cropping out near Mt. Cervarosa.

In certain areas, intercalations of Tertiary, predominantly Miocene, calcareous-clastic and terrigenous sediments are observed, completing the stratigraphic succession. The dominant morphogenesis is karstic, with both epigean and hypogean landforms that profoundly shape the landscape (Figs. 57, 58) (Bellucci et al., 1983, Brancaccio & Cinque, 1988b, Giulivo et al., 1988, Celico, 1988), characterized by dolines, karren fields, and endorheic depressions (poljes), as well as subterranean features of speleological interest such as caves and shafts, some of which are included in notable tourist circuits.



Figure 56 - Tectonised rudist limestones cropping out near Mt. Vena dei Lupi (Montella).

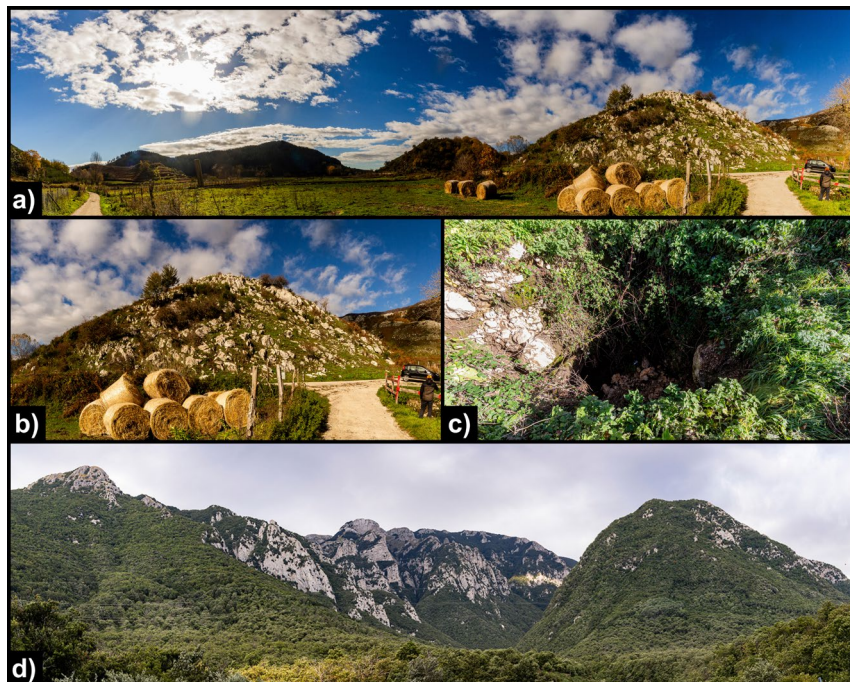


Figure 57 - a) Sant'Agata Polje, b) Hum within the Sant'Agata Polje, c) Swallow hole, d) Karst valley (Vallone Matruonolo).



Figure 58 - Stalactites and stalagmites in the Caprone Cave (Montella).

The genesis and evolution of the karst landscape within the UdP cannot be attributed solely to the dissolutive action of circulating and meteoric waters, as extensional tectonics and climatic fluctuations have jointly contributed to the complex morphodynamics that have affected this UdP since its emergence from the marine domain (Brancaccio et al., 1984, Brancaccio & Cinque, 1988).

Drainage is predominantly hypogean: meteoric waters, infiltrating into the karst network, re-emerge as springs at the base of the carbonate slopes, often under conditions of hydrogeological confinement (Fig. 59).



Figure 59 - Interior of the Pollentina Spring near Cassano Irpino.

The surface hydrographic network is generally absent or poorly developed, exhibiting a medium to low drainage density, particularly in areas where terrigenous clastic sediments crop out, characterized by low permeability and, in some cases, affected by localized gravitational instability processes (landslides, solifluction). Tectonic landforms (fault scarps and fault-related slopes) and structural features (monoclines) are widespread, imparting a pronounced geodynamic imprint to the landscape (Fig. 60).

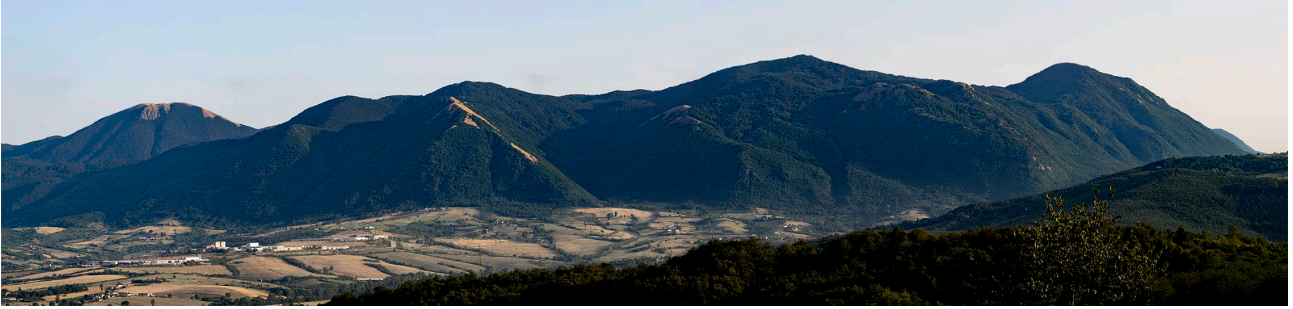


Figure 60 - Triangular-facet landscape in the upper Ofanto River valley.

The vegetation cover is rich and diversified, dominated by shrubland and forest formations composed of broadleaved species and conifers, occasionally interspersed with limited grassland areas used for grazing domestic livestock (cattle, sheep, goats) (Fig. 61).



Figure 61 - Different types of vegetation cover characterising the summit areas of the reliefs surrounding Chiusano San Domenico.

Soils, generally weakly developed and characterized by limited thickness, are predominantly of volcanic origin and can be classified as *Andosols*. The local montane climate is defined by a mean annual thermal excursion of approximately 14 °C, and by annual precipitation ranging between 1100 and 1500 mm, distributed irregularly throughout the seasonal cycle.

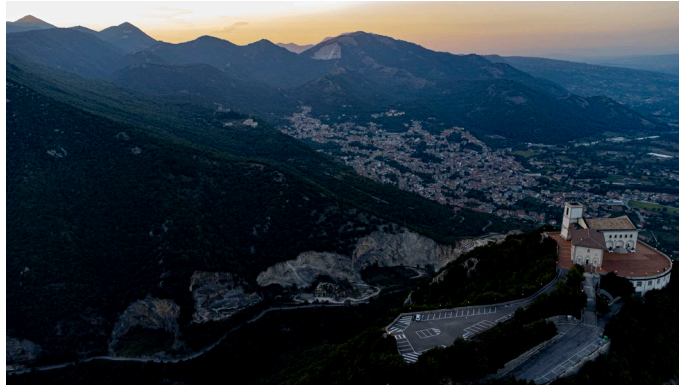


Figure 62 - The town of Montella at the foot of Monte Sassosano (1,439 m); the Sanctuary of the Santissimo Salvatore is visible on the right.

Human presence is sparse and spatially fragmented, with the population concentrated in small settlements located predominantly below 700 m a.s.l., often positioned marginally with respect to the main reliefs (Fig. 62).

Local agri-food productions are of particular relevance, being recognized and protected through DOP and IGP certifications. Among these, the chestnuts of Montella and Serino stand out for their high quality, together with *Caciocavallo Silano*, a traditional stretched-curd cheese of ancient origin (Cusano et al., 2022, Cusano et al., 2025).

UdP 2 – Landscape Unit of the Intermontane Depressions

At elevations exceeding 700 meters, the landscape is characterized by broad endorheic basins with gently undulating or nearly flat floors, geomorphologically identified as *poljes*, landforms of tectono-karstic origin generated through the interaction between tectonic subsidence processes and the chemical dissolution of carbonate lithotypes. These depressions are embedded among karstified calcareous-dolomitic reliefs and are often temporarily occupied by ephemeral lakes (e.g., Laceno Lake, Piana del Dragone) or by high-altitude grasslands subject to extensive grazing (Fig. 63a, b, c).

The sedimentary infill of the basins consists of clastic deposits of fluvio-lacustrine origin, generally less than 2–3 meters thick, frequently interbedded with centimetric layers of pyroclastic materials (ashes, lapilli) and colluvial deposits derived from gravitational transport processes (Celico, 1988). The soils developing on these substrates are predominantly hydromorphic, weakly evolved, and characterized by limited pedogenesis. They can be classified as Gleysols or Fluvisols, with textures ranging from silty loam to clay loam and impeded drainage conditions.

The vegetation cover (Fig. 63d) is dominated by perennial herbaceous species and cold-adapted grasses tolerant of saturated soils, exploited for summer grazing or converted into low-input arable land.

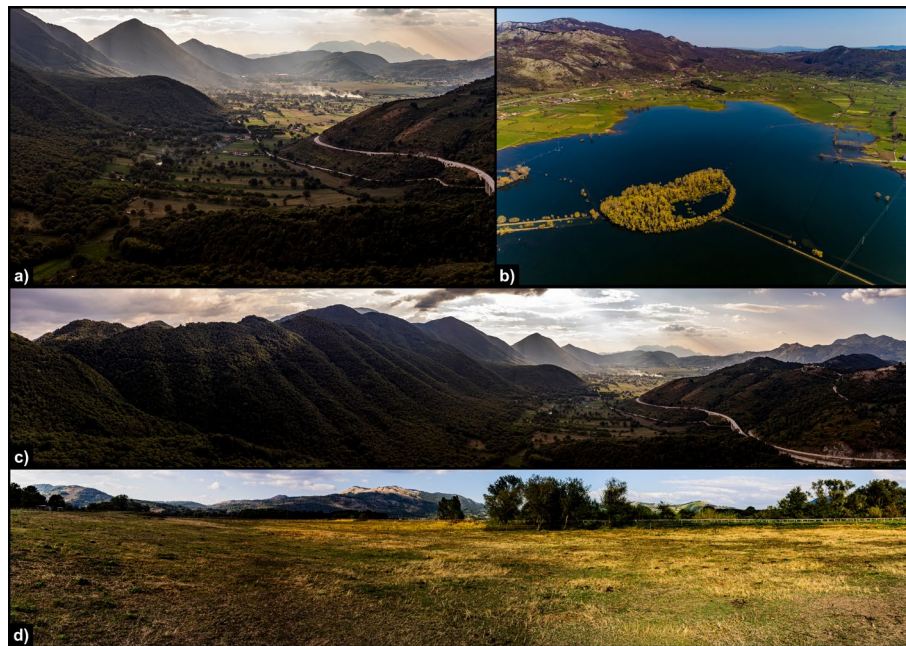


Figure 63 - Morphological features (a, b, c) and vegetation cover (d) of the Piana del Dragone (Vulturara Irpina). Seasonal conditions are evident: summer (a, c) and winter (b).

The mountain climate exhibits a pronounced annual thermal excursion ($\sim 12^{\circ}\text{C}$), with precipitation ranging between 1100 and 1500 mm yr^{-1} , irregularly distributed and showing seasonal maxima during autumn and winter. Snow constitutes a significant component of the winter hydrological budget.

Human settlement is sparse and highly fragmented, consisting of small residential nuclei and tourist facilities located along the margins of the basins or near spring emergences, often associated with deep karst circulation systems.

Typical agri-food productions derive from the surrounding forested slopes and include chestnuts (Montella and Serino PGI), hypogeous fungi (truffles), and stretched-curd cheeses such as *Caciocavallo Silano* PDO, rooted in transhumant pastoral traditions.

Below 700 meters of elevation, the landscape transitions into a hilly morphology interspersed with broad exorheic depressions of tectonic origin, attributable to graben-type structures, such as the Avellino depression, embedded between calcareous-dolomitic ridges (Partenio–Montevergine, Terminio–Tuoro).

These basins rest upon Cenozoic sedimentary substrates composed of calcareous-siliceous-clastic lithotypes and arenaceous-argillaceous-marly successions, tectonically down-faulted and subsequently filled with Quaternary deposits of fluvio-lacustrine origin and, predominantly, pyroclastic materials (volcanic tuffs sourced from the Campanian volcanic districts) (Pescatore et al., 1987, Sulpizio et al., 2010).

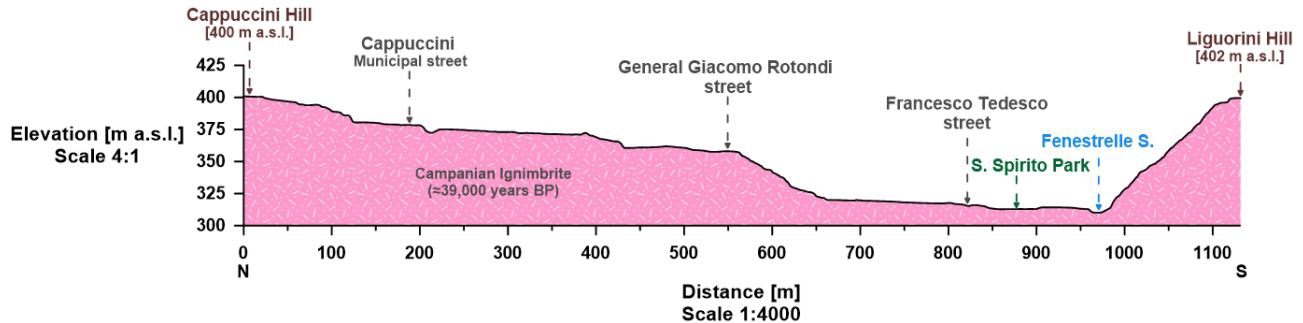


Figure 64 - Topographic profile connecting the Cappuccini and Liguorini hills across the basin hosting the territory of Avellino

An epigenetic hydrographic network has developed upon these substrates, characterized by medium-to-high drainage density and by torrential incisions that shape the landscape into elevated, gently undulating terraces, interpretable as relict erosional or depositional surfaces. These terraces host high-density urban and peri-urban settlements (Avellino and neighboring municipalities) (Fig. 64), distributed along historical transportation corridors of regional and national relevance (Via Appia, SS 7 bis).

The prevailing soils are of volcanic origin and can be classified as Andosols, exhibiting high water-retention capacity, good chemical fertility, and textures ranging from silty loam to clay loam. Vegetation cover is sparser than in the montane environment, with a predominance of deciduous and shrubland formations, often fragmented by horticultural crops and irrigated arable fields.

The climate is humid temperate, with mean annual precipitation between 1100 and 1200 mm and an annual thermal excursion of approximately 9–11 °C. Atmospheric humidity and soil fertility promote significant agricultural diversification. Typical local productions include artisanal nougats, chestnut-based confections (such as *croccantini*, *castagnacci*, *calzoncelli*), and high-quality agri-food products, including the Montella Chestnut PGI, the Cassanese Apple, and the *Fagiolo Quarantino*, recognized as a Traditional Agri-Food Product (PAT) and a Slow Food presidium.

UdP 3 – Volcanic Landscape Unit of Monte Vulture

This unit corresponds to a typical hilly-montane volcanic landscape that is highly evolved from a geomorphological perspective, extending across an altitudinal range between 600 and 1,326 m a.s.l. (Boenzi et al., 1987) (Fig. 65). The hillslopes exhibit predominantly concave profiles, with a dominant south–southwest exposure and gradients varying from approximately 40° in the summit areas to about 15° in the piedmont sectors. In these lower sectors, suspended erosional planation surfaces are preserved, representing remnants of ancient base-level conditions (Brancaccio & Cinque, 1988a).



Figure 65 – Panoramic view of Mount Vulture.

The relief is predominantly composed of effusive and pyroclastic volcanic rocks, including tuffs, lapilli, ignimbrites, and volcanic breccias (La Volpe et al., 1984, Peccerillo, 2005) (Fig. 66). The montane sector forms a wide caldera-like amphitheatre, the remnant of post-eruptive structural collapses, within which caldera lakes of the maar type (Monticchio Lakes) and thermo-mineral springs are located, indicating the persistence of hydrothermal activity (Schiattarella et al., 2005, Giannandrea et al., 2006). Small monogenetic scoria cones and lava domes (necks) complete the landscape of the quiescent volcanic edifice culminating at Monte Vulture.

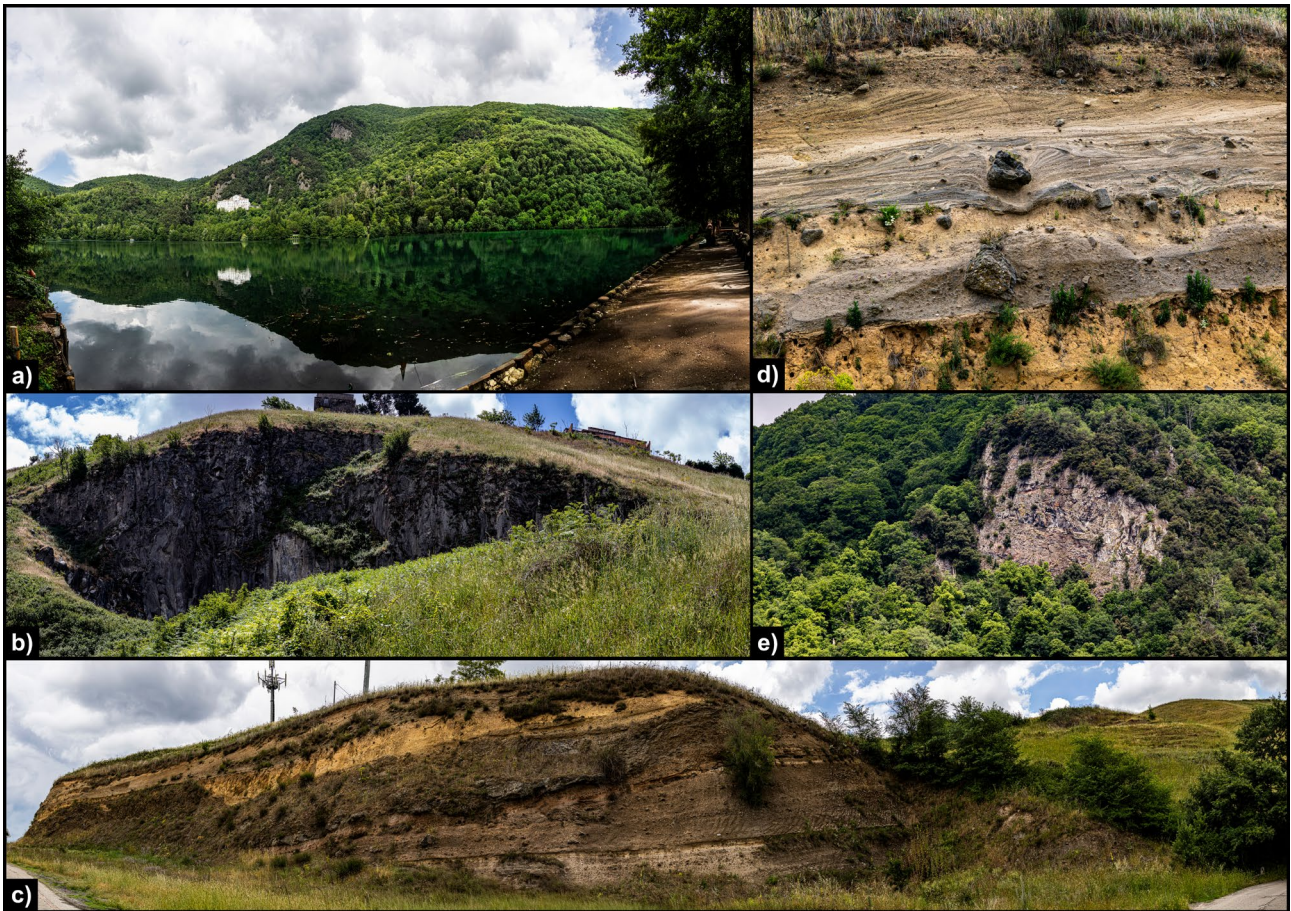


Figure 66 - The volcanic landscape of the Vulture: a) Lago Grande of Monticchio, b) the haüynophyre quarry near Melfi, c) an outcrop of pyroclastic deposits composed of tuffs, lapilli and ignimbrites near the Gaudianello facilities, where internal laminations and undulations are clearly visible, typical of subaerial depositional processes with subsequent reworking by water or wind, d) detail of the previous outcrop showing sedimentary laminae and large volcanic clasts embedded within the strata, e) volcanic neck.

The surface hydrographic network is incomplete due to the partial caldera collapse (Valle dei Grigi), yet it is highly developed and hierarchized, with medium-to-high drainage density and a centrifugal pattern altered by fluvial captures. The climate of the area is characterized by a mean annual thermal excursion of approximately 12 °C and by a pluviometric regime ranging between 850 and 950 mm, with precipitation concentrated in the autumn and winter months (ISPRA, 2020). The seasonal pattern results in hot and relatively dry summers and cold, humid winters, producing a marked hydrological seasonality. Vegetation cover at higher elevations is dominated by mature beech, Turkey oak, and chestnut forests, which play a crucial role in slope stability and biodiversity conservation. At the highest altitudes, shrublands and grasslands alternate, whereas the hilly sectors host agricultural crops and non-irrigated arable land, creating a landscape mosaic that integrates natural and anthropogenic elements.

The soils are of volcanic origin (Andosols), well-developed and highly fertile, characterized by elevated water-retention capacity and high organic-matter content (FAO, 2015). This fertility has supported the development of high-quality agri-food productions, including viticulture, exemplified by the renowned *Aglianico del Vulture Superiore* DOCG, olive cultivation yielding the “Vulture”

PDO extra-virgin olive oil, and a variety of traditional products such as PDO cheeses and local chestnuts, emblematic of the region's gastronomic heritage.

The area is sparsely populated, with small urban centers scattered and perched on the lava reliefs, preserving valuable historical and architectural layouts. The main urban poles, such as Melfi and Rionero in Vulture, have developed in the more suitable piedmont areas, where morphology and resource availability have favored settlement and economic growth.

UdP 4 – Arenaceous–Clayey–Marly Hill Landscape

The hilly landscape extends altitudinally between 400 and 800 m a.s.l. and typically characterizes the inland areas of the Campanian–Lucanian Apennines. From a lithostratigraphic perspective, the orographic framework is dominated by predominantly detrital sedimentary successions composed of stratified siliciclastic and calciclastic deposits attributable to flysch-type facies (Flysch Rosso, Numidian Flysch, Irpinian Flysch, *Argille Varicolori* Auct., etc.). These units, mainly of Cenozoic age, represent the product of turbiditic depositional processes in deep-marine basins subsequently deformed during Miocene tectogenesis (Fig. 67) (Bonardi, 2009, Vitale & Ciarcia, 2018).

The hillslopes exhibit average gradients between 25° and 30°, with a predominant S–SW exposure (Fig. 68). The morphology is generally concave or concave-convex, strongly conditioned by gravitational instability processes of varying typology and magnitude (earthflows, rotational and translational slides, creep phenomena) (Budetta et al., 1990, Parise & Wasowski, 1996, Del Prete & Liuzzi, 1981, Martino et al., 2001), which confer high geomorphological vulnerability. The spatial distribution of these processes is closely linked to lithological characteristics, structural discontinuities, and local hydrogeological conditions (Figs. 69 and 70).



Figure 67 - Various outcrops of the lithologies characterising LU 4: a) Red Flysch outcrop near Monteverde, b) carbonate olistoliths embedded in varicoloured clays between Candela and Rocchetta Sant'Antonio, c) Siliceous Schists outcrop near San Fele, d) Castelvetere Flysch outcrop near Chiusano San Domenico.



Figure 68 - Hillslope developed on the argillaceous–marly terrains of the Castelvetero Flysch. The town of Lapio stands on the summit.

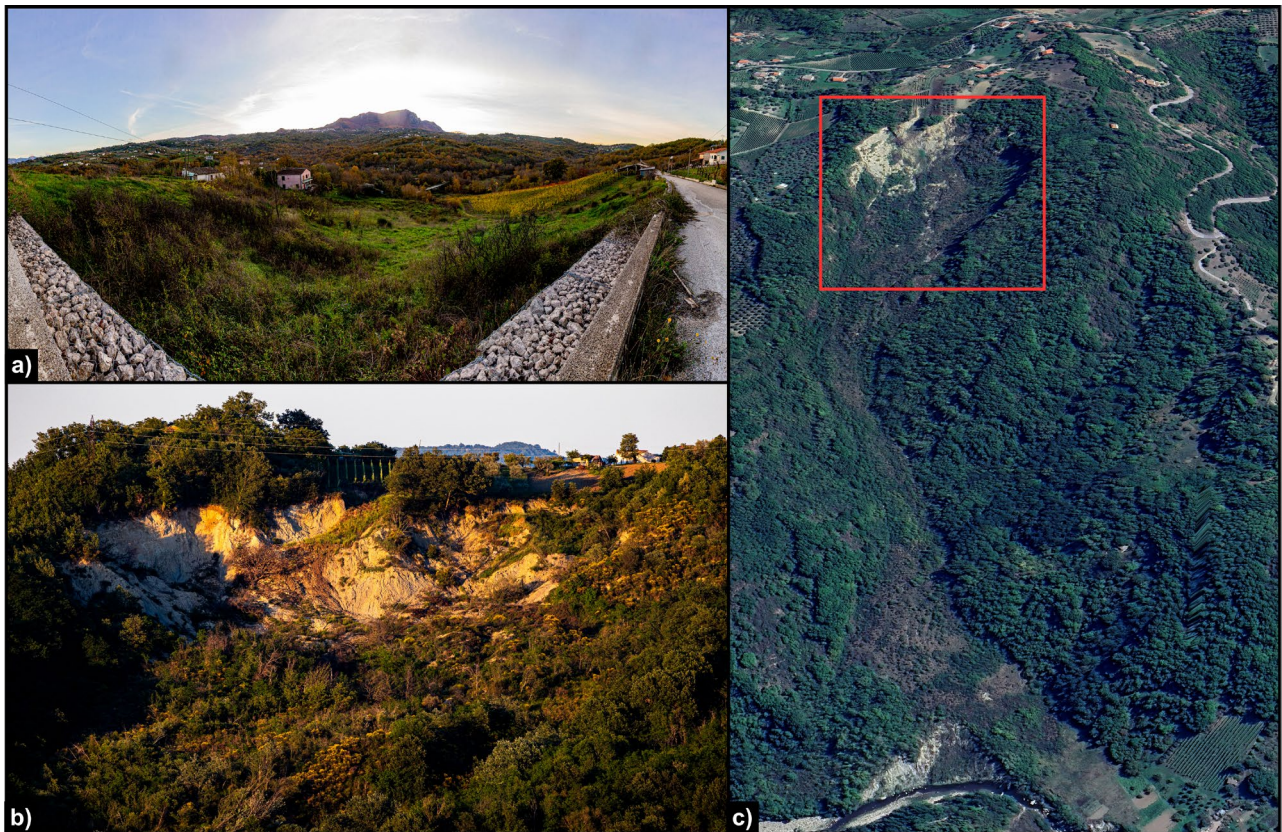


Figure 69 - a) Landslide slope near Paternopoli, already documented by Bonardi et al. (1988), b) landslide affecting vineyards near Castelfranci, c) satellite image of the Castelfranci landslide, with the red area corresponding to the portion shown in panel b.

The minor hydrographic network is well developed and hierarchized, with medium-to-high drainage density, indicative of a considerable erosive capacity and an efficient hydrological organization. This configuration is favored by the differentiated permeability of the lithologies and by the presence of weakly developed surface covers, which limit deep infiltration and enhance surface runoff.

The climatic regime is temperate sub-continental, with an annual thermal excursion between 8 and 12 °C. Mean annual precipitation ranges from 700 to 1000 mm, with a seasonal distribution typical of the Apennine regions, characterized by autumn and winter maxima and summer minima. These conditions significantly influence pedogenetic processes and hydro-geomorphological dynamics.

The soils are weakly developed and poorly mature, classifiable as Inceptisols, with predominantly clay-loam textures and a moderate content of primary and secondary minerals. The presence of pyroclastic fractions, derived from Quaternary volcanic events, enhances the chemical fertility of the soils. Vegetation cover consists of moderately extensive woodland and shrubland formations, interspersed with broad agricultural surfaces.

Agricultural activity plays a primary role, with specialized vineyards and olive groves producing high-quality certified products recognized at national and international levels: *Taurasi* DOCG and *Fiano di Avellino* DOCG wines, and the “Irpinia – Colline dell’Ufita” PDO extra-virgin olive oil. Non-irrigated arable land, orchards, and horticultural crops are also present, completing the agricultural mosaic of the area (Fig. 71).

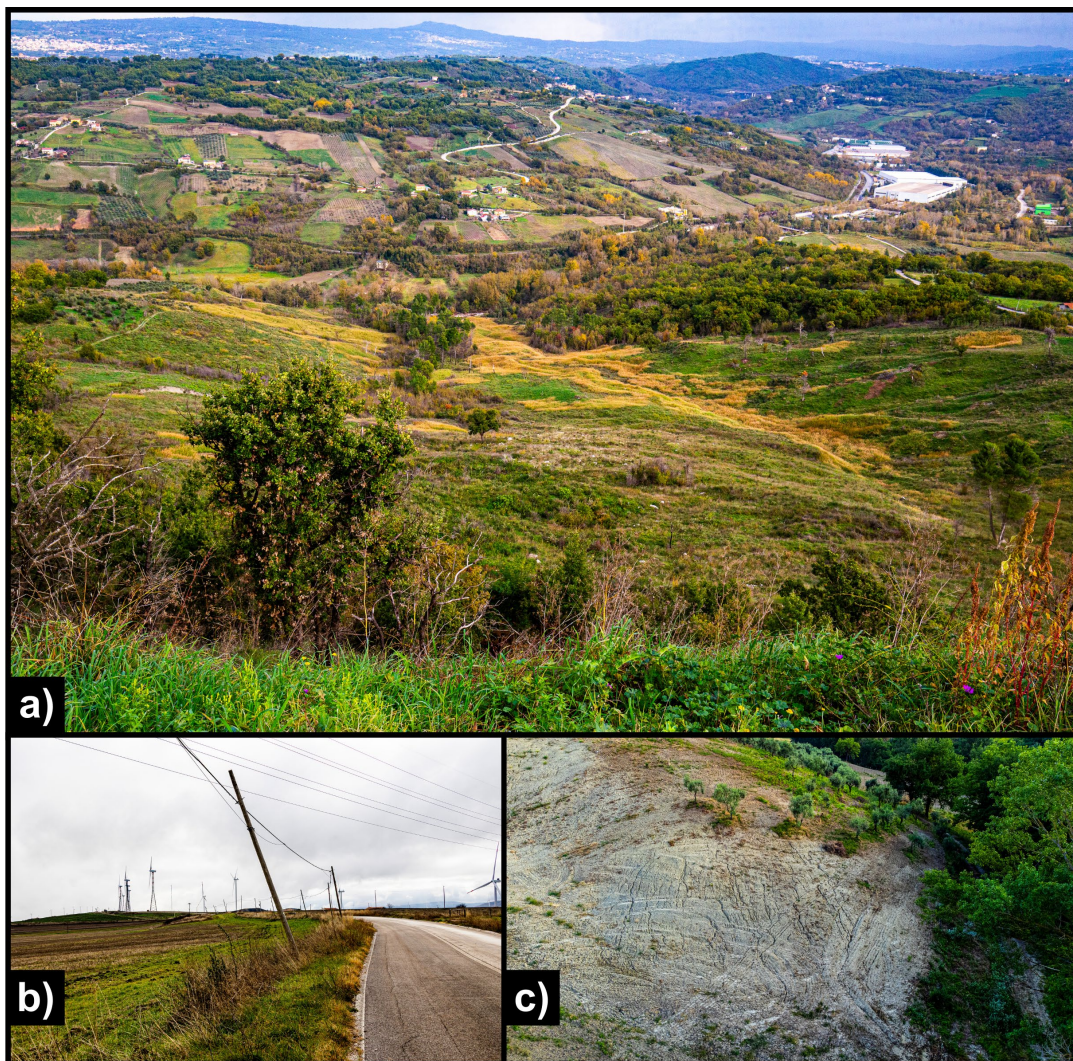


Figure 70 - a) Landslide slope within the municipality of Lapio, b) slope affected by slow regolith movements near Monteverde, c) slope affected by rill erosion near Montefusco.

The settlements are small in size and are distributed in a scattered or isolated pattern, predominantly occupying ridge positions or hilltop summits. This spatial arrangement reflects historical choices linked to defensive needs and adaptation to morphological constraints, with settlement structures that preserve features typical of Apennine territorial organization (Fig. 72).

A site of remarkable relevance and interest within this landscape unit is the Mefite in the Ansanto Valley, near the village of Rocca San Felice, as it represents a geosite of exceptional scientific and cultural value (Sisto et al., 2020). Since antiquity, this locality was dedicated to the worship of the ancient Italic goddess Mephitis, deity of fertility and mediator between opposing realms – life and death, sky and earth (Prosdocimi, 2006). The site hosts lethal mofetic emissions and poisonous sulfurous waters and has, throughout history and through various vicissitudes, served as a place of worship (Torelli, 1990) for the different civilizations that inhabited these territories.

The Vallone dei Bagni, where the Mefite is located (Fig. 73), is incised along the right flank of the Fredane River and hosts a system of hyper-acid gas emissions (CO_2 and H_2S), which attest to the persistence of deep hydrothermal circuits. The lethal fluids ascend along major active tectonic lineaments.



Figure 71 - a) Aerial view illustrating the various land-use types within this Landscape Unit, b) detail of a vineyard-cultivated slope within the *Taurasi* DOCG terroir, c) the town of Castelfranci seen from one of the many vineyard-covered slopes.



Figure 72 - Aerial view of the ridge on which the town of Montefusco is located.

These exhalation phenomena, similar to those observed at the Solfatara of Pozzuoli and in Yellowstone National Park (Wyoming, U.S.A.), are, however, not of volcanic origin, and this has led numerous scientists to devote studies of various kinds to the site in an attempt to explain its genesis, which remains debated and controversial to this day (Gordon et al., 2012). Despite the scientific, naturalistic, and historical-archaeological interest that attracts many visitors to the Mefite site, it still suffers from a lack of protection and geoconservation policies, with interventions insufficient to mitigate risks and enhance its accessibility and valorization.



Figure 73 - The Mefite site in the Ansanto Valley and the Vallone dei Bagni.

UdP 5 – Landscape Unit of the Sandy–Conglomeratic and Clayey Hills

This unit is characterized by a hilly landscape (Fig. 74) that develops predominantly at elevations between 250 and 600 m a.s.l., forming an intermediate altimetric belt between valley plains and mountainous areas. The hillslopes generally exhibit concave profiles, with slopes that sometimes decrease abruptly: inclinations close to 30° in the summit sectors transition to values below 10° at the base, where the reliefs frequently merge with alluvial valley floors.



Figure 74 - Morphological features of the hilly landscape near the Atella *fiumara*.

The slope exposure is evenly distributed between northern and southern aspects, contributing to a relative microclimatic homogeneity. The hilltops are mostly rounded and convex, although broad sub-planar surfaces are not uncommon; these are sometimes interpreted as orographic terraces, remnants of ancient subaerial erosion surfaces.

From a lithological perspective, the substrate consists predominantly of a regressive succession of clayey-arenaceous, sandy, and conglomeratic sediments deposited in transitional, mainly deltaic environments. The sedimentary facies document shallow continental-shelf settings alternating with fluvio-alluvial systems and marine beach environments (Fig. 75), as highlighted by sedimentological and stratigraphic studies conducted in the area (D'Argenio et al., 1975, Chiocchini et al., 1992, Ascione et al., 2012, Vitale & Ciarcia, 2013, Giannandrea et al., 2014) (Fig. 76).

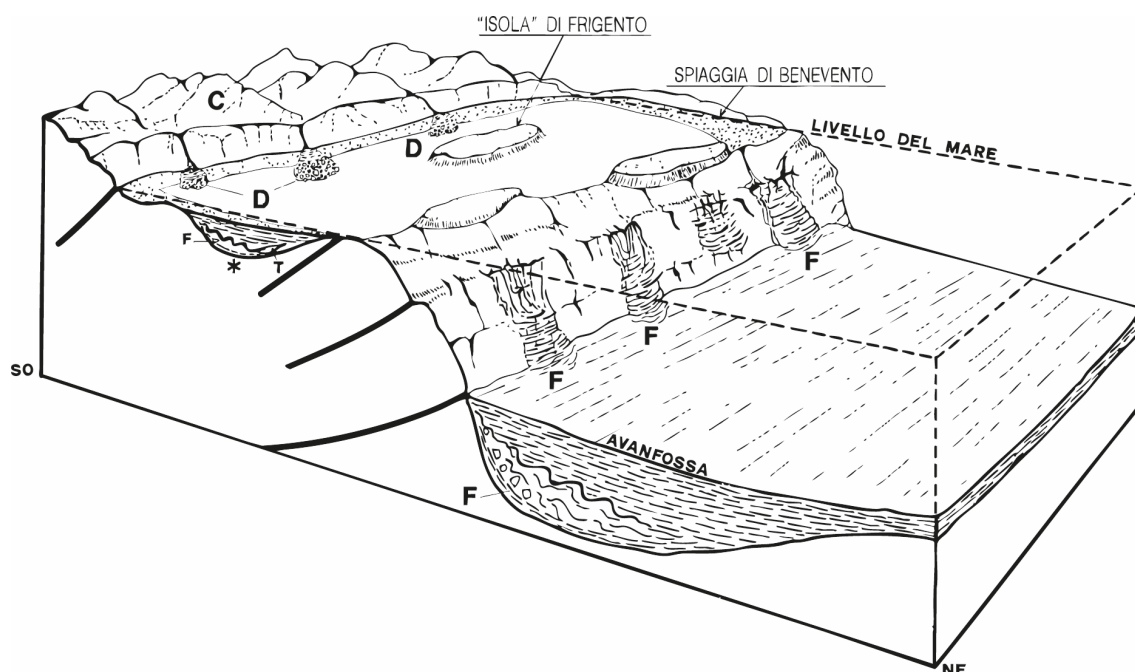


Figure 75 - Palaeogeographic sketch of the depositional environment of the Pliocene sedimentary cycle forming the geo-lithological units of LU 5 near Guardia Lombardi (after Chiocchini et al., 1992).

Legend: C) Apennine Chain, D) Delta systems, F) Submarine landslides, T) Turbidites.

The hydrographic network is overall poorly developed, with medium-to-low drainage density and moderate hierarchization, particularly where sandy-conglomeratic lithologies prevail. Conversely, clayey-marly formations promote higher drainage density and a more structured hydrographic network, with the occurrence of badland (calanchi) phenomena in some areas, indicative of surface instability and accelerated erosion.

Gravitational instability processes (landslides and rockfalls) are generally superficial and of limited magnitude. More widespread are areal gravitational movements affecting the regolith cover, which is poorly developed and discontinuous, with low moisture-retention capacity and limited pedogenetic evolution (Budetta et al., 1990) (Fig. 77).

Climatic conditions are characterized by a modest annual thermal excursion, below 8 °C, and by a mean annual precipitation of approximately 900 mm, with a relatively uniform distribution throughout the year. These conditions favor a discontinuous vegetation cover, with soils predominantly classifiable as Regosols, Lithosols, and Inceptisols, all weakly developed and with limited water-retention capacity.

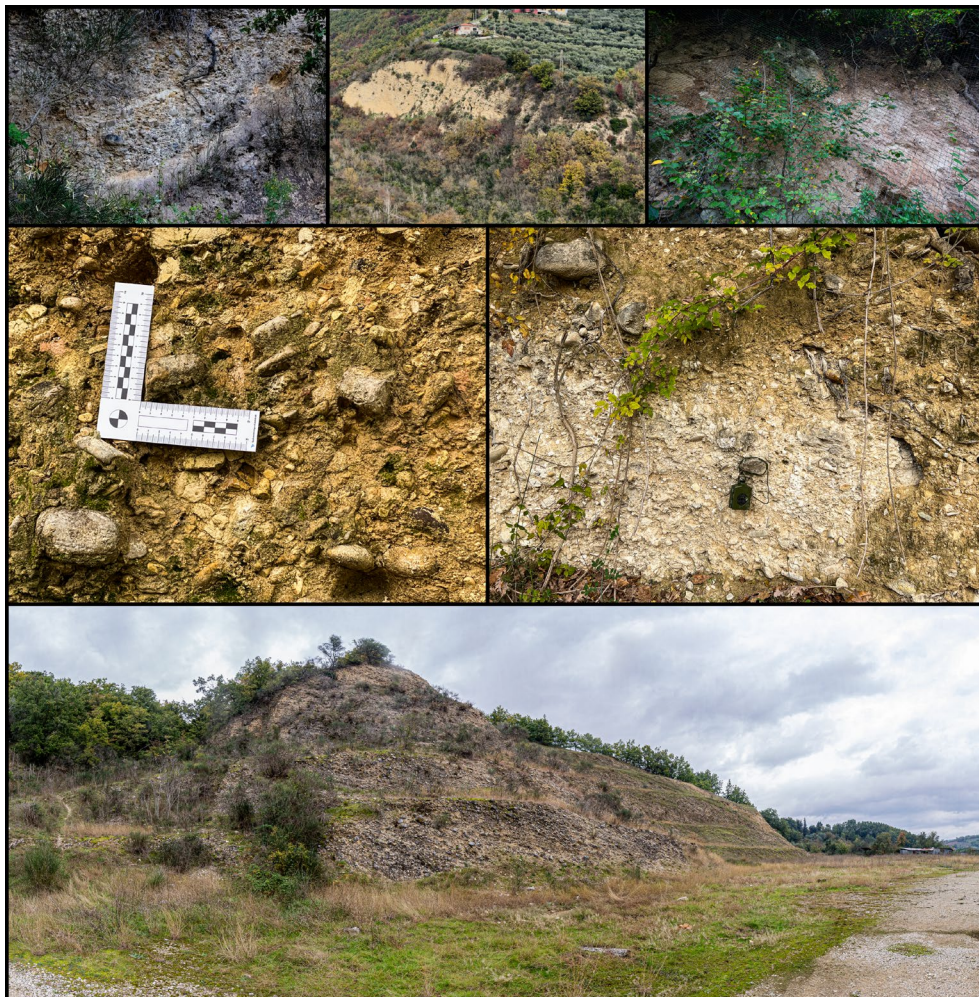


Figure 76 - Outcrops of the lithologies characteristic of Landscape Unit 5, belonging to the Pliocene sedimentary cycle, observed in the areas of Lapio, Luogosano, Taurasi and Santa Paolina.

Land-use is highly diversified: sparse woodland and shrubland alternate with non-irrigated arable land, cereal crops, vineyards, orchards, and olive groves. Of particular relevance is the production of

the “Vulture” PDO Extra-Virgin Olive Oil, one of the region’s most renowned agri-food excellences (Fig. 78).

The settlements are sparsely distributed and characterized by low population density. They are predominantly located along ridgelines or on leveled hilltop summits, occupying strategic positions that historically ensured natural defense, territorial visibility, and access to agricultural resources (Fig. 79).



Figure 77 - Various types of slope instability affecting LU 5: a) Collapse in Pliocene sands, b–c) Badland erosion at the confluence of the Atella *fiumara* with the Ofanto River. The red line marks the contact between Pliocene clays (below) and Pliocene conglomerates (above), also highlighted by the vegetation change.



Figure 78 - Typical land-use pattern within Landscape Unit 5.



Figure 79 - The town of Cairano perched atop the hilly relief.

UdP 6 – Landscape Unit of the Valley Floors and Alluvial Plains

Landscape Unit 6 is characterized by the typical valley-floor morphology that develops at the foot of the Apennine reliefs, generally at elevations below 300 m a.s.l., forming a characteristic intramontane valley system (Fig. 80).



Figure 80 - Aerial view of a stretch of the Calore River between the municipalities of Lapio and Taurasi.

Within the study area, this Landscape Unit owes its morphological configuration to the combined action of the three main watercourses that traverse it: the Ofanto River, the Calore River, and the Sabato River (Brancaccio, 1969). These fluvial systems have incised the geological substrate, generating broad alluvial plains, partly terraced, which host Quaternary deposits of varying grain size. The morphological setting is further conditioned by the presence of hydraulic infrastructures of significant impact, such as artificial levees, dams, weirs, and reclamation canals.

From a topographic perspective, the landscape is predominantly sub-planar, with local discontinuities represented by narrow fluvial incisions (gorges) and active erosional scarps (Fig. 81), which attest to a fluvial system still undergoing morphological evolution.



Figure 81 - Fluvial erosion scarp with slope retreat, observed at Ischia della Spina (Taurasi) along the Calore River.

The exposed lithology consists of loose gravelly–sandy sediments (Fig. 82), locally interbedded with clay layers, as well as sporadic travertine outcrops. These deposits are of Quaternary age, with Pleistocene sediments prevailing in the terraced piedmont sectors and Holocene deposits characterizing the true valley-floor areas. The stratigraphy reveals depositional cycles linked to climatic and tectonic variations, with discontinuity surfaces marking phases of stasis or erosion.



Figure 82 - a) Gravel bed of the Calore River near Ponte della Lavandaia (Montella), b) detail of a gravel bar along the Ofanto River at Ponte Santa Venere.



Figure 83 - a) Aerial view of a meander of the Calore River showing typical features of active fluvial dynamics: erosion of the concave bank with slope retreat, erosion of the point bar with chute channels on the convex bank, b) formation of a gravel bar downstream of a check dam along the Calore River at Fontana di Castelvete



Figure 84 - c) bank erosion along the Ofanto River near Monticchio, incised into the quartzose sandstones of the Numidian Flysch.

The hydrographic network exhibits medium-to-high drainage density, with morphogenesis dominated by alluvial processes (alluvial fans, fluvial terraces) (Fig. 84) and fluvial dynamics (meandering and braided channels, fluvial islands, floodplain areas, etc.; Figs. 83a, b). Among the main hydraulic regulation structures, the reservoir on the Ofanto River (Conza della Campania Dam; Fig. 85) and the reservoir on the Osento Stream (Lake San Pietro) are noteworthy, both of which contribute to environmental settings of high ecological and landscape value.



Figure 85 - Terraced surfaces of fluvial origin in the Ofanto River valley.

The climatic regime of the area is temperate sub-humid, with a limited annual thermal excursion (10–13 °C) and precipitation ranging from 900 mm/year in the Ofanto Valley to 1300 mm/year in the Calore Valley. These conditions ensure good water availability and significantly influence pedogenetic processes.

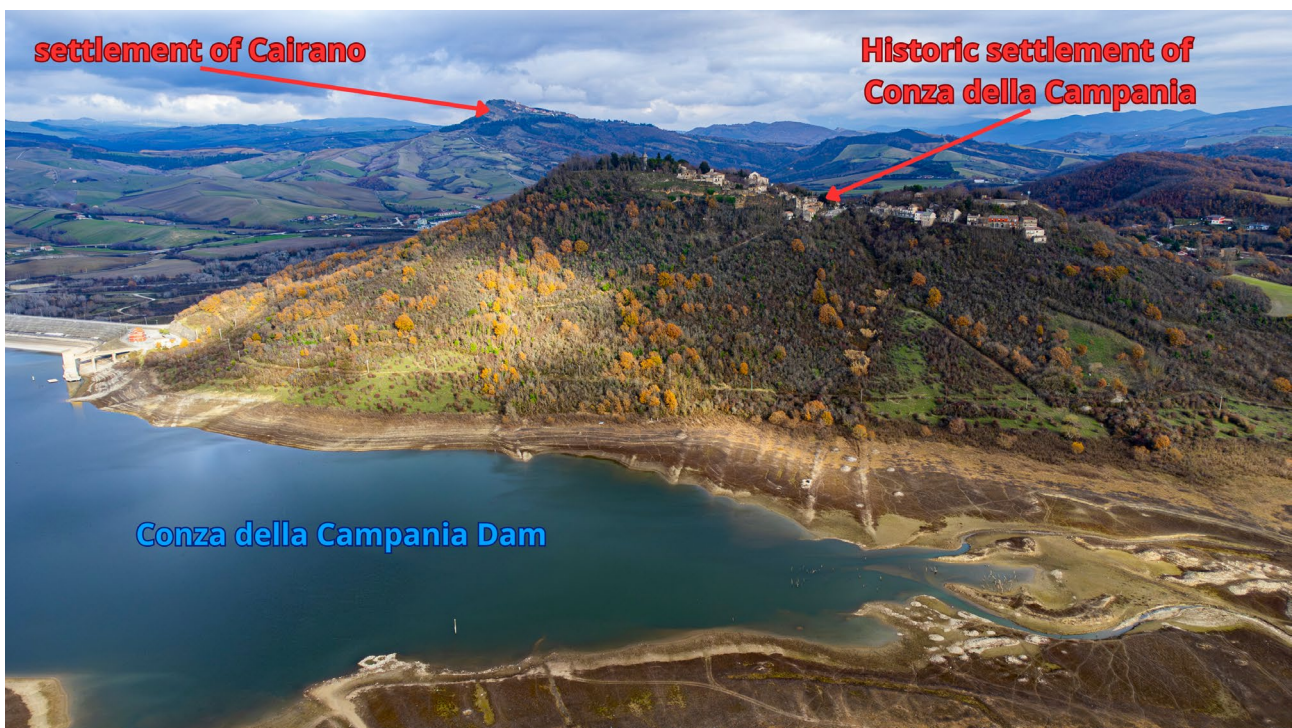


Figure 86 - Aerial view of the Conza della Campania dam. In the foreground lies the old settlement of Conza della Campania, while in the background the monocline hosting the town of Cairano stands out.

The soils are predominantly weakly developed (Inceptisols), although more mature units also occur depending on topographic position and hydrological regime, including Luvisols, Mollisols, and hydromorphic soils. The predominantly loam or silt-loam texture, combined with favorable moisture conditions, makes these soils particularly suitable for intensive agriculture. Widespread crops include horticultural and cereal cultivations, irrigated arable land, orchards, and citrus groves. Viticulture is of particular importance, with controlled and guaranteed designation of origin labels (Taurasi DOCG, Fiano di Avellino DOCG, Greco di Tufo DOCG), as well as olive cultivation, producing the

renowned Ravece extra-virgin olive oil, appreciated for its high organoleptic quality (Fig. 86) (Cusano et al., 2022, Cusano et al., 2025).



Figure 87 - Landscape features of agricultural land-use along the Calore River valley: a) Taurasi DOCG vineyard near Avellino, b) non-irrigated arable field.

From a settlement perspective, the area is suitable for diffuse urbanization, with medium- and large-sized urban agglomerations (Avellino, Atripalda, Serino) developing along historical infrastructural routes. These road axes, active since antiquity, form a strategic corridor between the Tyrrhenian side and the Adriatic and Ionian sectors, conferring upon the study area a pivotal territorial and functional role (Fig. 87).



Figure 88 - a) Hannibal's Bridge at Spineto (San Mango sul Calore) along the Calore River, b) Roman Bridge along the Ofanto River at Alifano (Lioni).

4.5 ANALYSIS AND DATA PROCESSING FOR THE DETERMINATION OF GEODIVERSITY

As previously discussed, the Geodiversity of a territory refers to the variety of geological, geomorphological, hydrological, and soil–land-use elements present within an area, recognized as fundamental components for environmental conservation (Sharples, 2002a). The following sections present the results of the procedures described earlier (see § 3.2.8), which led to the estimation of the four components of Geodiversity.

4.5.1 Geo-lithological variability index (Geoi)

The statistical analysis of the results related to the Geo-lithological Variability Index (Fig. 89) reveals a structured distribution. The “Medium” class is the most represented, accounting for 30.56% of the cells, followed by the “Low” class (27.50%). Together, these two categories cover 58.06% of the area, indicating that most cells exhibit moderate geo-lithological variability, meaning the coexistence of multiple lithotypes without reaching high levels of complexity. The extreme classes (“Very Low” and “Very High”) constitute only 23.05%, suggesting that cells characterized by strongly homogeneous or strongly heterogeneous lithology are less widespread and likely confined to specific geological contexts.

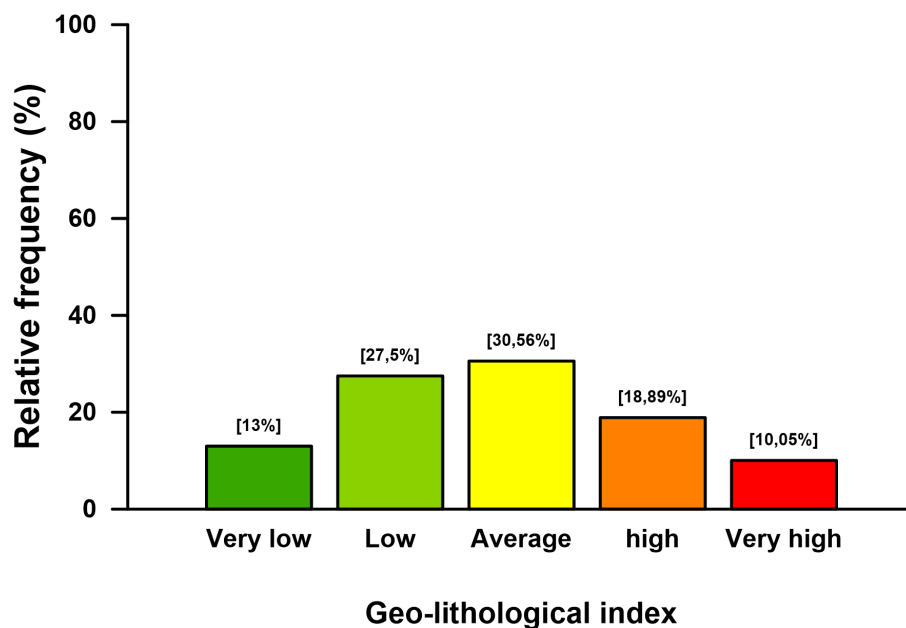


Figure 89 - Statistical distribution of the Geo-lithological Index.

The distribution exhibits a slight negative skewness, with a higher incidence of low-variability classes (“very low” + “low” = 40.50%) compared to high-variability classes (“high” + “very high” = 28.94%). This pattern suggests that the study area is dominated by relatively homogeneous geo-lithological complexes, consistent with well-stratified sedimentary bodies (Geo-lithological Complex P), coherent turbiditic successions (Geo-lithological Complex AV), and tectonic units with limited lithological mixing (Geo-lithological Complex CD). This lithological homogeneity is clearly observable within the Ofanto piggy-back basin, where the P and AV geo-lithological complexes predominate. Conversely, cells characterized by “High” and “Very High” lithological index values

correspond to portions of the territory marked by pronounced geological heterogeneity. A representative example is the area surrounding the settlement of Taurasi (Fig. 90), where the coexistence of numerous distinct geo-lithological complexes is evident.

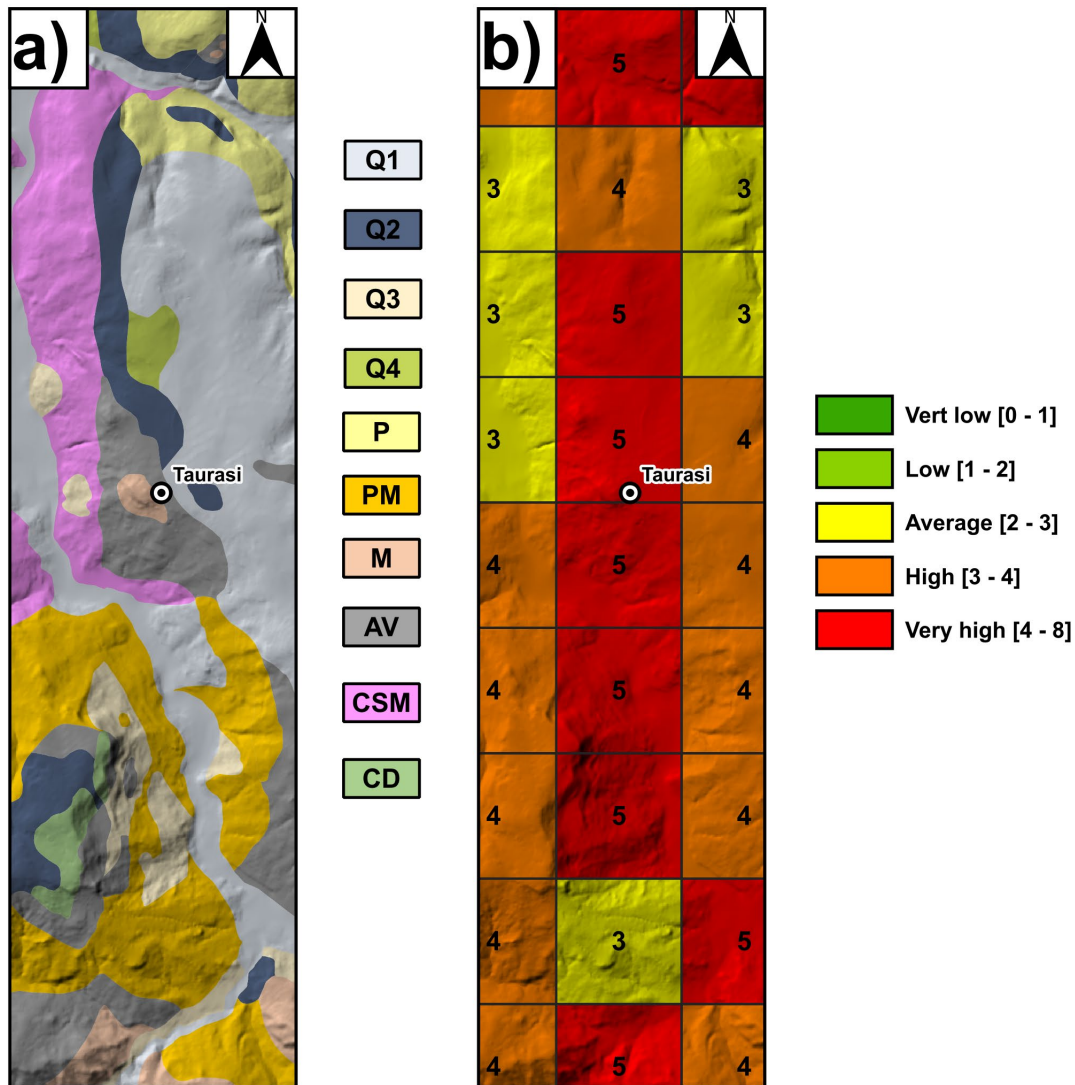


Figure 90 - a) Geo-lithological complexes cropping out in the study area, b) variation of the Geo-lithological Index.

In particular, Quaternary deposits belonging to the detrital Quaternary complex (Q1, Q2, Q3, Q4), units attributable to the Geo-lithological Complex P, terrains associated with Complex M, as well as lithotypes referable to Complexes AV and CSM, are present. This superposition of different lithologies, distributed within a relatively restricted area, contributes significantly to the high value of the geo-lithological index. Adding to this complexity is the presence of a high number of faults, which further accentuate geo-lithological fragmentation and the lithological variability of the sedimentary successions exposed in the study area. The intersection between tectonic elements and distinct lithological units generates a geological mosaic characterized by high diversity, consistent with the maximum index values recorded in this portion of the territory.

4.5.2 Hydrogeological variability index (Hydroi)

The statistical analysis of the results related to the Hydrogeological Variability Index reveals a non-uniform distribution, with a clear predominance of intermediate and low classes (Fig. 91).

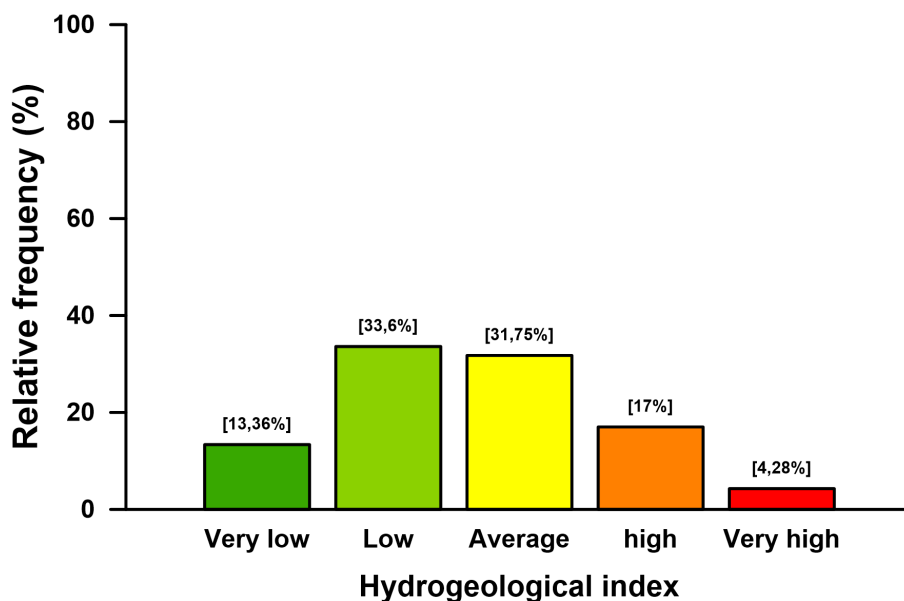


Figure 91 - Statistical distribution of the Hydrogeological Index.

More specifically, the “Low” class is the most represented (33.60%), followed by the “Medium” class (31.75%), whereas the “High” and “Very High” classes account for 17.00% and 4.28% of the total, respectively. The “Very Low” class represents 13.36%.

The integrated analysis of geo-lithological and hydrogeological complexes highlights a significant correlation between geo-lithological variability indices and hydrogeological variability indices. Areas characterized by greater geo-lithological homogeneity tend to correspond to more uniform hydrogeological complexes, whereas those exhibiting high geo-lithological complexity show a more pronounced hydraulic fragmentation.

4.5.3 Soil and Land-Use variability index (Slui)

The statistical analysis of the data related to the Soil and Land-Use Variability Index highlights (Fig. 92) a clear predominance of the lower classes, with 56.96% of the cells falling within the “Very Low” category and 21.20% within the “Low” category, for a total of 78.16% of the area. This indicates that most of the analysed territory is characterized by low variability in this index, which reflects limited land-use intensity, low anthropogenic pressure, and a relative preservation of the physical and chemical properties of the soils.

The “Medium” class accounts for 13.23% of the cells, whereas the “High” (4.56%) and “Very High” (4.04%) classes are marginal. This suggests that areas subjected to more intensive land-use and greater pedological variability are scarce and likely confined to specific environmental or anthropogenic contexts.

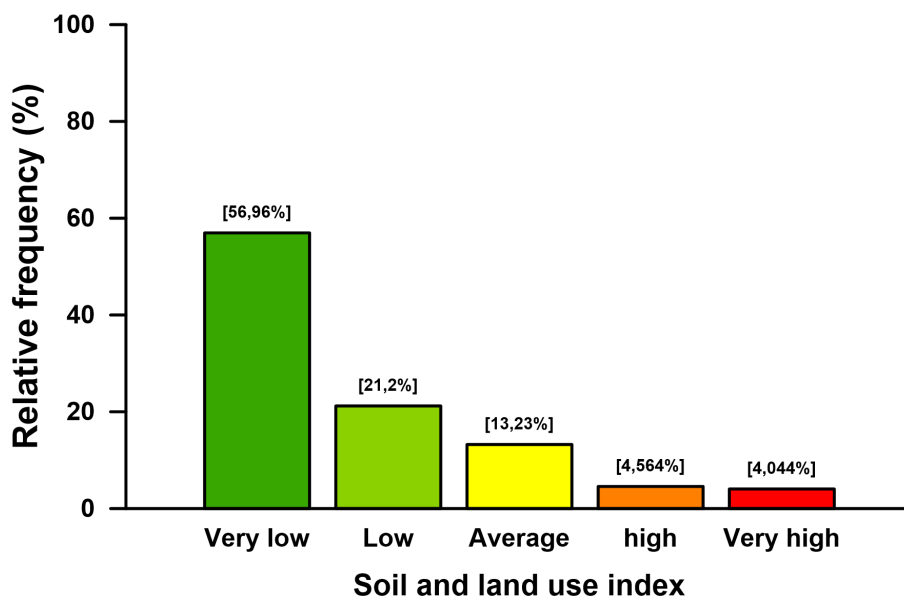


Figure 92 - Statistical distribution of the Soil and Land-use Index.

4.5.4 Geomorphological variability index (Geomi)

The statistical analysis conducted on a total of 1,731 cells produced a distribution of the Geomi values articulated into five classes of morphological variability (Fig. 93): very low, low, medium, high, and very high. The results show a predominance of intermediate classes, with 31.43% of the cells falling within the “Medium” class and 25.90% within the “Low” class. The “High” and “Very High” classes represent 23.92% and 11.55%, respectively, whereas the “Very Low” class accounts for only 7.22%.

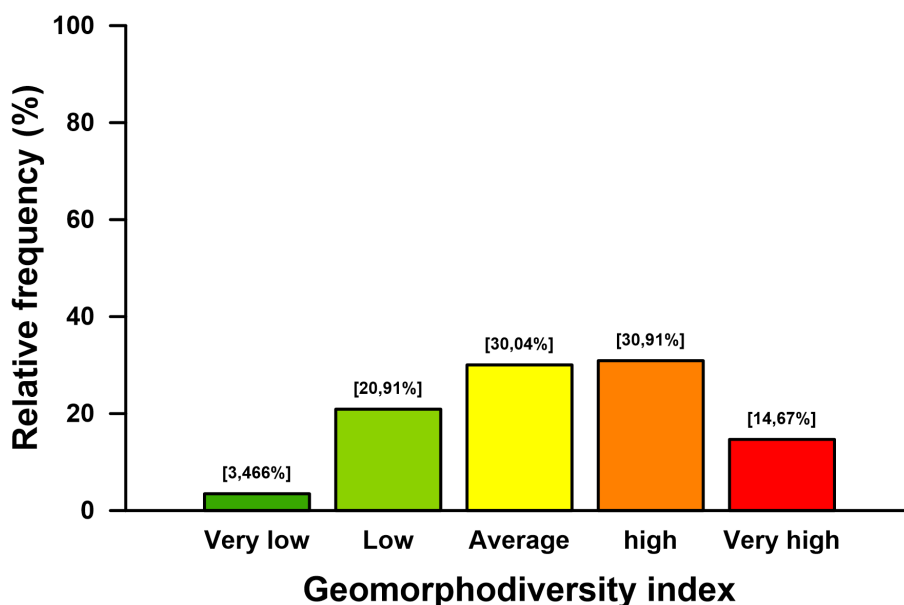


Figure 93 - Statistical distribution of the geomorphological index.

The skewness index calculated for the distribution is -0.29 , indicating a slight negative asymmetry, with a tendency toward moderate values and a tail extending toward the higher classes. The standard deviation, equal to 1.17 , highlights a significant morphological variability within the analysed area, confirming the presence of an articulated and geologically heterogeneous landscape.

This distribution reflects a predominantly moderate morphological variability, with localized sectors where the high relief energy and the potential instability of slopes contribute to enhancing morphotopographic heterogeneity.

4.6 ANALYSIS AND DATA PROCESSING FOR THE DETERMINATION OF GEOMORPHODIVERSITY

As previously discussed (see § 3.2.9), the Geomorphodiversity of a territory refers to the variety of landforms and the processes that shape them, occurring within a given area and recognized as fundamental components for environmental conservation (Reynard & Coratza, 2013, Sharples, 2002a). The following sections present the results of the procedures described earlier (see § 3.2.9.1), which led to the estimation of the four components of Geomorphodiversity.

4.6.1 Slope variability index (Sp)

The statistical analysis conducted on a total of 1,731 cells produced a distribution of Sp values articulated into five classes of slope-variability (Fig. 94): very low, low, medium, high, and very high.

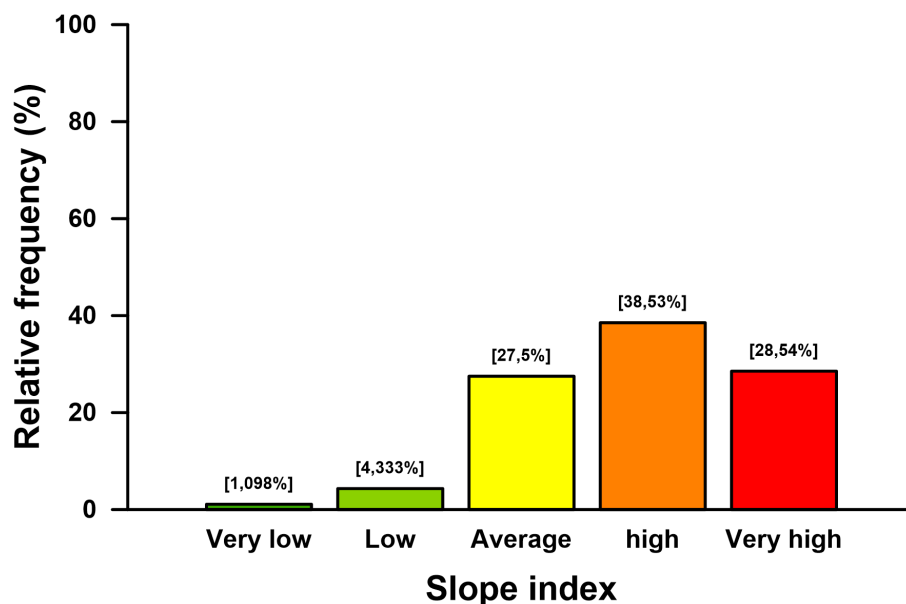


Figure 94 - Statistical distribution of the Slope Index.

4.6.2 Drainage density variability index (Dd)

The statistical analysis of the results related to the Drainage Density Variability Index (Fig. 95) shows that Class 3 (Average) is the most represented, covering 41.48% of the area, followed by Class 4 (High) with 36.40% and Class 2 (Low) with 9.76%. Together, these three categories account for nearly 88% of the analysed territory, indicating that most cells exhibit medium-to-high drainage density values, typical of landscapes characterized by a widespread and well-developed hydrographic network.

The extreme classes, Very Low and Very High, together represent only 12.36% of the area, suggesting that surfaces with very low or very high drainage density are less common and likely confined to specific morphological contexts: the former in flat or alluvial-deposit areas, the latter in mountainous sectors or in lithologies more susceptible to erosion.

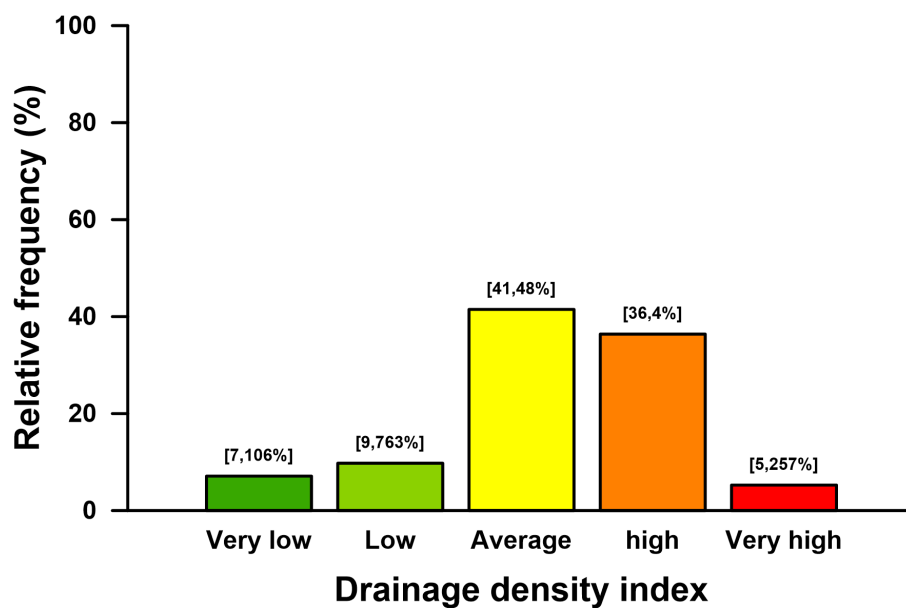


Figure 95 - Statistical distribution of the drainage density index.

PART V

RESULTS AND INTERPRETATION OF THE DATA

The following pages describe the main results obtained from the procedures and analytical processing through which, in the previous section, the collected data concerning the territory of the study area were examined. Where possible, these descriptions will be accompanied by an initial, logically consistent interpretation of their significance with respect to the objectives originally set by this research.

5.1 RESULTS OF DATA PROCESSING FOR THE DETERMINATION OF GEODIVERSITY

Following the determination and representation of the indices of the components characterizing the Geodiversity of the study area, processed according to the quantitative model proposed by Ferrando et al. (2021), the analysis proceeded, in continuity with the previous evaluations, to the quantification and integrated cartographic representation of the Geodiversity Index (Gdi), shown in Fig. 96.

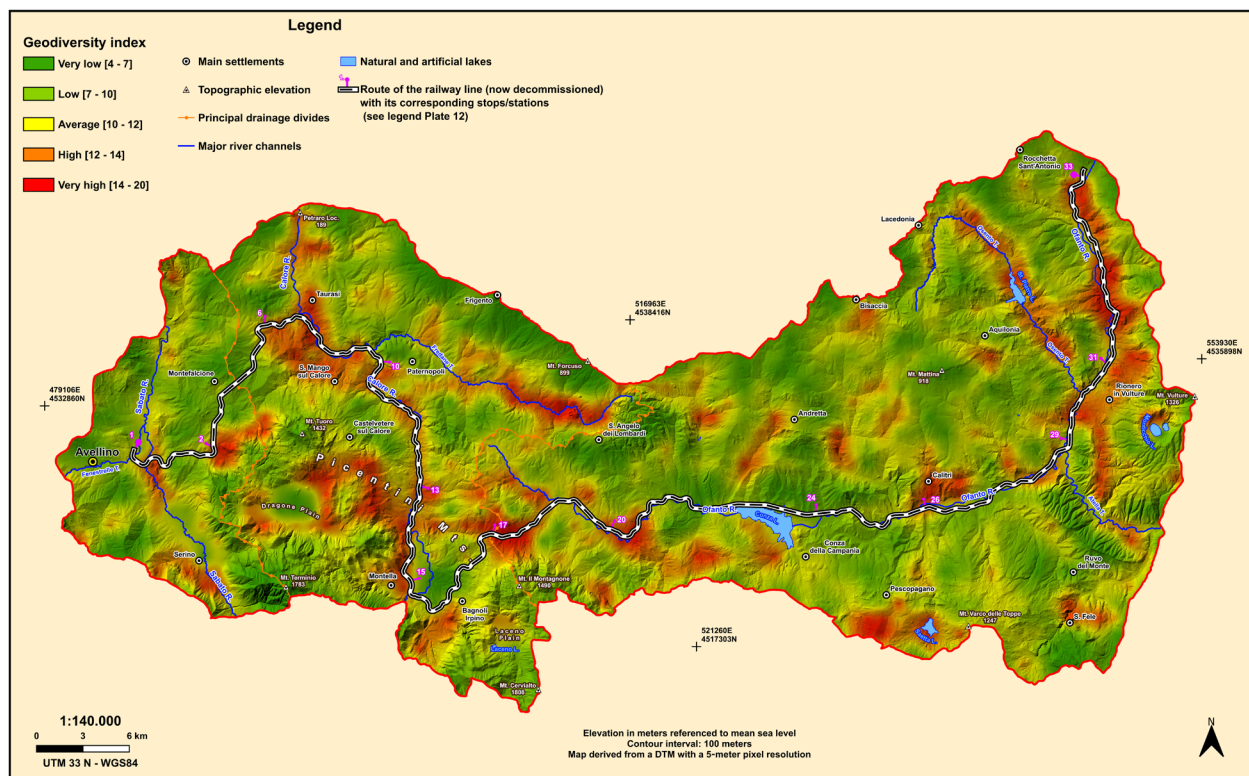


Figure 96 - Map of the Geodiversity Index for the study area (see Plate 20).

The statistical analysis conducted on 1,731 cells (Fig. 97) highlights a structured distribution of the aggregated Geodiversity Index. The “Low” (35.70%) and “Medium” (24.49%) classes are predominant, followed by the “Very Low” class (17.39%). The “High” and “Very High” classes account for 14.10% and 8.32% of the total area, respectively.

This distribution suggests a predominance of environmental conditions characterized by moderate complexity, with a significant tail extending toward the upper classes, indicative of the presence of sectors exhibiting high geological diversity.

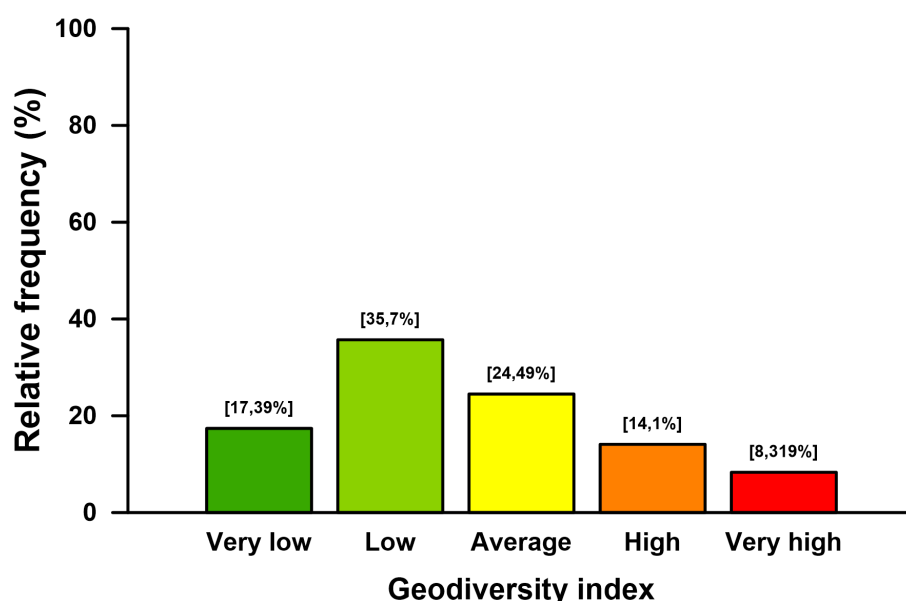


Figure 97 - Statistical distribution of the Geodiversity Index.

To obtain a comprehensive understanding of the structure of Geodiversity within the study area, a linear correlation matrix (Tab. 16) was employed. This analytical tool enables the assessment of the degree of association among the thematic indices (Geo_i – Geo-litological Index, $Hydro_i$ – Hydrological Index, $Geom_i$ – Geomorphological Index, and Slu_i – Soil and Land-use Index) included in the formulation of the Geodiversity Index, thereby highlighting functional relationships and internal dependencies among the environmental variables.

	Geo_i	$Hydro_i$	$Geom_i$	Slu_i
Geo_i	1.000	0.913	0.068	0.051
$Hydro_i$	0.913	1.000	0.109	0.104
$Geom_i$	0.068	0.109	1.000	0.151
Slu_i	0.051	0.104	0.151	1.000

Table 16 - Linear correlation matrix among the four thematic indices.

The results of the correlation matrix, obtained through the computation of linear correlations based on Pearson's r coefficient in the R environment, delineate a hierarchical structure among the thematic indices of Geodiversity. The strong correlation between lithology and hydrogeology ($r = 0.913$) indicates that rock composition directly conditions the hydrological properties of the substrate, thereby defining a dominant geological axis. Conversely, correlations with the geomorphological index are weak ($r < 0.15$), suggesting that landform morphology develops in a relatively autonomous manner with respect to lithological and hydrogeological parameters.

The highest correlation between $Geom_i$ and Slu_i ($r = 0.151$) reflects a partial influence of morphology on anthropogenic land-use and territorial organization, whereas the relationships between Slu_i and the Geo_i ($r = 0.051$) and $Hydro_i$ ($r = 0.104$) indices are negligible.

Overall, geo-lithological complexes emerge as the primary drivers of Geodiversity within the study area, while the remaining thematic indices play a clearly secondary or marginal role.

5.2 RESULTS OF DATA PROCESSING FOR THE DETERMINATION OF GEOMORPHODIVERSITY

Following the determination and representation of the indices describing the components that characterize the Geomorphodiversity of the study area, processed according to the quantitative model proposed by Burnelli et al. (2023), the analysis proceeded, in continuity with the previous evaluations, to the quantification and integrated cartographic representation of the Geomorphodiversity Index (GmI), shown in Fig. 98.

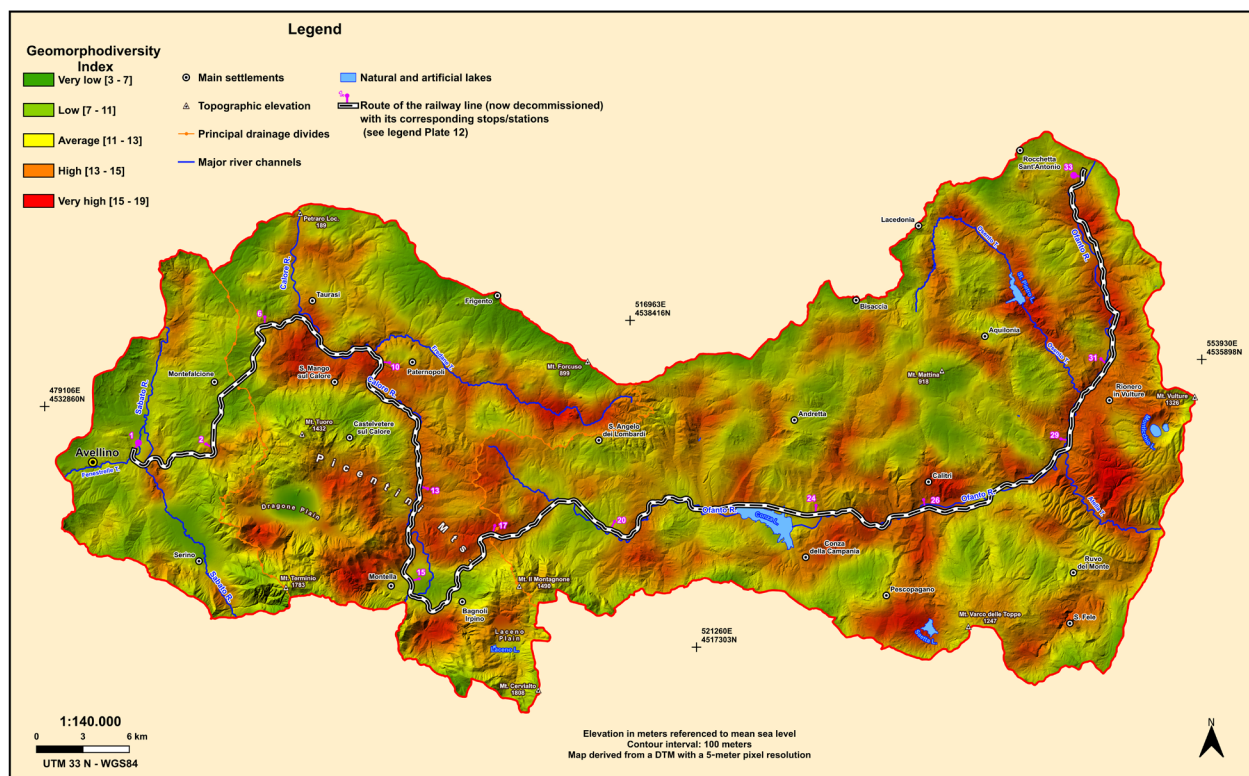


Figure 98 - Map of the Geomorphodiversity Index for the study area (see Plate 22).

The spatial distribution of the Geomorphodiversity Index, presented in cartographic form (Fig. 97), not only quantitatively documents the morphological complexity of the landscape but also provides useful comparisons among the various indices and insights into the modelling effectiveness of morphogenetic processes.

The statistical analysis (Fig. 99) highlights a balanced distribution of the GmI. Class 4 (High) is the most extensive, covering 30.91% of the area, followed by Class 3 (Average) with 30.04% and Class 2 (Low) with 20.91%. Altogether, these three categories account for more than 80% of the territory, indicating a predominance of medium-to-high geomorphological diversity values, typical of hilly landscapes and relatively uniform slopes. The extreme classes, Class 1 (Very low) and Class 5 (Very high), together represent only 18.14%.

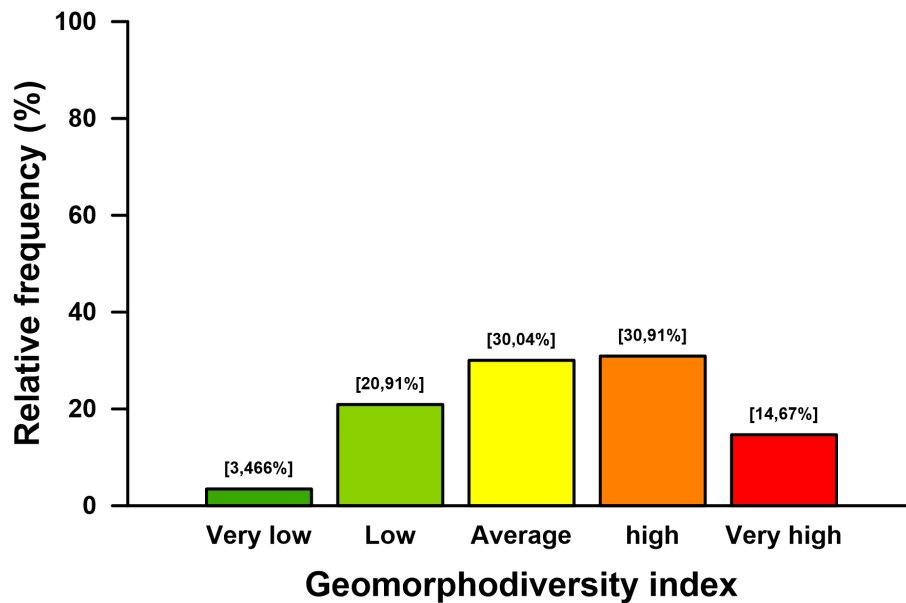


Figure 99 - Statistical distribution of the Geomorphodiversity Index.

From a geomorphological perspective, the lowest classes (Very low and Low) identify homogeneous and flat surfaces, typical of alluvial depositional areas or leveled erosional surfaces. Class Average, which alone covers approximately one third of the territory, represents transitional hilly landscapes in which erosional processes are active but not extreme. The highest classes (High and Very high) correspond instead to heterogeneous and highly dissected slopes, characterized by steep gradients and vulnerable substrates, where the morphological configuration is strongly influenced by the geo-lithological framework.

Overall, the distribution of the GmI depicts a predominantly hilly landscape, characterized by regular landforms and a well-structured geomorphological diversity. Class High, the most widespread, represents the defining feature of the territory: a mosaic of intermediate morphologies that connect the plains to the uplands.

To obtain a comprehensive understanding of the spatial structure of Geomorphodiversity within the study area, a linear correlation matrix (Tab. 18) was employed. This analytical tool enables the assessment of the degree of association among the thematic indices, highlighting functional relationships and internal dependencies among the environmental variables.

	Sp	Dd	Li	Gm
Sp	1.000	0.247	0.091	0.497
Dd	0.247	1.000	0.188	0.561
Li	0.091	0.188	1.000	0.546
Gm	0.497	0.561	0.546	1.000

Table 18 - Linear correlation matrix among the four thematic indices determining geomorphodiversity.

The analysis of the correlation matrix, derived from the computation of linear correlations among the various indices based on Pearson's r coefficient in the R environment, reveals a pattern of positive associations among the considered variables, with intensities ranging from weak to moderate. In particular, geomorphodiversity shows the strongest correlation with drainage density (0.561), followed by lithology (0.546) and slope (0.497). Conversely, the relationships among the indices themselves are weak, with coefficients below 0.25. This indicates that drainage, lithology, and slope influence the overall landscape morphology in differentiated and complementary ways.

Drainage density thus emerges as a structuring factor: denser hydrographic networks intensify incision and segmentation, promoting the multiplication of micro-landforms. Lithology, through its heterogeneity in resistance and fracturing, introduces additional contrasts that diversify erosional morphogenetic processes (morphoselection). Slope, although playing a less pronounced role, contributes through its energetic gradients to increasing the dynamism of sediment transport systems and the instability of surface materials.

The interaction between drainage and lithology, although not strongly correlated, may amplify geomorphodiversity where the substrate favours incision and the hydrographic network efficiently channels runoff. The weak correlation among these indices confirms that each contributes a distinct component to the overall mosaic of geomorphodiversity.

5.3 COMPARISON BETWEEN GEODIVERSITY AND GEOMORPHODIVERSITY VALUES

The results previously presented for the Geodiversity and Geomorphodiversity indices reveal a significant variation in their values, expressed through five intensity classes (Very Low, Low, Average, High, Very High) (Fig. 100).

Geodiversity exhibits an overall decreasing trend along the gradient (red dashed line): the lower-to-middle classes (Very Low – 17.39%, Low – 35.70%, and Average – 24.49%) cover more than 77% of the territory, indicating that most cells display low to moderately low values. The High (14.10%) and Very High (8.32%) classes represent the remaining 22.46% of the area. This pattern suggests that Geodiversity is broadly and relatively uniformly distributed within the lower segments of the gradient, then progressively decreases across the moderate and high diversity classes, and finally contracts more markedly in the very high diversity class, where its incidence becomes secondary.

Geomorphodiversity, on the other hand, shows an increasing trend along the gradient (green dashed line). The upper-middle classes (Average – 30.04%, High – 30.81%, and Very High – 14.76%) collectively cover 76% of the territory, indicating that most cells exhibit medium-to-high values.

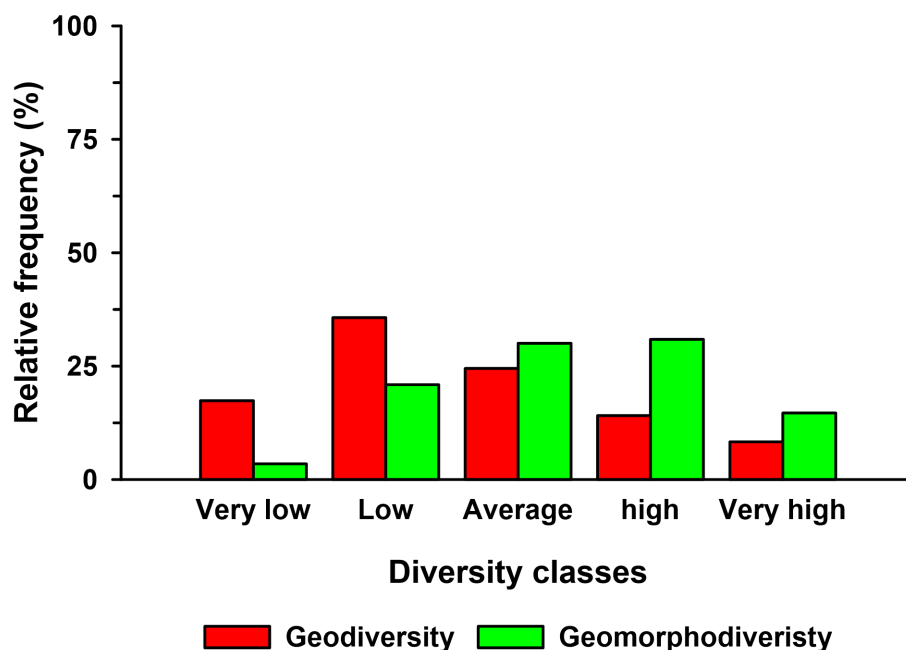


Figure 100 - Comparison between geodiversity and geomorphodiversity values in the study area.

The Very Low (3.74%) and Low (20.91%) classes represent the remaining 24.65% of the area. This pattern highlights how Geomorphodiversity tends to intensify along the gradient, reaching its maximum expression within the intermediate and high classes, before decreasing again under conditions of very high diversity. This suggests that medium-to-high levels favour the concentration of morphotypes.

The joint analysis of the two gradients reveals a clear evolution in their relationship. In the lower classes (Very Low and Low), Geodiversity prevails, since in geologically homogeneous contexts the morphological variety primarily reflects the nature of the lithotypes. The Average class represents a transitional phase in which Geomorphodiversity begins to exceed Geodiversity due to the intensification of morphogenetic processes. In the upper classes (High and Very High), Geomorphodiversity becomes dominant: the high relief energy, the dense drainage network, and the complexity of the slopes generate a multiplicity of landforms that renders the contribution of geological diversity alone marginal.

It follows that Geodiversity constitutes a fundamental factor that feeds into Geomorphodiversity, which in turn emerges as a privileged indicator of morphogenetic dynamics and landscape complexity.

5.3.1 Geodiversity and geomorphodiversity values in the western and eastern sectors of the study area

The analysis of the quantitative data derived from the Geodiversity and Geomorphodiversity indices clearly highlights the geological and geomorphological differences that characterize the western and eastern sectors of the study area.

With regard to Geodiversity (Fig. 101), the western sector shows a marked predominance of the lower-to-middle classes (Very Low – 9%, Low – 14.8%, Average – 9%), which together account for 33.6% of the total area. The High (6.53%) and Very High (3.93%) classes cover the remaining 10.46%. In the eastern sector, a similar trend is observed, although with a significant increase in the Low (20.9%) and Average (14.8%) classes. The lower-to-middle classes (Very Low – 8.4%, Low – 20.9%, Average – 14.8%) represent 44% of the total area in this sector, indicating a more articulated geological diversity.

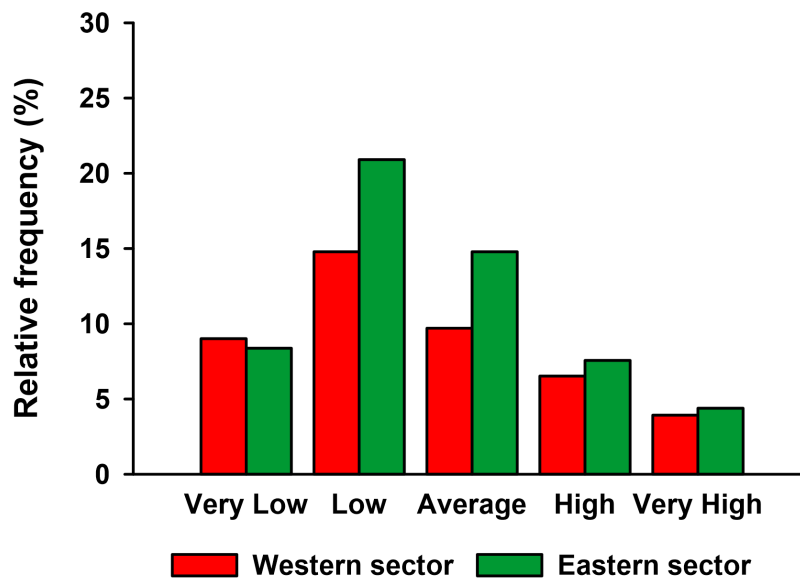


Figure 101 - Comparison of geodiversity values within the western and eastern sectors of the study area.

This distribution shows that, although the eastern sector maintains a substantial presence in the intermediate classes, it tends to extend toward higher levels, outlining a more complex and dynamic geological and geomorphological framework compared to the western sector.

Geomorphodiversity (Fig. 102) confirms and reinforces the trend already observed for Geodiversity, highlighting significant differences between the two sectors. In the western sector, the central classes (Low – 11.27%, Average – 13.63%, and High – 13.63%), which together cover 36.16% of the area, are relatively evenly distributed, while the extreme classes (Very Low – 1.91% and Very High – 5.89%) play a marginal role. This configuration suggests a varied landscape without strong polarizations, where diversity is concentrated in the intermediate classes and the conditions of highest complexity remain limited.

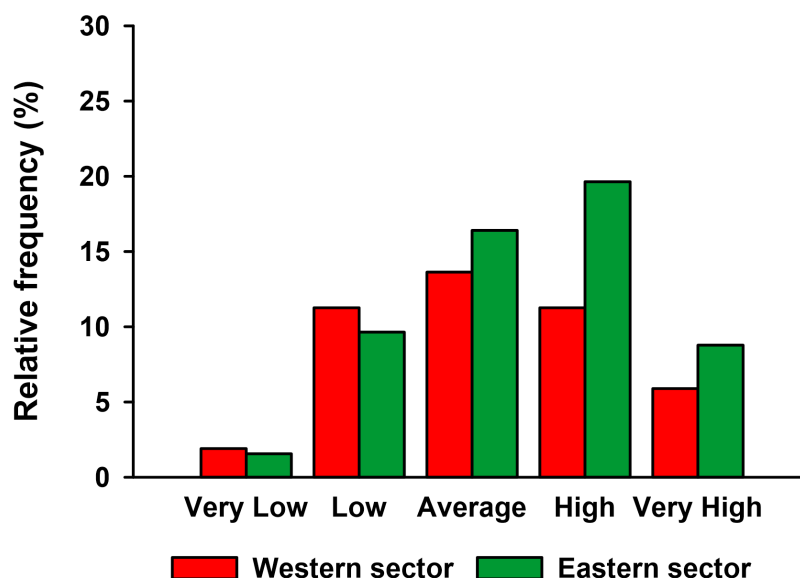


Figure 102 - Comparison of geomorphodiversity values within the western and eastern sectors of the study area.

In the eastern sector, by contrast, the situation appears more unbalanced and dynamic. The upper-middle classes dominate (Average – 16.41%, High – 19.64%, Very High – 8.78%), covering 44.83% of the area, while the lower classes are secondary. This configuration indicates that the eastern sector not only maintains a solid presence in the intermediate classes but also tends to extend toward higher levels of diversity, outlining a more complex and dynamic morphological mosaic than that of the western sector.

Overall, the comparison of the spatial distribution of Geodiversity and Geomorphodiversity in the two sectors allows for a first interpretation of the data: the western sector exhibits a more balanced distribution centred on the intermediate classes, with a moderately varied geological-geomorphological structure but without strong polarizations. Conversely, the eastern sector shows a marked tendency toward the upper-middle classes, both for Geodiversity and Geomorphodiversity, outlining a more articulated and dynamic framework.

This configuration suggests that the eastern area represents a complex environment capable of expressing a greater variety of lithological and morphological conditions and of integrating more diversified processes, whereas the western area, although displaying some degree of variability, appears as a more stable and homogeneous sector, with a lower incidence of highly complex components.

5.3.2 Geodiversity and geomorphodiversity values within the individual landscape units

The results concerning the distribution of Geodiversity and Geomorphodiversity values within the different Landscape Units (UdP) outline a complex and differentiated framework (Fig. 103).

In UdP1, corresponding to the mountainous carbonate reliefs of the Campanian Apennines, Geodiversity is moderate, with a concentration in the Low class (4.36%), whereas Geomorphodiversity exhibits higher values in the Average (4.30%) and High (3.22%) classes. This indicates a morphologically articulated landscape in which the variety of morphotypes contrasts with the homogeneity of the geo-lithological substrates.

In UdP2, representing the intermontane depression landscapes, overall diversity decreases: Geodiversity is concentrated in the Low (1.66%) and Average (1.24%) classes, while Geomorphodiversity follows a similar pattern, with higher values in the Low (1.62%) and Average (1.50%) classes. The resulting landscape is weakly articulated, with limited geo-lithological and morphological variability.

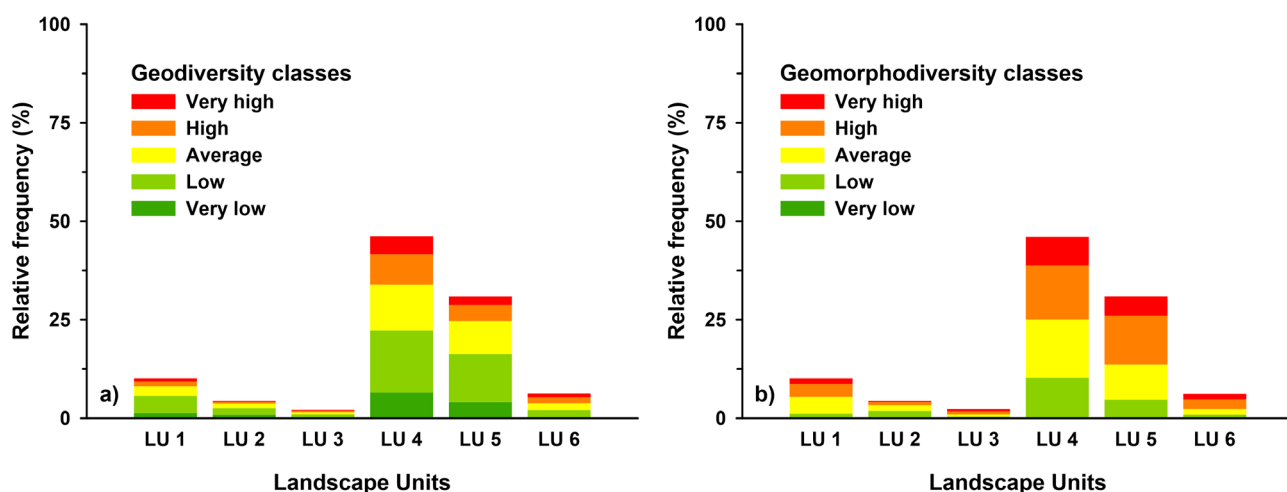


Figure 103 - Comparison between geodiversity and geomorphodiversity values within the individual Landscape Units.

This trend becomes more pronounced in UdP3, the volcanic landscape of Monte Vulture, which displays the lowest values: Geodiversity reaches a maximum of 0.79% in the Low class, and Geomorphodiversity peaks in the Average class (0.77%). This corresponds to a landscape of low complexity, with reduced geo-lithological and morphological variety.

In UdP4, the landscape of arenaceous, clayey, and marly hills, the situation changes markedly: Geodiversity is high in the Low (15.83%) and Average (11.60%) classes, while Geomorphodiversity reaches its maximum in the Average (14.83%) and High (13.67%) classes. The landscape is highly complex and heterogeneous, characterized by a mosaic of landforms and geo-lithological substrates enhanced by the morphogenetic action of multiple geomorphic processes.

UdP5 confirms this trend: the landscape of sandy-conglomeratic and clayey hills shows high values of Geodiversity (Low 12.18%, Average 8.41%) and Geomorphodiversity (High 12.38%, Average 8.95%), outlining an articulated landscape rich in diverse morphotypes, although with overall values lower than those observed in UdP4.

Finally, UdP6, representing valley floors and alluvial plains, displays intermediate values: Geodiversity is concentrated in the Average (1.81%) and High (1.48%) classes, while Geomorphodiversity reaches its maximum in the High class (2.43%). The landscape is moderately complex, with a fair degree of morphological articulation and moderate geo-lithological variety.

Overall, a clear gradient of landscape diversity emerges: UdP4 and UdP5 represent the poles of maximum complexity; UdP2 and UdP3 constitute low-diversity units, characterized by homogeneous and weakly articulated landscapes; UdP1 and UdP6 occupy an intermediate position, with moderate morphological diversity but less varied geo-lithological substrates.

PART VI

DISCUSSION OF THE DATA AND ANTHROPO-GEOGRAPHICAL IMPLICATIONS

In this final section, in addition to a necessary discussion of the performance of the quantitative models used to estimate the Geodiversity and Geomorphodiversity of the study area, the main results obtained through this research will be examined in light of the predefined objectives, particularly with regard to their significance for the enhancement of territorial georesources and their implications for the anthropo-geographical characteristics of the examined area. In this context, several important repercussions for the agro-food and cultural heritage of the region (typical products, myths and legends, etc.) will be illustrated. In particular, the potential role of the abandoned railway line as a tool for enhancing the Geodiversity of the territory and its agro-food and cultural resources will be discussed, with a view to strengthening the tourism sector and promoting the conservation and protection of geoheritage.

Furthermore, this section will also present and discuss the proposed geotouristic itinerary, conceived as an operational framework for integrating geological, geomorphological, cultural, and agro-food assets into a coherent strategy for territorial valorization.

6.1 PERFORMANCE OF THE MODELS USED FOR THE ESTIMATION OF GEODIVERSITY AND GEOMORPHODIVERSITY

The integration of the quantitative models for estimating Geodiversity (Ferrando et al., 2021) and Geomorphodiversity (Burnelli et al., 2023) applied to the study area has demonstrated their effectiveness in describing and representing the geological and geomorphological complexity of the territory. The adopted approach made it possible to accurately discriminate landscape sectors characterized by high levels of diversity and to assess their impact on areas of anthropo-geographical value, such as viticultural terroirs, the Ofanto landscapes, or the volcanic reliefs of Monte Vulture.

It was therefore possible to quantify geological and geomorphological features as defining characteristics of territorial systems that act as drivers of socio-economic and cultural development for local communities, contributing to long-term processes of territorial identity construction. A significant aspect emerging from the application of these methods concerns their methodological flexibility and scalability. Although the study area covers a relatively limited extent, the models maintained excellent discriminative capacity, despite having been originally tested on much larger surfaces, approximately three to four times greater for Geodiversity and about 190 times greater for Geomorphodiversity.

Based on the results obtained, this experience confirms the suitability of the models for application in heterogeneous morpho-topographic contexts such as the one examined, without compromising their effectiveness or interpretative resolution. The possibility of transferring these methods across different scales represents a significant methodological advantage, as it enables accurate mapping even in territories characterized by strong lithological fragmentation, structural complexity, and active geomorphological dynamics.

Alongside these positive outcomes, the analysis also highlighted a relevant methodological limitation: the decisive role of data resolution in ensuring a faithful representation of geological and geomorphological complexity. Although the literature reports successful applications of these models at resolutions similar to those adopted in this study (Najwer et al., 2013; Pereira et al., 2013; Brilha, 2014; Forte et al., 2018; Nobre et al., 2019; Carrión-Mero et al., 2022; Alberico et al., 2023; Borato et al., 2023), the results obtained here show a systematic tendency toward underestimation of Geodiversity and Geomorphodiversity levels.

The main source of this underestimation concerns the resolution of the available geological mapping, which in the study area does not exceed the scale of 1:100,000. This limitation reduces the model's ability to capture the actual heterogeneity of lithotypes, especially where small outcrops or complex lithostratigraphic units are generalized or not represented. This issue reflects a broader gap at the national level, where the lack of updated and homogeneous detailed geological mapping limits not only Geodiversity studies but any quantitative approach aimed at fine-scale characterization of geological landscapes.

A second critical aspect concerns the resolution of the digital terrain models (DTMs) used for the automatic classification of landforms through the Geomorphon tool (Jasiewicz & Stępiński, 2013). Although a resolution of 5×5 m is adequate for identifying major landforms, it tends to overlook a set of microforms that significantly contribute to local Geodiversity and Geomorphodiversity. These include fluvial bars, small karst features, isolated residual reliefs, older and narrow fluvial terraces, and small-scale or extremely slow gravitational movements. The failure to detect such elements results in a non-negligible loss of information, as these microforms represent the most sensitive indicators of active geomorphological processes and of the morpho-structural complexity of the landscape.

Taken together, the results demonstrate that integrating Geodiversity and Geomorphodiversity models constitutes a methodologically robust and replicable approach capable of providing a coherent interpretative framework of the relationships between geological substrate and morphogenetic processes, and of their implications for cultural development dynamics. However, the identified limitations suggest the need for a deeper reflection on the adequacy of commonly employed resolutions and the opportunity to develop integrated approaches combining multi-resolution datasets validated through fieldwork and more sophisticated model-refinement techniques.

Only through such strategies will it be possible to further improve the descriptive and interpretative capacity of the models, enabling a more complete, accurate, and faithful representation of the geological and geomorphological complexity of the analysed territories.

6.2 SIGNIFICANCE OF GEODIVERSITY AND GEOMORPHODIVERSITY RESULTS FOR THE VALORIZATION AND GEOCONSERVATION OF THE GEOHERITAGE OF THE STUDY AREA

In light of the results obtained in terms of Geodiversity and Geomorphodiversity, it is essential to highlight how these findings affect, with different repercussions and implications, the cultural, socio-economic, and anthropo-geographical dimensions that characterize the study area. The aim is to establish a quantitative connection, thus far only hypothesized, between these aspects and the physical-geographical attributes of the territory. Within this framework, particular emphasis must be placed on the role that the abandoned Avellino – Rocchetta S. Antonio railway line could assume as a “privileged” route through the physical-geographical complexity and the cultural potential expressed by the territory of the study area.

Below, only a selection of particularly significant examples is presented, illustrating how physical-geographical features generate socio-economic, anthropo-geographical, and cultural implications within the study area. These examples may serve as catalysts for territorial valorization, provided that appropriate geoconservation measures are implemented to safeguard the local geoheritage and promote its dissemination.

6.2.1 Implications for viticultural terroirs

Without doubt, the most striking example of this type of anthropo-geographical implication is represented by one of the viticultural terroirs within the study area that also enjoys international recognition: the Taurasi DOCG. This area constitutes one of the largest clusters of Geodiversity and Geomorphodiversity in the province of Avellino, with approximately 83% of its territory falling within the study area. The landscape (Fig. 104), reflecting the geological and geomorphological complexity typical of the Campanian Apennines, corresponds to the mid-hill Irpinian environment, predominantly sandy-clayey-conglomeratic, with a Miocene terrigenous substratum and a mainly volcaniclastic cover. High and very high values of Geodiversity and Geomorphodiversity are associated with optimal conditions of water availability, climate, and soil and landscape characteristics (Sisto et al., 2022c; Cusano et al., 2025), constituting a key factor in the environmental and productive distinctiveness of this territory.



Figure 104 – Typical landscape of the Taurasi DOCG terroir (Torre Le Nocelle, Avellino).

The Geodiversity of this typical cluster within the study area (Fig. 105) displays a structured distribution: 14.7% of the area shows very low values and 33.8% low values, corresponding to flat zones and Quaternary deposits; 23.3% falls within the intermediate classes, representing transitional areas with alternating carbonate and terrigenous substrata. The high and very high classes, amounting to 28.3% overall (18.2% high and 10.1% very high), are concentrated in the hilly and mountainous sectors, where terrigenous and volcanoclastic lithologies, together with tectonic and erosive processes, confer to the soils a notable mineral richness and pedological variability, which translates into optimal agro-food and viticultural production.

Similarly, Geomorphodiversity (Fig. 106) shows a predominance of intermediate classes (Low, Average, and High), which together cover more than 82.7% of the territory. This distribution reflects the complexity of the hilly and valley landforms, with slopes, ridges, and plateaus modulating exposure, ventilation, and thermal regimes, thereby favouring differentiated microclimates and a heterogeneous distribution of vineyards. Class 1 (Very low) is entirely marginal (only 1.8% of the total area), whereas Class 5, covering 15.5% of the area, is the most significant, as it corresponds to the highest (Very high) geomorphological diversity, located in the most elevated and articulated zones (Monte Tuoro and surrounding reliefs).

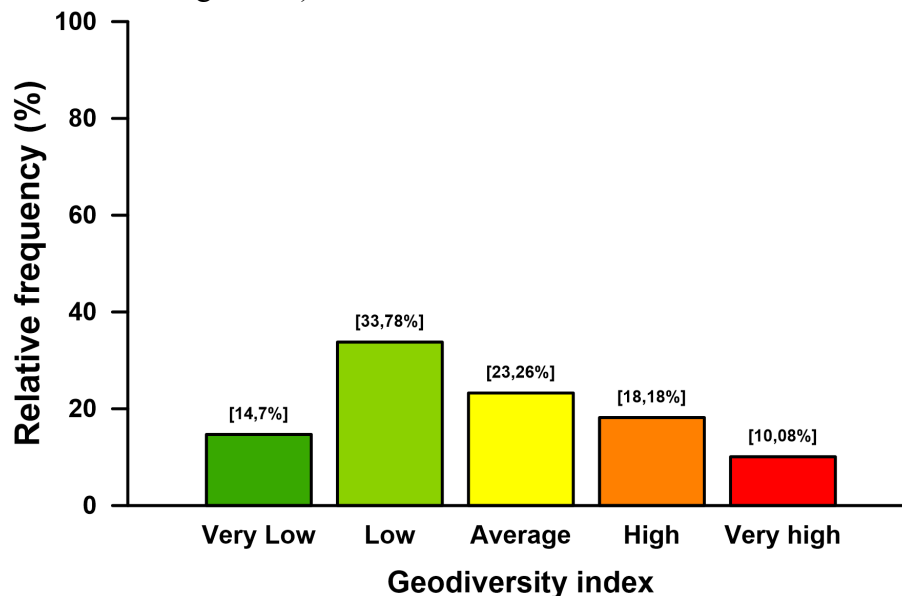


Figure 105 – Statistical distribution of geodiversity classes within the portion of the Taurasi DOCG terroir included in the study area.

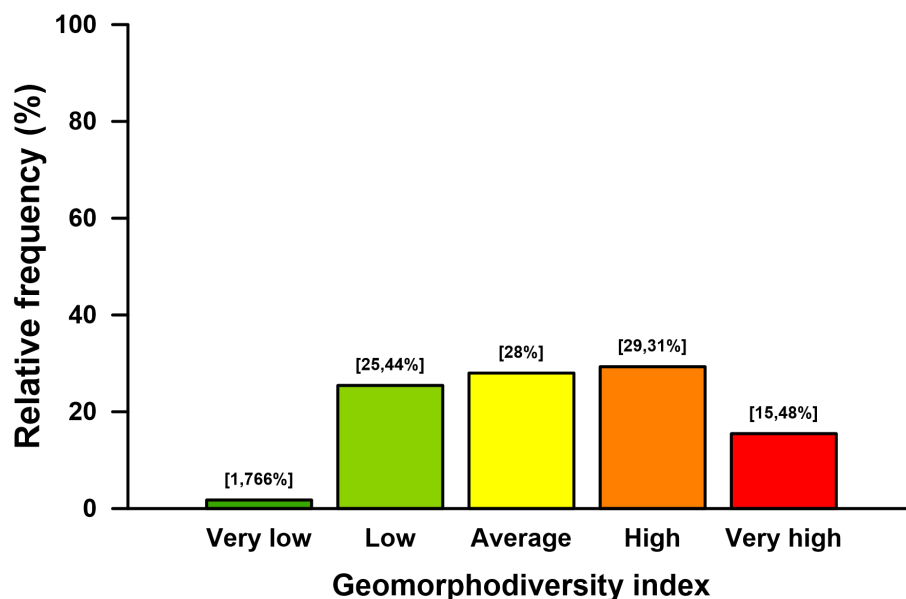


Figure 106 – Statistical analysis of the distribution of geomorphodiversity classes within the portion of the Taurasi DOCG terroir included in the study area.

The combination of Geodiversity and Geomorphodiversity, expressed through lithological variety, morphological complexity, and microclimatic diversification, directly defines the physical-geographical characteristics of the Taurasi DOCG terroir. This physical richness, distributed along altitudinal, lithological, and climatic gradients, results in substantial soil variability and

diversified agro-climatic conditions, making the area a unique viticultural environment capable of producing high-quality wines.

6.2.2 Implications for agro-food products

Pecorino Carmasciano is one of the symbolic products of Irpinian agro-pastoralism and takes its name from the Carmasciano district, located in the Ansanto Valley (Fig. 107) within the municipality of Rocca San Felice (AV). This area is of considerable geological interest due to the presence of non-volcanic mofetic emissions (Sisto et al., 2020). The valley, known in ancient sources as *Lacus Amsancti*, was considered a sacred place by the Oscan populations, who performed rituals in honour of the goddess Mephitis, a divinity associated with the underworld and fertility. The site known as the Mefite, from which the name derives, is among the most active degassing areas of the southern Apennines, releasing high concentrations of CO₂ and H₂S. These emissions generate extreme chemical-physical conditions that have long fuelled a collective imagination suspended between myth and reality among the populations that have inhabited the area over time. Even today, a thermal establishment exploiting sulphurous waters remains active (Sisto et al., 2020).



Figure 107 – Aerial view of the Ansanto Valley.

Within this context, the interaction between geology, history, and cultural perception defines the production area of Pecorino Carmasciano, a territory in which Geodiversity and Geomorphodiversity play a central role. These factors shape the quality of pastures and strongly influence the organoleptic characteristics of the cheese produced there.

The analysis of the Geodiversity Index for the production area of this traditional cheese (Fig. 108) reveals a predominance of very low (32.250%) and low (30.651%) classes, associated with flat surfaces and Quaternary deposits. The medium (17.952%), high (11.446%), and very high (7.702%) classes, although less widespread, play a decisive role: in these zones, characterized by greater lithological complexity, a rich and aromatic spontaneous flora develops, including medicinal species such as *Thymus vulgaris* and *Origanum vulgare*, which are particularly abundant in areas influenced by sulphurous emissions. The correlation between Geodiversity and phytodiversity is reflected in the composition of sheep's milk, enriched with aromatic and mineral compounds that give the cheese its distinctive and highly appreciated organoleptic profile.

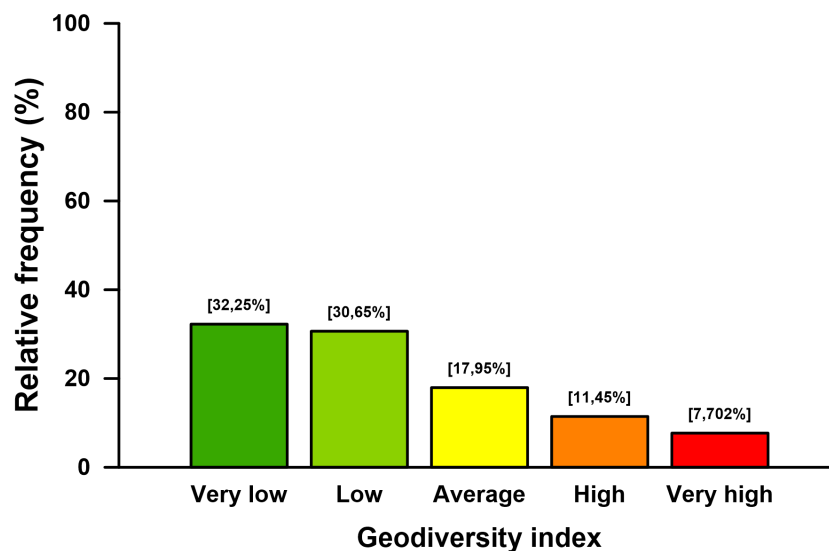


Figure 108 – Statistical trend of the Geodiversity Index within the Pecorino Carmasciano PDO production area.

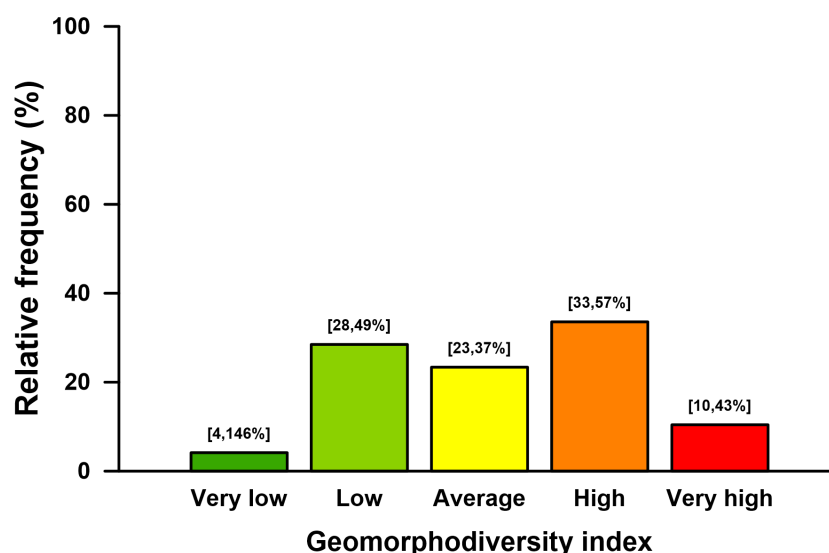


Figure 109 – Statistical trend of the Geomorphodiversity Index within the Pecorino Carmasciano PDO production area.

The Geomorphodiversity Index of this production area (Fig. 109) also confirms a complex morphological structure: the low (28.487%) and medium (23.368%) classes are accompanied by a substantial proportion of high (33.573%) and very high (10.426%) classes, while the very low class is marginal (4.146%). This distribution reflects the presence of diversified morphological units—valley depressions, ridges, and hilly reliefs—that generate local microclimates, with humid zones in depressed areas and drier, more ventilated environments on exposed slopes. Such heterogeneity favours differentiated habitats and complex ecological processes, contributing to the plant biodiversity of the pastures.

From this interplay of nature and myth, and from the geological and geomorphological complexity of the production area, arises the marked ecological diversity that translates into the characteristic sulphurous note of Pecorino Carmasciano, accompanied by spicy and aromatic nuances that make this cheese a unique product within the Italian dairy tradition.

6.2.3 Socio-cultural implications

The relationship between geology, myth, and folklore represents a privileged domain for understanding how communities have interpreted and symbolically re-elaborated natural landforms over the centuries. In agreement with Gray (2013), Geodiversity constitutes a true cultural matrix in which the physical elements of the landscape are transposed into the collective imagination as mythological components unique to local folklore. Rock outcrops, karst phenomena, volcanic dynamics, and hydrological processes are transformed into *geosymbols*, that is, natural elements endowed with religious, mythical, and identity-related meanings.

Within this perspective, the comparative analysis of places such as the “Piesco re lo Riavolo”, the sacralized morphologies of Rocchetta Sant’Antonio, the volcanic landscape of Monticchio, the dolmen of Pratola Serra, and the Piana del Dragone illustrates how Geodiversity has continuously nourished the folkloristic construction of the territory (Sisto et al., 2022a).

The “Piesco re lo Riavolo” (Sisto & Russo, 2024), located near Torella dei Lombardi in the valley of the Fredane River, represents an emblematic case: a limestone outcrop with natural cavities, interpretable as microforms of karst corrosion or as voids produced by mechanical disintegration, has been reinterpreted by local tradition as the footprint of the devil during a clash with the Archangel Michael. The very etymology (piesco from *petriscus*, “boulder”, and riavolo from “devil”) reveals the superimposition of geological evidence and religious imagination, transforming a natural landform into a moral and narrative symbol.

A similar process characterizes Rocchetta Sant’Antonio, where Geodiversity shaped by fluvial erosion, gravitational phenomena, and hydrological dynamics has produced a complex landscape rich in fractures, monoliths, and clefts. These forms have been interpreted as traces of supernatural forces, fuelling narratives of demonic presences and cosmic conflicts. The toponyms “Murgia Spaccata” and “Caca Riavule” (Fig. 110) testify to the capacity of the local community to attribute transcendent meanings to unusual geological features, transforming them into components of a sacralized landscape.



Figure 110 – Limestone olistolith embedded within the Varicoloured Clay Complex, locally nicknamed “Caca Riavule”.

Watercourses also contribute to the construction of the local collective imagination. For example, the Ofanto River, an impetuous watercourse known in Roman times as *Aufidus*, has long been perceived as a liminal space between the natural and the supernatural, giving rise to legends of demonic apparitions and miraculous interventions. The San Gennaro stream, with its cavities, marshes, and stagnant zones, has instead nourished narratives involving *masciare*, *janare*, *Lupnar*, and *Scazzamuriedd*, illustrating how geomorphological peculiarities can become the material substrate for the projection of collective fears and for the construction of apotropaic narratives (Sisto et al., 2022; Corvino, 2002).

At Monticchio, the volcanic morphology of the Vulture (crater lakes, thermal springs, chromatic variations of the waters) has favoured the sacralization of the landscape (Burgassi, 2015). The monastic complex of San Michele (Fig. 111), built on a spur of volcanic tuff near the Grotta dell'Angelo, already a *locus sacer* in pre-Roman times, demonstrates how the geomorphology of the volcanic area conditioned the construction of a sacred building in a place already predisposed to worship. Indeed, the tuffaceous escarpment, with its natural cavities formed by the easy erodibility of the rock, is located in a liminal position between rock and spring waters, elements that have sustained the continuity of cult practices at the site over the centuries.



Figure 111 – Monastic complex of San Michele in Monticchio.

A parallel can be found in the dolmen of Pratola Serra, the so-called “Casa dell’Orco”, a megalithic structure built with local stones and situated within a context of high Geodiversity. The monumentality of this ancient construction and the long-standing human presence at the site demonstrate how Geomorphodiversity contributed to the sacralization of space, gradually generating folkloric interpretations that transformed the megalithic monument into a place of mystery and otherness (Cipolloni Sampò, 1990).

The Piana del Dragone in Volturara Irpina (AV), a tectono-karstic depression subject to seasonal flooding, has given rise to the legend of the three-headed dragon, transfiguring real geological processes into identity-bearing symbols. In this landscape, where geology, seasonal hydrology, and myth overlap, the karstic nature of the area becomes a shared narrative and an element of the community's intangible heritage (Corvino, 2002).

6.2.4 Historical and Urban-Planning Implications

The present municipality of Aquilonia, located in the northeastern sector of the study area, represents an exemplary case of how geodiversity and geomorphodiversity can decisively influence the settlement evolution of a territory, orienting and re-orienting socio-cultural development choices. The relationship between the geological nature of the area, landform morphology and settlement strategies is particularly evident in the medieval origins of this municipality, a village founded in the 9th century under the name *Carbonara* (Fig. 112).



Figure 112 – Ruins of ancient Carbonara.

The earliest settlement nucleus of medieval Carbonara arose on a rocky promontory protected by steep slopes on all sides, a top-hill position that met the defensive requirements of early medieval fortification. The solidity of the bedrock, the panoramic visibility and the isolation ensured by the surrounding morphology demonstrate how local geomorphodiversity guided site selection, offering strategic advantages and favourable conditions for human permanence. Even the toponym “Carbonara” reflects a direct link with the local geology. The origin of the name is not related to the production of charcoal, but rather to the presence, in the nearby locality of Sassano, of bituminous rocks rich in organic compounds and impregnated with crude oil. These lithotypes, highly flammable and sometimes subject to spontaneous combustion, constituted a distinctive element of the geological landscape, influencing territorial perception and contributing to the definition of its cultural identity.

Geodiversity, therefore, not only shaped the physical landscape, but also translated into symbols, narratives and place names.

Over the centuries, the ancient village, favoured by a territorial configuration that ensured protection, developed into an important rural centre with relative autonomy and resource availability. Only in the 19th century, after the Unification of Italy, did Carbonara assume its current name, Aquilonia, in memory of the ancient Samnite city destroyed by the Romans in 293 BC, completing a cultural stratification that began in remote times (Ianneci, 1996), in which historical memory intertwines with geological materiality and with the identity-related perception of the territory.

From a geological perspective, the substrate of the area on which Aquilonia/Carbonara stands is characterised by heterogeneous terrains: Mesozoic calcareous olistoliths embedded within Miocene turbiditic successions and overlain by Pliocene marly-clayey deposits. These units document the transition from deep marine depositional environments to shallower basin contexts, reflecting the deformation and uplift phases of the Apennine orogen. In this sector, the latter is composed of superimposed tectonic units characterised by folds, reverse faults and thrusts, which have shaped a complex landscape of ridges, basins and steep slopes. This geo-lithological and geomorphological richness has historically influenced resource use, slope stability and settlement distribution.

The Vulture earthquake of 23 July 1930, with magnitude 6.7, profoundly marked the history of the village, causing the complete destruction of the ancient settlement of Carbonara. The seismic event, part of the active Apennine seismicity framework, deeply affected the settlement continuity of the site. The reconstruction of the new centre of Aquilonia, completed in only three months, was carried out on a nearby and more stable hilltop, reflecting a greater awareness of seismic risk. This represents clear evidence of how geomorphodiversity, by conditioning the relocation of settlements, historical routes and agricultural practices, is not a mere scenic backdrop but a key factor for settlement continuity and for the enhancement of territorial identity.

In recent decades, the area of the ruins of ancient Carbonara has been protected through the establishment of the *Parco della Memoria*, now an open-air laboratory for studying interactions between natural dynamics, anthropic vulnerability and landscape transformations. The abandoned village has become a place of collective reflection on the relationship between humans and the environment, a paradigmatic case capable of restoring meaning to the memory of the seismic disaster as a cultural vehicle for promoting seismic prevention and resilience.

6.2.5 Infrastructural Implications

Within the framework outlined by the obtained results, the route of the decommissioned Avellino–Rocchetta S. Antonio railway line emerges as an infrastructure of particular relevance for the integrated enhancement of geodiversity and the agri-cultural heritage of this part of Irpinia. Its longitudinal extension continuously intersects geological, geomorphological and landscape contexts that are profoundly different, allowing the territory to be interpreted as a geo-cultural corridor in which physical diversity is combined with settlement and social history, local agro-food productions and specific territorial identities. In this perspective, the abandoned railway route can be considered an alternative mobility path with didactic, experiential, educational and emotional functions, playing an important role in narrating the geoheritage components of the study area.

The succession of lithotypes, landforms, hydrographic systems and landscape units crossed by the railway constitutes a territorial laboratory of perceived geodiversity (and at times also lived or experienced) in its dynamic dimension. Along the route, one encounters volcanic edifices, carbonate ridges, fluvial terraces, slopes affected by active erosional processes, alluvial plains and hills shaped by different morphogenetic agents. This variability, already highlighted by the geodiversity and geomorphodiversity indices discussed previously, finds in the abandoned railway a primary driver that can be valorised through interpretive panels, thematic geo-itineraries, observation points and environmental education activities.

In addition to the physical and landscape aspects, the railway route also represents a unique sequence, at the local scale, of territorial excellences expressed through a kaleidoscope of typical agro-food productions (e.g., *Taurasi DOCG*, *Carmasciano* cheese, etc.), whose quality is closely linked to local geological, pedological and microclimatic factors. These territorial peculiarities can be effectively integrated within a multidimensional tourism model that reflects both local geodiversity and territorial identity, and that can serve as a resource for the socio-economic development of these inner Apennine areas.

In this perspective, the abandoned railway route can be understood as an important infrastructural connector between geosites, farms, historic villages and memory sites, promoting forms of slow, sustainable and de-seasonalised tourism. From another viewpoint, it can be considered a greenway or eco-geotouristic itinerary in which innovative geoconservation practices can be tested to protect the extraordinary local bio-geo-heritage through slow and sustainable enjoyment, the result of a “pact” for the protection of natural resources between local communities and visitors. As a greenway, this infrastructure could act as a catalyst for scientific dissemination, enabling the creation of thematic geo-itineraries, educational activities, citizen science programmes and landscape interpretation initiatives aimed at spreading knowledge about geological processes, the evolutionary history of the area and the relationships between geodiversity and cultural identity.

In this way, the abandoned railway route could represent the opportunity for a new shared cultural process based on a widespread and solid awareness of values that transcend the strictly technical-administrative domain. It is not unreasonable to imagine that, in such an auspicious context, passive protection measures (e.g., access regulation, definition of buffer or attention zones, etc.) and active protection measures (ordinary maintenance, territorial monitoring, natural hazard mitigation, ecological restoration interventions, etc.) could be more easily implemented.

6.3 PROPOSED GEOTOURISTIC ITINERARY

The proposed geotouristic itinerary unfolds along the decommissioned Avellino–Rocchetta S. Antonio railway line (Fig. 112) and constitutes a continuous narrative of the territory, capable of conveying in an integrated manner the geological, landscape and cultural complexity of the study area. The variety of environments crossed, from carbonate ridges to alluvial plains and volcanic reliefs, allows the landscape to be interpreted as a dynamic system shaped by natural processes that have defined local forms and identities over time. Visitors are guided along a route that intertwines direct observation with scientific value and historical memory.

This proposal contributes to disseminating a renewed local landscape culture, grounded in the awareness of the natural and cultural heritage of the study area. The itinerary becomes a tool for narrating the geological and social history of the territory, enhancing its distinctive features and supporting more balanced development models for the inner Apennine areas, encouraging a rethinking of the relationship between communities and the environment and recognising geodiversity as a strategic resource for the future.

6.3.1 Geodiversity elements (Geosites) along the itinerary

Along the itinerary, several geodiversity elements of significant cultural interest can be observed. Some of these have been designated as geosites (e.g., the springs of Cassano Irpino, the site of Conza della Campania, the Calitri landslide, the landscape of the extinct Monte Vulture volcano, etc.) and are formally recognised and included in the Regional Geosite Inventory of the Campania Region (CA.RE.Geo) and in the Geodata Catalogue of the Basilicata Region. They document a wide range of natural phenomena (karst processes, seismic histories, slope instability, volcanic manifestations) that highlight the geological variety and complexity of the area. Collectively, they outline a coherent framework of the geological processes that have shaped the territory over time and therefore legitimately constitute part of the local geo-natural heritage of the area crossed by the proposed itinerary.

Starting from the Avellino railway station, the itinerary extends for approximately 2 km across the landscape of the intermontane depressions of the Avellino Basin (Landscape Unit 2, cf. §4.4.1). The route also includes short segments entering the fluvial landscape of the Sabato River valley (Landscape Unit 6, cf. §4.4.1), reaching, near the settlement of Atripalda, the curvilinear “Milano” viaduct over the Sabato River. In this first segment, the itinerary exhibits geodiversity and geomorphodiversity values ranging from very low to low.

Continuing onward, the itinerary develops for approximately 20 km across the arenaceous-argillaceous-marly hills of Landscape Unit 4 (cf. §4.4.1), which border the carbonate reliefs of the Picentini Mountains, clearly visible in the background (Landscape Unit 1, cf. §4.4.1). Of particular interest is the Montefalcione tunnel which, crossing the watershed, connects the Sabato River valley with that of the Calore River. Upon exiting the tunnel, the itinerary enters the Calore valley and, after passing the settlements of Taurasi, renowned for the DOCG wine bearing its name, and Lapio, reaches the evocative Ponte Principe, located centrally between the two towns.

From this point, for approximately 6 km, the itinerary offers a unique panorama, crossing four distinct Landscape Units: to the left, the sandy-conglomeratic and clayey hills of Landscape Unit 5; to the right, the arenaceous-argillaceous-marly hills of Landscape Unit 4; below, the fluvial landscape of the Calore valley (Landscape Unit 6); and in the background, the carbonate reliefs of Landscape Unit 1 (cf. §4.4.1). This segment represents a unicum not only for the variety of landscapes observable, but also for the high geodiversity and geomorphodiversity that characterise it. Indeed, it is one of the segments with the highest values in the entire study area, ranging from high to very high.

Beyond the settlement of Paternopoli, the itinerary continues for approximately 14 km towards Cassano Irpino, entering a gorge of the upper Calore valley (Landscape Unit 6, cf. §4.4.1). In this stretch, the itinerary is flanked on both sides by the arenaceous-argillaceous-marly hills of Landscape

Unit 4. Approximately 30 minutes by car from the Castelfranci station (stop no. 12), along the state road 400 (SS400), one can reach the nationally significant geosite of the Mefite of the Ansanto Valley, in the territory of Rocca San Felice. The site is known for its intense non-volcanic mofetic emissions, evidence of the high degree of geodiversity and geomorphodiversity (high – very high) that also characterises this portion of the itinerary. The Mefite is additionally linked to local traditions associated with the cult of the goddess Mefitis and with the high-quality agricultural production of *Pecorino Carmasciano* (cf. §6.2.2, Fig. 109). A few kilometres from the Mefite lies the national geosite of the San Teodoro Thermal Springs in Villamaina (AV063). Their bicarbonate-sulfate-calcium waters (11–28 °C) derive from the mixing of waters circulating within the limestones of the Flysch Rosso and deeper waters rising from the carbonate basement.

Returning to the itinerary and exiting the gorge, one reaches the Cassano Irpino station (stop no. 13). Only 350 metres away lies the nationally significant geosite of the Cassano Springs (CA.RE.Geo – AV056) (cf. §4, Fig. 51), one of the most important hydrogeological systems of the Picentini Mountains. The springs, fed by the deep karst reservoirs of the Terminio–Tuoro massif, emerge from four main outlets (Bagno della Regina, Peschiera, Prete and Pollentina). The site has considerable scientific value for two reasons: hydrogeological studies (Celico, 1988; Calcaterra, 1994) have demonstrated the underground connection between the Bocca del Dragone swallow hole and the Cassano Irpino springs, an emblematic case of karst circulation; moreover, the Terminio–Tuoro aquifer constitutes one of the main water supply systems of southern Italy, providing water to numerous municipalities in Campania, Apulia, Basilicata and Molise (Santo & Giulivo, 2005). Testifying to their landscape and cultural value, the spectacular Cassano Irpino Springs have also been featured on an Italian postage stamp.

Beyond the Cassano Irpino station, the itinerary enters the Montella alluvial plain (Landscape Unit 6, cf. §4.4.1), crossing it for approximately 5 km. The plain is bounded on the right by the carbonate reliefs of the Picentini Mountains (Landscape Unit 1, cf. §4.4.1) and on the left by the arenaceous-argillaceous-marly hills of Landscape Unit 4. In this segment, the itinerary exhibits geodiversity and geomorphodiversity values ranging from high to very high. From the Montella station (stop no. 15), along the state road 7 (SS7), one can reach the nationally significant geosites of the Piana del Dragone (AV065), a tectono-karst depression (polje), and the Bocca del Dragone swallow hole (AV065), both fundamental components of the Terminio–Tuoro aquifer system. Along this segment, it is also possible to admire the isolated relief on which stands the Sanctuary of the Santissimo Salvatore, a symbolic place of worship reflecting the deep religious tradition of the study area. Completing the array of territorial excellences in this segment is the *Castagna di Montella* PGI, a high-quality agro-food product.

Beyond the Montella plain, the itinerary continues for approximately 9 km towards Bagnoli Irpino, crossing the arenaceous-argillaceous-marly hills of Landscape Unit 4, which in this stretch also border the carbonate reliefs of the Picentini Mountains (Landscape Unit 1). On the right side of the itinerary, numerous tectonic landforms can be observed, particularly evident here, which have shaped the limestone reliefs of the Picentini Mountains during the deformational phases responsible for the structuring of the Apennines. In this segment, geodiversity and geomorphodiversity values range from very low to low.

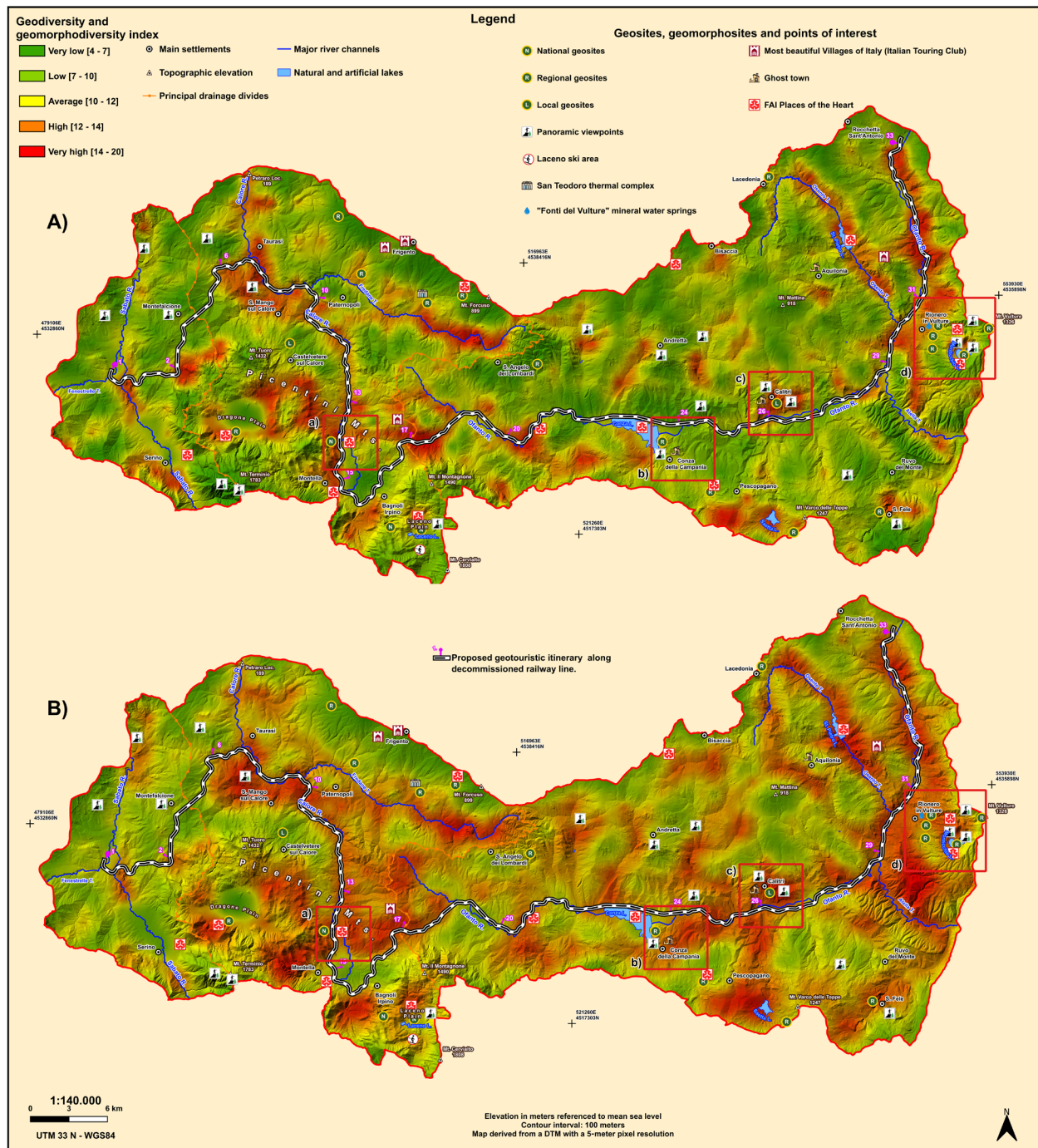


Figure 112 - Proposed geotouristic itinerary through the geodiversity (A) and geomorphodiversity (B) of the study area.

From the Bagnoli Irpino station (stop no. 16), travelling for 11 km along the provincial road 368 (SP368), one reaches the nationally significant geosites of Piano Laceno (AV006) and the Grotta del Caliendo (AV028). The Piano Laceno geosite is a tectono-karst depression that, following seasonal flooding, gives rise to Lake Laceno. Its only outlet is the Ponte Scaffa swallow hole, which channels the waters into the underlying Grotta del Caliendo. The Grotta del Caliendo is one of the most significant caves in the Campania region, second in extent only to the Castelvita Cave. With a development of nearly 4 km, it constitutes the hydrogeological outlet of Lake Laceno and represents

a karst system of high scientific and morphological interest. This segment is also notable for the production of *Pecorino Bagnolese*, a local agro-food excellence recognised as a P.A.T.

Leaving the settlement of Bagnoli Irpino and the imposing carbonate reliefs of the Picentini Mountains, the itinerary crosses the Apennine watershed through a tunnel near Nusco, then begins a route of approximately 19 km within the Ofanto River valley. The Apennine watershed plays a fundamental geological and geomorphological role, as it sharply separates the western sector of the study area from the eastern one, which are characterised by profoundly different evolutionary histories and landscapes (cf. §). This contrast is clearly perceptible from the Nusco viewpoint, one of the “Most Beautiful Villages of Italy” according to the Touring Club. Within the Ofanto valley (Landscape Unit 6), the itinerary crosses, on both sides, the landscapes of the sandy-conglomeratic and clayey hills of Landscape Unit 5. The symmetry of landforms and lithotypes fully reflects the geological evolution of the Ofanto Basin. In this segment, geodiversity ranges from very high–high values to low–very low values, while geomorphodiversity remains consistently high–very high, demonstrating that even in lithologically homogeneous contexts, a remarkable variety of landforms can develop.

From the Lioni station (stop no. 20), travelling 6 km along the SS400, one reaches the renowned religious complex of the Goleto Abbey, located between the municipalities of Sant’Angelo dei Lombardi and Lioni. Continuing onward, and alighting at the Teora station (stop no. 22), from 17 January, the day dedicated by the Church to Saint Anthony the Abbot, it is possible to witness the appearance of the traditional “Squacqualacchiun”: masked men who roam the streets of the town reenacting ancient pagan rituals, in a moment of exhilaration and freedom in which Christian worship intertwines with archaic traditions, giving rise to a celebration where the sacred and the profane coexist and renew themselves over time.

Leaving the Teora station, the itinerary continues for approximately 25 km through the sandy-conglomeratic and clayey hills (Landscape Unit 5) of the Ofanto valley, crossing the Naturalistic Oasis of the Conza della Campania dam, classified by the Ministry of the Environment as a Site of Community Interest and a Special Protection Area. Alighting at the Conza della Campania station (stop no. 24), it is possible to visit the Conza della Campania geosite (AV020). The Conza geosite (cf. §4, Fig. 78), located about 3.5 km from the station and easily reachable by bicycle, is of particular importance because the area lies within one of the zones of highest seismicity in the southern Apennines. The territory is indeed affected by frequent and high-magnitude events linked to extensional processes that have affected this sector of the chain since the early–middle Pleistocene (Ascione et al., 2020, Ward, 1994). Conza is a unique case in Italy for the recurrence of macroseismic intensities up to IX MCS with a secular frequency, and it is precisely these repeated destructions that have allowed the unearthing of the forum, the amphitheatre and numerous artefacts of ancient Compsa, now exhibited in the archaeological area museum along the route to the geosite (Porfido et al., 2024).

After passing Conza della Campania, it is possible to observe along the left side of the itinerary the Cairano cliff (Fig. 113), a landscape feature of particular geological interest. The territory of Cairano is located on the northern flank of a broad syncline whose axis coincides with the upper Ofanto valley. This structure originated during the compressive tectonic phase that, in the Middle Pliocene, affected the Southern Apennines, deforming the Pliocene sedimentary successions and the

underlying Irpinian and Lagonegrese Units, causing their compression and folding (Ascione et al., 2020, Ward, 1994). The syncline is bounded to the south by the Pescopagano anticline and to the north by the Monte Mattina anticline.



Figure 113 - Cairano Cliff.

The synclinal core is composed of clayey, arenaceous and conglomeratic successions belonging to the Ariano Units (Lower–Middle Pliocene), resting upon clayey-arenaceous lithotypes of the Irpinian and Lagonegrese Units, which reach a total thickness of 2500–3000 m and overlie the carbonate rocks of the Abruzzi–Campania platform. The basal grey-blue clays attain thicknesses of several hundred metres, whereas the upper arenaceous-conglomeratic levels exceed 100 m and constitute the substrate of the settlement. In the eastern sector, alternations of sands and clays also crop out, with thicknesses ranging from a few metres to several tens of metres.

From a seismotectonic perspective, the Cairano syncline lies within a structural belt 30–40 km wide, characterised by deep NW–SE-oriented faults that have undergone significant uplift during the last 700,000 years. This belt is bounded by the western alignment extending from the upper Agri valley to the eastern Matese, and by the eastern alignment extending from the Vulture area to Ariano Irpino. The position of Cairano within this sector results in a marked vulnerability to earthquakes generated along the deep structures of the western margin.

From Cairano, continuing for approximately 5 km along the itinerary, one reaches the Calitri geosite (Fig. 114), which represents a significant example of a seismically induced landslide reactivated after the 23 November 1980 earthquake. The slope failure, probably initiated in the Late Quaternary due to erosion by the Ofanto River, has been interpreted as a deep rotational movement with thicknesses reaching up to 100 m (Del Prete & Trisorio Liuzzi, 1981, Hutchinson & Del Prete, 1985). The 1980 earthquake caused a marked reactivation of the landslide, affecting more than 160 hectares and part of the Calitri settlement, with movements continuing in the following months and leading to the evacuation of much of the historic centre (Parise & Wasowski, 1998). The geosite is easily accessible from the Calitri Pescopagano station (stop no. 26), located approximately 4 km away.



Figure 114 - Aerial view of the town of Calitri.

After passing the Calitri geosite and continuing along this segment of the itinerary, one reaches the Rapone–Ruvo del Monte station (stop no. 27). From here, travelling along the provincial road 19, it is possible to reach the settlement of San Fele, from which the nationally significant geosite of the San Fele Anticline can be observed (Fig. 115).



Figure 115 - View of the San Fele Anticline.

The San Fele Anticline is a kilometre-scale compressive structure affecting the Mesozoic succession of the Lagonegro Basin, composed of *Calcari con Selce*, *Scisti Silicei* and *Galestri*. The fold, oriented predominantly NW–SE and extending for more than 4 km, exhibits marked asymmetry: the southwestern limb shows gentle to moderate dips, whereas the northeastern limb is steep, locally verticalised or overturned, indicating NE vergence. Within the *Scisti Silicei*, particularly in the basal calcarenitic member, thickness variations are observed that are controlled by the Monte Fieno Fault, a Jurassic synsedimentary structure later reactivated under compression. The anticline is also developed above a low-angle WSW-dipping thrust surface, interpretable as the upper branch of a duplex system belonging to the Lagonegrese Units. Associated mesoscopic folds display axes parallel to that of the macrostructure, suggesting a shortening field oriented SW–NE. During the Pleistocene, the anticline was finally truncated by a system of NW–SE-oriented normal faults, interpretable as expressions of post-orogenic extension.

From the Rapone station, continuing along this segment of the itinerary, it is possible to observe on the right side the Fiumara di Atella, another landscape element of considerable geological interest within the study area. The Fiumara di Atella (Fig. 117), a right-bank tributary of the Ofanto River, crosses a morphologically complex sector of the southern flank of Monte Vulture. Along its course, the main pre-Pliocene sedimentary formations crop out, including the *Flysch Rosso*, the *Flysch Numidico* and the Gorgoglione Formation, followed by Pliocene sediments and volcanic products belonging to the trachytic-phonolitic and tephritic-foiditic cycles. This stratigraphic configuration illustrates how the fiumara progressively incises units of different ages and lithological characteristics, providing a natural section of great value for reconstructing the geological evolution of the area.



Figure 116 - Aerial view of the Fiumara di Atella.

Within the study area, the Pliocene successions are well exposed (cf. §4, Fig. 68). These units constitute the upper portion of the infra-Meso-Pliocene sedimentary cycle and document a pronounced regressive trend. The series begins with grey-blue marly clays in a shelf-mud facies (Fig. 117via), cropping out in the southern and western sectors, followed upward by thin sandy and conglomeratic intercalations indicative of a progressive increase in depositional energy.

Overlying these units are the yellowish sands (Fig. 117b), clearly visible along the right bank of the Fiumara di Atella, characterised by shoreface facies and by frequent conglomeratic lenses and clayey layers. These deposits record the landward migration of the shoreline and the continuation of marine regression. The uppermost portion of the succession is represented by polygenic conglomerates (Fig. 117c), cropping out mainly along the left bank. They display features typical of a deltaic system evolving toward continental conditions, as suggested by the reddish coloration of the upper levels and by the composition of the clasts, derived from the surrounding pre-Pliocene formations.

The Pliocene successions exposed in the sector of the Fiumara di Atella included within the study area clearly document the transition from shallow-marine environments to coastal and, ultimately, continental conditions. These deposits record the progressive emergence of the southern sector of the Vulture area, which occurred prior to the onset of volcanic activity and the subsequent formation of the Atella lacustrine basin.

After crossing the Fiumara di Atella, the itinerary proceeds along its final 20 km toward the Rocchetta Sant'Antonio station. In this segment, while following the Ofanto River valley (Landscape Unit 6), the itinerary displays on the left the landscapes of the arenaceous-argillaceous-marly hills of Landscape Unit 4, whereas on the right the landscapes alternate between the sandy-conglomeratic and clayey hills of Landscape Unit 5 and those of the Monte Vulture volcanic edifice (Landscape Unit 3). In this final stretch, both geodiversity and geomorphodiversity exhibit values ranging from very high to high, reflecting the pronounced lithological and morphological heterogeneity of the area.

Stopping at the Monticchio station (stop no. 31), it is possible to reach five geosites associated with the Monte Vulture volcanic edifice. The first geosite is the Crocco Spring ($40^{\circ}56'4''\text{N}$, $15^{\circ}34'32''\text{E}$), located near Monticchio Bagni and easily accessible by bicycle from the Monticchio station via the provincial road SP401. This geosite represents significant evidence of the hydrothermal circulation linked to the Monte Vulture volcanic system and of the geochemical processes still active in the area. The spring is named after the well-known brigand Carmine Crocco, a prominent figure of the Risorgimento period in southern Italy.

The waters of the Crocco Spring, similar to those of the Cacarella Spring in Atella, belong to the group of high-salinity waters of the Monte Vulture area. They exhibit low discharge (0.1 L/s), high total dissolved solids (approximately 1.5 g/L), an acidic pH (6.0) and a temperature of about 17 °C. They are also characterised by marked effervescence due to the abundant presence of CO₂ of magmatic origin, associated with the ascent of deep mantle-derived fluids. The high concentrations of iron and other heavy metals render the water non-potable and give it an unpleasant taste. Nevertheless, since the time of Crocco, these waters were believed to possess beneficial and therapeutic properties, which explains their historical popularity (Giannandrea et al., 2020).

A few minutes' walk from the Crocco Spring, along the SP401, lies the Cava Piana Ferriera geosite ($40^{\circ}56'56.39''\text{N}$, $15^{\circ}34'8.40''\text{E}$). This geosite is a rare example of an explosion centre. Located on the western flank of the volcanic edifice, which has preserved its conical morphology, the quarry at the top of the ridge has exposed both the hydromagmatic deposits along the conduit walls and the scoriae and bombs produced during the final strombolian activity (<https://www.isprambiente.gov.it/>).

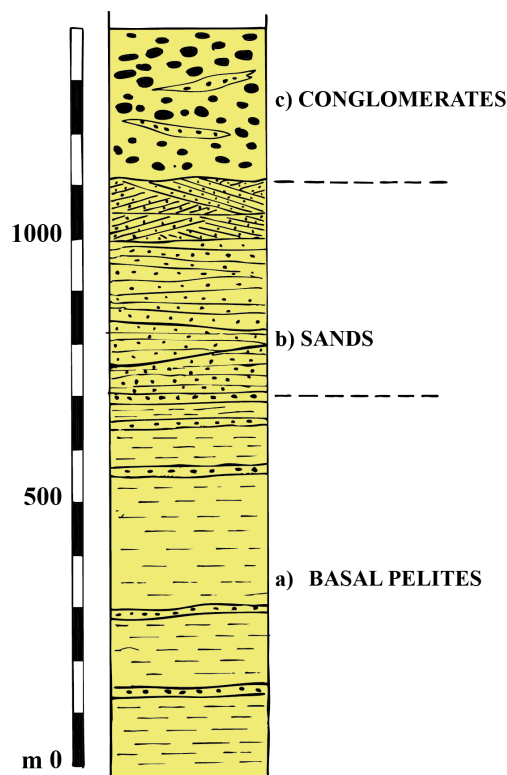


Figure 117 - General log of the regressive cycle of the Lower-Middle Pliocene in the Benevento-Potenza Basin.

From the Cava Piana Ferriera geosite, continuing for approximately 2 km on foot or by bicycle along the SP401, one reaches the Valle dei Grigi geosite (40°57'3.60"N, 15°35'6"E). The Valle dei Grigi is a major volcano-tectonic structure within the Monte Vulture system. It develops along an E–W-oriented tectonic lineament, shared with the Fosso del Corbo, which caused the downthrow of at least 100 m of the southern sector of the volcanic edifice, disrupting the altimetric continuity of the Monte Vulture–Monte San Michele caldera rim (Boenzi et al., 1987). The valley's watercourses, aligned along this fracture, exhibit deep incisions and steep slopes, providing evidence of the geomorphological evolution of the volcano. The associated fault plays a fundamental draining role, controlling deep groundwater circulation and facilitating the ascent of CO₂-rich fluids of magmatic origin. This structural setting has influenced the location of the main springs and mineral-water bottling plants of the Vulture area.

From the Valle dei Grigi, travelling approximately 8 km along the SP167, one reaches the Monticchio Lakes geosite. The Monticchio Lakes area corresponds to a caldera formed after an intense phase of tectonic activity that deformed the original conical structure of Monte Vulture. Within the depression, three maar-type craters can be identified, Piano Comune, Lago Grande and Lago Piccolo, whose morphological relationships allow the reconstruction of the sequence of eruptive phases. The area hosts a significant natural heritage, including the habitat of the endemic species *Brahmaea europaea*, as well as important historical features such as the Abbey of San Michele Arcangelo (cf. §6, Fig. 113), now home to the Vulture Natural History Museum.

The two crater lakes have nearly elliptical shapes but distinct characteristics. Lago Grande reaches a maximum depth of approximately 36 m, has a surface area of 4.3×10^6 m² and a volume of 3.25×10^6 m³. Lago Piccolo reaches 38 m in depth, has a surface area of 1.7×10^5 m² and a volume of 3.98×10^6 m³; along its steep walls, emissions of warmer, CO₂-rich mineralised fluids can be observed. The two basins are connected by an artificial channel approximately 200 m long. From a limnological perspective, both are quiescent lakes. Lago Piccolo is meromictic, with a permanent stratification of its waters into four layers characterised by increasing temperature and dissolved solids toward the bottom. Lago Grande is monomictic, with complete water circulation in winter and chemical stratification in spring. Both lakes are enriched in gases of mantle and biogenic origin, with concentrations varying according to depth. Differences in their hydrochemical dynamics depend on distinct density profiles, influenced by temperature, dissolved gases and concentrations of chemical elements, particularly iron, which is abundant in the deep waters of the meromictic lake.

Leaving the Monticchio station, this segment of the itinerary leads to the final stop, the Rocchetta Sant'Antonio railway station. From here, moving through the surrounding territory, it is possible to observe, within the landscape of the arenaceous-argillaceous-marly hills of Landscape Unit 4, numerous limestone olistoliths belonging to the Apennine carbonate platform. Among these, the olistolith of the locality "Cacariavule" illustrates the ability of the local community to attribute symbolic and transcendent meanings to unusual geological elements, transforming them into components of a sacralised landscape. Along this terminal stretch of the itinerary, one also encounters important historical and artistic landmarks, such as the archaeological park of Carbonara (ancient Aquilonia), the castle of Monteverde, offering a striking view of Monte Vulture, and the d'Aquino castle in the village of Rocchetta Sant'Antonio, recognisable by its characteristic "flat-iron" shape.

CONCLUSIONS

The primary objective of this research was the development of a methodological framework for the quantification of geodiversity and geomorphodiversity along the decommissioned railway line Avellino–Rocchetta Sant’Antonio. This objective was pursued through an interdisciplinary approach integrating physical-geographical, geological and cultural data, thereby providing a coherent representation of the landscape complexity of the area and demonstrating that quantitative analysis, when appropriately structured, can be effectively applied even in heterogeneous and morphologically articulated territorial contexts.

The analysis conducted along the abandoned railway corridor highlights how this infrastructural axis constitutes a complex territorial system in which geological, geomorphological, landscape and cultural diversity intertwines with the settlement and productive history of local communities. The application of quantitative models enabled the identification of the spatial distribution of the main abiotic components and the interpretation of their role in shaping territorial identity. The results show that lithological variability, slope morphology, hydrographic network density and landscape diversification are key elements in defining the environmental quality of the area and in influencing its cultural, economic and perceptual dynamics.

The comparison between the western and eastern sectors of the study area revealed significant differences attributable to distinct geological evolutions and morphogenetic processes that have shaped the territory. These differences are reflected in the distribution of geodiversity and geomorphodiversity indices, confirming the need for a territorial interpretation capable of linking physical processes with the cultural dynamics that stem from them. The implications of geodiversity for the viticultural landscapes of the Taurasi DOCG, for the genesis of *pecorino Carmasciano*, for the formation of geomites and for the evolution of the settlement of Aquilonia demonstrate that geodiversity acts as a generative factor of identity, traditional knowledge and local productions with high symbolic and economic value. In these cases, the relationship between geological substrate, landform configuration, microclimates and anthropogenic practices emerges as a coherent system capable of producing unique and recognisable territorial qualities.

Within this framework, the proposed geotourism itinerary along the Avellino–Rocchetta Sant’Antonio railway line represents the natural territorial application of the research outcomes, assuming a demonstrative and operational role of particular relevance. The route sequentially crosses the main landscape units and geolithological complexes that contributed to the definition of the indices, transforming quantitative analysis into a direct and legible field experience. The presence of geosites of national relevance makes the itinerary an open-air geological section, capable of narratively conveying the abiotic complexity quantified by the research.

The succession of lithotypes, landforms and geomorphological processes observable along the route allows for the recognition of geodiversity and geomorphodiversity gradients in the field, highlighting segments with very high values alternating with more homogeneous stretches. This continuity of interpretation strengthens the understanding of the relationship between geodiversity, local identity and cultural heritage, showing how geosites, typical productions and historical memories are distributed in relation to the abiotic characteristics of the territory. The itinerary not

only confirms the analytical results but renders them tangible, offering a coherent narrative of the geological and cultural evolution of the southern Apennines.

The interpretation of the data confirms that the decommissioned railway line possesses all the characteristics required to be considered a strategic geo-cultural corridor in which geodiversity can become a resource for new forms of sustainable fruition and for a renewed perception of the landscape. The route can be transformed into a narrative and interpretative device capable of connecting places, histories and landscapes, offering an innovative model of territorial enhancement grounded in scientific knowledge, shared perception of territorial values and the active involvement of local stakeholders. In this perspective, geoconservation assumes a cultural as well as technical role, recognising the value of abiotic heritage as an essential component of the landscape and as a foundation for responsible and participatory development policies.

The research also demonstrates that the promotion of geotourism, when based on solid scientific characterisation and an integrated reading of natural and cultural components, can contribute to strengthening the resilience of inland areas, counteracting marginalisation processes and generating new economic and social opportunities. This perspective is further enriched by considering the role of perception, understood as the modality through which individuals, communities and stakeholders recognise and attribute value to the landscapes they inhabit and manage. The Avellino–Rocchetta Sant’Antonio railway line, with its richness of landscapes, geosites, cultural features and identity-based productions, represents a privileged laboratory for experimenting with sustainable management models capable of enhancing geodiversity not only as an interpretative and planning matrix, but also as a perceptual device able to renew the way the territory is experienced and shared.

Ultimately, the work confirms that geodiversity is not merely a scientific indicator but an ordering principle of the territory, capable of guiding conservation strategies, environmental education and local development. Its integration with cultural heritage and socio-economic dynamics enables the interpretation of the landscape as a complex system in which nature and culture coevolve and mutually reinforce one another. The enhancement of the Avellino–Rocchetta Sant’Antonio railway line can thus become an emblematic example of how geoscientific knowledge, supported by the coordinated contribution of stakeholders, can contribute to building a sustainable future for the inland areas of the Apennines, restoring centrality to territories rich in history, diversity and still-unexpressed potential.

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